A

PRACTICAL TREATISE

ON

RAIL-ROADS,

AND INTERIOR COMMUNICATION IN GENERAL.

CONTAINING

NUMEROUS EXPERIMENTS ON THE POWERS OF
THE IMPROVED LOCOMOTIVE ENGINES:

AND

TABLES OF THE COMPARATIVE COST OF CONVEYANCE ON CANALS,
RAILWAYS, AND TURNPIKE ROADS.

THIRD EDITION, WITH ADDITIONS.

Illustrated by several New Engravings.

BY NICHOLAS WOOD,

COLLIERY VIEWER, MEMBER OF THE INSTITUTION OF CIVIL
ENGINEERS, ETC.

"Should we live to see fully developed all the powers and energies of this system, we have no doubt we shall also live to see it recognised, as one of the very greatest benefits which either philosophy or art has ever conferred on mankind."—*Quarterly Review.*

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DEDICATED, BY PERMISSION,

TO

THE RIGHT HONORABLE LORD RAVENSWORTH,

THE

RIGHT HONORABLE LORD WHARNCLIFFE,

AND

JOHN BOWES, Esq., M.P.

BY

THEIR MUCH OBLIGED AND HUMBLE SERVANT,

NICHOLAS WOOD.

INTRODUCTION

TO THE

FIRST EDITION.

In offering these pages to the Public, little explanation is, perhaps, necessary; the acknowledged importance of Railroad conveyance, and the intense anxiety existing in the public mind, respecting the relative value of Canals and Railroads, as species of internal communication, render any information concerning them of interest; and, if that information is founded on the result of experiments performed on a working scale, it is conceived that, whether they tend towards establishing the one system or the other, they will be equally entitled to attention.

The want of practical information, on the subject of Railroads, has been much lamented; detached observations and opinions have at times been circulated, but little has been done towards the exhibition of the subject in a systematic manner. The want of experiments on the friction of carriages,—the want of detailed observations on the performance of horses, and of other kinds of motive power, have alike been the subject of regret among those interested in such enquiries; and little more than mere conjecture has transpired in the writings of those, who have not been more immediately concerned in the practical application of this mode of conveyance.

In attempting to supply these defects, considering the importance of the subject, some apology may be necessary; but in giving the result of facts, which have come under our knowledge in the course of professional practice, and also of several experiments made with the express view of obtaining the requisite information; it is trusted, that it will be a sufficient excuse for any errors, when it is considered, that the path is almost an unbeaten one, and that little, except general observations, has hitherto been published.

The greatest care has been used in the prosecution of the different experiments, and the most minute details are given, in order that the reader may be able to judge of the credit to which they are entitled; our object has been to furnish practical data on the subject, and in doing so, not to assume any theory, or deduce any proposition, which is not supported by experiment; and if, in doing this, we have rendered the work less suited to the taste of general readers, or have fallen into prolixity in the details; we trust that it will be attributed to our desire of rendering the subject clear and familiar to the capacity of every one, whether acquainted, or unacquainted, with the technical phraseology of the enquiry.

It would be too much for us to assume that we have supplied all the information of which the subject is susceptible; on the contrary, we wish it to be understood, that what is herein contained must be considered only as an approximation. It will be sufficient, if what we have done be of use in the practical elucidation of this species of internal communication, and serviceable in establishing a more correct judgment of its nature and utility.

KILLINGWORTH, *April*, 1825.

INTRODUCTION

TO THE

SECOND EDITION.

At the period of the publication of the first edition of this Work, Railways were, so far as regards their application for general purposes, quite in a state of infancy.

With the exception of the Surry, and the Stockton and Darlington Railway, they had been almost exclusively confined to private purposes, for the conveyance of coals, lead, iron, &c., from the great coal, lead, or iron works. Being thus blended with, and forming part of a general establishment, though their utility to complete the operations of such works was never questioned, it yet remained to be proved, how far they were applicable and useful, as an independent and distinct mechanical process, for the purposes of general traffic.

The example of the Surry, which was a Tram Railway, tended to produce an unfavourable opinion, in this respect; and the Stockton and Darlington, though in a very advanced state, was not then brought into operation. Public opinion was, therefore, in an unsettled state, as to the value of Railways for such purposes, when the mania of 1825 brought every scheme, alike good, bad, and indifferent, before the public, and, amongst the rest, Railways. The re-action and languor which succeeded that year of excitement, involved Railways in the general gloom of hostility, produced against almost every scheme which had been agitated at that period; and few, if any, except the Liverpool and Manchester, were enabled to struggle through the mass of opposition, induced by such feelings, and the machinations of conflicting interests.

The success attending the Stockton and Darlington Railway, again, however, drew the public attention towards Railways, and dispelled many of the objections which were urged against their adoption for general conveyance.

In the mean time, improvements were made in every part of their economy; the establishment of coaches, dragged by horses, upon that part of the Railway between Stockton and Darlington, shewed that, to a certain extent, they were capable of being applied to the conveyance of passengers, as well as goods, but still they made little progress.

The great work of the Liverpool and Manchester railway, advancing towards completion, seemed, by a common unanimity of opinion, to be deemed as *the* experiment which was to decide the fate of railways. The eyes of the whole scientific world were upon that great undertaking; public opinion on the subject remained suspended, and hence its progress was watched with the most intense interest.

Though forming a branch of the subject of Railways of no ordinary importance, yet it is not necessary, perhaps, to pursue the history of the progress of that Railway further in this place. In the body of the work, that part which relates more immediately to the object of our enquiries, has, it is trusted, been exhibited and illustrated, in a sufficiently comprehensive manner, to make the reader fully acquainted with every scientific particular; and the brilliant description, in the work of Mr. Booth, furnishes a complete history of its progress and completion.

The experiments previous to, and the subsequent practice of that Railway, since the opening, have exhibited a result as astonishing as it is important. Not only has the question been decided, and in the most conclusive and practical manner, that Railways are fitted for the conveyance of general merchandize; but with the assistance of Locomotive engines, it has been proved that they are capable of effecting a rapidity of transit, greater than by any other practical mode of travelling. The greatest exertions have been used to accelerate the speed of the mails, (which have hitherto been the quickest species of conveyance,) without being able to exceed 10 miles an hour; and that only with the exercise of such destruction of animal power, as no one can contemplate with feelings except of the most painful nature; while, upon the Liverpool Railway, an average rate of 15 miles is kept up with the greatest ease; and, on an extraordinary occasion, nearly double that rate, or 30 miles in one hour.

Being therefore applicable, at greater rates of speed, than by any mode, not only for the conveyance of passengers, but also for general merchandize, has affixed a value to Railroads, possessed by no other single species of conveyance.

Uniting, then, the several qualities of being alike adapted for the transit of light and heavy goods, and the conveyance of passengers, will unquestionably lead to the substitution of railways for other modes, not possessing such properties, in all cases where the extent of traffic is such as to justify the outlay of capital, necessary for their formation.

The importance which, under those circumstances, attached to a correct knowledge of all the minutiæ of the construction, capabilities, and economy, not only of the Railway itself, but of the motive power to be used upon it; had, as previously stated, been sufficient to induce the author, at a former period, to present to the public such information, as their then state of improvement exhibited.

The preceding observations, shewing the rapid progress which Railways have made, since the publication of that edition, imply that very important changes must have taken place in their powers and capabilities. Considering, therefore, the necessity of a work, exhibiting the latest improvements, and bringing up the information to the latest period, the author has been induced to enter upon the revision of the former edition, which he now takes the liberty of presenting to the notice of the public.

In accomplishing this, the author has availed himself of every opportunity which his practice has afforded, of obtaining information on the subject; in addition to which, he has to acknowledge his obligation to several friends, from whom he has obtained very valuable information. These, together with numerous experiments made with a view of supplying, not only what was wanting in the first edition, but also of elucidating the various improvements which successive experiments elicited, form the principal additions to the former edition. The whole has been revised, and such parts only retained as appeared to be useful, in illustrating the progress towards the present state of improvement. The author is, however, afraid, that the detached way in which, at intervals of professional relaxation, this has been done, has, in many instances, produced repetitions, and in other cases obliged him to pass more hastily over subjects than he would otherwise wish. He has, however, bestowed all the attention which, under such circumstances, he was capable of doing, and he therefore throws himself upon the candour of the public.

KILLINGWORTH, *22d February* 1831.

INTRODUCTION

TO THE

THIRD EDITION.

THE increasing importance of Railway communication, and the anxiety of the public for information on the subject, has rendered it necessary that a third edition of this Work should be produced; and in offering it to the public, it is only necessary to state shortly the changes which have taken place since the period of the publication of the last edition.

In the Introduction to that edition, we stated that the result of the completion of the Liverpool and Manchester Railway was looked forward to, with great anxiety, as *the* experiment which was to decide the fate of Railways; that great work has now been completed, and in operation for seven years, and the success has been such as to exceed the expectation of its most sanguine projectors.

This Railway, having, therefore, as it were, been the creation of the system of rapid communication, and the company having had, in establishing that system, to contend with all the difficulties incidental to raising it from comparative inferiority to its present state of perfection; the experience elicited in the progress of this great work, exhibits such a mass of information, as would of itself form sufficient materials for another edition. But no sooner had the success of this Railway been established, than other great lines were projected;—the London and Birmingham, and Grand Junction Railways, forming a line of communication between the Metropolis and Liverpool and Manchester;—the Newcastle and Carlisle, forming a line of communication between the east and west seas;—the London and Southampton forming a line between London and the Channel;—all of which are partially opened, and in operation, and which will be shortly completed.

In addition, therefore, to the experience of the Liverpool and Manchester Railway, and those for the conveyance of minerals and heavy goods, in the North of England; we have all the information displayed in the formation of those great lines of Railway communication, together with several other lines in England and Scotland.

With the exception of some of the Railways in Scotland, all those lines have been constructed on the principle, and of the same width, as that of the Liverpool and Manchester Railway. In forming a line of communication, however, between London and Bristol, Mr. Brunel has constructed a Railway, of an increased width between the rails, and upon a principle essentially different from that of these other Railways, a portion of which has recently been opened to the public.

An historical, and descriptive, account of all the improvements made in the progress of these great works, not only in the construction of the Railways but in the motive power, and all the machinery used upon them; constitute, therefore, part of the additional matter presented to the public in this edition. Numerous additional experiments, made to elucidate the powers of Railways as a system of communication, are given in this edition, resulting from the increased opportunities, afforded by the different Railways now in operation.

In this edition also we have availed ourselves of the very valuable information given by M. Pambour, in his work on the Locomotive Engine; which contains a complete elucidation of the powers of that machine, and whose experiments are of the utmost importance in exhibiting the capabilities of the improved engines. Professor Barlow's experiments and calculations on the strength of rails have also contributed largely to our stock of information, which has enabled us to enter more into detail upon this part of the subject, than in the last edition.

Considering, from the experience of the Liverpool and Manchester Railway, that we had sufficient materials to justify us in entering into calculations of the expense of working Railways; we have in this edition gone into estimates of the cost of all the different charges of Railway conveyance, for both goods and passengers, and have given tables of the expenses, under various heads of charge, at different rates of travelling. We have also gone into the expense of conveyance by turnpike roads and canals, which we have compared with the cost of conveyance by railways, at the several rates of speed usually accomplished in the conveyance of heavy and light goods, and passengers, on these different systems of internal transport.

These additions have necessarily increased the size of the work considerably, but we trust the additional information will be a sufficient justification, and that, though not so complete as we could have wished, compiled as it has been at casual intervals, snatched from professional avocations, the work will be found generally useful on so important a subject as that of Railway communication.

KILLINGWORTH, 8*th June* 1838.

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I HAVE to acknowledge the important information obtained from the very valuable work of the Chevalier de Pambour, published by Mr. Weale, in 1836, which I have omitted to notice in the "Introduction" to this edition, particularly the basis of the Theory given in pages *555—577*, which has been derived from that work.

N. W.

A
PRACTICAL TREATISE
ON
RAILROADS.

CHAPTER I.

INTERNAL COMMUNICATION.

§ 1.—*Pack Horses.*

It is not necessary, perhaps, in a work of this kind, to enter into the history of internal intercourse, further than merely to glance at the introduction of the various kinds of wheel carriages, and the different descriptions of roads necessary for their use. Previously to the invasion of England by the Romans, articles of trade were transported from one place to another upon the backs of horses, and for many centuries subsequently thereto, we find the same mode of transport practised; even so late as the middle of the last century, almost the whole land carriage of Scotland, and of several parts of England, was conducted on the backs of horses, which were called "pack horses;" and we find, at the present day, in most of the mountainous parts of Wales, and in the Highlands of Scotland, the whole traffic carried on by the same means;—and even at this time, the only mode of transporting heavy goods from one place to another, in the mountainous countries in Europe and America, is on the backs of mules.

So long as the intercourse and traffic of the country was carried on in this manner, we may presume the roads were in a very rude state, and the greatest weight which could then be conveyed would be very limited, probably not amounting to more than two or three hundred weight, and in extreme cases to very little more. We may therefore easily imagine, how contracted the means of intercourse would be at that period, and the impossibility of carrying on any kind of traffic, except on the margin of the navigable rivers. A very striking instance of the restriction put upon the energies of a country, whose only means of internal intercourse was of this description, occurred with regard to the mines in the interior of South America, during the mania of speculation in 1825; it was supposed the only drawback to the prosperity of these mines was the want of proper machinery for drawing and working them. In more than one instance, massive castings of iron were sent out from England to supply this deficiency; but when landed on the shores of America, it was found, the only mode of carriage to the mines was on the backs of mules, which were of course quite incapable of carrying such heavy loads, and the machinery could not consequently be conveyed to the mines.

§ 2.—*Military Roads.*

The invention of forming hard and smooth roads, by covering either the natural or artificially prepared ground, with stones broken into fragments of a certain size, and similar to our present paving, is attributed to the Carthaginians.

The Romans acquired their knowledge from these people, and the famous Appian Way which they constructed about the year 442 of the foundation of Rome, is a proof of their industry in the formation of this species of road. It does not appear, that the numerous roads constructed by the Romans, were for the purpose of facilitating internal commerce;—their appellation "military roads," at once indicates the purpose for which they were intended.

The Romans, it is therefore probable, were the first who made any regular roads in Great Britain. For the purpose of facilitating the subjection of the inhabitants, and to secure a communication at all times between their armies occupying different quarters of the island, they formed what are now termed "military roads," which consisted of paths stretched across the country from one place to another, and paved with large stones. These were generally of very considerable lengths, and made to pursue a straight line from station to station, thus affording a hard, durable, and safe road; infinitely superior to the swampy, soft, and marshy paths indiscriminately formed in all parts of the country by its early inhabitants. Many of these roads are yet in existence in various parts; and, as may be expected, considering the purposes for which they were originally intended, they are very uneven and undulating.

The "military stations," or "watch towers," being generally placed upon the most elevated parts of the country, for the purpose of watching the motions of the enemy; these roads invariably avoid the more level parts of the country, and stretch from hill to hill.

The paved and hard roads of the Romans, would afford a comparatively good track for horses; but as the inhabitants advanced in civilisation, and commerce required the transportation of bulky articles, this mode of conveyance, would be inconvenient, and inapplicable to the purpose.

It is probable, the next advance of interior communication, would be the introduction of sledges, where the articles to be conveyed were placed upon a square frame of wood, which was dragged along by the horse; and when the goods were very bulky, the united efforts of several horses could be thus employed, which could not be done when it was laid upon their backs.

It is very uncertain at what period wheel carriages were first introduced into Great Britain; the war-chariot of the ancient Britons, formed a species of wheel carriage, but it does not appear that at that period they were used for the purposes of conveying goods.

The Romans would, no doubt, introduce many of the Eastern articles of trade, and of the arts; but such is the force of habit, that it appears, long after the invasion of the island by that people, the ancient inhabitants retained their native habits and customs.

By degrees, however, when civilisation reached a higher degree of perfection, and commerce became more extended, the occurrence of articles of trade or comfort, in the interior districts of the country, would enforce the adoption of some mode of communication suitable to the advanced state of the arts and manufactures; and the use of wheel carriages, where the weight that could be conveyed by a horse, would be considerably greater than either what he could drag upon a sledge, or carry on his back, would proportionably extend the facility of internal traffic.

On the first introduction of military roads, they were formed, by paving the track whereon the horses travelled with large stones, or with small pebbles and gravel arranged with peculiar care, and beat down by manual labour. The great lines of communication in England, or turnpike roads, have all been established and supported by legislative enactments, enabling individuals who advanced the money for the construction and repair of these roads, to be repaid, by levying tolls upon the traffic passing along them; all the district roads being kept in repair by a rate or tax upon the occupiers of the property in the district. Recently, all the roads in the country have been very much improved, by the adoption of a system of road-making suggested by the late Mr. M'Adam, by which the expense of keeping the roads in repair has been much diminished, and the resistance to the carriages very much decreased.

§ 3.—*Railways.*

The next alteration in interior communication, appears to have been the substitution of wooden railways, in place of the common or military roads; and these appear to have been first adopted in insulated districts, where the quantity of goods to be transported was considerable, and always over the same ground.

It is, however, very difficult to trace the precise date, when railways were first introduced into Great Britain.

Where the traffic was inconsiderable, and consisted of various articles, to be conveyed in numerous directions, the difficulty of forming roads suitable for all parties, and the expense of branching them off to all the different parts where the goods were to be carried, would operate to prevent the introduction of them, as a species of general communication.

The most probable supposition is, that the adoption of these artificial roads, first took place where the goods were of a uniform, and of a heavy description, and had to be conveyed to one place only, and where the quantity also was considerable. Continually passing along the same road, where perhaps the materials for upholding and keeping it in repair were expensive, might induce them to seek out some remedy; and it is not unlikely, that the laying down of timber, in the worst parts of the road, might tend to the introduction of wooden rails the whole distance. Such is the practice in Russia, and it appears to have been as ancient as civilisation in that country.

At the coal works in the neighbourhood of Newcastle-upon-Tyne, the expense of conveying the coals, from the pits to the places where they were to be shipped by sea, would be very great. Down to the year 1600, the only mode appears to have been by carts on the ordinary roads, and in some instances by "panniers" on horseback.

A record in the books of one of the free companies in Newcastle, dated 1602, states, "That from tyme out of mynd, yt hath been accustomed that all cole-waynes did usually carry and bring eight baulls of coles, to all the staythes upon the ryver of Tyne, but of late several hath brought only, or scarce, seven baulls." The cost of transporting such a heavy article as coal along common roads, which may be supposed would not be of the best description, in carts containing seven or eight bolls, would operate very powerfully, in accelerating the introduction of some improvement in the mode of conveyance, to lessen the expense.

In a work published at Newcastle, in the year 1649, by a Mr. Gray, called "A Chorographia," or survey, of Newcastle-upon-Tyne, the following account of the coal trade is given :—"Many thousand people are employed in this trade of coales ; many live by conveying them in waggons and waines to the river Tyne," &c. And in page 31 of the same work, he states, "Some south gentlemen hath, upon great losse of benefit, come into this country to hazard their monies in coale pits. Master Beaumont, a gentleman of great ingenuity and rare parts, adventured into our mines with his £30,000, who brought with him many rare engines not known then in those parts, as the art to boore with iron rodds, to try the deepnesse and thicknesse of the coale; rare engines to draw water out of the pits; waggons with one horse to carry down coales from the pits to the staythes on the river, &c.; within a few years he consumed all his money, and rode home upon his light horse."

Considering that the carts employed in conveying the coals were, in 1602, called "waynes," and the carriages introduced by Master Beaumont, "waggons;" and also, that ever since that period the carriages employed upon railroads have been designated by the latter name, we may infer, that the "waggon" of Mr. Beaumont was applied upon a railway, and that he was the first to introduce them into the North.

The date of the introduction of railways as a substitute for common roads at Newcastle would then be between the years 1602 and 1649; probably a considerable time prior to the latter period, as we find Master Beaumont had at that time expended his £30,000.

Whether they were used, in any other part of the country before this time or not, I have not had the means of ascertaining.

In 1676 they are thus described:—"The manner of the carriage is by laying rails of timber from the colliery to the river, exactly straight and parallel; and bulky carts are made, with four rollers fitting those rails, whereby the carriage is so easy that one horse will draw down four or five chaldron of coals, and is immense benefit to the coal merchants." *

At that time it is probable the road would be of the simplest construction, consisting of single rails fastened upon transverse sleepers stretched across the road. The

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* Life of Lord Keeper North.

following description is given of them in Jaa's Voyages Métallurgiques in 1765 (vol. i. p. 199):—"When the road has been traced at six feet in breadth, and where the declivities are fixed, an excavation is made of the breadth of the said road, more or less deep, according as the levelling of the ground requires. There are afterwards arranged, along the whole breadth of this excavation, pieces of oak wood of the thickness of four, five, six, and even eight, inches square; these are placed across, and at the distance of two or three feet from each other; these pieces need only be squared at their extremities, and upon these are fixed other pieces of wood well squared and sawed, of about six or seven inches in breadth by five in depth, with pegs of wood; these pieces are placed on each side of the road along its whole length; they are commonly placed at four feet distance from each other, which forms the interior breadth of the road."

This kind of railroad, shown in *Figs.* 1 and 2, *Plate I.*, was very imperfect, and had many disadvantages. Though probably, at first made of greater strength than necessary to support the weight, yet by frequent use, the rails would soon become reduced in depth, by the action of the wheels, and would break long before they were worn through. It would thus be necessary, that the rails should be often renewed; and as the road required to be always of the same width, the bearing section of the sleepers, by the frequent perforation of the holes, to fasten the rails down, would soon be rendered useless. Though much superior to the common roads, in point of economy, and of transit; yet the frequent renewal of the rails and sleepers, would be attended with considerable expense, not only of time, and labour, but also in the cost of the material.

The waste of timber thus occasioned, principally by the rail, when partly worn, being insufficient to support the weight of the carriages, and being therefore thrown away, would no doubt produce many attempts to remedy the inconvenience; and it is not improbable, but the addition of another rail, upon the surface of that which rested immediately on the sleeper, was the next improvement, thus forming what is called the "*double way.*" The upper rail, or that subjected to the action of the wheels of the carriages, could then be almost completely worn away, without affecting, to a great degree, the strength of that which supported the weight. (*Figs.* 3 and 4, *Plate I.*) This description of railroad appears to have continued in use for a considerable period, and was extensively used at the collieries of Northumberland and Durham, and also in other districts of Great Britain. The yielding nature of the material, especially when saturated with wet, would create very considerable resistance to the wheels, which, by sinking into and compressing the rails, would always form a rising surface, and thus impede the progressive motion of the carriages; still, a horse was enabled to convey a greater weight along a railway of this kind, than upon a common road. At that time we find eight bolls of coals, (equal to 17 cwt.) was the regular load, for a horse with a cart or wain upon the common roads, while upon the railroad, the general load for one horse was nineteen bolls, or about 42 cwt.

The formation of the railroad, would certainly be attended with considerable expense; but the advantages derived from the increased load would soon compensate for this, and also for an increase of expense in keeping up the rails. In general, the collieries were situated at a much higher level, than the depôt or places to which the coals were to be conveyed; consequently the railroads would mostly descend, in the direction of the load. Except levelling down abrupt undulations, little care appears to have been taken to make the road with an uniform descent; as, to this day, those which are in existence, show them to undulate very considerably. For many years after the introduction of the wooden railway, a waggon containing nineteen bolls, or about 42 cwt., was the universal load attached to a horse, and the road was levelled accordingly; the only desideratum being, it would appear, to enable a horse to convey that quantity.

In some parts of the road, where occasional acclivities occurred, which could not be levelled, or where sudden windings of the road were obliged to be made; thin plates of wrought iron were laid upon the surface of the rails, and fastened down with common nails, to diminish the resistance opposed to the wheels, and equalise the draught of the horse. This, no doubt, would be found a great improvement, not only in diminishing the friction, but also in preventing the rails from wearing. Yet we do not find the use of them much extended, beyond the above-named instances; probably, from the difficulty of keeping the plates fast upon the rails; as the nails, by the elasticity of the wood, would be constantly working loose, and occasioning a continual expense in keeping them right. Upon the whole, however, the use of such plates would, in many cases, be attended with considerable benefit; and might, had they not been superseded by the introduction of a different kind of road, have been much improved.

About this period, in all the extensive mining districts, we find canals the only system of internal communication for general traffic; and these by the indefatigable and enterprising genius of Brindley, assisted by other eminent engineers, were carried into every quarter of the island. Railways were thus confined to a very limited and subordinate sphere of action;—to short distances, or over uneven or highly inclined ground, where the number of locks required, precluded the use of canals. The attention of all scientific men, being thus absorbed in another species of conveyance, the subject of railways would be little attended to; and this, perhaps, will account for the slow progress made in the improvement of them, compared with that of the other mode of conveyance; accordingly, we find a long period intervene, after the introduction of wooden railways, before the application of any other material.

The diminution of friction, by the malleable iron plates, upon the wooden rails, is very likely to have suggested the propriety of using that material entirely; but we cannot find, that wrought iron was any where used alone, until within a very recent period. The next improvement, in the order of time, and also of importance, appears to have been the use of cast iron, as a substitute for the wooden rails; and, like the introduction of railways, though comparatively of a very modern date, the precise period of its first adoption is involved in mystery.

A late anonymous author says, without advancing his authority, "that, in 1738, cast-iron rails were first substituted for wooden ones; but, owing to the old waggons continuing to be employed, which were of too much weight for the cast iron, they did not completely succeed in the first attempt. However, about 1768, a simple contrivance was attempted, which was to make a number of smaller waggons, and link them together, and by thus diffusing the weight of one large waggon into many, the principal cause of the failure in the first instance was removed, because the weight was more divided upon the iron." (Trans. Highland Society, vol. vi. p. 7.) It is somewhat singular, when the failure of the attempt to introduce cast iron, arose from the want of strength in the rails, it should require thirty years to discover, that, with a lighter load, they could be made to answer. Mr. R. Stevenson of Edinburgh, whose inquiries into railroad conveyance have been pretty extensive, states, "I some years since visited the great iron-works of Colebrook Dale, in Shropshire, where cast iron was indisputably first applied to the construction of bridges; and according to the information which I have been able to obtain, it was here also that railways of that material were first constructed. It appears, from the books of this extensive and long-established Company, that between five and six tons of rails were cast on the 13th of November 1767, as an experiment, on the suggestion of Mr. Reynolds, one of the partners."

I think there is every reason to believe that the latter is the more probable term of the first introduction of cast-iron rails. In the first place, iron wheels were not used until about 1753, and at that time only very partially, and it was not until several years after that they came into general use; so long, therefore, as wooden wheels were made use of, we may suppose cast-iron rails had not been invented.

Mr. Curr, in his "Coal Viewer and Engine Builder," published in 1797, says, "the making and use of iron railroads were the first of my inventions, and were introduced at the Sheffield colliery, about twenty-one years ago." This would make the date of their introduction about 1776, which is subsequent to that of Colebrook Dale.

The next improvement was the introduction of malleable iron rails; about the year 1805 they were tried at Walbottle Colliery near Newcastle-upon-Tyne by Mr. C. Nixon; the rails were square bars, two feet in length, they were joined together by a half-lap joint, with one pin, one end of the rail projecting beyond the end of the adjoining one, two or three inches. Their use at this time was not extended, the narrowness of their surface, would cut and indent the periphery of the wheels of the carriages; and they were on that account superseded, by the cast-iron rails with a broader surface.

Mr. R. Stevenson of Edinburgh states, that malleable iron rails were first introduced at Lord Carlisle's coal-works, at Tindale Fell, Cumberland, in 1815. As above stated, they were used long before that period near Newcastle; he must also have been misled as to their introduction at Tindale Fell, as, according to Mr. Thompson, the present agent, they were laid down on that railroad in 1808.

The use of malleable iron rails was extremely limited until 1820, when Mr. John Birkinshaw, of the Bedlington iron-works, obtained a patent for an improvement of their form. Previously to this, their section was rectangular; and either the narrowness of their surface produced great injury to the wheels; or, by increasing the breadth, the sectional area was increased, and consequently their cost became so great, as to exceed that of cast iron, and thus cause the latter to be preferred. Mr. Birkinshaw produced a rail, which combined the same bearing surface as the cast-iron rails, with that form which likewise exhibited the greatest strength, and thus obviated the objections to the use of those rails. Various modifications of Mr. Birkinshaw's form of rail have since been adopted, but this principle of manufacture now forms the description of rails most generally used. Their safety, in rapid rates of travelling, renders the use of them almost indispensable; and they have, on that account, entirely superseded the use of cast iron, on all public railroads.

§ 4.—*Canals.*

Having thus given a brief history, of the introduction of railroads, as a species of internal communication; we shall now proceed to give, a short sketch of the introduction of canals, as another mode of artificial intercourse, for the purposes of commerce, and general traffic,

Canals, it appears, were used in Egypt, long before the invasion of Great Britain, by the Gauls; in China, their introduction, is said to have taken place, at a very early date. Their utility and extension, as a means of interior communication, would, however, be restricted to particular places, until the invention of locks, by which they could be extended into the interior of countries, of considerable elevation above the sea. It is somewhat doubtful, when this contrivance was first adopted, but it is certain, that locks were constructed upon the Milan canal, about the end of the fifteenth century; and that they were introduced into France, upon the canal of Briare, in the reign of Henry IV., and very extensively used in the canal of Languedoc, in the reign of Louis XIV.

The attempt, to form the Sanky Brook into a navigable canal, from the river Mersey to St. Helans, in Lancashire, in 1755, appears to have been the first of the kind in England; and since that period, they have been extended into almost every quarter of the island. Such was the rapidity of their extension in England, that, between the years 1760 and 1803, no less than 2295 miles of canal were opened.

Until very recently, canals have been used exclusively for the transport of heavy goods, merchandise, and passage boats, at a moderate rate of speed. Within a few years, attempts have been made to convey passengers at a quicker rate of speed, and, in some cases, apparently with success.

It is not necessary, here, to pursue the history of internal communication further, as we shall have to illustrate this more particularly hereafter. The benefits resulting to commerce, from a cheap and expeditious communication, between one place and another, for the conveyance of goods, being so very evident, need no comment; the importance has been discussed and admitted, by every political economist. In a manufacturing, and commercial nation, the facility of transporting goods from the place where the raw material is produced, either to the consumer directly, or to the manufacturer, and from thence to the consumer, is not only a subject of essential importance; but, next to the value of being able to manufacture cheaply, and in a superior manner, enables that country, where such facilities are afforded, not only to carry on a successful competition with other countries less favoured, but also to support a pre-eminence in the market, which is the great desideratum, in all commercial speculations.

If the importance of facilitating commerce, by a cheap and expeditious mode of conveyance required illustration, every political economist, who has written on the subject may, therefore, be quoted in support of it. This does not, however, come within the limits which we have prescribed to ourselves, in the present Work. It has already been discussed, in every shape, in the different periodical publications, and also in some works written expressly for the purpose. The only question which we have undertaken is, to ascertain, what species of internal communication, presents those conditions in the greatest perfection.

Without anticipating, at this early stage of the Work, conclusions, which can only be obtained by the result of ulterior deductions, derived from detailed observations, and experiments; it may be necessary, briefly to state, that the competition seems almost wholly to rest between railroads, and canals. It may be a question, in many cases, where the traffic and intercourse is inconsiderable, if railroads can compete with existing common roads, in the economy of conveyance of goods and passengers; but whether railroads be proposed to supersede canals, or common roads, it is alike a subject of the deepest importance, to be fully acquainted with their nature, construction, and the extent of their capabilities, as a mode of internal communication.

The sudden change in the public opinion, respecting the superiority of railroad to canal conveyance, may excite surprise in the minds of many; on more attentive consideration, however, it will be seen to result from the natural course of events, and to be what, from the nature of the two modes, might have been anticipated. No doubt, the capital and enterprize of the country, may have operated to accelerate the result; but the real cause proceeds, from the peculiar character and condition of the two modes.

At the time of the introduction of canals into Great Britain, railroads were in a state of relative insignificance, compared with the character, which they at present assume; like other arts, they have been gradually, and progressively improving; and, since the application of steam power, to drag the carriages upon them, and more particularly, since the discovery of producing such immense volumes of steam, so rapidly, with boilers so very small and portable, they have attained a feature of value, which entitles them to the most serious attention of the public.

Canals, ever since their adoption, have undergone little or no change; some trivial improvements may have been effected, in the manner of passing boats from one level to another, and light boats have been applied for the conveyance of passengers; but in their general economy, they may be said to have remained stationary. Their nature almost prohibits the application of mechanical power to advantage, in the conveyance of goods and passengers upon them; and they have not, therefore, partaken of the benefits which other arts have derived from mechanical science.

The reverse of this is the case with railroads; their nature admits of the almost unrestricted application of mechanical power upon them, and their utility has been correspondingly increased.

No wonder, then, that canals, which at one time were unquestionably superior to railroads, in general economy, by remaining in a state of quiescence, should at some period or other be surpassed by the latter, which have been daily and progressively improving, and that time has arrived. The human mind is generally averse and slow, in adapting itself to the changes of circumstances; and from this cause, the competition might not have been so speedily brought into action, had not the prosperity of the country, and the enterprise of its merchants, induced capitalists to seek out every source of speculation, affording the least prospect of success. The natural course of events would, however, soon have developed the real situation of the two modes in their respective relations to each other; and though the time might have been prolonged when railroads were to be brought into active competition with canals, yet its arrival would not be the less certain. One might be led to suppose, that the question could readily be solved by an appeal to facts, or by the comparison of particular canals with similar railways; but it is here, we presume, where the difficulty lies. We cannot, perhaps, find canals and railways whose external features are precisely the same; we are obliged, therefore, to have recourse to a comparison of general facts, or principles peculiar to each mode, which, again, cannot be accomplished unless we are fully and intimately acquainted, with all the various properties and characteristics of each system. The want of proper data was felt; and it was with a view of furnishing these that the present Work was undertaken; which, by a concise, and at the same time sufficiently explicit, description of the construction, uses, and advantages of railroads, together with an elucidation of the various principles of their action, might enable the reader to make a comparison with other modes of internal communication, and thus form a judgment of their relative value.

The present state of commerce requires, that goods should be conveyed from place to place with the utmost rapidity, and perhaps we owe no small portion of our mercantile prosperity, to our facility of despatch. The slow, tardy, and interrupted transit of canal navigation, must therefore, of necessity yield to other modes; affording a more rapid and certain means of conveyance, (especially when their relative economy is the same), unless they can be made to partake of the general activity, and additional celerity be given to the boats conveyed upon them.

At the time of the publication of the first and second editions of this Work, scarcely any experiments had been made on a large scale, to elucidate the capabilities of canal navigation,—none, certainly, satisfactory; since then, the competition of railways has aroused the dormant spirit of the canal proprietors, and various experiments have been made, to ascertain the amount of resistance of boats dragged at different velocities; attempts have been likewise made, to adapt the power of steam to propel the boats upon them, and other expedients have been adopted, to increase their activity, as a mode of traffic, and especially for the conveyance of passengers. So far as we are able, and with the information which a restricted inquiry has enabled us to acquire, upon the subject of so important a question; it will be our duty, to place those modes in competition with each other, before the public fairly and impartially.

CHAPTER II.

DESCRIPTION OF RAILS AND PROGRESS OF RAILROADS.

§ 1.—*Wooden Rails.*

The kind of railroad first introduced into England, was the wooden railway. *Figs.* 1 and 2, *Plate I.*, represent an elevation, and plan, of the wooden railway as originally constructed, or what was called the "single way;" *aa*, *aa*, are wooden rails, about four inches square, laid parallel to each other, upon the sleepers or transverse bearing rails, *b b*, *b b*. The mode of fastening them together, was by means of pins or pegs of wood, shewn at *c c*, holes being bored through the rail and sleeper, and the pins driven through the rail, and about half way through the sleeper.

The rails are generally six feet long, and the sleepers laid two feet apart; the ends of the two rails meet together upon the same sleeper, as at *c′ c′*; and the two pins being driven into the same sleeper, while they fasten the ends of the rail down, they likewise prevent them separating from each other. The surface of the road being levelled, to as nearly an uniform level, or slope as practicable, the rails were laid down, and the road material levelled, to the height of the upper surface of the sleeper, or to the lower surface of the rail.

To secure the free passage of the flanch of the wheels, along the sides of the rails, little or no road material could be laid above the level of the top of the sleepers; the action of the horses' feet soon, therefore, wore the sleepers through: added to this, the frequent perforation and insertion of the pins, through the same part of the sleepers, rendered them unserviceable. These defects led to the adoption of what is termed the "double way."

Figs. 3 and 4, *Plate I.*, are representations of this form of rail; *a a* are the rails fastened down upon the cross sleepers, *b b b b*, as in the "single way;" *a' a'*, rails laid upon those, and firmly secured to them by wooden pins, in the same manner as the rails of the single way are fastened to the sleepers. In the "single way" the joinings of the rails are, necessarily, upon a sleeper, as shown at *c c*, *Figs.* 1 and 2; but in the double way the upper surface of the under rail being quite level, the joining of the upper rail can be made in any part of its length, and not upon a sleeper. *c' c'*, *Fig.* 3, shows the joinings of the upper rail, midway between the sleepers; but this can be varied at pleasure, and consequently, prevents the under rail from being destroyed, by the frequent perforation of the pinholes in the same place, which was the great defect of the single way.

The sleepers of this, as well as of the single way, were generally formed from the young sapling or strong branches of the oak, obtained by thinning the plantations; and were six feet long, by four to five or six inches in thickness, and about the same breadth. At their first introduction, the under rail of the double way was generally of oak, but afterwards fir was substituted; they were generally six feet long, reaching across three sleepers, each two feet apart, and about five inches broad on the surface, by four or five inches in depth. The upper rail was of the same dimensions, and was almost always made of beech, or sycamore.

The surface of the ground being formed into the required level, or inclination, for about six feet in width from the pits to the staiths, or the whole length of the intended railroad, or "waggon-way," as it was termed; the sleepers were then laid down, two feet distant, and the under rail properly secured to them. The ashes or material, forming the surface of the ground, were then beat firmly against the under surface of the rail, for the purpose of strengthening it, and making it more rigid; the upper rail was then placed upon the other, and firmly bound down by the pins or pegs of wood, and the road material filled up to the height of the upper surface of the under rail.

This combination, had many obvious advantages over the single rail; for, independently of the waste of timber before described, by the frequent perforation of the pins, the destruction of the sleepers, in the single rail by the feet of the draught horses, was very considerable.

The double rail, likewise, by allowing the inside of the road, to be filled up with ashes or broken stones, to the under side of the upper rail; and consequently raising the path of the horses, four or five inches above the level of the sleepers, thus effectually secured the sleepers, from the action of the feet of the horses.

The use of wooden railways, has not been much extended in England, beyond that of the early stage of railway communication; as before stated, it was mostly used on the colliery railways, in the north of England, before the introduction of cast iron; and as it could not compete with that material, either in durability, or with the quantity of work which could be done upon it, the latter, or wrought iron, has almost entirely superseded its application, as a railway.

As previously stated, in some parts of the colliery railways, where the draught was heavy, a plate or bar of malleable iron, was laid along the upper surface of the rail, on which the wheels rolled; this plate was generally about two inches broad, and half an inch in thickness; and was fastened to the wooden rail, by nails counter-sunk into the iron bar.

This contrivance was adopted, however, more with a view of equalising the draught, upon the undulating surface of the railway, than as a distinct kind of railway; for we cannot find that, any entire line of railway was ever constructed of this description, but only those portions where any occasional increased inclination of the road existed: and although the addition of the plate of iron, tended in a great degree to form a rigid and smooth surface, and consequently diminished the resistance to a certain extent; yet the bar not being of sufficient thickness, a considerable bending took place, when the carriages were loaded, and the resistance was consequently very little reduced, below that of a well constructed double wooden railway.

In the United States of America, where iron is costly, and timber plentiful and cheap, a greater temptation exists for railways of this description, and we accordingly find that, a great proportion of the railways in that country, consist of timber plated with iron. The abundance and cheapness of timber has, however, enabled the Americans to improve this description of railroad, far beyond what it existed originally, or what the capabilities of England afforded. The sleepers of the American railroads, are generally made of white oak, from eight to ten inches broad, and ten inches deep; two parallel trenches are cut along the line of railway, and of a distance from each other, equal to the width between the rails; these trenches are filled with broken stones or gravel, on which the wooden rails are laid; similar trenches are cut across, and filled with broken stone, for the sleepers to rest upon. This foundation, for the rails and sleepers effects two objects; it not only acts as a drain, to keep the rails and sleepers dry, but the stones and gravel, being spread and levelled down to a firm and level surface, it forms a very considerable support to the rails. The scantling of the rails, are five to six inches broad, and seven to ten inches deep; they are not always fastened to the sleepers, with pins of hard wood; the outer side of the rail is squared vertical, the inner side inclined, making it wider at the bottom than the top; a notch is cut in the sleeper corresponding with this form of the rail, into which it is laid, and a wedge being driven against the outer side, presses the bevelled edge of the rail into the notch, and it is thus prevented from rising upwards. This plan was adopted on the railways in the State of Pennsylvania, where railways were first introduced into America. Another mode has been adopted in that state by Moncure Robinson, the sleepers are imbedded deeply in the ground, and thus protected from the feet of the horses and the action of the air; square blocks of locust or other durable timber are attached to them by trenails near their extremities, and projecting above them to the surface; the rails rest in notches cut into these blocks, as previously described, and are kept in their proper position by keys or wedges. In some cases, detached blocks of oak two feet square, are used to support the rails.

The bar or plate of iron, laid upon the top of the rails, is generally from two to two and a quarter inches broad, and half an inch, to five eighths of an inch thick; it is cut off obliquely at the ends, to prevent the jarring of the wheels, by square joints; and is fastened to the rails by iron spikes, mostly about four and a half inches long, which pass through oblong holes pierced in the bars eighteen inches apart. In some places, a small piece of sheet zinc, is placed beneath the ends of the iron rails, to prevent them sinking into the wood.

§ 2.—*Cast-iron Rails. Plate Rail.*

We have previously stated, that cast iron was first adopted for rails about the year 1767; *Figs.* 5, 6, and 7, *Plate I.*, shew the form of these rails, used by Mr. Curr for an underground railway, at the Duke of Norfolk's colliery near Sheffield, in 1776, and which were called the "plate rail." These rails, as shewn in the plates, consist of a flat bar of cast iron, *c e*, with an upright ledge, *c d*, for the purpose of keeping the wheels upon the line of the former; they were generally made six feet long, the flat part of the rail and upright ledge being each about two inches; near the ends of the rail small holes were cast in the base, through which nails or wooden pins were driven into the wooden sleeper shewn at *b′ b′*, the latter being generally of the same description, as those used in the wooden railway previously described in *Figs.* 1 and 2.

As shewn in *Figs.* 5 and 6, the joinings of the rails were quite square, two pins, *b′ b′*, being used at the joining, and one pin, *b*, at the intermediate sleeper.

Various forms of this kind of rail have been used, either with wooden sleepers, stretched across the whole breadth of the railroad, as in *Figs.* 1 and 2; or with square wooden sleepers, as shown in *Figs.* 5, 6, and 7, on which the rails were nailed.

In the year 1800, we are told that Mr. Benjamin Outram, an engineer, in adopting this rail on the public railway at Little Eton in Derbyshire, first introduced stone props instead of timber for supporting the ends, and joining of the rails.

Mr. Outram, however, was not the first who made use of stone supports, as the late Mr. Barns employed them, in forming the first railroad which was laid down in the neighbourhood of Newcastle-upon-Tyne, viz., from Lawson Main colliery, to the river, in 1797.

This kind of rail, has undergone many alterations in form, since it first came into use.

Fig. 8, *Plate I.*, is an elevation, *Fig.* 9 a plan, and *Fig.* 10 a section, of the most improved form of this kind of rail; *c c c c*, are the rails placed upon stone supports, as shewn in *Figs.* 8 and 9, at the ends of each rail, where they are laid against each other on the stone support; a small square piece is left out in casting the metal, increasing in size upwards, or bevelled, so that when the two ends are laid together, they form a square hole through the ends of the rail, narrowing downwards; a perfectly level, or horizontal groove is then made on the top of the stone, and the rail imbedded on it; a hole larger than the square hole of the rails is drilled into the stone about half the depth, into which is inserted a wooden plug, shewn at *g*, *Fig.* 8, and an iron pin, *b*, is then driven into this plug through the hole in the rails; which pin, having a bevelled head, fastens them down to the stone, one half of the pin securing one rail, and the other half the adjoining rail, as shewn in the drawing; these rails are generally from three to four feet long.

Fig. 10, is a section of the rail; *a d*, the base of the rail or wheel-track, about four inches broad and an inch thick, and which is made quite level; *d e*, the flange or upright ledge to keep the wheel upon the base, *a d*, of the rail; and *a f a*, *Figs.* 8 and 10, the flange projecting downwards to strengthen the rail. The upright flange, is the same height throughout the whole length of the rail, as shown in *Fig.* 8 or 10, being no higher than is necessary to secure the wheel upon the proper track, and which of course, requires no greater depth in one part than another; and the height adding to the friction of the carriage-wheels, it should therefore be made as low as possible; hence, we find it never exceeding three inches.

This restriction in the height of the upright ledge limits the form of the section, and renders it not that of the greatest strength, the resistance to fracture being, as the breadth and square of the depth; the horizontal part, *a d*, of the rail, while it adds to the weight and cost, does not in the same degree add to the strength; the upright section, *d e*, being the only part in that position, which presents the strongest form of section; this, however, as previously stated, being limited in height, a downward projection has been cast upon the opposite side of the bearing section of the rail, shewn by *a f*, *Fig.* 10, and *a f a*, *Fig.* 8. The form of this projection, as shewn in the latter figure, is such as to secure equal strength in every part of the rail, being deeper in the middle, *f*, and tapering away in a parabolic, or semi-elliptic form, in both directions, to the ends of the rail.

This form of rail, with very trifling modifications, constitutes the most modern plate rail; until very lately, they were universally made of cast iron, but about the year 1824, some were formed of wrought iron; and at present almost all the rails of this description, used in the collieries in the north of England, are made of wrought iron, rolled into the form shewn in *Fig.* 5.

These rails, have generally been laid down either upon transverse sleepers of wood, as in *Figs.* 5, 6, and 7, or upon stone blocks, as in *Figs.* 8, 9, 10; but they have been laid, in some instances, upon cast-iron sleepers, stretched across the whole width of the way. *Fig.* 11 shews a section and plan, of this kind of sleeper and rail; *a a a* is the base of the metal sleeper, a longitudinal cavity is cast at each end of the sleeper at *c c*, with a raised part on the inside, at *b b*; within this recess or cavity, the rail is laid, and a wedge being driven between the upright ledge, *b b*, and the back of the rail, it is thus secured to the sleeper. This plan has not been much used, the great expense of the cast-iron sleeper operating much against its adoption.

The great objection to the plate rail, is the friction of the wheels, against the upright flanch; and the liability of the bearing part, to receive the dust and mud of the road and wheels, which its form renders it peculiarly liable to, and of which no care can prevent the accumulation.

§ 3.—*Cast-iron Rails. Edge Rail.*

Soon after the introduction of cast-iron rails, a form of rail, called the "edge rail," was brought into use. Mr. W. Jessop, in 1789, formed the public railroad at Loughborough, with this kind of rail; the upper surface of which was level, and the under section, of an elliptical figure; and as the rail itself, did not present any means of keeping the wheel upon it, a flanch was cast upon the wheels, to guide them along the top of the rail.

In the wooden railways, the upper rails being convex on the surface, upon one side of the periphery of the wheels, a flange projected downwards, about an inch, which served to keep the wheels upon the rail; when the plate rail was introduced, the form of the periphery of the wheel was altered, being made quite flat and of less breadth; and again, when the edge rail was introduced, the rim of the wheel was brought back to the same form, as that for the wooden railway.

A A, *Fig.* 1, *Plate II.*, represents an elevation or side view; and B B a section of the edge rail. It consists of a bar of cast iron, from three to four feet long, and about one half or three quarters of an inch thick, swelling out at the upper part to two or two inches and a half broad, for the wheel to run upon.

These rails, when first used, were not secured upon the stone or wooden sleeper by a separate chair or pedestal; but had a flat base projecting outwards on each side at the end of the rail, through which square holes were cast, for the pins or nails to pass, to fasten them to the sleepers.

It is evident that this form of rail, combines the greatest strength with the least expenditure of material; the metal being disposed upright, it presents the greatest depth of section, in the direction of the stress or strain. The form first used was nearly a parallelogram. BB and CC, *Figs.* 1 and 2, *Plate II.*, will shew a section of a later form; the breadth of the upper surface, *a*, is about two inches and a half; after keeping this breadth a little way down, as shewn in the drawing, it is made to diminish gradually to three quarters of an inch, and finally to half an inch, near the bottom at c. This was the section of them for a long period, but they were subsequently made again to swell out at the lowest extremity, as shewn at cc *bb*. The lateral thickness of the rail, is generally the same throughout the whole length. The depth, as shewn in the elevation, is varied according to the distance from the supports; and thus the rail is of that form, which is intended to present the same strength, wherever the wheels of the carriage may be placed upon it.

The form of the chairs will be readily understood by a reference to the drawings, *Plate I.* and *II.*, and especially the enlarged section c c of *Fig.* 6; they consist of a flat base, *a a*, generally four inches, by seven, and about three quarters of an inch thick; the upper surface upon which the rail rests, being also flat and horizontal; from this base, two upright ledges, *r r*, are cast as far apart as the breadth of the rail, thus forming a sort of vaulted cavity, into which the ends of the rails are laid; holes are made near the ends of the rails, corresponding with similar holes cast in the chairs, through which iron pins are driven; these pins thus fasten the ends of the rails, to the upright ledges of the chair, and prevent their ends from starting upwards out of the cavity, and the sides or cheeks of the uprights, prevent the ends of the rail from moving laterally or sideways.

These chairs are placed, either upon stone supports, or square pieces of timber, which are firmly imbedded upon the surface of the road; when of stone, they have generally been from sixteen to twenty inches square, and eight inches deep; but upon the Liverpool and Manchester, and all the modern railroads, they have been laid down twenty-four inches square, and twelve in depth. When of wood they are from two to three feet long, ten inches broad, and four to eight inches deep; but in the colliery railways they are frequently made of old oak plank, obtained from the breaking up of old ships. In some cases, the wooden sleepers are made to stretch across the road, as in the old wooden railways. The mode first practised, of fastening the chair to the block, was by a circular hole being cast on each side of the base of the chair, and a hole of a similar size drilled into the block; an oak plug was then driven through both, which having a wedge-shaped head, and being dry when driven, secured the chair to the block or sleeper.

Such was the form of rail, and mode of securing it to the block, which was used in all the private railways, near Newcastle, for several years; when, however, the utility of railways became more known, and attempts were made to introduce them, as a mode of conveyance for general traffic, the public attention was directed to some of the defects known to exist in the private railways, and several improvements were suggested; we shall now point out some of these defects, and the plans proposed or adopted to remedy them.

To form a perfect and complete railway, the upper surface of the rail, should be made to remain always quite parallel with the inclination of the general line of road; when this is the case, the rails will form a continuous, smooth, and uninterrupted line, with the exception of the joinings of the rails; and if the joinings are neatly fastened together, and the ends of the rails well fitted to each other, the interruption to the continuity ought to be scarcely visible, and the carriage wheels in rolling along such a road will meet with little obstruction; and the friction or resistance consequently will be comparatively trifling. To accomplish the formation, and secure the permanence of such a perfect road, the surface of the ground, whereon the blocks or sleepers rest, should be first of all formed perfectly parallel with the general inclination of the line of railway, longitudinally, and perfectly horizontal transversely; it should likewise be perfectly firm, and hard, to prevent the blocks from sinking into it, so as to destroy its parallelism: the blocks should next be made, all of precisely the same thickness and size; and the chairs fitted precisely into the centre of the block; with all these perfections, and supposing the rail well fitted up, and firmly secured to the chair, and that the action of the carriages did not derange any of these requisites, or destroy the parallelism of the whole, we should then have a nearly perfect railroad.

We find in practice, however, that it is extremely difficult, if not impossible, to form the surface upon which the blocks rest, so perfectly uniform in solidity that it will not yield to the pressure, when the carriages come upon it, and allow the blocks to sink on one side or other, and then destroy their parallelism with the general line of road. Now, as the chair or pedestal, is immoveably fixed to the block, and partakes of its displacement, the sinking of the blocks causes the rails to form an undulating surface; and to correct this, recourse has been had to the mode of joining the rails to the chairs, to endeavour, if possible, to preserve the parallelism of the rails when the blocks sink.

In the old plan of joining, it is before stated, that the rails were fastened to the chair, by two pins passing through the sides of the chair, and through holes near the ends of the rail. In the chair, these holes are situated in a line, parallel with the base of the chair on which the rails rest; and in the rails, they are at equal distances from the top or bearing surface, or parallel thereto. The rails therefore either rest upon the flat base of the chair, or upon the pins. When the pins do not quite fill the holes, the rails will of course rest upon the chair; but if the pins are driven tightly through the holes of the rails, they will necessarily be supported by the pins; and in either case, the parallelism of the surface of the rails, will depend upon the parallelism of the base of the chair, with the line of the road.

If the surface of the ground, on which the blocks rest, be not of the same degree of firmness throughout, or the chair be not placed precisely in the centre of, and parallel with, the bearing section of the block, the weight of the carriages passing along the rail will displace the blocks, move them from their parallelism with the line of the road, and throw them down on one side, into the position represented at *c c*, *Fig.* 1, *Plate II.* This necessarily depresses one side of the base of the chair, and also one of the pins below the other, and consequently depresses the end of the rail fastened to it, below the line of the other, as shewn at *d d.* And this derangement of the rails will take place, whenever the line of the base of the stone does not correspond with the line of the road; and will be in proportion to the angle, the one forms with the other.

When the nature of the ground on which the blocks rest is considered, and also the difficulty of always compelling the workmen to bed the chair precisely in the centre of, and parallel with, the base of the stone, and also of obtaining stones of the proper form, it will not be wonderful that such a derangement frequently takes place; accordingly, it is found in practice extremely difficult to keep the rails in proper order, from the liability of the stones thus to fall down and depress the one end of the rail considerably below that of the other; in some cases, so much so, as to form a rising surface of considerable height, like that represented in the drawing, which is by no means a magnified representation of the derangement.

The evil arising from such projections need scarcely be stated, the shocks to the carriage wheels, the obstruction to the moving power, and the injury to the carriages, and the rails themselves, must be so very apparent as to need no illustration; and the necessity of remedying such a defect, if possible, so very obvious, as to strike in the most forcible manner any one at all conversant with the subject.

Various plans of chairs and of rails, were devised by different persons to remedy this defect, and in 1816 a patent was obtained for a form of rail and chair by William Losh, Esq., of Wallsend, and Mr. George Stephenson of Killingworth. A, *Fig.* 2, *Plate II.*, is an elevation, C, a section, and B, a plan of their patent rail, shewing the rails, *a a a*, connected with each other, fixed in chairs, and placed upon stone supports, similar to those for the other rails. The joinings of the rails with each other, are accomplished by means of what is denominated a half-lap, shewn at *e e*, the sides of the top of the rails being bevelled away near the ends, for about two inches and a half; so that when the two bevelled ends are laid against each other, they only form the same breadth of surface as the top of the rail in other parts; one pinhole, therefore, passes through the two ends, and a single hole being made in the chair, a strong iron pin is driven through the hole, which keeps the ends of the rails from separating: *d d* shews a plan of the chair, the half-lap extending the length of the chair, 1 2; *g* shews the pinhole, which passes through both rails. The base of the chair on which the rail rests, is shewn by the dotted line *i*, being convex; and the bearing or under surface of the rail being quite straight and parallel with the top of the rail, as shewn by the dotted line *h*; the rail thus rests on the apex of the curved base of the chair. The patentees state, "Our objects are, first, to fix both the ends of the rails or separate pieces, of which the ways are formed immoveable in, or upon the chairs or props by which they are supported; secondly, to place them in such a manner, that the end of any one rail shall not project above or fall below the corresponding end of that with which it is in contact, or with which it is joined; thirdly, to form the joinings of the rail with the pedestals or props which support them, in such a manner that if these props should vary from their perpendicular position in the line of the way, (which in other railways is often the case,) the joinings of the rail with each other would remain as before such variation, and so that the rails should bear upon the props as firmly as before; and the rails being applied to each other by what is called a half-lap, the pin or bolt, which fixes them to each other, and to the chair in which they are inserted, is made to fit exactly a hole, which is drilled through the chair and both ends of the rails, at such a height as to allow both ends of the rail to bear on the chair; and the bearance being the apex of a curve, they bear at the same point. Thus the end of one rail cannot rise above that of the adjoining one; for although the chair may move on the pin in the direction of the line of road, yet the rails will still rest upon the curved surface of the bearing without moving."

This plan of joining the rails was evidently a great improvement upon the common mode, and was therefore adopted on several new lines of road. The blows and shocks to which the carriage wheels were exposed, in the old plan of joining, were almost entirely exterminated in this; and the benefit was not confined to the carriages alone, for the reaction of those shocks was liable to break the rails in return.

The difference is very sensible, in passing along the two kinds of rails in carriages; on the one you travel smoothly along, with scarcely the least tremor of the carriage; but immediately you come upon the other, especially where it is not in good repair, a continuance of jolts and shakes is felt, as the carriage wheels successively pass over each joint. The injury caused to the carriages, though not immediately felt, yet by frequent repetition must eventually tend to shake them to pieces; the wear of the wheels of the carriages, also, by the blows, will be considerable.

Nothing, however, can be more decisive in estimating the benefits obtained by this mode of fixing the rails, than the diminution of the resistance opposed to the wheels of the carriages. Many practical examples could be adduced, where the difference has been found to be very great indeed, the projections acting as successive obstacles, to retard the progressive motion of the wheels, and which are to be surmounted at every joining.

Various modifications of this mode of fixing the rails, have been attempted; to describe the whole of them would be impossible. *Figs.* 3 and 4, *Plate II.*, shew two which are worth notice. In the first, the ends of the rails are square, similar to the old rails, at each end of the rail a semicircular hole is cast, equal in diameter to the pinhole in the chair, which, when the ends of the two rails are laid together, forms a circular hole, through which the pin is driven. The pin has no effect in fastening the rails together in the direction of their length; but as they cannot separate in that direction when laid down, the pin will prevent their rising up, being the only way in which they have a tendency to separate. *Fig.* 4 represents a mode of preventing the rails from rising up, without a pin; the ends of the rails are cast in the form shewn by the dotted lines at *d*, one end having a convex projection, which fits into a concave indentation cast in the end of the adjoining rail; the sides or cheeks of the chair keeping the ends always opposite each other, the projecting piece upon the end of one rail fitting into the concavity of the other, prevents the one end of one rail from rising above that of the other.

In all chairs of these forms which we have seen, the base whereon the rails rest is flat. In *Fig.* 3, if the rail rested or hung upon the pin only, the stone might then be depressed considerably, without materially affecting the joining, the stone turning upon the pin as a pivot or centre; but if the rail rests upon the flat base of the chair, this cannot take place, without subjecting the pin to considerable strain, and causing it to work loose.

Something of this takes place, though not to so great an extent, in the patent mode of Messrs. Losh and Stephenson; for if the pin completely fill the hole through the end of the rail and chair, which it is intended to do, the stone can only move upon the pin as a centre. If the rail then rest upon the apex of the curve of the chair, and the block becomes depressed on one side, the apex bearing of the chair is not at liberty to move round the pin as a centre, being prevented by the flat surface of the under side of the rail, forming a tangent to the arc it would describe; the pin in such cases must therefore, yield to the action of the weight, and consequently have a tendency to work loose, similar to the rail above described. This is, however, the only imperfection it has, for the overlap effectually prevents the distortion of the joinings of the rails; whereas in the other plans, the ends are liable to rise, and get out of the same plane. A B C, *Figs.* 5, *Plate II.*, is a plan of rail and joining, adopted by Mr. B. Thompson on the Brunton and Shields railway. In this plan, the chair has only one cheek or side, *a b*, and the rail is fastened to the chair by a screw bolt, *c*, by which a concave nut, *f*, is screwed against a convex projection on the rail, and this secures it to the single upright cheek of the chair. *k l*, shews opposite sides of this mode of fastening, *k* shewing the head of the nut on one side, and *l* the upright cheek and screw bolt on the other. The inconvenience of this plan in practice, is, that the thread of the screw becomes rusted by long exposure to the weather, and breaks off when it is attempted to screw the joints, in case they work loose.

Mr. Losh, in 1829, obtained a patent for a mode of joining, without the aid of a pin; in this mode, that part of the base of the chair whereon the rails rest is concave, the ends of the rails being convex. The rails are made with half-lap joinings, the end of one passing the other about three inches. A B C D, *Fig.* 6, *Plate II.*, shews an elevation, plan, and section, of this mode of joining; *a b* are the two ends of the half-lap of the rails joining each other, supposing them cut off at the middle of the half-lap; upon the outside of each rail a circular projecting knob, *c d*, is cast; on the inside of the rail *b*, a similar knob, *a*, is cast, fitting into a corresponding concavity on the rail *d*; when the rails are kept together, as shewn in the drawing, the knob *a* prevents the rails from being drawn asunder longitudinally.

The chair is made of the usual form, with upright cheeks, to keep the ends of the rails together; on each of the sides of these cheeks, a perpendicular cavity is cast for the purpose of receiving the knobs *c* and *d*, which keep the chair in the proper position; the weight of the rail, and their connection with each other, keeping them down upon the base of the chair.

The object of all railroads being, as before stated, to present to the wheels of the carriages, a smooth, straight, and level surface; all depressions or displacement of the rails therefore, defeat the object for which such a road is formed. The nature of the foundation upon which we have generally to form a railway, renders this a task of no ordinary difficulty; perhaps it is almost impossible to form an absolutely perfect railway, according to the above principles. We must, therefore, endeavour to approximate as nearly as possible towards such a perfection; two modes of effecting this suggest themselves, either to form the joinings of the rails to the chairs, in such a manner, that the stone supports can adapt themselves to the yielding of the foundation, without disturbing the parallelism of the rail; or, that the stone supports be made of that size, and be so imbedded upon the foundation, that the weight of the carriages shall not be capable of disturbing them; in which latter case, the joinings of the rails to the chairs must be such, that the action of the carriages has not the power of deranging the continuity of the rail. To carry the former of these modes into practice, and to preserve the continuity of the rail with ease and freedom, the stone should be capable of moving round, or assuming any degree of inclination, to the line of the road that might occur in practice, without straining either the pin, or distorting the ends of the rails. To effect this, if the pin be made the centre of motion, the under side of the rail should be a portion of the circumference of a circle, formed from the pin as a centre; the base of the chair, could then be either the apex of a curve, or a circular cavity corresponding with the exterior semicircular surface of the rail; the stone might then be depressed on either side, without straining the pin or deranging the joints. Or, we might otherwise make, the bearance of the rail upon the chair or pedestal, the centre of motion; in such case, the pinhole should be a circular slit or opening, formed from the bearing upon the chair as a centre; the pin being made exactly to fit this cavity in a perpendicular direction, would prevent the rails from starting upwards out of their proper position, and the semicircular slit would allow it to turn longitudinally; when the stone became depressed towards one side or the other, the chair could then move round, without injuring the pin or deranging the joints of the rails. The form of chair, *Fig.* 4, nearly partakes of these properties, without a pin, if the bearance of the rail upon the chair, had been upon a point instead of a flat surface,—for the chair could then move upon such point, without affecting the joinings of the rails,—but in that case, the ends of the rails should form an over-lap; or, if the rails rested upon the top of the chair, and the top was of a circular form, described from the middle of the chair as a centre, the bearance of the rail on the middle of the chair, being the apex of a curve, the same effect would take place.

Innumerable forms of joinings might be devised, every one of which might, in some degree, effect the purpose intended; the essential consideration being, to secure a continued and permanent parallelism in the rails, under every derangement that may take place of the supports on which they rest.

It is not enough that the bearing be such, that the rails are all in the same plane, when the blocks on which they rest are in good order, or in their proper position, parallel with the line of the road; the parallelism of the rails should be preserved, when, by the yielding of the ground, or from any other cause, the blocks are displaced from their proper position, and are made to form a considerable angle with the line of the road. It would not have been necessary to have been thus diffuse on this point, had we not found that several even of the most modern forms of chairs were evidently formed contrary to this principle, many with a view of causing the mode of joining to keep the support or stone in its proper position, rather than allowing it to adapt itself to the unavoidable yielding of the ground on which it rests; but the least consideration will evince the futility of this, especially when the yielding of the ground causes the stone to rest entirely on one side: it will at once be seen, that when the carriages come upon the rails, something must yield and give way, by the great strain thrown upon the fastening, from the oblique action of the weight; but as we shall again have to revert to this subject, when treating on the formation of railways, we shall not enlarge on it further in this place.

§ 4.—*Malleable Iron Rails.—Edge Rail.*

We have previously stated, that malleable iron rails are now exclusively used on all public lines of railways; it will, therefore, be of great importance, to give a sketch of the successive improvements, made in that description of rails, down to the present period.

At the first introduction of malleable iron rails, they were simply a rectangular, or flat bar of iron, from one to two inches square; or of that breadth, and three inches deep,—the length various. Being very narrow they cut the wheels much, especially, as at that time case-hardening the wheels of the carriages was not invented; and when the bearing surface was made broader, the weight and expense became greater than cast iron; and hence for some years they were very little used.

To remedy these defects, and at the same time to secure sufficient strength, Mr. Birkinshaw, of Bedlington Iron Works, in October 1820, obtained a patent for an improved mode of rolling railway bars. This patent consisted of a mode, of manufacturing or rolling, bars of iron, into a similar shape to that of the most improved form of cast-iron rail. A, B, C, *Fig.* 7, *Plate II.*, represents this kind of rail; A, being an elevation, B, a plan, and C, a section; the form of this, it will be seen, does not differ materially from that of the most improved plan of the cast-iron rail. These rails are formed by passing bars of iron, when red hot between two rollers, one of which has a groove in its periphery corresponding with the intended shape of the rail; and being fixed on a false centre, the under side of the rail is rolled as nearly as possible into the outline of a true ellipse; and indeed expert workmen, by cutting out the groove correctly, can form it perfectly true. This mode of rolling bars or rails, giving them not only an elliptical figure on the under side, but likewise producing a lateral swell, as at 1, 2, is very ingenious; and has led to the extension of the use of wrought iron, in many cases where the simple form of rolling it heretofore rendered it inapplicable. The elliptical form thus produced, was considered at the time it was accomplished, to be a very great improvement in this description of rail, and to remedy that defect in its shape, as compared with the cast iron, which existed when it could only be manufactured in the form of rectangular bars.

These rails are generally rolled into lengths of fifteen feet, subdivided into bearing lengths of three feet each; eighteen feet lengths were recommended by the patentee, but experience has shewn that the former are the most practicable.

The joinings of the ends of these rails, were at first square at the ends, similar to the old cast-iron rails; but they are now formed with a half-lap, as shewn in B, *Fig.* 7, and thus they now possess all the properties of the improved cast-iron rails.

A, B, *Fig.* 8, shews an elevation and plan, of the rail originally laid down by Mr. Stephenson upon the Liverpool and Manchester railway. These rails were in lengths of fifteen feet, subdivided into bearing lengths three feet apart, and weighed thirty-five pounds per yard, and were made with square joints. C and D are sections of the same rail, the former through the middle of the three feet lengths, and D, near the joint of bearing in the chair. On the one side, *c*, of the rail C, the lateral swell was continued throughout the whole length of the rail, but on the other side, *d*, it was made to terminate before reaching the point of bearing, and thus forming sections, as shewn in the figures. E, being a section through *a b*, or at the joint, shews the mode of joining the rails to the chair or pedestal; on one side of the chair a cavity is cast, corresponding to the lateral projection on the rail; on the other side of the chair a similar cavity, *d*, is cast, for the purpose of receiving an iron key; when the rail is laid into the chair, the key is driven longitudinally into the cavity *d*, and being wedge-shaped; it presses against the side of the rail, forces the projection *c*, into the cavity on the opposite side, and effectually prevents the rail from rising upwards out of the chair.

Figure E, likewise shews the mode of fastening the chair to the block, *k k* is the block of stone, two feet square and twelve inches deep; two large holes, two inches diameter, are drilled into the block, and wooden plugs, represented by *n n*, are driven into these holes; the wooden plugs are bored with a three-eighth inch auger, and iron pins, *o o*, half an inch diameter, are driven into the plugs, which secure the chair to the block.

A B, *Fig*. 9, represents the rail laid down upon the Garnkirk railway, near Glasgow; which, it will be seen, is nearly the same section as that of the Liverpool and Manchester railway; the keying, and mode of fastening the chair to the block, being likewise similar, as well as the plan of wedging the rail to the chair.

A B, *Fig*. 10, *Plate II.* is another form of rail, which has been made the subject of a patent by Mr. Losh. In the preceding figures, the under side of the rail, within the chair, and likewise that part of the chair whereon the rail rests, are parallel with the top of the rail; and although, when the key is driven against the side of the rail, if the parts are well fitted, it prevents the rail from rising upwards, yet the key has no tendency to tighten the rail down into the chair, especially when the projecting part of the rail does not fit tight into the longitudinal cavity of the chair. In Mr. Losh's plan, the key, being slightly tapered vertically, or of a wedge form, when driven presses against the chair on the upper side, and thus wedges the rail downwards into the chair; the key, being likewise tapered laterally, presses the rail sideways into a longitudinal recess on the other cheek of the chair, similar to the Liverpool pattern. This plan of keying, is a great improvement, as when the keys work loose, by driving them, the rail is again wedged downwards into the chair; whereas, in the other plan, when the *base* of the rail works loose in the longitudinal cavity of the chair, no driving of the key can again effectually tighten it. This principle of keying, has been adopted on the Newcastle and Carlisle railway; with this difference, that, instead of one side of the rail being merely pressed into the cavity of the chair, as shewn at E, both sides are keyed in the same manner; E, *Fig.* 10, shews this mode of keying, which has been found to effectually secure, and steady the rail into the chair. When wrought-iron rails were first introduced, the mode of fastening the rails to the chairs was by means of pins, driven through the cheeks of the chair and rail, similar to the single lengths of cast-iron rails. Experience, however, soon proved that there was a great difference in the practical effect between the two kinds of rail; each bearing length of the cast-iron rails was an independent one; not so with the fifteen feet lengths of wrought-iron rails, having five bearances. The expansion, and contraction of the rails, by the varieties of temperature, the action of the wheels of the carriages, and the inequality, and yielding of the railway itself; all tend to cause a working of the joints of the long lengths of rails; and consequently, pins were soon found to be quite inadequate to keep the rails in order. The mode of keying adopted in *Figs.* 7, 8, and 9, tends to remedy this evil to a certain extent, but does not do so effectually; the keys in those rails and chairs, it will be seen, act entirely by the friction of their surfaces, in fastening the rails down; the operation of the several causes above enumerated acting imperceptibly upon the keys, produces a working of them, and they soon become loose; and it only requires a minute inspection of the different railroads so constructed, to observe that, after a few years experience, almost all the keys and ends of the rails at the joints are loose; and that no renewed keying, operates in keeping them long in a firm state.

To remedy the defect of the keys working loose, and under an impression that, if the ends of each length of rail could be firmly keyed into the chair, it would materially add to the strength of the rail; Mr. Losh projected a rail, for which he procured a patent, the form of which is shewn in *Fig.* 10. The subject of this patent consisted in rolling a projecting convexity, or knob, upon the rail at each of the bearances, as shewn at *b b*, and which fitted into a corresponding concavity in the chair. The effect of this plan of rail is, that when once keyed firmly into the chair, any expansion or working of the rail at the joints, tending to separate the two ends, only operates in tightening the keys; as when any force acts longitudinally upon the rail to separate the two ends, it must cause, or have a tendency to raise the rail vertically, to allow the convex knob to rise out of the concave base of the chair; but the action of the wedge is directly opposed to this, and consequently, the greater the force tending to draw the rails asunder, the greater will be the effect of the wedge in keeping the rail down in the chair; for so long as the wedges act, it will be impossible to draw the convex projection of the rail out of the concavity of the chair, and by keeping the rail firmly fixed to the chair, any longitudinal working of the rail is prevented. Mr. Losh further attempted to make this plan of rail, and mode of keying, adapt itself to the yielding of the blocks; the upper side of the longitudinal cavity of the chair, into which the key is driven, instead of being parallel with the bead upon the rail, is made a curve, as shewn at *c d*, *Fig.* 10; the key therefore, while it presses against the bead of the rail along the whole length on its under side, is only wedged against the apex of this curve on the upper side; and this curve, as well as that of the convex projection and concave base of the chair, having the same radius, the chair is at liberty to move round to such an extent, as to adapt itself to a slight yielding of the blocks.

These rails are formed with a half-lap joint, as shewn in B, and the base of each rail at the joints is laid to one side, as shewn by the dotted lines; by which a greater breadth of bearing on the base of the chair, is obtained, than if the half-lap was formed by cutting through the middle of the vertical section of each rail.

This form of rail has been laid down upon the Newcastle and Carlisle railway, E, *Fig.* 10, *Plate II.*, shewing a section and the mode of keying, with a key on each side of the rail; the weight forty-two pounds per yard, and the supports three feet distant. The experience upon this railway shews, that this mode of keying keeps the rails more firmly into the chair than the common mode. The chair in *Fig.* 9, *Plate V.*, shews this mode of keying on a larger scale. The form thus described has been called the "fish-bellied rail;" soon after its introduction another form of rail was made, the upper and under surfaces of which, being parallel to each other, has, in contradistinction to the other form, been called the "parallel rail:" *Fig.* 1, *Plate III.*, represents this form of rail, A B, being elevations, C D, plans, and E F, sections.

As considerable difference of opinion exists amongst engineers, and scientific men, as to the comparative merits of these two forms of wrought-iron rails, and the question being of greater importance in railway economy, we shall make it the subject of a separate chapter; together with the consideration of the proper section, and the comparative strength of the different sections of rails; and shall therefore, at present, describe the different rails adopted upon some of the principal railways already laid down.

§ 5.—*Malleable Iron Rails—Different Forms of Rails.*

Fig. 1, *Plate III.* is the form of rail laid down on the Clarence railway, in the county of Durham; A C, being the elevation and plan, of a portion of the rail, at the intermediate bearing, and B D, at the joint-bearing. F, is a section of the rail itself, the dimensions of the different parts of it being shewn in the plate. E, is a section of the rail and chair, shewing the plan adopted of keying the rail to the chair. One side of the chair is cast to fit the side of the rail, the other side is plain, but a little bevelled at the bottom; a cast-iron wedge, one side of which fits the plain side of the chair, and the other side cast to fit the section of the rail, is driven between the two, and which, pressing the rail firmly against the opposite side of the chair, the rail is prevented rising upwards by its bulbed base; and the bevelled side of the cheek of the chair and wedge gives the action of the wedge a downward tendency; wooden wedges have in some cases been used instead of cast iron. *Fig.* 2, A B C D, is the form of rail laid down upon the St. Helens and Runcorn railway, in the County of Lancaster. This rail varies from the Clarence, in the section of the base of the rail, which in this rail is semicircular, instead of being circular; the plan of keying is likewise different, and is certainly superior. The action of the wedge of *Fig.* 1. being sidewise, does not tend to press the rail downwards into the chair, except obliquely and on one side; in *Fig.* 2, both sides of the chair being bevelled, and the upper side of the base of the rail being horizontal, when the wedges are driven they act with a vertical and direct pressure upon the rail, to force it down into the chair; and there being a wedge on both sides of the rail, it is kept more steadily within the chair. The weight of this rail is forty-two pounds per yard, the distance of the supports three feet. Fig. 5, is a plan of rail laid down upon the Loire railway by Mr. M'Mellet et Henry, by which it will be seen that, the effect of the wedge is to press the rail against the opposite cheek of the chair, similar to the Clarence rail; but in this, the upper side of the wedge acts against a square projection on the side of the chair; these rails weigh about twenty-eight pounds per yard, the distance between the supports being thirty-three inches.

Fig. 6 is the plan of a rail projected for another French railway, — the proposed Paris and Pontoise railway. The section of this rail differs materially from that of *Fig.* 5; the wedge is likewise different, having a bead cast on the cheek of the chair, against which the wedge acts to press the rail against the chair, and to force it downwards.

Figs. 3, and 4, are plans of a different description of rail from the preceding; in both the fish-bellied, and parallel rails previously described, the rails are made to rest upon stone blocks, or upon cross wooden sleepers, and having no supports except at each length of rail, they are required to be of adequate strength to support the weight of the carriages, without any assistance from the block or sleepers between the points of bearing. In America, where timber is very plentiful and cheap, and where iron is dear, and stone in some parts difficult to obtain, a different principle rail has been adopted; longitudinal blocks of timber, or wooden rails, similar in every respect, except in the dimensions, to the single wooden way, *Fig.* 1, *Plate I.*, are first of all laid down, and then either common iron bars are laid upon these sills, as previously described, or longitudinal rails, rolled to a particular form for the purpose.

The longitudinal wooden rails, on which the iron rails are placed, are from eight to nine inches broad at top, with a base increased to ten or twelve inches; and these longitudinal sills are placed either upon cross sleepers, similar to those used for the wooden railways, or upon square blocks of hard wood. The iron rails, having a broad base, being laid upon these sills, meet with considerable support from them, and their vertical section is not, therefore, required to be so deep, as when the rails rest upon detached blocks or sleepers.

Fig. 3 is a plan of rail, laid down on some of the railroads in the United States; with this rail, chairs are dispensed with, the base of the rail being very broad, and being laid upon the longitudinal sills, is fastened to them by the clamps, *c* and *d*, which are driven into the wooden sills. *Fig.* 4 is a variation of the same description of rail, which is fastened down to the sills by a single clamp. In the former of these, the heads of the clamps bend over the edge of the base of the rail; but in the latter, the clamp passes through a hole in the base of the rail; in some cases, these rails are fastened down by clamps, passing through both sides of the base of the rail. The direction of these clamps, is not vertical, but a little oblique. These rails weigh from thirty-five to forty pounds per yard.

From the great quantity of material, disposed in the base of the rail, this form of section is not so strong as the preceding figures of rails; but as they rest upon the wooden sills throughout their whole length, they are, of course, much strengthened, and are found in practice to be sufficiently rigid.

Fig. 7, is the fish-bellied or elliptical rail, some of which have been laid down upon the London and Birmingham railroad, by Mr. Robt. Stephenson; these rails weigh fifty pounds per yard, and are laid with bearings three feet apart. A, is the elevation, B, the plan, and C, the section. The joints are half lapped. The mode of fastening the rail to the chair, is different from any previously described, and is the subject of a patent by Mr. Stephenson. The rail fits the chair as nearly as possible, leaving no space for side vibration; the only object, then, is to force it down into the seat of the chair. Mr. Stephenson states that, when the key is in contact with, or is made to act directly against, the rail, the working and vibration of the latter, by the carriages travelling along; and the expansion and contraction of the rail, by the change of temperature, all tends to cause the key to work loose. To obviate this, he interposes a pin between the key and the rail, which counteracts the effect of the shaking and vibration of the rail upon the key, and prevents it from working loose. *d*, *Fig.* C, is the pin which passes through the chair, shewn likewise in B; through this pin, at *a*, is an oblong hole, with a similar hole passing longitudinally through the chair; a key, shewn at *b b*, *Fig.* B, and nearly filling the hole through the chair, and tapering towards one end, is driven through the chair, which, acting upon the pin, forces it against the rail. This pin is sharp-pointed; and when the key is firmly driven, the pin can be wedged into the rail with such force as to indent itself into the rail. In practice, we are told, this mode of joining answers very well.

Fig. 8, is the parallel rail, laid down upon the London and Birmingham railway, and weighing sixty-five pounds per yard; and which is likewise the section of rail laying down upon the Grand Junction railway by Mr. Locke. These rails are secured to the chair by a wooden key, *a a*, *Figs.* B and C. One side of the chair is bevelled vertically, against which the wedge acts, and pressing against the upper side of the base of the rail, forces it downwards, into the chair, while it, at the same time, forces the rail against the other cheek of the chair. These keys are made of oak, and well dried, so that when driven, and exposed to the humidity of the atmosphere, by expanding, they act with very powerful effect in fastening the rail to the chair; so much so as, in some cases, to split the chair. The plan B, of *Fig.* 8, shews the form of the wedge, *a a*, longitudinally; by this it will be seen, that the side of the chair is convex; when, therefore, the wedge, being quite dry, is driven between the rail and chair, and expanding by the damp of the atmosphere, it is very tightly compressed by the convexity of the chair, which produces a corresponding expansion at the ends, and thus fastens the wooden wedge so securely, that not the least working takes place between it and the rail or chair. This key has, of course, no tendency, except the mere friction or pressure of its sides, to prevent the ends of the rails at the joint, from separating.

Having thus described almost all the different modes of keying the rails to the chairs, adopted on the great lines of railway, now in operation; we shall now give sections, on a large scale, of rails of different weights per yard, either already in use, or about to be adopted on some of the principal railways in this country, and upon several of which experiments have been made, to ascertain their comparative rigidity.

Fig. 9, *Plate III.*, is a section of a parallel rail by

Mr. Daglish, and for which he obtained a premium, by the London and Birmingham railway company, as being the best section of rail produced. The figure shews part of the chair, with the mode of keying; this is done by two semicircular keys, tapered towards the ends, the dotted lines shewing the section of the keys, at the opposite side of the chair from that shewn in the plate, the keys being driven from opposite sides. This is the section of a rail, weighing fifty pounds per yard.

Fig. 10, is the section of an experimental fish-bellied rail, rolled by the Newcastle and Carlisle railway company, for the purpose of ascertaining the comparative rigidity of this kind of rail, and parallel rails of the same weight per yard; the weight of this rail was about fifty pounds per yard. The figure shews the extreme depth, and the dotted line, *a b*, the smallest depth; the longitudinal section was similar to *Fig*. 10, *Plate II.*, with convex bearings.

Fig. 11, is the section of the parallel rail, rolled for the purpose above described, the weight of which was as nearly fifty pounds per yard as it could be rolled; the area of the wearing or top part of the two rails is precisely the same, as likewise the breadth of the base; but they differ in the depth and thickness, of the middle part of the rail.

Fig. 12, is the section of a parallel rail, used upon the Liverpool and Birmingham, or Grand Junction railway, and weighing about sixty-two pounds per yard. The top and base of this rail are the same section, and it differs in little respect, from the section given in *Fig*. 8; the mode of keying is the same.

Fig. 13, is the section of a rail, used on the Dublin and Kingston railway, and which is likewise a parallel rail, and weighing about forty-five pounds per yard.

Fig. 14, is a fish-bellied rail, made by Mr. Stephenson, and weighing about forty-four pounds per yard. The entire section on the drawing, shews the extreme depth in the middle, and the line *a b*, the depth at the bearing parts. This rail does not swell out at the base, being intended to be keyed into the chair, in the same manner as shewn at C D, in *Fig.* 7.

Fig. 15, is the section of a parallel rail, of the weight of fifty pounds per yard, a few of which are laid down on the Liverpool and Manchester railway.

Fig. 16, is the section of a rail intended for the Great North of England railway, designed by Mr. Story, the weight of which is about sixty pounds per yard. This is likewise a parallel rail; the mode of keying this rail differs from any of the preceding plans, and is shewn in *Figs.* 6 and 7, *Plate V.*, *Fig.* 6 being a section, and *Fig.* 7 a plan. One side of the chair is cast to fit the rail; on the other side of the chair, a loose intermediate wedge slides between the cheeks of the chair, shewn at *e*; this intermediate wedge is keyed against the rail, by the driving key, *f*, which may be driven with any degree of tightness; the intermediate key prevents the vibration of the rail from loosening the key, *f*. This chair, it will be seen, has four pins to fasten it to the block.

Fig. 17, is the section of a parallel rail, laid down on the Liverpool and Manchester railway, and weighing sixty pounds per yard. In all the preceding figures of rails, both sides of the top or wearing part of the rail, whereon the wheels roll, is the same; but as it is only on one side of the rail, that the flanch of the wheel rolls against it below the plane of the top of the rail, the wheel on the other side rolling along the plane of the surface, it is evident, that there is no necessity to have both sides the same. Mr. Booth has, in this case, made that side of the top, acted against by the flanch of the wheel, of the same outline, as that part of the wheel; while, on the opposite side, the section is at right angles to the plane of the top. This plan, however, prevents the rail from being turned, with the opposite side to the flanch of the wheel, which it is sometimes found requisite to do.

Fig. 18, is a section of the thirty-five pounds per yard fish-bellied rail, originally laid down upon the Liverpool and Manchester railway; the entire figure shewing the extreme depth in the middle, and the line *a b*, the depth, in the bearing parts of the rail; the mode of keying this rail is shewn in *Fig.* 8, *Plate II.*

Fig. 19, is a section of a fifty pound per yard elliptical, or fish-bellied rail, laid down on the Liverpool and Manchester railway: the section of this is nearly similar to the preceding figure, except in the area, and weight: the keying is precisely similar; the line *a b*, shews the depth at the bearings.

Fig. 20, is a parallel rail, weighing seventy-five pounds per yard, and laid on the London and Birmingham railway. The mode of keying is similar to that shewn in *Fig.* 8; the distance of the supports, five feet.

Fig. 21, is the section of the parallel rail, laid down upon the Liverpool and Manchester railway, weighing seventy-five pounds per yard; the top of this rail is made of the shape explained in *Fig.* 17.

Fig. 22, is another sixty pounds per yard parallel rail, which has been laid down upon the Liverpool and Manchester railway.

Fig. 23, is the section of the rail, laid down upon the Newcastle and Carlisle railway, it is an elliptical or fish-bellied rail, of the plan of Mr. Losh's patent, shewn in *Fig.* 10, *Plate II.*, with a convex projecting knob, at the bearing points. The entire figure in the plate shews the extreme depth of section at *a′ b′*, *Fig.* 10. *Plate II.*, and the line *a b*, *Fig.* 23, *Plate III.*, the depth near the knob, the latter swelling out the depth of half an inch more within the chair. These rails weigh forty-two pounds per yard, and are laid in fifteen-feet lengths, with five bearings, of three feet each.

Fig. 24, is the section of a parallel rail, about four miles of which are laid down upon the Newcastle and Carlisle railway, they weigh fifty pounds per yard. The section of this rail is different from any of the preceding, inasmuch as the joining of the middle portion with the top and bottom is with a square outline, the object of which is, that the keys should act against the square parts, *a b*, *a b*, of the top and bottom, on each side; two wedges being used similar to E, *Fig.* 10, *Plate II.*, the bearing lengths of this rail, are three feet apart.

§ 6.—*Comparative Qualities of cast and wrought Iron for Rails.*

When wrought-iron rails were first introduced, it was objected to them, by some engineers, that they were subject to oxidation, and that the mode of rolling rendered them fibrous, and liable to lamination.

Mr. W. Chapman, of Newcastle, in his report on the Newcastle and Carlisle communication, objected to their use on these grounds; stating it as his opinion, that their duration would not be so great as cast iron; and that the rails, being formed by being drawn out between rollers, and consequently fibrous, the great wheels rolling on them would expand their upper surface, and at length cause it to separate in their laminæ.

This report caused a reply from Mr. Longridge, one of the proprietors of the Bedlington iron works, and he produced a letter from Mr. Thompson, Lord Carlisle's agent at Tindale Fell, stating "that the malleable iron "rails had been laid down for sixteen years, and had no "appearance of lamination." — "The whole of the

" wrought iron, (says he) which has been used from " twelve to sixteen years, appears to be very little worse. " The cast iron is certainly much worse, and subject to " considerable breakage, although the rails are about " double the weight of the malleable iron rails. The " waggons used carry near a Newcastle chaldron, viz., " fifty-three hundred weight." — (*Newcastle Courant*, Dec. 18th 1824.)

" Mr. R. Stevenson, engineer, of Edinburgh, states, " regarding the description of materials to be used in the " formation of railways. I have no hesitation in giving " a decided preference to malleable iron, formed into " bars of from twelve to twenty feet in length, with " flat sides and parallel edges, or in the simple state, in " which they commonly come from the rolling mills of " the manufacturer."—(*Transactions Highland Society*, vol. vi. p. 139.)

Mr. G. Stephenson of Newcastle, the patentee of the cast-iron improved rail, has allowed us to insert a copy of a report made by him on the subject. "The great " object, in the construction of a railroad, is, that the " materials shall be such as to allow the greatest quantity of work to be done, at the least possible expenditure; and that the materials, also, be of the most " durable nature. In my opinion, Birkinshaw's patent " wrought-iron rail possesses those advantages, in a " higher degree than any other. It is evident, that " such rails can, at present, be made cheaper than those " that are cast, as the former require to be only half " the weight of the latter, to afford the same security " to the carriages passing over them; while the price " of the one material is by no means double that of " the other. Wrought-iron rails of the same expense, " admit of a great variety in the performance of the " work, and employment of the power upon them, as

" the speed of the carriages may be increased, to a very " high velocity, without any risk of breaking the rails, " their toughness rendering them less liable to fracture, " from an impulsive force, or a sudden jerk. To have " the same advantages in this respect, the cast-iron rails " would require to be of enormous weight, increasing, " of course, the original cost.

" From their construction, the malleable iron rails are " much more easily kept in order. One bar is made " long enough, to extend over several blocks; hence " there are fewer joints or joinings, and the blocks and " pedestals assist in keeping each other in their proper " places.

" On this account, also, carriages will pass along " such rails more smoothly, than they can do on those " that are of cast iron.

" The malleable iron rails are more constant and " regular in their decay, by the contact and pressure of " the wheel; but they will, on the whole, last longer " than cast-iron rails. It has been said by some en" gineers that the wrought-iron exfoliate or separate in " their laminæ, on that part which is exposed to the " pressure of the wheel. This I pointedly deny, as I " have closely examined rails, which have been in use " for many years, with a heavy tonnage passing along " them, and on no part are such exfoliations to be seen. " Pressure alone will be more destructive to the co" hesive texture of cast iron, than to that of wrought " iron. The true elasticity of cast iron is greater than " that of malleable iron; i. e., the former can, by a " distending power, be drawn through a greater space " without permanent alteration of the form; but it " admits of very little change of form, without pro" ducing total fracture. Malleable iron, however, is " susceptible of a very great change of form, without

" diminution of its cohesive power. The difference is " yet more remarkable, when the two substances are " exposed to pressure; for a force which, in conse- " quence of its crystalline texture, would crumble " down the cast iron, would merely extend or flatten " the other, and thus increase its power to resist the " pressure.

" We may say, then, that the property of being " extensible, or malleable, destroys the possibility of " exfoliation, as long as the substance remains un- " changed by chemical agency. A remarkable differ- " ence as to uniformity of condition or texture in the " two bodies, produces a corresponding want of uni- " formity, in the effects of the rubbing or friction of the " wheel. All the particles of malleable iron, whether " internal or superficial, resist separation from the " adjoining particles, with nearly equal forces. Cast " iron, however, as is the case with other bodies of " similar formation, is both harder and tougher, in the " exterior part of a bar, than it is in the interior. This, " doubtless, arises from the more rapid cooling of the " exterior. The consequence is, that when the upper " surface of a cast-iron rail is ground away, by the " friction of the wheel, the decay becomes very rapid.

" The effects of the atmosphere in the two cases, " are not so different as to be of much moment. On " no malleable iron railway, has oxidisation or rusting " taken place to any important extent.

" I am inclined to think, that this effect is prevented, " on the bearing surfaces of much-used railways, by the " pressure upon them. To account for their extra- " ordinary freedom from rust, it is almost necessary to " suppose, that some diminution takes place, in the " chemical affinity of the iron for the oxygen or car- " bonic acid. The continual smoothness in which

" they are kept by the contact of the wheels, has the
" usual effect of polish, in presenting to the destroying
" influence a smaller surface to act upon. The black
" oxide or crust, which always remains upon iron,
" appears to act as a defence, against the oxidising
" power of the atmosphere or water. This is the
" reason why the rail does not rust on its sides."

One phenomenon, in the difference of the tendency to rust, between wrought iron laid down as rails, and subjected to continual motion, by the passage of the carriages over them, and bars of the same material, either standing upright, or laid down, without being used at all, is very extraordinary.

A railway bar of wrought iron, laid carelessly upon the ground, alongside of one in the railway in use, shows the effects of rusting, in a very distinct manner; the former will be continually throwing off scales of oxidated iron, while the latter is scarcely at all affected.

Experience of the use of these rails, has now established the fact, that there is no waste or destruction, from oxidation or exfoliation, in rails of the proper quality of iron, and well manufactured, and that the wear is less than cast iron; there cannot, therefore, exist any doubt, at present, which of the two descriptions of material is preferable, as rails for public railways.

The rapid rate of travelling, now adopted on all those railways for the conveyance of passengers, renders the use of cast-iron rails absolutely dangerous, as breakage of a rail might be attended with the most disastrous consequences.

Upon private railways, the cast-iron rail is still considered by some as the most economical, especially as the first cost is less than that of the wrought-iron rail. There seems no doubt, that the wear of the wrought, is less than that of the cast iron; this point, therefore, rests entirely upon the relative price of the two kinds of iron, the comparative strength and stiffness being well ascertained. But the fact of malleable iron rails, being gradually more and more extensively used on private railways, where economy is strictly considered, and of their being exclusively used on public lines of railway, is a strong proof of the opinion of engineers in their favour; and goes far towards, if it does not completely establish, malleable iron, as being the best material for railways.

§ 7.—*Comparative Properties of Edge and Plate Rails.*

It seems to us a matter of great astonishment, that the plate rails have yet many advocates; and what seems more unaccountable, on the mistaken notion of the friction being less upon them, than upon the edge rail. We should have thought, that the number of railways of both kinds, now in existence, would have afforded sufficient opportunity of ascertaining this fact, without having recourse to surmise or opinion. Sufficient proof will be adduced hereafter, in the account of experiments on friction, to show the absurdity of retaining such a supposition, which is also apparent from the nature of the action of the carriage wheels upon the two rails. Certainly, if the rolling part of the wheels, used on the plate-rails, was equal in breadth, to the surface of the edge-rails, and if the wheels on the plate-rail always rolled along it, without rubbing against the upright ledge, more than the flanch of the wheel rubs against the side of edge-rail, then the friction in the two cases might be equal; but the rubbing of the wheels, against the upright ledge of the plate-rails, is considerably greater than the rubbing of the flanch of the wheels, against the sides of the edge-rails. The general height of the ledge of the flat rail, is three inches; and the projecting flanch of the wheels of the other, one inch; and supposing the tendency to rub against the sides, to be the same in each, the friction will be as the height of the respective ledges, and consequently greater in the plate-rail. This is supposing each of the rails equally free from obstruction, or extraneous matter, affecting the free rolling of the wheels upon them. But any person will see, that the form of the plate-rails necessarily causes them to be more subject to the presence of such an obstruction, than the edge-rail; the one forming a sort of receptacle for the dust, dirt, and other substances, falling upon them; while the other, from its narrow surface and elevated position, tends to throw off any extraneous matter, which may accidentally fall upon it. Mr. Palmer, in his description of a patent railway, gives a very interesting experiment, on the obstruction caused to the carriages, by the dust upon the plate-rails, which we shall take the liberty of inserting. He states, "I made " an experiment on a branch of the Cheltenham tram- " road (which was nearly new, and in good condition), " with a view to ascertain the difference of resistance, " occasioned by dust lying upon the rails. The carriage " and its load weighed 5264 pounds; the rails being " swept clean, the resistance was thirty-six pounds; the " rails being slightly covered with dust, the resistance was " forty-three pounds; consequently, the difference of " resistance to that weight was seven pounds, being " upwards of one fifth increase."

The tendency of the edge-rail to form a rut or groove, on the periphery of the wheels, and thus to increase the friction, was, for a long period, a motive for preferring the other; and this was considerable at first, owing to the narrow surface of the rails, and the

the softness of the metal of the wheels; afterwards, when the bearing of the rails was made greater, and now, since the introduction of case-hardened wheels, this objection is entirely removed. Certainly, when the wheels were indented, the increase of friction occasioned thereby, might cause an uncertainty which ought to be preferred. This having been obviated, and the other reasons for preferring the edge-rail still remaining good, together with the saving of weight, by the more proper distribution of the metal, to resist the transverse strain of the carriages; renders it no longer a subject of dispute, that the edge-rail is decidedly the best.

§ 8.—*Stone Railways.*

There is another description of railway, which originated in Italy several centuries ago, and is still in use in the streets of Milan, and which requires a casual consideration. It is composed of long stone blocks, laid in a continuous line, on each side of a paved horse-path, on which common carriages run. A portion of the commercial road in London, was thus paved by Mr. Walker; and when first laid down, a horse could drag very considerably more, than upon the common road, the common carriages of the latter running upon it. Experiments were made by Mr. Walker, which shewed that, when perfectly smooth, and free from dust or dirt, the resistance was not much greater, than upon an iron railway; a few years use of it has, however, shewn that, though the stones were granite, and basalt, they wear into ruts, and that these ruts increase the resistance very considerably, still, when heavily loaded, the carters prefer travelling upon it, to that of the common road adjoining. Von Bäadar, of Munich, in Germany, proposed an improvement to this form of railway, by laying a bar of iron upon the upper surface of the stone, on which the wheels of the carriages should move; to protect the stone from abrasion, and to lessen the resistance. A few furlongs of the Quincy railroad, near Boston, have been made in this manner, and is stated to have been attended with success; and it has since been extensively adopted on the Baltimore and Ohio, and on the Pennsylvania railroads, in the United States of America.

Forty miles of the Baltimore and Ohio railway, of a single line, is laid with granite sills, these sills are continuous, and are eight inches thick, and fifteen inches broad; they are laid in trenches, filled with broken stone. The iron rail is attached to the inner edge of the stone, but the bearing not being uniform, the stability of the railway is stated to be impaired, although that has been lessened, by placing the iron rail nearer the centre of the stone sill.

On the Philadelphia and Columbia railroad, the first ten miles, westward from Philadelphia, are laid with granite sills. It is thus described, by the Editor of the American copy of the second edition of this Work. " The granite sills are from five to nine feet long, " one foot wide, and one foot thick; and the trenches " are twenty-two inches deep, including the thickness " of the road metal, and are filled with small broken " stone; these sills are arranged in continuous parallel " lines. On the upper surfaces, near the inner edges, " flat iron bars, fifteen feet long, two inches and a " quarter wide, and five eighths of an inch thick, are " attached by square nails, three and a half inches long, " and eleven thirty-seconds of an inch in diameter, " driven into cedar plugs, five eighths of an inch in " diameter, which are inserted in holes, three and a

" half inches deep, drilled into the sills at intervals of
" eighteen inches asunder. This part of the railway
" has recently been carefully examined by the engineer.
" The severe winter of 1831-2 (during which the frost
" was intense, and several thaws occurred) has not,
" in the slightest degree, affected the stability of the
" rails."

CHAPTER III.

ON THE STRENGTH AND STIFFNESS, AND BEST FORM OF SECTION, OF CAST AND MALLEABLE IRON RAILS.

§ 1.—*General Remarks on Material best adapted for Railroads.*

Since cast iron superseded the use of wood for rails, it has been most extensively used, in the construction of railroads. As usual in like cases, at its first introduction, considerable opposition was made to its use, its brittleness and liability to break, its cutting the wheels, when in the form of edge-rails, and several other objections, were urged against it; time and experience have, however, confirmed its utility, and extirpated those prejudices. Though its nature renders it liable to break, when subjected to sudden blows, and its strength is considerably affected, by the unavoidable occurrence of air bubbles, and other imperfections in its organisation; yet still we are enabled to form a railroad with it, on which weights of considerable magnitude, can be conveyed, at moderate rates of speed, without much risk of breakage. And as it is a consideration of paramount importance, in the construction of a railroad, to form it of such materials, as combine strength and durability with economy; cast-iron is superior to timber.

Cast iron, while its hardness presents a surface that opposes little obstruction to the wheels of the carriages, forms a substance, which is also very durable, and resists the action of the wheels, with great effect. Its brittleness forms the only source of reasonable objection; and, as this cannot be obviated, without increasing the section of the rail, and adding to the weight, and consequently to the cost, it has led to the substitution of malleable iron rails, the tenacity of which resisting sudden fracture, obviates the danger, inconvenience, and cost of the breakage of cast iron.

In describing the different kinds of rails, used in the construction of railroads, we have previously given the opinion of some engineers, on the comparative merits of cast and malleable iron rails, offered previously to 1825. Since that period wrought-iron rails have been more extensively, or almost exclusively, used upon all the public lines of railways; and the prejudice, which then existed against their adoption, experience has since dispelled. There were then wanting experiments, on the comparative *strength*, *durability*, and the *resistance* to the carriages moved along them; which the numerous applications of this mode of transit, have since presented many opportunities of furnishing.

§ 2.—*Strongest Form of Section.*

We shall now endeavour to supply these deficiencies, and in doing so, we shall first of all endeavour to determine the strongest form of section, which applies equally to both cast and malleable iron rails. This question, however, involves several considerations, we require, first of all, a certain breadth of bearing surface, for the wheels to run upon, and that breadth must be such as not to produce unnecessary wear in the wheels, nor yet too great, so as to make them unnecessarily heavy; then there must be a certain thickness, or depth of that bearing surface, to make the rail sufficiently durable; next, the depth of section must be such, as to render the rail sufficiently rigid. All these requisites must, therefore, be considered, in determining upon the proper form of section.

Two, or two and a half inches in breadth, at the top, seems to be established, as the proper width for the wheels, to run upon; the latter being the breadth, adopted on all the public railways in Great Britain. The strength of rails, being as the breadth, and square of the depth, a greater breadth, than what is absolutely necessary, is, therefore, adding to the weight of the rail, without increasing the strength, more than in the direct ratio of the breadth; whereas, the same quantity of material, disposed in terms of the depth, increases the strength, in the duplicate ratio.

It does not appear, from the experience of the wear of the rails, and wheels, that they should be of less breadth than two inches; nor does it appear necessary, to make them of greater width, than two and a half inches.

We shall now, give some of the results of the wear, of cast and wrought iron rails, with a view of determining the depth of bearing surface.

In the former edition of this Work, we gave an account of two experiments, on the wear of cast and wrought iron rails, upon the Stockton and Darlington railway, as follows:—*Malleable-iron rails,* fifteen feet long, over which locomotive engines pass, weighing from eight to eleven tons; waggons loaded, four tons each; 85,000 tons passed over in a year, exclusive of engines and empty waggons; weight of rail, 136½ pounds; loss of weight, in twelve months, eight ounces; the breadth of the top of the rail, being two and a quarter inches, gives one tenth of a pound, per yard per annum; and Mr. Story informs us, that subsequent experiments furnish nearly the same result. In determining the premium for the best form of rail, for the

London and Birmingham Railway Company, with Professor Barlow, and Mr. Rastrick; we found the annual wear, estimated by some of the competitors, at one sixth of a pound, per yard, per annum. Upon the Killingworth railway, I have had some of the rails, which were weighed, and laid down, in 1825, taken up, and re-weighed; and find the average loss of weight of several rails, to have been eight pounds, for each fifteen-feet rail, in twelve years, which gives about one eighth of a pound, per yard, per annum. These rails were laid down, at a time, when the manufacture of malleable-iron rails, was not so well understood as at present; and, on examining, I found part of the loss of weight was attributable, to exfoliation on the sides. About 100,000 tons of coals would pass over these rails, annually, exclusive of the weight of the engines and empty carriages. Mr. Dixon, the resident engineer upon the Liverpool and Manchester railway, states, the wear of the rails, upon that railway, to be one tenth of a pound, per yard, per annum, which was determined, by taking up three rails, cleaning and weighing them; and then, at the end of twelve months, taking them up again, cleaning and weighing them, as before; and this being repeated, for two years, the wear was found to be the same. [Note A. Appendix.]

We may, therefore, take the wear of the rails to be about one tenth of a pound, per yard, per annum, which, supposing the whole to result from the wear, on the upper surface, will be one eighty-fourth part of an inch; if the top, or wearing part, of the rail were, therefore, an inch in depth, the rail would wear eighty-four years. The whole of the wear, above alluded to, does not, however, take place upon the top; a part, though, probably, a very small portion, is attributable to exfoliation, by the action of the air:

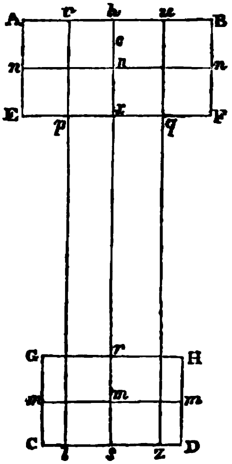
supposing, however, that the wear, by the action of the wheels amount to one tenth of a pound, per yard, per annum; if the top, or bearing part, of the rail, be made an inch, in depth, it will be sufficient, for all the purposes required. Any increased depth, and weight, which would not be required, for above eighty years; would, at compound interest, at the end of that period, amount to a greater sum, than it would be expedient to expend, for such a purpose, considering the remote period, at which it becomes useful.

Having, therefore, determined the area of section of the head, or wearing surface, of the rail; it then becomes a question, in what manner, the other part of the material is to be distributed, so as to present the strongest form of section.

It is necessary, however, to have, a projecting bead, or flanch, at the base of the rail, for the purpose of securing it to the chair. In cast-iron rails, this may be done; near the ends of the rail, leaving it open, to mould the other part of the rail into that form, which presents the strongest form of section. In wrought-iron rails, it is different, whatever breadth of base is required, to secure the rail to the chair, must, from the mode of manufacture, be given, throughout its whole length; it, therefore, becomes of paramount importance, to determine what width of base, can be given, without impairing the strength of the rail.

Professor Barlow, in his "Second Report, to the London and Birmingham Railway Company," has given a solution of this question (see note B. Appendix), by which it is shewn, that a maximum strength is obtained, when "$x^3 - \frac{3}{4}\left(\frac{a+eb}{b}\right)x^2 = \frac{-e^2a}{4b}$; a being "the whole, of the sectional area, below the neutral "axis; b, the breadth of the middle rib, pq; and

“ e, the depth of the lower flanch; x being any variable
“ depth of the rail.



“ From this, x may be determined, for any given
“ values of $a\,b$, and e. Thus, let A B C D represent
“ the section of a rail; A B E F
“ being the head, and G C H D the
“ lower rib, or flanch. Suppose the
“ middle rib is ·78 inch, or $b = {\cdot}78$,
“ to find what lower flanch must be
“ given, and the corresponding depth
“ of rail, to produce the maximum
“ strength.

“ The rail, being four and a
“ half inches below the neutral
“ axis $n\,n$, and its breadth $p\,q$ ·78,
“ its area is ${\cdot}78 \times 4\tfrac{1}{2} = 3{\cdot}51 = a$, and it
“ is required to distribute this area,
“ so as to produce a rail of maximum strength, the
“ depth of the proposed flanch being 1 inch. Sub-
“ stituting $a = 3{\cdot}51$, $b = {\cdot}78$, $c\,e = 1$, the foregoing equa-
“ tion becomes $x^3 - 4{\cdot}11\,x^2 = -1{\cdot}12$; whence, $x = 4{\cdot}04$,
“ the depth of the rail required.

“ Now, $4{\cdot}04 \times {\cdot}78 = 3{\cdot}15$, area middle rib; $a - b\,x =$
“ $3{\cdot}51 - 3{\cdot}15 = {\cdot}36 = b'$; or, ·36, the area of the lower
“ flanch, which is, also, its breadth, its depth being 1.

“ The strongest rail, therefore, of this weight, whose
“ breadth is ·78, is that whose depth is 4·04 inches,
“ and the breadth of the lower flanch, including the
“ middle rib, is $\cdot78 + \cdot36 = 1{\cdot}14$ inch.”—(*Barlow’s Second Report*, p. 95.)

In this solution, the strength, or resistance, of the head, which is very little, has been neglected; the resistance of the tensile portion of the rail, from the neutral axis, being taken; and this, it must be observed, is, perhaps, the most correct way of calculating; inasmuch as we should take the strength of the rail, when the head, or upper portion, is nearly worn down, and not when the rail is first put into use. It is true, as the head wears down, the neutral axis is changed; but still it is better, that the solution should shew the strength below, rather than above, the correct result.

Comparing this result, with some of the rails now in use, viz., *Figs.* 3. 12, 13. *Plate III.*, it will be seen, that most of them exhibit, too great a quantity of material, in the base of the rail.

In a general way, suppose the depth of the head, or bearing part, of the rail is equal to one inch, and the neutral axis, *n n*, half an inch from the upper surface; we can, from the preceding formula, calculate that form of section of the base of the rail, which exhibits a maximum strength.

§ 3.—*Rigidity of different Kinds of Rails.*

Having the best form of section, we then come to the degree of strength, or rigidity required; the two requisites are, that the rail present such a depth of wearing surface, as may be sufficient for all the economical purposes of durability; and that the deflection be such as not to present any resistance, to the carriages passing along them. We have already determined the requisite section of the head, or upper table, of the rail, the formula, page 70, determines that form of the remaining part of the rail, which presents the strongest section; we shall now, therefore, give some experiments, made with a view of ascertaining the strength, and stiffness of different sections of rails; and that amount of deflection, which presented an obstacle, to the wheels of the carriages. We cannot, however, give experiments, upon all the forms of sections, required for the different railways; and, therefore, it becomes necessary, having first ascertained, by experiment, the degree of rigidity of a given form of section, to give formulæ, for calculating the rigidity of other rails, of different forms of sections.

The law of resistance, of bars of cast and malleable iron, subjected to pressure, has been so well illustrated by Tredgold, in his work on cast iron; and by Professor Barlow in his report already alluded to; and in his recent publication on the strength of materials; that, without entering into all the details of their calculations and experiments, on the subject, we shall here give only their formulæ, for the calculation of the strength, and rigidity of the various forms of railway bars, referring the reader to those works, for complete information on this important subject.

Mr. Tredgold, having found, from experiment, that the tensile, or cohesive power of cast iron, was equal to 15,300 per square inch, gives the following formula for calculating the strength of any section of rail, with a given weight of carriage.

Let the marginal figure, page 70, represent a section of rail, and

w = the utmost strain, to which the rail is subjected, in lbs.
l = the distance between the supports, in feet.
b = the extreme breadth of section A B C D, in inches.
d = the extreme depth of section A B C D.
$q\,b$ = the difference between the breadth in the middle, and the extreme breadth.
$p\,d$ = the depth of the narrow part, or rib $p\,q$.

Then $\frac{w\,l}{850} = b\,d^2(1-q\,p^3)$.—(See *Tredgold on Cast Iron*, art. 148.)

Consequently $d = \sqrt{\frac{w\,l}{850\,b}(1-q\,p^3)}$, and

$$w = \frac{850bd^2}{l}(1-q\,p^3).$$

This calculation is on the supposition that the thickness of the head, middle rib, and lower flanch are all the same; but as these are varied in practice, we shall therefore also give Professor Barlow's solution, which includes every possible shape; and being, therefore, more particularly adapted to malleable-iron rails, will be more generally applicable, for this description of rails.

Having previously ascertained, by experiment, that the ratio of the resistance of wrought iron, to tension and compression, was as 4 : 1.

Let A B C D, page 70, represent the section of a rail, $n\,n$=the neutral axis.

c=the centre of compression, $c\,n$ being two thirds of $h\,n$, and the point m which is in the centre of $r\,s$. The breadths, $n\,n$ and $m\,m$, are also known. t=the tension of iron per square inch, just within the limits of elasticity.

Then the resistance of the whole section, referred to the centre of compression, c, may be considered to be made up of the three resistances.

1. Of the middle rib, continued through the head and foot tables, $v\,t\,z\,w = \frac{1}{3}\,h\,s \,.\, n\,s \,.\, p\,q \,.\, t$.

2. Of the head A E F B, minus the breadth of the centre rib $= \frac{1}{3}\,h\,x \,.\, n\,x \,.\, (n\,n - p\,q)\,\frac{n\,x}{n\,s}\,t$.

3. Of the lower web, G C D H, also minus the continuation of the centre rib $= n\,m \,.\, r\,s \,.\, (m\,m - p\,q)\,\frac{\delta''}{d'}\,t$.

(See *Barlow*, p. 58.) [Note C. Appendix.]

These three resistances being computed, let their sum be called s, and the clear bearing l; then $\frac{4\,s}{l} = \mathrm{W}$, the load the bar ought to sustain, at its middle point, for an indefinite time, without injury to its elasticity.

To determine the strength of any rail, of a given section, by the above formula, we only require the tensile force of cast and wrought iron, or the value of *t*.

Mr. Tredgold made several experiments, on various kinds of cast iron, by which he ascertained, that the strain, which a square inch of cast iron would bear, without permanent alteration, was equal to 15,300 lbs., or 6·83 tons. (*Tredgold on Cast Iron*, p. 77.)

By experiments, very carefully conducted, Professor Barlow found the tensile force, per square inch, of different kinds of wrought iron, as follows:—

Bar, No. 1,	(re-manufactured iron) -	- 10 tons.
Bar, No. 2,	ditto - - -	- 11 tons.
Bar, No. 3,	new bolt - - -	- 11 tons.
Bar, No. 4,	ditto - - -	- 10 tons.
Bar, No. 5	(re-manufactured) - -	- 9·5 tons.
Bar, No. 6,	ditto from old furnace bars	- 8·25 tons.
Bar, No. 7,	new bar, by Messrs. Gordon	- 10 tons.

He therefore assumes the force of resisting tension, in wrought-iron bars, as equal to ten tons, per square inch. —(*Barlow First Report*, p. 37.)

Having determined this, Mr. Barlow gives the following practical rules, for calculating the strength of the different sections, of wrought-iron rails, deduced from the formula page 73.

" *Resistance of the Head, or upper Table.*

" 1. Subtract the thickness of the middle rib from
" two inches, the breadth of the upper table, A B; and
" multiply the remainder by ten.

" 2. Subtract half an inch from the whole depth,
" and multiply the remainder by twelve.

" Then the former product, divided by the latter,
" will be the resistance in tons, due to the head, not
" including the middle rib.

" *Resistance of the Centre Rib.*

" Multiply the whole depth of the rail, by the whole " depth, minus half an inch, and that product by ten " times the thickness of the rib; and the last product, " divided by three, will be the resistance, in tons, of " the middle rib, continued through the whole depth, " i. e., through the upper and lower tables.

" *Resistance of the lower Web.*

" 1. Multiply the whole depth of the rail, minus " one inch, by the thickness of the bottom web, minus " the thickness of the rib, and that product by ten.

" 2. From the whole depth of the rail subtract one " inch; and to twelve times the square of the remainder, " add six times the remainder, and call this the first " number. From this subtract twice the remainder, " and add one, and call this the second number. Then " say, as the first number is to the second; so is the " product, obtained in the former part of the rule, to the " resistance of the lower web, not including the continuation of the middle rib.

" Lastly, The sum of these three resistances, multiplied by four, and divided by the clear bearing " length, will be the weight the rail will sustain, without " injury."

These will give the weight, which any malleable iron rail will support, without injuring its elasticity; and, for cast iron, we may take two thirds of the weight, as producing the same effect; in practice, however, we must keep the strain, to which the rail is subjected, considerably within these limits.

Besides that of strength, we require, in practice, another property in railway bars; viz., a sufficient degree of stiffness, that they may not present any obstacle, to the wheels of the carriages passing over them.

In cast-iron bars, the great depth of section, required to ensure adequate strength, necessarily causes them to be sufficiently rigid; but wrought-iron bars, from their superior tensile power, requiring a less depth of section, may yet be sufficiently strong, and be so flexible as to present considerable resistance to the carriages; it will, therefore, be necessary to ascertain, in the first place, whether the flexibility of wrought-iron rails does present any obstacle to the carriage wheels; if so, to what extent; and then to ascertain the strain to which they may be subjected in practice, without impairing their utility.

The law of deflection, in such cases, is well known; being as the weight and cube of the length, and inversely as the breadth and cube of the depth; or, $\delta = \frac{l^3 \text{w}}{ad^3}$; and consequently, $\frac{l^3 \text{w}}{ad^3 \delta} = \text{E}$, a constant quantity.

We have, in the preceding investigations, ascertained the strength of any railway bar, corresponding with the limit of elasticity; if, therefore, we ascertain experimentally, the deflection due to such limit, we can then calculate the extent which any railway bar will be deflected, by any given weight.

For $\frac{l \text{w}}{4 ad^2} = \text{s}$, also a constant quantity, w being the weight the bar will bear, without injuring its elasticity, and consequently, as l is the same in each, $d\,\delta$ will be also constant. That is, all rectangular bars, having the same bearing length, and loaded in their centre to the full extent of their elastic power, will be so deflected, that their deflection (δ) being multiplied by their depth (d), the product will be a constant quantity, whatever may be their breadths, or other dimensions, provided their lengths are the same.

For the purpose of determining the amount of deflection of wrought-iron bars, Professor Barlow instituted a series of experiments, the results of which were as follows :—

That any rectangular malleable-iron bar, of thirty-three inches bearing, being strained to its full elasticity, will be so deflected, that its depth, multiplied by the deflection, will produce the decimal ·278 ; consequently, $\frac{\cdot 278}{d} =$ the deflection ; d being the whole depth in inches. (*Barlow*, p. 47.)

This, however, applies only to rectangular bars. To make it general, we must estimate it from the neutral axis, which, in rectangular bars, being one fifth of the depth below the upper surface ; the above constant, when thus referred, becomes $\cdot 278 \times \frac{4}{5} = \cdot 22$, so that the formula is, $d' \delta = \cdot 22$; d' denoting now the depth of the bar below the neutral axis, and in this form it is general for all parallel rails.

Mr. Tredgold made a great many experiments, on the strength, and flexibility of cast iron, by which he found that cast iron was capable of sustaining a weight, of nearly seven tons, within the limit of elasticity, per square inch, and that it is crushed by a force of forty tons, per square inch. (*Tredgold on Cast Iron*, p. 271.)

The result of his experiments, on the deflection of cast-iron bars, was, that a bar an inch square, and length of bearing thirty-six inches, was deflected ·18, at the limit of permanent elasticity (*Tredgold*, p. 20): reducing this to the same length of bearing, as in the wrought-iron bar, it would give $\delta = \cdot 19$, and consequently $\frac{\cdot 19}{d}$ for the deflection of any rectangular bar of iron, length of bearing thirty-three inches.

If we take the ratio of tension, and compression of cast-iron, as 7 : 40; or that the neutral axis will be one-sixth of the depth, below the upper surface, then $\cdot 1911 \times \frac{5}{6} = \cdot 17 = d'\delta$.

Mr. Tredgold's experiments shew that the tensile force of cast iron is equal to seven tons, per square inch; making, therefore, $t = 7$ tons; we can therefore apply the preceding formula, to any form of cast-iron bars, as well as to those of malleable iron.

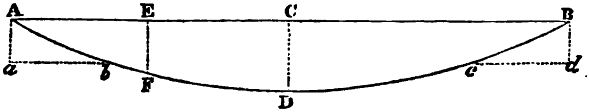
Having ascertained the best form, of cross-section of railway bars, and the law of deflection in terms of the depth, the next consideration is, as to the longitudinal section; we can now determine this, having, by the preceding inquiries, fixed upon the proper area of bearing surface, and the depth and form of the base of the rails.

Engineers have been greatly divided, in opinion, as to the best form of the longitudinal section. Some contending that the bar should be perfectly parallel, between the points of bearing; and others, that the under surface should be a semi-ellipse, or be what is called an "elliptical" in contradistinction to that of a "parallel" bar.

On the first introduction of cast iron, the form of the edge rail, was that of a parabola on the under side, the upper side being quite straight; this, however, is not the strongest form for a railway bar.

When a beam is supported at each end, and loaded in the middle, the upper side being quite straight, and its breadth uniform, the strongest form of section, with the least material, is that of two parabolas, the vertex being the point where the force acts. But in the case of a railway bar, the weight is rolled along the rail, and, consequently, every part in succession has to bear the weight; the line bounding the under side of the rail, which presents the greatest strength, when the beam is supported at each end, and loaded equally throughout its whole length, is a semi-ellipse; for the strain being as the square of the depth, and inversely as the distance from the point of support; the square of the depth should vary, as the rectangles of the segments, which is the property of the semi-ellipse.

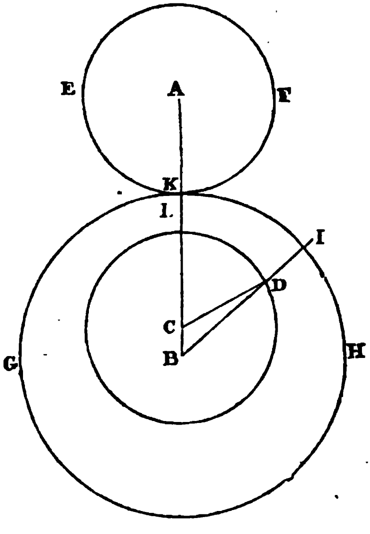
In the rail A B, let C D=the depth in the middle of the rail=d, A C $= l$, A E $= x$. Then the depth, D, at any part, E F, will be $D^2 = \frac{d^2}{l^3}(lx - x^2)$.



This will give the ordinate, of the curve of the base of the rail; but as these run into a point at A and B, an increased depth is given at those points, as shewn by the dotted lines a b, and c d, for the purpose of receiving the chairs.

In cast-iron rails, which are moulded to any shape, the correct elliptical form can be preserved; but as wrought-iron rails are formed, from rollers of a peculiar construction, the true elliptical curve cannot be given, although it is a very near approximation to it; so much, as not to be of any practical disadvantage.

Let E F represent a section of a roll; G H, the section of another, the latter being upon a false centre, C, and a groove turned in its periphery, varying in depth as shewn by L D. The roll, G H, being placed upon its true centre, the elliptical form is given to the rail, by passing the bars of iron between the two rolls, at K L.



Professor Barlow has given a formula for calculating the ordinates of such a curve. Let the radius of the roll C D $=r$, the distance of the centres B C $=d$, and x any angle L C D; then the ordinate
L D $=$ B I $-\sqrt{(r^2+d^2-2rd\cos.\,x.)}$—(*Barlow's First Report*, p. 14.)

The following table will shew the ordinates, of some of the elliptical rails now in use, with the ordinates of the true ellipse:—

TABLE OF ORDINATES.

Distances from end.	Ordinates in fish-bellied rail. Greatest depth 5 in. Least do. 3 in.	Ordinates in fish-bellied rail. Greatest depth 5 in. Least do. 3¾ in.	Ordinates in the ellipse.
Inch	Inches	Inches	Inches
0	3·00	3·75	·0
1	3·01	3·76	1·64
2	3·05	3·78	2·29
3	3·12	3·82	2·76
4	3·21	3·88	3·14
5	3·31	3·95	3·46
6	3·44	4·04	3·72
7	3·59	4·14	3·96
8	3·75	4·23	4·16
9	3·92	4·34	4·33
10	4·09	4·45	4·48
11	4·27	4·55	4·61
12	4·43	4·66	4·71
13	4·59	4·75	4·80
14	4·72	4·84	4·87
15	4·84	4·91	4·93
16	4·93	4·95	4·97
17	4·98	4·99	4·99
18	5·00	5·00	5·00

The last of these rails are those laid down by Mr. R. Stephenson, on the London and Birmingham railway, the rigidity of which is shewn in Table X.

By examining this table, it will be seen, that the curve given, by the mode of manufacturing wrought-iron bars, is not materially different from that of a true ellipse. Expert manufacturers of rails can, however, roll them into that of the true ellipse, if required, by cutting the rolls to the proper depth, though it is, we believe, seldom attended to in practice.

Reverting again, to the proper form of the longitudinal section of railway bars; as the depth of section of cast-iron rails, to secure the proper degree of strength, is such, as to render them sufficiently rigid, the elliptic shape is, unquestionably, the best, and hence all cast-iron rails are made of that form. In wrought iron, it is different; the tensile force of this material is so great, that, as railway bars, it is never subjected to that degree of strain, compared with its ultimate strength, as to render its tensile force the subject of consideration alone. Before it is so strained, the deflection is such, as to present considerable resistance to the carriages, and hence the elasticity of wrought-iron bars is the predominant consideration; and, therefore, the question is between the relative flexibility, or rigidity, of elliptic and parallel bars, and whether the saving of material, in the former case, is, or is not, compensated for by the superior stiffness of the latter. Any increased expense of manufacturing, or any superiority in other respects, as railway bars, which the one has over the other, must, likewise, be taken into the calculation.

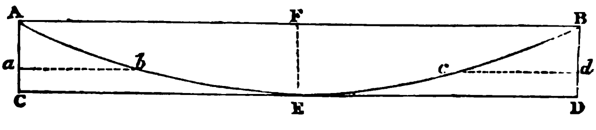
In the reports so often alluded to, Professor Barlow has gone into this question rather fully, and has shewn that the comparative deflections, of rectangular and elliptic bars of the same length, and of the same extreme depth, the breadth and load being also the same in each, are as 33 : 41.

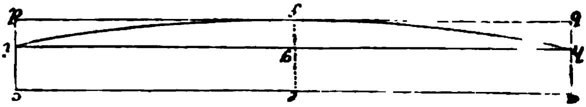
Mr. Tredgold, in his work on cast-iron, brings out nearly the same result, viz., ·857 : 1.

The relative weight of an elliptic and rectangular bar is as ·7854 : 1; we find, therefore, that the want of stiffness of the elliptic bar is compensated for by the saving of material; or, that, by making the two bars of the same weight, by adding to the breadth of the elliptic bar, the comparative stiffness would be nearly the same, or ·0716 in favor of the elliptic bar.

Considered theoretically, therefore, if there were no other circumstances to influence the question, on one side or the other, the two forms would be nearly equal to each other, in point of rigidity; but we must carry the subject further, and consider it in a practical point of view. In the first place, the form, which we have been considering theoretically, is not that which is used in practice; and there are other considerations, both as regards this, and the application of the two descriptions of rails, which must not be overlooked.

Let A B C D be a rectangular, or parallel railway bar; A E B will then be a semi-elliptic bar, such as we have considered theoretically; the comparative stiffness of which, as compared with A B C D, is as 33 : 41. In practice, the ends of the ellipse are formed nearly in the shape of the dotted lines, *a b*, *c d*, so that A B, *a b*, E, *c d*, B, will represent a fish-bellied rail; this, it will at once be seen, alters both their comparative stiffness and weight.





Let *a b c d*, be a parallel bar, the deflection will be $\frac{l^3}{a d^3}$, *d* being the depth *ef*; and of the bar *a h i c*, $\frac{l^3}{a d'^3}$, *d'* being the depth *eg*; rejecting l^3 and *a*, which are the same in both cases, the relative elasticity of the two bars will be as $d^3 : d'^3$; or the additional stiffness, given by the depth *fg*, will be $d^3 - d'^3 = \text{E}$. Now, suppose, instead of the rectangular portion *b h d i*, the two semi-elliptic parts, *fg h*, *fg i*, be added; the additional stiffness, E, must, therefore, be diminished in the ratio, which the semi-elliptic part, *fg h*, and *fg i*, gives to the bar, instead of the rectangular portion, *h b d i*. The relative rigidity of rectangular and elliptic bars, we have before seen, is as 41 : 33, but they will be varied by the peculiar shape of the elliptic part in the formation of the rail. If, however, the under side of the rail, or the curve, *h f i*, was that of a perfect ellipse, and if the sides were perfectly parallel, we might calculate the relative rigidity of the two bars; that of a rectangle, *a b c d*, and that of all the elliptic bar, *a h f i c*. But we have seen, that, in the mode of manufacture, the line bounding the under side is not that of a perfect ellipse; besides this, although the line *a h f i c* of the elliptic rail, is generally of that form shewn by the formula, page 79, or that of a perfect ellipse, yet we know that the lateral breadth varies very much, and likewise the breadth and depth of the lower rib. We shall therefore, as the subject is of great importance, give the result, of a series of experiments, of the deflection of differently formed parallel and elliptical rails, made with a view of determining this question; and, we are the more inclined to rely upon this mode of settling the relative rigidity, inasmuch as it is not improbable, that the mode of manufacturing the elliptic rails may have some effect, in altering their rigidity, in different parts of the rail, as compared with what theory would deduce.

§ 4.—*Experiments on the Comparative Rigidity of different Sections of Rails.*

The following are experiments, made on the flexibility of different sections of rails. The weights were applied by means of a steelyard, and the deflection was measured by a micrometer screw, seventeen threads to an inch, with a dial-plate, shewing the sixty-fourth part of a revolution of the screw, and thus exhibiting the 1088th part of an inch deflection.

In conducting the experiments, a strong framing of timber was erected, the chairs of the rails were bolted firmly to the framing, and the rails fastened to the chairs, by the same keys which were intended to be used, in laying them for permanent use.

In all the experiments, the distance between the centre of the supports was, precisely, three feet; but as each end of the rail rested upon the chairs, intended for their use, the width of the base of the chair is stated, in the account of each experiment, thereby giving the length of clear bearing. They are stated, either to have been fixed or loose; when loose, the two ends, only, of the three-feet length, subjected to experiments, were firmly fixed to the two chairs, forming its support; but, when stated to be fixed, the entire rail was firmly keyed down to each chair, and all the remaining divisions of the rail, or all the chairs, at every three feet, were firmly screwed down to the timber framing.

The first column of the tables shews the weight, applied to the middle of the rail, in cwts.; the second column shews the deflection in the middle of the rail, while the weights were resting upon it; and the third column shews the deflection, after the weights were removed. The deflection, after the weights were removed, and again applied, is, also, shewn in the tables. Thus, in Table I., weights were successively applied, amounting to sixty-eight cwt., when the deflection was found to be ·0386 of an inch; they were then taken off, and no permanent deflection observed. The weights were applied again, and the deflection found to be the same as before. This was the case with five weights; but on six being applied, equal to 102 cwt., the deflection was ·0615; they were then removed, and a permanent set of ·0027 had taken place; the weights were again applied, and the deflection was found to be greater than when the same weights were applied, or ·00624, shewing that the rail had been injured. The third column, in each set of experiments, gives the deflection, corresponding to each seventeen cwt. of insistent weight.

TABLE I.

Wrought-iron rail, *Fig.* 7, *Plate II.*, 14 feet 11⅛ inches long, of five lengths, weight 167 lbs., 33 lbs. per yard. Breadth of top 2¼ inches, depth 1 inch; depth of rib 1$\frac{1}{16}$ inches, breadth ⅝ inch; depth of keel ¾ inch, breadth ¾ inch; extreme depth in middle 3$\frac{1}{16}$ inches, tapering away, in a semi-elliptical curve, to 2⅜ inches at each end. Breadth of chair 3¼ inches.

Weight applied, in cwts.	SUPPORTS FIXED.						SUPPORTS LOOSE.		
	Experiment I.			Experiment II.			Experiment III.		
	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.
17	·0091			·0091			·0147		
			·0092			·0102			·0147
34	·0183			·0193			·0294		
			·0101			·0110			·0138
51	·0284			·0303			·0432		
			·0102			·0110			·0147
68	·0386	·0		·0413	·0		·0579	·0018	
	·0386		·0082	·0413		·0055	·0579		·0165
85	·0468	·0		·0468	·0		·0744	·0036	
	·0468		·0147	·0468		·0156	·0744		·0175
102	·0615	·0027		·0624	·0027		·0919	·0101	
	·0624		·0138	·0634		·0138	·0956		·0290
119	·0753	·0055		·0762	·0055		·1149	·0202	
	·0753		·0147	·0762		·0148	·1149		·0321
136	·0900	·0122		·0910	·0091		·1470	·0367	
	·0910		·0207	·0910		·0196	·1499		·0331
153	·1107	·0165		·1106	·0156		·1801	·0615	
	·1108		·0019	·1107		·0018	·1930		·0772
170	·1126	·0248		·1124	·0275		·2573	·1264	
	·1127		·0032	·1127		·0044			
187	·1158	·0477		·1168	·0496				
Mean deflection per ton ·0123							·014		

TABLE II.

Wrought-iron rails, *Fig.* 10, *Plate II.*, 14 feet 10 inches long, of five lengths, weight 157 lbs., 32 lbs. per yard. Breadth of top 2¼ inches, depth ¾ inch; depth of rib 1¾ inches, breadth ¾ inch; depth of keel $1\frac{3}{16}$ inches, breadth 1 inch; extreme depth in middle 3⅛ inches, tapering away, in a semi-elliptical curve, to 2½ inches, within 1½ inch of each end.* Breadth of chair 3¼ inches.

	SUPPORTS FIXED.						SUPPORTS LOOSE.		
	Experiment I.			Experiment II.			Experiment III.		
Weight applied, in cwts.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.
17	·0110			·0128			·0174		
			·0119			·0091			·0184
34	·0229			·0219			·0358		
			·0138			·0093			·0165
51	·0367			·0312			·0523		
			·0110			·0138			·0175
68	·0477	·0018		·0450	·0018		·0698	·0036	
	·0477		·0166	·0450		·0138	·0707		·0193
85	·0643	·0036		·0588	·0036		·0891	·0082	
	·0643		·0175	·0588		·0128	·0891		·0219
102	·0818	·0073		·0716	·0055		·1110	·0147	
	·0827		·0284	·0726		·0147	·1112		·0048
119	·1102	·0128		·0863	·0091		·1158	·0404	
	·1106		·0045	·0882		·0245	·1163		·0132
136	·1147	·0367		·1108	·0165		·1290	·1159	
	·1152		·0086	·1112		·0035	·1310		·0184
153	·1233	·1102		·1143	·0404		·1474	·1217	
	·1246		·0183	·1147		·0046			
170	·1415	·1268		·1189	·0716				
Mean deflection per ton ·0135							·0205		

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* In this and the two following rails, a convex projection at the end of each, 3 feet length, about ⅜ inch deep, and 3 inches long, is rolled upon the under side, which fits into a corresponding cavity in the base of the chair.

TABLE III.

Wrought-iron rail, *Fig.* 10, *Plate II.*, 14 feet 8 inches long, of five lengths, weight 162 lbs., 33 lbs. per yard. Breadth of top 2$\frac{2}{16}$ inches, depth 1 inch; depth of rib 1$\frac{1}{8}$ inches, breadth $\frac{5}{8}$ inch; depth of keel 1$\frac{7}{16}$ inches, breadth $\frac{7}{8}$ inch; extreme depth in middle 3$\frac{9}{16}$ inches, tapering away, in a semi-elliptical curve, to 2$\frac{7}{8}$ inches, within 1$\frac{1}{8}$ inches from the end. Breadth of chair 3$\frac{1}{4}$ inches.

	SUPPORTS FIXED.						SUPPORTS LOOSE.		
	Experiment I.			Experiment II.			Experiment III.		
Weight applied, in cwts.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.
17	·0064			·0064			·0091		
			·0110			·0119			·0129
34	·0174			·0183			·0220		
			·0120			·0129			·0120
51	·0294			·0312			·0340		
			·0082			·0110			·0119
68	·0376 ·0376	·0		·0422 ·0422	·0		·0459 ·0459	·0	
			·0111			·0111			·0147
85	·0487 ·0487	·0		·0533 ·0533	·0		·0606 ·0606	·0	
			·0119			·0101			·0120
102	·0606 ·0615	·0		·0634 ·0634	·0		·0726 ·0707	·0018	
			·0092			·0128			·0092
119	·0698 ·0698	·0036		·0762 ·0762	·0027		·0818 ·0836	·0036	
			·0083			·0148			·0137
136	·0781 ·0781	·0055		·0910 ·0919	·0055		·0955 ·0955	·0073	
			·0138			·0202			·0168
153	·0919 ·0974	·0128		·1112 ·1115	·0220		·1123 ·1130	·0211	
			·0204			·0039			·0154
170	·1123 ·1125	·0303		·1151	·0496		·1277	·1156	
			·0038						
187	·1161	·0616							
Mean deflection per ton ·013							·015		

TABLE IV.

Wrought-iron rail, *Fig.* 10, *Plate II.*, 15 feet ½ inch long, of five lengths, weight 196 lbs., 39 lbs. per yard. Breadth of top 2¼ inches, depth 1 inch; depth of rib 1¾ inches, breadth ⅝ inch; depth of keel $1\frac{3}{16}$ inches, breadth 1 inch; extreme depth $4\frac{1}{16}$ inches, tapering away, in a semi-elliptical curve, to 3⅜ inches, within 1½ inches from the end. Breadth of chair 3½ inches.

	SUPPORTS FIXED.						SUPPORTS LOOSE.		
	Experiment I.			Experiment II.			Experiment III.		
Weight applied, in cwts.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.
17	·0036			·0035			·0082		
			·0074			·0075			·0092
34	·0110			·0110			·0174		
			·0074			·0055			·0111
51	·0184			·0165			·0285		
			·0091			·0083			·0101
68	·0275	·0		·0248	·0		·0386	·0	
	·0275		·0073	·0248		·0046	·0386		·0073
85	·0358	·0		·0294	·0		·0459	·0027	
	·0358		·0074	·0294		·0092	·0459		·0110
102	·0432	·0		·0386	·0		·0569	·0055	
	·0432		·0064	·0386		·0073	·0569		·0120
119	·0496	·0018		·0459	·0027		·0689	·0110	
	·0496		·0083	·0459		·0083	·0698		·0147
136	·0579	·0045		·0542	·0045		·0836	·0184	
	·0579		·0091	·0551		·0083	·0836		·0266
153	·0670	·0082		·0625	·0064		·1102	·0303	
	·0670		·0120	·0634		·0101	·1106		·0054
170	·0790	·0128		·0726	·0110		·1156	·0716	
	·0799		·0175	·0735		·0156			
187	·0965	·0229		·0882	·11				
	Mean deflection per ton ·0085						·0115		

TABLE V.

Wrought-iron rail, *Fig.* 1, *Plate III.*, 14 feet 11¾ inches long, of five lengths, weight 186 lbs., 37 lbs. per yard. Breadth of top 2¼ inches, depth ¾ inch; depth of rib 1 15/16 inches, breadth ⅝ inch; keel round, 1 3/16 inches diameter; extreme depth 3⅞ inches, parallel the whole length. Breadth of chair 5 inches.

	SUPPORTS FIXED.						SUPPORTS LOOSE.		
	Experiment I.			Experiment II.			Experiment III.		
Weight applied in cwts.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.
17	·0073			·0064			·0082		
			·0055			·0058			·0091
34	·0128			·0122			·0173		
			·0045			·0061			·0084
51	·0173			·0183			·0257		
			·0066			·0065			·0092
68	·0239	·0		·0248	·0		·0349	·0	
	·0239		·0082	·0248		·0064	·0349		·0110
85	·0321	·0		·0312	·0		·0459	·0018	
	·0321		·0065	·0312		·0074	·0459		·0110
102	·0386	·0		·0386	·0		·0569	·0055	
	·0386		·0073	·0386		·0073	·0569		·0092
119	·0459	·0021		·0459	·0021		·0661	·0101	
	·0459		·0063	·0459		·0083	·0661		·0113
136	·0522	·0045		·0542	·0045		·0774	·0202	
	·0522		·0084	·0542		·0064	·0774		·0089
153	·0606	·0064		·0606	·0055		·0863	·0386	
	·0606		·0064	·0606		·0064	·0882		·0302
170	·0670	·0082		·0670	·0073		·1165	·0808	
	·0670		·0065	·0670		·0102			
187	·0735	·0101		·0772	·0110				
Mean deflection per ton ·0076							·0114		

TABLE VI.

Elliptic rail, No. I., similar to that of Experiment I., length 15 feet 2 inches, weight 39 lbs. per yard.				Portion of a parallel rail, No. II., similar to Experiment V., weight 37 lbs. per yard.		
Weight applied, in cwts.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.	Deflection with weight applied.	Permanent deflection.	Deflection for each 17 cwt.
17	·0064		·0092	·0064		·0101
34	·0156		·0092	·0165		·0156
51	·0248		·0092	·0321		·0101
68	·0340		·0110	·0422		·0101
85	·0450 ·0450	·0	·0111	·0523 ·0523	·0	·0092
102	·0561 ·0561	·0	·0155	·0615 ·0615	·0	·0129
119	·0716 ·0716	·0	·0157	·0744 ·0744	·0	·0175
136	·0873 ·0900	·0036	·0309	·0919 ·0919	·0042	·0192
153	·1182 ·1198	·09	·0169	·1111 ·1116	·0257	·0135
170	·1351	·1193		·1246	·1154	
Mean deflection per ton ·0117				·013		

TABLE VII.

Wrought-iron rails, *Fig* 10, *Plate II.*, for elevation, and *Fig.* 10, *Plate III.*, for section. Breadth of top 2¼ inches, depth 1 inch; breadth of rib ·6 inch, depth 2¼ inches; breadth of bottom 1¼ inches, depth 1½ inches; extreme depth in middle 5 inches, tapering away, in a semi-elliptic curve, to 3¼ inches; 2 inches from end. Breadth of chair 4⅛ inches; base of chair concave, with semicircular projection on rail, 3 inches by ½ inch.

Weight in cwts.	Experiment I.		Experiment II.		Experiment III.	
	49·3 lbs. per yard.		50·9 lbs. per yard.		50·9 lbs. per yard.	
	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.
20	·0018		·0018		·0014	
34	·0036	·0018	·0045	·0027	·0036	·0022
48	·0055	·0019	·0073	·0028	·0064	·0028
62	·0082	·0027	·0110	·0037	·0092	·0028
76	·0110	·0029	·0156	·0046	·0119	·0027
90	·0146	·0036	·0183	·0027	·0146	·0027
104	·0174	·0028	·0220	·0037	·0165	·0019
118	·0202	·0028	·0247	·0027	·0183	·0018
132	·0229	·0027	·0274	·0027	·0202	·0019
146	·0257	·0028	·0293	·0019	·0220	·0018
160	·0293	·0036	·0321	·0028	·0238	·0018
174	·0321	·0028	·0348	·0027	·0257	·0019
188	·0339	·0018	·0376	·0028	·0275	·0018
202	·0376	·0037	·0404	·0028	·0303	·0028
216	·0404	·0028	·0422	·0018	·0330	·0027
230	·0440	·0036	·0458	·0036	·0358	·0028
	Permat deflecn	·0018	Permat deflecn	·0018	Permat deflecn	·0009
Mean deflection with 10 tons 16 cwt.		·0386		·0404		·0316

Mean deflection per ton ·0035.

TABLE VIII.

Wrought-iron rail, breadth of top 2¼ inches, depth 1 inch; breadth of rib ·75 inch, depth 1·875 inches; breadth of bottom 1¼ inches, depth 1·125 inches, extreme depth 4 inches. Parallel rail. Breadth of chair 4½ inches. Section, *Fig.* 11, *Plate III.*

Weight in cwts.	Experiment I.		Experiment II.		Experiment III.	
	48·47 lbs. per yard.		49·4 lb. per yard.		49·4 lb. per yard.	
	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.
20	·0027		·0022		·0022	
34	·0073	·0046	·0055	·0033	·0046	·0024
48	·0119	·0046	·0082	·0027	·0092	·0046
62	·0165	·0046	·0119	·0037	·0128	·0036
76	·0211	·0046	·0146	·0027	·0165	·0037
90	·0257	·0046	·0183	·0037	·0192	·0027
104	·0294	·0037	·0220	·0037	·0229	·0037
118	·0348	·0054	·0275	·0055	·0266	·0037
132	·0385	·0037	·0312	·0037	·0293	·0027
146	·0422	·0037	·0339	·0027	·0330	·0037
160	·0459	·0037	·0367	·0028	·0367	·0037
174	·0505	·0046	·0404	·0037	·0404	·0037
188			·0449	·0045		
202 216	Permaᵗ deflecⁿ	·0027	·0477	·0028	No permanent deflection.	
			·0541	·0064		
230			·0624	·0083		
			Permaᵗ deflecⁿ	·0110		
Mean deflection with 8 tons		·0432		·0345		·0345

Mean deflection per ton ·0046.

Table IX.

Experiments made at Woolwich, to ascertain the strength, and stiffness, of the parallel rail, with double flanch, for the North Union railway, by Professor Barlow, *Fig.* 12, *Plate III.*; weight per yard, 62 lbs., area of section 6 inches, depth 4½ inches.

Result obtained from three single experiments.

Weight in tons.	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.
1	·028		·035		·009	
2	·031	·003	·039	·004	·016	·007
3	·036	·005	·044	·005	·020	·004
4	·038	·002	·048	·004	029	·009
5	·043	·005	·054	·006	·033	·004
6	·046	·003	·059	·005	·034	·001
7	·050	·004	·064	·005	·038	·004
8	·055	·005	·069	·005	·042	·004
9	·060	·005	·076	·007	·046	·004
10	·066	·006	·082	006	·050	·004
11	·074	·008	·086	·004	·055	·005
12	·084	·010	·096	·010	·066	·011
Mean deflection, with 11 tons -	·051		·055		·051	

Result obtained fron the mean of three experiments.

Weight in tons.	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.
1	·027		·021		·018	
2	·031	·004	·026	·005	·024	·006
3	·036	·005	·031	·005	·028	·004
4	·039	·003	·036	·005	·033	·005
5	·044	·005	·041	·005	·037	·004
6	·048	·004	·044	·003	·040	·003
7	·052	·004	·048	·004	·044	·004
8	·057	·005	·053	·005	·048	·004
9	·063	·006	·059	·006	·053	·005
10	·070	·007	·064	·005	·059	·006
11	·077	·007	·071	·007	·067	·008
12	·087	·010	·081	·010	·077	·010
Mean deflection, with 11 tons -	·055		·055		·054	

Mean deflection per ton ·005.

TABLE X.

Experiments, by Professor Barlow, on Mr. Stephenson's 50 lbs. per yard elliptic rail; greatest depth 5 inches, least depth 3¾ inches, thickness of rib $\frac{9}{16}$ inch, bearings 3 feet apart.

Weight in tons.	Experiment I.		Experiment II.		Experiment III.		Experiment IV.	
	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.	Deflection by index.	Deflection for each ton.
1	·035		·014		·018		·045	
2	·045	·010	·022	·008	·025	·007	·056	·011
3	·055	·010	·030	·008	·038	·013	·065	·009
4	·065	·010	·042	·012	·054	·016	·075	·010
5	·071	·006	·050	·008	·062	·008	·084	·009
6	·076	·005	·062	·012	·069	·007	·095	·011
7	·087	·010	·075	·013	·080	·011	·105	·010
7½	·095	·018						
8			·085	·010	·094	·014	·110	·005
8½					·100	·012		
9			·101	·016	·112	·018	·116	·006
9½					·118	·018		
10			{elasticity injured.}		·126	·014	·125	·009
11			·300		·160	·034	·165	
17					destroyed			

Mean deflection per ton, No. 1 — ·0097
2 — ·0101
3 — ·0110
4 — ·0090

Mean - ·0100

Table XI.

	Fish-bellied rail, same as Table VII., weight 49·3 lbs. per yard; distance of supports 3 ft. 0⅛ inch. *Fig.* 10, *Plate III.*						Parallel rail, same as Table VIII., weight 48·47 lbs. per yard; distance of supports 3 ft. 0⅛ inch. *Fig.* 11, *Plate III.*					
	6 chairs fixed, and rail keyed.		2 chairs fixed, and rail keyed.		2 chairs quite loose, and rail keyed.		6 chairs fixed, and rail keyed.		2 chairs fixed, and rail keyed.		2 chairs loose, and rail keyed.	
Weight in cwts.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.	Deflection by index.	Deflection for each 14 cwt.
20	·0018		·0018		·0027		·0027		·0036		·0055	
34	·0036	·0018	·0055	·0037	·0064	·0037	·0073	·0046	·0082	·0046	·0119	·0064
48	·0055	·0019	·0101	·0046	·0101	·0037	·0119	·0046	·0128	·0046	·0174	·0055
62	·0082	·0027	·0137	·0036	·0137	·0036	·0165	·0046	·0192	·0046	·0247	·0073
76	·0110	·0028	·0174	·0037	·0174	·0037	·0211	·0046	·0256	·0046	·0303	·0056
90	·0146	·0036	·0211	·0037	·0202	·0028	·0257	·0046	·0330	·0074	·0385	·0082
104	·0174	·0028	·0247	·0036	·0247	·0045	·0312	·0055	·0395	·0065	·0458	·0073
118	·0202	·0028	·0284	·0037	·0284	·0037	·0348	·0036	·0477	·0082	·0477	·0019
132	·0239	·0027	·0320	·0036	·0311	·0027	·0395	·0047				
146	·0257	·0028	·0348	·0028	·0357	·0046	·0431	·0036				
160	·0293	·0036	·0385	·0037	·0394	·0037	·0458	·0027				
174	·0321	·0028	·0422	·0037	·0422	·0028	·0505	·0047				
Mean deflection per ton	·0032		·0043		·0042		·0051		·0073		·0071	

Table XII.

Dublin old rail, *Fig.* 13, *Plate III.*; 3 feet bearings; 3¼ inches deep, 2 inches in breadth at bottom, 2½ inches at top; 15 feet long; parallel; weight 45 lb. per yard.				Same rail, *Fig.* 13, *Plate III.*; with top downwards or reversed; 3 feet bearings.—13th May 1835.			
Weight on press.	Observed deflection.	Deflection per ½ ton.	Permanent set.	Weight on press.	Observed deflection.	Deflection per ½ ton.	Permanent set.
3 lbs.	·011			3 lbs.	·014		
		·013				·009	
6 –	·024			6 –	·023		
		·007				·006	
9 –	·031			9 –	·029		
		·009				·008	
12 –	·040			12 –	·037		
		·011				·012	
15 –	·051			15 –	·049		
		·006				·009	
18 –	·057			18 –	·058		
		·011				·009	
21 –	·068			21 –	·067		
		·009				·009	
24 –	·077		·001	24 –	·076		·002
		·010				·011	
27 –	·087		·002	27 –	·087		·003
		·010				·005	
30 –	·097		·003	30 –	·092		·004
		·010				·008	
33 –	·107		·004	33 –	·100		·006
		·011				·011	
36 –	·118		·008	36 –	·111		·008
		·013				·012	
39 –	·131		·011	39 –	·123		·012
		·020				·015	
42 –	·151		·019	42 –	·138		·018
		·017				·019	
45 –	·168		·027	45 –	·157		·030
		·026				·029	
48 –	·194		·047	48 –	·186		·051
		·052				·052	
51 –	·246		·100	51 –	·238		·095
Mean deflection per ton ·019				Mean deflection per ton ·018			

Table XIII.

Mr. Stephenson's fish-bellied 44 lbs. per yard rail, *Fig.* 14, *Plate III.;* 3 feet bearings, 4½ inches deep in middle, 3¼ at ends.

Weight on press.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Same rail, top downwards.		
				Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·008			·009		
6 –	·018	·010		·019	·010	
9 –	·026	·008		·027	·008	
12 –	·036	·010		·035	·008	
15 –	·045	·009		·042	·007	
18 –	·054	·009		·051	·009	
21 –	·062	·008		·057	·006	
24 –	·070	·008		·065	·008	
27 –	·076	·006		·072	·007	
30 –	·084	·008		·079	·007	
33 –	·091	·007		·086	·007	
36 –	·099	·008	·003	·094	·008	·004
39 –	·109	·010	·004	·103	·009	·004
42 –	·116	·007	·004	·111	·008	·006
45 –	·125	·009	·005	·122	·011	·007
48 –	·135	·010	·007	·130	·008	·010
51 –	·148	·013	·012	·143	·013	·014
54 –	·162	·014	·018	·158	·015	·022
57 –	·180	·018	·029	·183	·025	·040
60 –	·238	·058	·078	·280	·097	·121
81 –	crippled.		1·280	crippled.		1·280
Deflection per ton ·0166				·0154		

TABLE XIV.

Grand Junction—Mr. Locke's 62 lbs. parallel rail, *Fig.* 12, *Plate III.*; 3 feet bearings, 4½ inches deep.

Weight on press.	Observed deflection.	Deflection for each ½ ton.	Perma-nent deflection.	Observed deflection.	Deflection for each ½ ton.	Perma-nent deflection.
3 lbs.	·006			·005		
6 —	·010	·004		·010	·005	
9 —	·014	·004		·013	·003	
12 —	·017	·003		·017	·004	
15 —	·021	·004		·022	·005	
18 —	·024	·003		·024	·002	
21 —	·028	·004		·028	·004	
24 —	·032	·004		·032	·004	
27 —	·035	·003		·035	·003	
30 —	·039	·004		·039	·004	
33 —	·042	·003		·042	·003	
36 —	·044	·002		·046	·004	
39 —	·048	·004		·050	·004	
42 —	·055	·007		·054	·004	no set.
45 —	·060	·005		·058	·004	
48 —	·064	·004		·062	·004	per set.
51 —	·069	·005	·002	·065	·003	·001
54 —	·074	·005		·070	·005	
57 —	·079	·005		·074	·004	
60 —	·084	·005	·004	·078	·004	·003
63 —	·088	·004		·084	·006	
66 —	·092	·004		·089	·005	
69 — 5 minutes	·102 and after a rest of ·108	·010		·098 ·100 }	·009 rest.	·015
72 —	—	—	—	·113		
75 —	—	—	—	·134		
84 —	—	—	—	·166 ·250 }	rest.	 ·172
Deflection per ton ·0077				·0075		

Table XV.

Grand Junction, or Mr. Locke's, parallel rail, *Fig.* 12, *Plate III.*; 62 lbs. per yard; 5 feet bearings, 4½ inches deep.

Weight on press.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·017		
6 –	·034	·017	
9 –	·051	·017	
12 –	·070	·019	
15 –	·086	·016	
18 –	·104	·014	
21 –	·123	·019	
24 –	·140	·017	
27 –	·158	·018	·003
30 –	·177	·019	·003
33 –	·198	·021	·004
36 –	·216	·018	·005
39 –	·232	·016	·006
42 –	·255	·023	·009
45 –	·292	·037	·027
Weight removed, and rail left to rest for a short time.			
33 –	·187		·003
36 –	·217	·030	·015
Weight removed again.			
30 –	·177		·001
33 –	·194	·017	·002
36 –	·222	·028	·004
39 –	·245	·023	·007
42 –	·264	·019	·010
45 –	·292	·028	·026
Deflection per ton ·034			

Grand Junction, or Mr. Locke's, 62 lbs. per yard parallel rail, *Fig.* 12, *Plate III.*; 3 feet 9 inches bearings, 4½ inches deep.

Weight on press.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·009		
6 –	·020	·011	
9 –	·026	·004	
12 –	·033	·007	
15 –	·041	·008	
18 –	·049	·008	
21 –	·058	·009	
24 –	·066	·008	
27 –	·074	·008	
30 –	·082	·008	
33 –	·088	·006	
36 –	·097	·009	·001
39 –	·105	·008	·002
42 –	·114	·009	·003
45 –	·123	·009	·004
48 –	·133	·010	·008
51 –	·144	·011	·010
54 –	·159	·015	·016
57 –	·180	·021	·028
60 –	·232	·052	·068
Deflection per ton ·0154			

TABLE XVI.

Grand Junction, or Mr. Locke's, parallel rail, *Fig.* 12, *Plate III.*; 62 lbs. per yard; 4½ feet bearings, 4½ inches deep.

Weight on press.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·013			·012		
6 –	·024	·011		·022	·010	
9 –	·034	·010		·030	·008	
12 –	·044	·010		·038	·008	
15 –	·052	·008		·045	·007	
18 –	·060	·008		·054	·009	
21 –	·069	·009		·069	·008	
24 –	·075	·006		·068	·006	
27 –	·081	·006		·075	·007	
30 –	·092	·011	·001	·084	·009	
33 –	·101	·009	·002	·096	·012	
36 –	·110	·009	·003	·106	·016	·001
39 –	·123	·013	·006	·120	·014	·006
42 –	·132	·009	·011	·149	·029	·011
45 –	·150	·018	·022	·162	·013	·018
48 –	·190	·040	·051	·187	·025	·031
51 –	·264	·074	·118	·240	·053	·037
54 –	·400	·136	·240	·335	·095	·162
57 –	·550	·150	·383	·470	·035	·281
60 –	—	—	—	·640	·170	·433
Deflection per ton ·017				·0168		

TABLE XVII.

Grand Junction, 62 lbs. per yard parallel rail, *Fig.* 12, *Plate III.*; 3 feet bearings, with lower web reduced to 1½ inch broad with chisel. Experiment after the rail was heated and cooled.

Weight on lever.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·004	·003		·004	·002	
6 –	·007	·005		·006	·004	
9 –	·012	·004		·010	·003	
12 –	·016	·004		·013	·002	
15 –	·020	·004		·015	·004	
18 –	·024	·004		·019	·002	
21 –	·028	·001		·021	·003	
24 –	·029	·004		·024	·003	
27 –	·033	·002		·027	·004	
30 –	·035	·004		·031	·003	
33 –	·039	·003		·034	·003	
36 –	·042	·005		·037	·003	
39 –	·047	·005		·040	·003	
42 –	·052	·004		·043	·004	
45 –	·056	·005	·002	·047	·005	·002
48 –	·061	·004	·003	·052	·005	·003
51 –	·065	·005	·004	·057	·004	·005
54 –	·070	·008	·005	·061	·006	·007
57 –	·078	·007	·008	·067	·008	·010
60 –	·085	·015	·016	·075	·015	·014
63 –	·100	·023	·026	·090	·015	·027
66 –	·123	·047	·046	·105	·025	·038
69 –	·170	·050	·088	·130	·037	·060
72 –	·220	·065	·134	·167	·048	·095
75 –	·285	·075	·200	·215	·061	·137
78 –	·360	·086	·270	·276	·079	·197
81 –	·446	·094	·360	·355	·095	·274
84 –	·530		·440	·450		·368
Deflection per ton ·0074					·006	

TABLE XVIII.

Elliptic rail, 50 lbs. per yard, *Fig.* 19, *Plate III.*; bearings 3 feet, greatest depth 4 inches, depth at ends 2¾ inches.

Weight on press.	Experiment I.			Experiment II.			Experiment III. Same rail, top down.		
	Observed deflection.	Deflection for each ¼ ton.	Permanent deflection.	Observed deflection.	Deflection for each ¼ ton.	Permanent deflection.	Observed deflection.	Deflection for each ¼ ton.	Permanent deflection.
3 lbs.	·010			·008			·007		
6 –	·020	·010		·016	·008		·013	·006	
9 –	·026	·006		·024	·008		·020	·007	
12 –	·032	·006		·028	·004		·025	·005	
15 –	·042	·010		·037	·009		·030	·005	
18 –	·050	·008		·043	·006		·036	·006	
21 –	·056	·006		·050	·007		·042	·006	
24 –	·063	·007		·056	·006		·048	·006	
27 –	·070	·007		·063	·007		·056	·008	
30 –	·075	·005		·068	·005		·063	·005	
33 –	·082	·007		·077	·009	·001	·070	·007	·001
36 –	·094	·012	·005	·080	·003	·003	·080	·010	·004
39 –	·104	·010	·010	·092	·012	·006	·089	·009	·006
42 –	·111	·007	·010	·100	·008	·007	·098	·009	·008
45 –	·120	·009	·011	·110	·010	·009	·110	·012	·012
48 –	·126	·006	·011	·124	·014	·014	·118	·008	·020
51 –	·137	·011	·017	·146	·022	·030	·135	·017	·032
54 –	·156	·019	·023	{·206 ·209}	060	·084	·160	·025	·054
57 –	·183	·027	·047	·274	·065	·139	·220	·060	·106
60 –	·230	·047	·086	·390	·116	·259	·295	·075	·176
63 –	·304	·074	·154				·450	·055	·317
66 –	·404	·100	·244				·630	·080	·492
72 –									
81 –	1·660		1·480	2·160		1·960	1·640		1·480
	Deflection per ton ·0144			·0133			·0125		

TABLE XIX.

Liverpool and Manchester, 35 lbs. per yard elliptic rail, *Fig.* 18, *Plate III.;* 3 feet bearings, greatest depth 3¼ inches, depth at ends 2½ inches.

Weight on press.	Experiment I.			Experiment II.		
	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·018			·013		
		·012			·012	
6 –	·030			·025		
		·014			·011	
9 –	·044			·036		
		·015			·015	
12 –	·059			·051		
		·012			·015	
15 –	·071		·001	·066		
		·018			·012	
18 –	·089		·004	·078		·001
		·014			·014	
21 –	·103		·005	·092		·003
		·016			·013	
24 –	·119		·006	·105		·004
		·015			·016	
27 –	·134		·009	·121		·006
		·022			·017	
30 –	·156		·016	·138		·013
		·023			·019	
33 –	·179		·028	·157		·019
		·083			·028	
36 –	·262		·098	·185		·033
		·080			·049	
39 –	·342		·167	·234		·069
					·112	
42 –	—	—	—	·346		·167
Deflection per ton ·0265				·025		

TABLE XX.

Liverpool and Manchester railway company, 50 lbs. parallel rail, *Fig.* 15, *Plate III.*; 3 feet bearings, 3⅝ inches deep.

Weight on press.	Experiment I.			Experiment II.		
	Top downwards.			Top upwards.		
	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·012			·008		
6 –	·023	·011		·016	·008	
9 –	·031	·008		·023	·007	
12 –	·038	·007		·031	·008	
15 –	·046	·008		·037	·006	
18 –	·054	·008		·045	·008	
21 –	·059	·005		·049	·004	
24 –	·066	·007		·060	·011	
27 –	·074	·008		·067	·007	
30 –	·084	·010	·002	·076	·009	·001
33 –	·092	·008	·005	·086	·010	·002
36 –	·103	·011	·010	·097	·011	·006
39 –	·122	·019	·020	·122	·025	·020
42 –	·166	·044	·058	·190	·068	·085
45 –	·235	·069	·119	·330	·040	·223
48 –	·335	·100	·207	·504	·174	·387
51 –	·434	·099	·313	·700	·196	·575
66 –	1·929		1·760	2·780		2·620
Deflection per ton ·0155				·0147		

TABLE XXI.

Liverpool and Manchester, 60 lbs. per yard parallel rail, *Fig.* 17, *Plate III.;* 3 feet 9 inches bearing, 4 inches deep.

Weight on press.	Experiment I.			Experiment II.		
	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·010			·009		
6 –	·019	·009		·016	·007	
9 –	·025	·006		·024	·008	
12 –	·033	·008		·030	·006	
15 –	·039	·006		·036	·006	
18 –	·046	·007		·045	·009	
21 –	·053	·007		·051	·006	
24 –	·060	·007		·058	·007	
27 –	·066	·006		·064	·006	
30 –	·074	·008	·001	·072	·008	
33 –	·082	·008	·002	·080	·008	
36 –	·088	·006	·002	·087	·007	
39 –	·097	·009	·003	·096	·009	·009
42 –	·104	·007	·004	·099	·003	·012
45 –	·110	·006	·006	·108	·009	·016
48 –	·119	·009	·009	·118	·010	·020
51 –	·123	·004	·016	·129	·011	·024
54 –	·130	·007	·021	·141	·012	·030
57 –	·145	·015	·032	·160	·019	·040
60 –	·184	·039	·065	·180	·020	·059
63 –	·243	·059	·122	·230	·050	·108
66 –	·323	·080	·197	·310	·080	·183
75 –	—	—	—	·663	·353	·520
84 –	—	—	—	1·190	—	1·035
Deflection per ton ·014				·014		

TABLE XXII.

Liverpool and Manchester parallel rail, *Fig.* 17, *Plate III.*; 60 lbs. per yard, 4½ feet bearings, 4 inches deep.

Weight on press.	Experiment I.			Experiment II.		
	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·021			·016		
		·011			·016	
6 –	·032			·032		
		·012			·013	
9 –	·044			·045		
		·014			·013	
12 –	·058			·058		
		·011			·013	
15 –	·069			·071		
		·011			·012	
18 –	·080			·083		
		·008			·012	
21 –	·092			·095		
		·010			·012	
24 –	·102			·107		·001
		·014			·013	
27 –	·116			·120		·001
		·010			·012	
30 –	·126		·002	·132		·004
		·014			·015	
33 –	·140		·003	·147		·008
		·018			·021	
36 –	·158		·010	·168		·018
		·034			·035	
39 –	·192		·033	·203		·042
		·098			·087	
42 –	·290		·123	·290		·121
		·134			·146	
45 –	·424		·246	·436		·257
		·243			·234	
48 –	·667		·470	·670		·471
Deflection per ton ·023				·026		

Table XXIII.

Liverpool and Manchester parallel rail, *Fig.* 17, *Plate III.*; Ex. I. weight 60¼ lbs. per yard; and Ex. II. and III. 50½ lbs. per yard. Ex. III. reversed; 3 feet bearings, 4 inches deep.

Weight on press.	Experiment I.			Experiment II.			Experiment III.		
	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.	Observed deflection.	Deflection for each ½ ton.	Permanent deflection.
3 lbs.	·005			·008			·005		
6 –	·010	·005		·017	·009		·017	·012	
9 –	·017	·007		·026	·009		·026	·009	
12 –	·021	·004		·032	·006		·033	·007	
15 –	·026	·005		·040	·008		·040	·007	
18 –	·031	·005		·048	·008		·046	·006	
21 –	·037	·006		·055	·007		·055	·009	
24 –	·042	·005		·062	·007		·060	·005	
27 –	·048	·006		·068	·006		·067	·007	
30 –	·052	·004		·076	·008		·074	·007	·002
33 –	·058	·006		·082	·006		·085	·011	
36 –	·063	·005		·091	·009	·005	·095	·010	·008
39 –	·069	·006		·102	·011	·010	·111	·016	·017
42 –	·075	·006		·116	·014	·016	·132	·021	·030
45 –	·080	·005	·001	·139	·023	·032	·163	·031	·052
48 –	·087	·007	·001	·158	·019	·045	·210	·047	·095
51 –	·094	·007	·004	·195	·037	·075	·268	·058	·138
54 –	·100	·006	·005	·258	·063	·130	·340	·072	·213
57 –	·112	·012	·013	·370	·112	·234	·428	·088	·300
60 –	·132	·020	·025						
63 –	·162	·030	·049						
66 –	·190	·028	·086						
69 –	·244	·054	·140						
Deflection per ton ·0107				·014			·155		

The following Table will shew the result of the several preceding experiments, and the amount of deflection, for each ton of insistent weight, upon the different rails.

TABLE XXIV.

Parallel rails.					Elliptic rails.				
No. of experiment.	Weight of rail per yard, in lbs.	Greatest depth of rail, in inches.	Length of bearing, in inches.	Deflection.	No. of experiment.	Weight of rail per yard, in lbs.	Greatest depth of rail, in inches.	Length of bearing, in inches.	Deflection.
V.	37	3⅞	31	·0114	I.	33	3 11/16	32¾	·014
VI.	37	3⅞	31	·013	II.	32	3⅛	32¾	·0205
XII.	45	3¼	36	·019	III.	33	3 9/16	32¾	·015
				·018	XIX.	35	3½	36	·0265
XI.	50	4	31½	·0051					·025
VIII.	50	4	31½	·0046	IV.	39	4 1/16	32½	·0115
XX.	50	3⅝	36	·0155	VI.	39	4 1/16	32½	·0117
				·0147	XIII.	44	4½	36	·0166
XXI.	50	4	45	·014					·0154
XXII.	50	4	54	·023	VII.	50	5	31½	·0035
				·026	XI.	50	5	31½	·0032
XXIII.	50	4	36	·014					·0043
	60	4	36	·0107					·0042
IX.	60	4½	36	·005	X.	50	5	36	·0097
XIV.	62	4½	36	·0077					·0101
				·0075					·0110
XVII.	62	4½	36	·0074					·0090
				·006	XVIII.	50	4	36	·0144
XV.	62	4½	45	·0154					·0133
			60	·034					

To compare the relative rigidity of parallel, with elliptic rails, it will be necessary to reduce all the experiments to the same length of bearing. With a view, therefore, of more clearly shewing the comparison, the following Table has been constructed, wherein the deflection shewn is, that which results from a length of bearing of thirty-six inches; those experiments only being exhibited, which are, more particularly, capable of comparison, and the mean result of each experiment only is given.

TABLE XXV.

Parallel rails.				Elliptic rails.			
No. of experiment.	Weight of rail per yard in lbs.	Greatest depth of rail in inches.	Deflection.	No. of experiment.	Weight of rail per yard in lbs.	Greatest depth of rail in inches.	Deflection.
V.	37	$3\frac{7}{8}$	·0181	I.	33	$3\frac{11}{16}$	·0189
VI.	37	$3\frac{7}{8}$	·0204	II.	32	$3\frac{1}{8}$	·0277
XII.	45	$3\frac{1}{4}$	·0185	III.	33	$3\frac{9}{16}$	·0203
VIII.	50	4	·0070	XIX.	35	$3\frac{1}{2}$	·0257
XI.	50	4	·0077	IV.	39	$4\frac{1}{16}$	·0158
XX.	50	$3\frac{5}{8}$	·0150	VI.	39	$4\frac{1}{16}$	·0160
XXIII.	50	4	·0140	XIII.	44	$4\frac{1}{2}$	·0160
IX.	60	$4\frac{1}{2}$	·0050	VII.	50	5	·0053
XXIII.	60	4	·0107	XI.	50	5	·0059
XIV.	62	$4\frac{1}{2}$	·0076	X.	50	5	·010
XVII.	62	$4\frac{1}{2}$	·0067	XVIII.	50	4	·0138

On examining the above Table, and comparing the result with the different sectional areas of the two kinds of rails, it will be seen, that, with the same weight per yard, the elliptic rail is more rigid than the parallel; the two sections, which appear most nearly alike, being VII. and XI. in the elliptic, and XIV. and XVII. in the parallel rail. But it will be seen, on examining the section of these latter rails, that the lower flanch is much broader, than that which would give the greatest strength with the least material; and which is proved by the experiments in Table XVII. where the breadth of the rail was reduced, and, consequently, its weight, without producing any sensible effect, upon the rigidity. The conclusion, from these experiments, appears to be, that, by adopting the elliptic form, and thereby obtaining a greater depth of iron, in the middle of the rail; a greater degree of rigidity is produced, in that form, with the same weight of material, than with a parallel bar, in the middle of the rail. In practice, however, it has been found, that the elliptic bars do not become injured, in the middle of the rail, but about nine inches from the bearing, or about one-fourth of the length between the bearings. This has been found to be the case, in the first rails laid down upon the Liverpool and Manchester railway, and, more particularly, upon other railways, which have come under our notice; where all the rails, which have broke, have failed about seven to nine inches from the bearing. This would shew, that, besides having to provide for a sufficient degree of rigidity, in the middle of the rail, the action of the carriages requires, that a greater degree of strength should be given to a railway bar, near the points of support, than is capable of sustaining the load, without injury; or, rather, that more than a uniform degree of strength should be given to that part of the bar. This, of course, extends only to a certain degree of additional strength, the above remarks applying to rails, either decidedly too weak, or of bad material; if stronger rails are used, which, we presume, will generally be done, no doubt, a saving of material, to a certain extent, may be accomplished, by the adoption of an elliptic form of rail.

Besides shewing the relative rigidity, of different sections of rails, these experiments are useful, in shewing the increase of effect between single lengths of rails, and long lengths, having several bearing points. In the first five Tables, the experiments will shew the result, between a single length of rail, and the whole combined. In those experiments, when said to be *loose*, the single division of the rail only, was fastened to its chairs at each end, and those chairs fastened to the timber framing, by which the experiment was made; but when said to be *fixed*, all the chairs, of the several divisions of the rail, were fastened to the timber. The result exhibits a considerable increase of rigidity, and points out the advantage of long lengths of rails, and the necessity of adopting such a mode of fastening the rails to the chairs, as will effectually bind the whole together, and prevent the ends of the rail from rising out of the chair.

Having thus shewn, as well the relative, as the actual, rigidity of different sections of rails; it now becomes necessary to inquire, to what extent railway bars can be deflected, without producing an increase of resistance to the carriages passing along them.

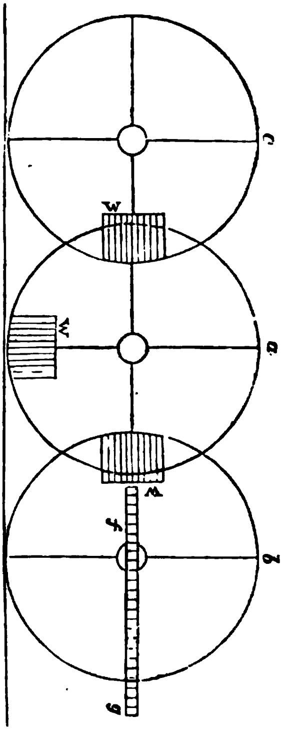
§ 5.—*Increase of Resistance, by the Deflection of Railway Bars.*

When wrought-iron rails were first introduced, it was objected to them, that the resistance to the carriages was greater upon them, than upon cast-iron rails; experience, having proved that such was actually the case, on some railroads. The wrought-iron rails, when first laid down, were, however, much too weak for the strain which they were to sustain, and it was surmised, that the increase of resistance arose from the nature of the material, and not from the bending of the wrought-iron rails, from their deficient strength.

To ascertain, if, in the first place, any increase of resistance does actually exist, from the nature of the material, and, next, to what strain wrought-iron rails could be subjected, without increasing the resistance, the following experiments were made.

Two lengths of rails were laid down upon balks of wood, one of cast, and the other of malleable iron; both of which were taken off the railway, in their working, and brightened, state; they were laid down, parallel with and close to each other, upon the same balks of timber, so that a pair of wheels resting on one could be readily lifted upon the other. Two wheels, joined together by an axle, and taken from one of the carriages in use, were then placed upon one of the lengths, and loaded on the lower side of the rim with weights, that could be varied at pleasure. The wheels, thus loaded on one point at the periphery, became like a pendulum; the centre of gravity, instead of being in the centre, was near the periphery. The wheels being placed on the rails, would, of course, only remain at rest, when the line of gravity, projected from the point resting on the rails, passed through the centre of the axle, joining the two wheels, and that part of the periphery which was loaded. When the wheels were rolled along the rails, until the line of gravity did not pass through the point of rest, but was several inches beyond it, and then let go, they, of course, vibrated backwards and forwards, until the resistance of the periphery of the wheels, upon the rails brought them to rest. This mode of experimenting was preferred, to trying the relative resistance by carriages; as, in experimenting with carriages, two species of friction are experienced, whereas, by this mode, there is no action, except that of rolling; and by lifting the wheels, alternately, from one kind of rail to the other, without altering the weight, the comparison upon cast and wrought iron became very delicate. A scale was used, to measure the extent of each vibration from the centre, and the observations were made by a telescope; and the number of oscillations were thus counted, while the extent of the vibrations was diminished each inch.

The marginal sketch will shew this mode of experimenting. *a b c* is the wheel, in different positions; *f g* the scale for measuring the extent of the vibrations; w w w the weight placed near the periphery.



Thus, at the commencement, the wheel was rolled by hand into the position *b* or *c*, when the extent of the vibrations, from the point of rest, was five or seven inches; the wheel was then left at liberty, and made so many vibrations, before the distance from the point of rest was diminished an inch, or until the extent of vibrations from the centre was four or six inches; and so on until the wheels became at rest, in the position *a*.

The cast-iron rails were three feet nine inches long, and weighed fifty-six pounds; section shewn in *Fig.* 3. *Plate II.* The wrought-iron rails weighed twenty-eight pounds per yard, the bearings three feet apart; section same as experiment on the strength of rails.

TABLE XXVI.

Extent of Vibrations.	Experiment I.				Experiment II.			
	Weight of wheels and load, W. 10 cwt.				Weight of wheels and load, W. 20 cwt.			
	Cast-iron rails.		Wrought-iron rails.		Cast-iron rails.		Wrought-iron rails.	
	No. of vib.	No. of vib.	No. of vib.	No. of vib.	No. of vib.	No. of vib.	No. of vib.	No. of vib.
in. in.								
5 to 4	56	62	54	64	52	50	52	52
4 – 3	74	78	68	80	64	70	64	66
3 – 2	88	82	84	100	84	82	92	86
2 – 1	87	86	98	84	99	110	142	150

TABLE XXVII.

Extent of Vibrations.	Experiment III.					Experiment IV.					
	Weight of wheels and load, W. 30 cwt.					Weight of wheels and load, W. 40 cwt.					
	Cast-iron rails.		Wrought-iron rails.			Cast-iron rails.		Wrought-iron rails.			
	No. of vib.	wedged. No. of vib.	No. of vib.	No. of vib.	wedged. No. of vib.	No. of vib.	wedged. No. of vib.	No. of vib.	No. of vib.	wedged. No. of vib.	wedged. No. of vib.
in. in.											
7 to 6	—	—	—	—	—	28	30	24	26	31	32
6 – 5	—	—	—	—	—	32	34	28	28	32	32
5 – 4	54	46	54	54	50	42	36	38	38	35	35
4 – 3	66	56	70	66	68	44	48	44	46	43	45
3 – 2	82	78	90	94	90	48	46	56	55	50	48
2 – 1	94	90	116	124	114	52	52	84	82	63	66

These experiments will shew, in the first place, that the resistance was the same, with malleable and cast-iron rails, until the incumbent weight reached 30 cwt. With 40 cwt. the number of vibrations from 7 inches to 3 inches, in cast iron, was 146; while, upon wrought iron, it was 134 and 138 respectively; shewing a trifling increase of resistance with that weight. The rails were then wedged up on the under side, to prevent them from bending, when the number of vibrations of cast iron was 148; shewing that scarcely any resistance was owing to the want of stiffness. With the wrought iron, the wedging had an increase of effect, and brought up the resistance nearly equal to that of cast iron; and thus proving, that, when no bending takes place in the wrought iron, the resistance is precisely the same as with cast iron.

We, however, find, by these experiments, that when the deflection is to a certain extent, an increase of resistance takes place, and that the rails of wrought iron, upon which these experiments were made, were only sufficient for carriages of four wheels, weighing three tons. When the wheels were loaded with 30 cwt., no increased effect took place on wedging up the middle of the rail; but when loaded with 40 cwt., the number of vibrations was increased by making the rail perfectly rigid. The deflection of the wrought-iron rail, as ascertained by experiment with 30 cwt., was ·032 inch, and with 40 cwt. ·043 inch; so that we find it will not be advisable to use rails, the deflection of which, when loaded, amounts to ·032 inch, especially when the rails are laid down; as, when they become worn, the deflection being greater, an increase of resistance will take place. With carriages mounted upon springs, which yield to all the inequalities and want of parallelism of the road, we may suppose the whole weight of the carriage divided equally upon the four wheels. But with carriages without springs, as before stated, the weight of the carriage, very frequently, rests upon two wheels only; and, in practice, therefore, we must, with these kind of carriages, suppose the whole weight acting upon two wheels.

To ensure, therefore, no increase of resistance in the use of wrought-iron rails, it would appear, from these experiments, that their rigidity should be such as, by carriages with springs, one fourth, and by carriages without springs one half, of the weight will not cause a deflection in the middle of the rail, equal to ·032 parts of an inch.

In the experiments previously detailed, the weights were applied carefully upon the rail, and, therefore, the rail was not subjected to the shocks and blows which occur in practice. It became, therefore, almost necessary that experiments should be made to ascertain the difference between the strain, to which railway bars were exposed in use, with the consequent deflection, and that which experiments carefully made presented. Professor Barlow, in his enquiries on the subject of the best form of rails for the London and Birmingham railway company, made some experiments on the Liverpool and Manchester railway, to ascertain the amount of deflection of different sections of rails, while the carriages passed over them.

The locomotive engines are the heaviest species of carriage upon that railroad, and, therefore, one of these machines was taken to perform the experiment. The deflection was measured by an instrument placed underneath the middle of the rail, equi-distant from the points of bearing, and the extent of the deflection was ascertained by a multiplying index.

The Speedwell, and Swiftsure engines were employed, the weight on the driving wheels of the latter being 5 tons 16 cwt.; and the velocity was varied from a slow rate, to that of twenty miles an hour.

The following Tables shew the result of these experiments:—

TABLE XXVIII.

No. I. experiment, Speedwell engine. Nos. II. and III., Swiftsure. Grand Junction, 62 lbs. rail, bearings 3 feet 9 inches.

—	Velocity 20 miles an hour.	Velocity 20 miles an hour.	Velocity very slow.	—
Deflection, joint length -	·0625	·0800	·0400	Mean ·0608.
Ditto, middle length -	·0425	·0320	·0240	Mean ·0353.
Ditto - ditto -	·0400	·0400	·0250	
Ditto - ditto -	·0400	·0420	·0320	

TABLE XXIX.

Swiftsure engine, same railway bars, with bearing lengths of 5 feet, at different velocities.

—	22 miles an hour.	22 miles an hour.	22 miles an hour.	30 miles an hour.	32 miles an hour.	23 miles an hour.	—
Deflection, joint length -	·083	·080	·123	·080	·105	·085	Mean ·117.
Ditto - ditto -	·108	·143	·130	·250	·120	·095	
Ditto middle length	·093	·077	·080	·112	·122	·083	Mean ·90.
Ditto - ditto -	·082	·070	·077	·091	·115	·085	

On prosecuting the enquiry further, it was found that the blocks yielded likewise, when the train passed over them; and therefore to ascertain accurately the amount of deflection in the middle of the rail, it was necessary to ascertain, at the same time, the depression of the two supporting blocks on which the rail rested. Experiments were made to ascertain this, the instrument being applied to the blocks, while the engine and train of carriages passed over them; the results of these experiments were very various, depending upon the nature of the base on which the block rested; the only conclusion being, that, in every instance, there was a yielding, to a certain extent, when the engine and train passed over.

The following experiments shew the depression of the blocks of different kinds of rails, when the engine and trains passed over them:—

TABLE XXX.

Swiftsure engine, 62 lbs. rails, 3 feet 9 inches bearings.				
———	Miles, v. 10.	Miles, v. 16.	Miles, v. 20.	Miles, v. 30.
Hanging block, depression -	·060	·090	·080	·085
Firm block, ditto - -	·010	·020	·022	·032
Ditto - ditto - -	·000	·012	·017	·032
Supposed not quite firm, ditto -	·018	·028	·028	·032

Rejecting the hanging block, which was partly suspended by the rail, the mean of the other experiments gives ·021 for the depression or disturbance of the block.

Table XXXI.

Swiftsure engine, same rails, 5 feet bearings.		
——	Velocity medium.	Velocity medium.
Middle block, depression - -	·016	·008
Joint ditto - ditto - - -	·036	·020
Middle ditto - ditto - - -	·018	·010
Middle ditto - ditto - - -	·023	·025

Mean of all these depressions ·019 of an inch.

Table XXXII.

Swiftsure engine, Mr. Booth's rail, parallel same as experiment, Table XXIII., 60 lbs. per yard, 3 feet bearings.				
1st block, supposed not firm -	·018	·028	·018	·023
2d ditto - ditto - - -	·036	·040	·036	·032
3d ditto firm - - -	·022	·013	·014	·011
4th ditto ditto - - -	·024	·020	·027	·023

Mean of the first and last two, which appear to have been firm, gives the disturbance ·020.

The mean of the three experiments with the Speedwell and Swiftsure engines, on rails similar to those of experiments in Table IX., page 94, with three feet nine inches bearings, gives a deflection, in the middle of the rail, with a forty-five inch bearing, equal to ·0353 inch. Experiments, Table IX., gave a mean deflection, at thirty-three inches clear bearing, of ·0050; consequently, for fifty-eight hundred weight, ·0145; and, reducing this to the clear bearing of 45—3=42 inches, we have as $33^3 : 42^3 :: \cdot 0145 : \cdot 0310$, the deflection with fifty-six hundred weight at rest. The mean of several experiments on the yielding of the blocks, with the same engine, gave about ·020, while the engine passed over the blocks. A part of this depression would take place while the engine passed over the middle of the rail, and, therefore, the deflection, due to the weight of the engine, while passing over the middle of the rail, should be reduced below ·0353; and, hence, we find that the deflection of the rail is not greater, when the engine and train pass over it, than when the rail was subjected to the same weight at rest.

The mean of the experiments with the same rail, with five-feet bearings, gives the deflection ·090. Experiments, Table IX., gave a mean deflection of ·0050, or, for three tons, ·0150. Deducting three inches from sixty, to obtain the clear bearing, we have $33^3 : 57^3 :: \cdot 0150 : \cdot 079$, the deflectometer shewing a deflection of ·090. Referring, however to the depression of the blocks, which amounts to ·019, and taking one half of this, as resolvable to the middle of the rail, we find, that there is not, in practice, a greater deflection of the bars than shewn by experiment at rest.

During the prosecution of these experiments, and while a train of carriages passed rapidly over the rails, or blocks, subjected to experiment, it was observed, that a sudden increase of strain would take place, by the lurching of the engine or carriages; and this was found to be very various in amount, but, in some cases, more than double that produced by the carriages and engine passing smoothly over.

This is shewn, very conspicuously, in the following experiment, made by Professor Barlow, with the same deflectometer as used in the previous experiments, upon the Liverpool and Manchester railway:—

TABLE XXIII.

Swiftsure engine, Dublin and Kingstown rail, 45 lbs. per yard, same as experiment, Table XII., 3 feet bearings.						
Joint length - -	·120	·120	·105	·167*	·177*	·105
Ditto - -	·120	·084	·098	·090	·080	·098
Middle length -	·125	·110	·130	·130	·156*	·130*
Ditto - -	·110	·103	·112	·112	·120	·108

The deflections marked with an asterisk, shew the effect of the lurching of the engine and carriages, and which amount to nearly double the smaller, or more natural, deflections.

It appears, therefore, that the rule, deduced from the experiments with the wheels vibrating on rails at rest, will be sufficiently correct for practice, when the carriages pass smoothly over the rails and blocks; but as lurches so frequently occur in practice, when travelling at great rates of speed, it will be advisable to consider the strain as equal to one half of the weight of the carriage on each wheel; and that no rail should be loaded with a weight capable of producing a deflection, in the middle, of ·032 parts of an inch; such weight being computed as equal to one half the whole weight of the carriage on each wheel.

In the Appendix, to a new edition of his Treatise on the strength of timber, iron, &c., Professor Barlow enters into a theoretical investigation, and gives some experiments on the increase of resistance to the carriages by the deflection of wrought-iron bars; the following being the result:—

TABLE XXXIV.

Bearing distances.		Deflections.	Equivalent planes.	Increase of friction per ton.
feet.	inches.			
3	0	·024	1 in 3000	·75 lbs.
3	9	·037	1 in 2432	·92 -
4	0	·041	1 in 2341	·95 -
5	0	·064	1 in 1875	1·20 -
6	0	·082	1 in 1756	1·30 -

Having ascertained the limit, which wrought-iron bars may be deflected, without producing an increase of resistance, and the ratio of increase, by a given amount of deflection; it becomes a question, of some importance, what weight of rail should be used, and the distance between the supports; this will depend greatly upon the cost of obtaining blocks, or supports for the chairs. The deflection of rails, with different lengths of bearings, being as the cube of the distance between the bearings, the relative amount of deflection can be readily calculated. Experiments XV., XXI., and XXII. shew the deflection at different lengths of bearing; having, therefore, the relative rigidity, and the cost of each bearing, the strength of rail, and the distance of each bearing, can readily be calculated.

§ 6. *Expansion and Contraction of Wrought-iron Bars.*

In the use of cast iron for railways, the bars or rails are necessarily short; and, therefore, the effect of the variation of temperature does not produce any practical evil, each length of rail being supported by a block. But in the use of malleable iron for railways, the rails are made of considerable length, of now generally fifteen feet, and, consequently, the amount of expansion and contraction upon that length of iron is considerable; and the rail being supported by several intermediate bearings, between the ends, it becomes a subject of importance to ascertain the effect, in practice, of the expansion and contraction of the rails, from the variation of temperature in summer and winter.

The amount of expansion and contraction of wrought-iron bars, by a variation of temperature, has been ascertained by several experimentalists. Mr. Smeaton found the expansion equal to $\frac{1}{143000}$th part of its length for each degree of temperature. Professor Daniel more recently, and with more accurate apparatus, found the expansion $\frac{1}{150000}$th part. Taking, therefore, the variation of temperature, between summer and winter, to be equal to 76°, a bar of malleable iron will expand and contract, between the two extremes of temperature, the 2000th part of its length. Taking railway bars, at fifteen feet in length, the amount of expansion and contraction will, therefore, be equal to the 11th part of an inch, for a range of temperature of 76°.

Amongst railway engineers, it has become a subject of discussion, whether the peculiar application of bars of iron as rails upon railways, and laid down upon blocks of stone, imbedded below the surface, did, or did not, follow the precise law of expansion and contraction of common bars of iron; and this was brought more prominently forward by the knowledge, that, when railway bars were laid upon blocks of stone, there did not appear the same twisting or bending of the rails, in summer, as with bars laid upon timber.

To determine this question, which is of great importance in railway practice, I had a double length of rails laid down upon the Killingworth railway, 152 feet in length, and composed of fifteen railway bars of nearly fifteen feet each long. The joinings of each bar with the next, were so constructed, that they could not separate, being formed with half-lap joints, and bolted together by a bolt, completely filling the hole in each half-lap. By this plan, all the bars were combined, and, therefore, the expansion and contraction were the same as for one bar 152 feet in length. The rails were supported, at each three-feet length, upon blocks of stone of three cubic feet each. The mode of measuring the amount of expansion and contraction was as follows:—On each side of the rails, at each end of the length, the subject of the experiment, wooden piles were driven into the ground, sufficiently deep to be quite firm and immoveable, the heads of which were level with the under side of the rails. Pieces of iron were fastened to the head of these piles, on each side of the rail, upon which a line was cut, transversely, from one side of the rail to the other. A similar line was cut upon the rail, corresponding with the mark on the iron of the pile; and the temperature taken, when the lines on the rail corresponded with the lines upon the iron of the pile. These, as before stated, were done at both ends of each length of rails so bolted together. When, therefore, the rails contracted, the lines upon the rails would be short of those upon the posts, and when expanded, they would extend beyond. Observations were made, therefore, at certain intervals, during the whole of the winter of 1836, and summer of 1837, and the extent of extension and contraction accurately measured. It is necessary to observe, that the joint at the end of this length of road, was not firmly united with the other part of the railway, but sufficiently loose to allow the rails to stretch or contract.

This experiment, therefore, gives the expansion and contraction of a length of railway or bar of iron in use equal to 152 feet, and the result of the experiment made during the whole year was, that the range of temperature, when the observations were made, was 50°, viz. from 31° to 81°, and the extent of contraction and expansion equal to ·685 of an inch; which gives the amount, equal to about the 15th part of an inch, for a fifteen-feet rail, between summer and winter, or from the freezing point to 81°.

We see, therefore, that the expansion of railway bars in use, does not vary from that shewn by common bars of iron, subjected to experiment by a variation of temperature, produced by artificial means; and that the amount of expansion or contraction of a railway bar, fifteen feet in length, is about the 750th part of an inch for each degree of temperature.

§ 7.—*Experiments on the Strength of Cast-iron Rails.*

We shall now give an account of some experiments on the strength of cast-iron rails, made at Walker Foundry, near Newcastle-upon-Tyne, the property of Messrs. Losh, Wilson, and Bell.

TABLE XXXV.

Number of Experiments.	Description of metal.	Weight of each rail	Weight which produces fracture.	Average weight of each kind of rail.	Average strength of each kind of rail.	Relative strength of mixed and unmixed metal, spec. grav. considered.
		lbs. oz.	*cwt. qrs. lbs.*	*lbs. oz.*	*cwt. qrs. lbs.*	
1	No. 1. metal A. -	56 6	126 3 0	55 9	114 1 14	146. 122
2	Ditto - -	56 0	99 3 0			
3	Ditto - -	55 8	108 3 0			
4	Ditto - -	54 7	122 1 0			
5	No. 1. A., same kind as preceding, mixed with old metal -	58 14	148 2 0	59 10	146 0 14	
6		58 9	144 0 0			
7	No. 1. metal B. -	55 10	113 1 0	56 6	106 2 0	156. 108
8	Ditto - -	57 1	99 3 0			
9	No. 1. B. mixed with old metal	57 13	162 3 0	57 10	156 0 8	
10		57 7	149 1 0			
11	No. 1. metal C. -	55 8	150 3 0	55 4	140 2 14	173. 128
12	Ditto - -	55 0	130 2 0			
13	No. 1. C. mixed -	56 4	184 2 0	56 10	173 3 0	
14	Ditto - -	57 0	162 0 0			
15	No. 1. metal D. -	56 3	113 1 0	56 2	115 2 0	194. 119
16	Ditto - -	56 1	117 3 0			
17	No. 1. D. mixed with old metal	59 9	207 3 0	58 4	194 1 0	
18		56 14	180 3 0			
19	No. 2. Ditto D. -	56 13	95 1 0	56 5	97 2 0	
20	Ditto - -	55 12	99 3 0			
21	No. 3. Ditto D. -	57 13	104 1 0	57 5	108 3 0	
22	Ditto - -	56 14	113 1 0			
23	No. 1, metal E. -	56 6	128 1 0	56 12	131 2 14	137. 144
24	Ditto - -	57 2	135 0 0			
25	No. 1. E. mixed with old metal	55 6	148 2 0	55 8	137 2 0	
26		55 10	126 0 0			
27	Rail, cast-iron, different kinds of metal, close fracture -	55 8	135 3 0			
28	Ditto open fracture	57 1	99 3 0			
29	Rail, 4 feet long -	58 0	120 0 14			
30	Rail, 3 feet long, No. 2. metal -	33 0	98 2 14			
31	Rail, 3 feet, Welch metal - -	33 0	100 3 14			
32	Rail, 3 feet, No. 1. metal - -	33 0	107 2 14			

The rails were all cast from the same pattern, the difference in weight being accidental. Sections similar to *Figs.* 1 and 3, *Plate II.*, two inches and a quarter broad on the upper side, and tapering away to one inch and a half in the middle, and again swelling out at the bottom into the square *c b*, each side of which is seven eighths of an inch. Extreme depth, in the centre, six inches, gradually decreasing towards the ends, or points of support, in a parabolic form, to four inches. In the experiments, the rails were fastened in the usual manner to the chairs, which were fixed upon beams of wood; distance between the points of support, three feet, and nine and a half inches.

In comparing the strength of the different rails with each other, we find a great variation, not only between the different kinds of metal, but also in rails cast from the same metal. The only constant and regular law appears to be, that the weight or specific gravity of rails, formed of a mixture of different kinds of metal, is uniformly greater than of one description of metal separately, and, also, that such a mixture makes the rails invariably stronger. This is a very useful discovery, and enables the founder, by mixing different metals in the proper proportions, to form a rail much stronger, with the same weight of metal, than otherwise could be done by casting them of any particular kind of metal alone. The depth of the middle section of the cast-iron rail renders them very rigid, and the deflection is comparatively trifling before fracture. The recorded weights are those which produced fracture; in loading the rails, the weight should, of course, be much less than that which breaks the rail. Inequalities of the road, or occasional obstacles occurring upon the surfaces of the rails, will sometimes produce jerks, or shocks to the wheels of the carriages, and the reaction will transfer those to the rails, and cause blows, which, from the brittleness of the material, will be very liable to produce fracture.

In the form of carriages with four wheels, when springs are not used, the weight upon any one of those wheels is far from being regular. The frame of the carriage is rectangular, and the centres of the axles are, as nearly as possible, in the same plane; now, when the bearing surfaces of the rails do not lie in a plane, exactly parallel to the plane of the axles, (and this, in practice, is seldom the case,) the weight of the carriage will rest upon three of the wheels only. If there be a want of correspondence in the undulations, or in the yielding of the rails, the weight may change its points of support, and will, during the instant of transmission, be sustained by two of the wheels alone, and those will be diagonally on opposite sides of the carriage; the transition of the weight, from one wheel to another, will, therefore, produce a continual succession of blows or shocks to the rails, which will be productive of considerable injury, and occasion breakage.

From these causes, and others, which it is not necessary to mention, we find, that, in practice, it is not advisable to subject the rails to a greater load than is considerably within the limit of their absolute strength. In the preceding experiments, the least weight borne by the rails, formed of a mixture of metals, is seven tons, and by the unmixed rails five tons; and the rails were of the size and weight of a railroad, on which the carriages that passed upon it were intended to be four tons, supported upon four wheels.

In extreme cases, when the inequalities of the road throw the weight from one wheel to another, the greatest strain upon any one rail cannot amount to more than two tons; therefore, the proportion, which the load that can be carried with perfect safety, bears to the absolute strength of the rails, is, in the one case, 3,5 : 1, and in the other, 2,5 : 1. But, as it may be supposed, that a mixture of metals will be mostly used; we may, in practice, say, that the strain to which the rails of any railroad should be subjected by the load, ought not to amount to more than about one third of their absolute strength, or of that weight which would produce fracture.

We may thus find the strength of any section of rail suitable for a given weight of carriage.

Let w = the utmost strain to which the rail is subjected, in lbs.;
l = the distance between the supports, in feet;
b = the extreme breadth of section, in inches;
d = the extreme depth of section, in inches;
$q\,b$ = the difference between the breadth in the middle and the extreme breadth; and
$p\,d$ = the depth of the narrow part or rib in the middle.

Then $\frac{3\,w\,l}{850} = b\,d^2\,(1 - q\,p^3)$. See *Tredgold, on Cast Iron.*

Consequently $d = \sqrt{\frac{3\,w\,l}{850\,b}\,(1 - q\,p^3)}$, and $w = \frac{850\,b\,d^2}{3\,l}\,(1 - q\,p^3)$.

§ 8.—*Comparative Durability, of Cast and Wrought Iron Railway Bars.*

In the formula for calculating the strength and rigidity of wrought-iron bars, we have given those necessary for cast-iron rails; and we now come to the question of comparative durability, between cast and malleable iron rails. The introduction of the latter being comparatively recent, the opportunity of subjecting them to the test of experiment has not existed sufficiently long, to produce any very conclusive decision from that source; the opportunities of doing so are, also, not numerous; and many people are more disposed to concur in, and yield to, the general or current opinion, than either wait the result, or submit to the tedious operation of experiment. In this case, also, no experiment can be decisive, unless acted upon for a number of years; we are, therefore, almost obliged to act upon speculative opinion, until sufficient time has elapsed to produce conclusive evidence, in favour of one mode or other.

Independent of economical considerations, with respect to the durability of wrought-iron rails, their safety, compared with cast-iron, upon public lines of road, has already produced a general concurrence in their favour; and, therefore, perhaps, the question of durability becomes of less importance. Still, as in some cases, where rapidity of transit is not necessary, relative economy may become an object, we shall, therefore,—such as our experience enables us, speak of the comparative durability of cast and wrought iron.

Experiments are going on at present, where both kinds of rails, accurately weighed, are laid down, and subjected to the passage of the same quantity of traffic over them; the result of these, so far as they have gone, is in favour of wrought iron. In the operation of making the cast-iron rails, the surface is partially case-hardened in the casting; this may be seen in all cast-iron rails, extending to a certain depth from the surface. Any experiment, shewing the comparative wear, must, therefore, be continued until after the outer hardened surface be worn through; and, it is presumed, that sufficient time has not yet elapsed to furnish this. We have, therefore, been obliged to reject the data founded on this mode of experimenting, and shall give the result of a different sort of test, more severe, and which, it is trusted, will be deemed sufficiently approximate, to justify its presentation to the reader.

Upon the Killingworth railway, we had originally cast-iron wheels upon the locomotive engines; about four years ago we adopted wrought-iron tires. Now, as we have, in this way, the relative wear of cast and wrought iron upon the wheels, which run upon the rails; and as the nature of the action will operate nearly alike, whether upon the surface of the rails or of the wheels, we shall, by that means, have a pretty near approximation to the relative wear upon the rails. In this way, we have a considerably more severe test; as, if we take the quantity of traffic equal to 2000 tons passing along the railway daily, and suppose the carriages to convey three tons each, with three-feet wheels, the relative wear of the wheels and rails is as 53 : 1, nearly.

The average wear of the cast-iron wheels was above half an inch in nine months; and, with the wrought-iron tire, the wear of one pair of wheels has been a quarter of an inch in three years, and with three other engines one eighth of an inch in twelve months; making the wear, at least, as five to one in favour of wrought-iron. The actual wear of the rails will not be to the same extent as this, as the engine wheels sometimes slip round, or slide upon the rails, in bad weather. The wear of the wheels of the common carriages will not be so much, for the same reasons; but although it should be observed, that, from this, we ought not to deduce the actual duration of wrought-iron rails, as, their surfaces being narrower than the wheels, the wear will be, perhaps, more than proportionably greater, yet the relative wear should, however, remain the same. We now give the following experiment made on the Stockton and Darlington railway:—

Cast-iron rails, four feet long, over which waggons only pass, weighing four tons each, when loaded: 86,000 tons passed over in a year, exclusive of waggons: weight of rail, 63 lbs.: loss of weight in twelve months, 8 oz. The loss of weight in malleable-iron rails was, in the same period, 8 ounces for 15 feet length: the same quantity of goods, 86,000 tons. This will give the difference of wear 15 : 4 in favour of wrought-iron rails.

These experiments shew, that if rails of the proper degree of strength be used, the durability is decidedly in favour of wrought-iron rails; and we have before observed, that in rails properly manufactured, none of the exfoliation or oxidation, originally dreaded, exists.

§ 9.—*Comparative Resistance to the Carriages, of Cast and Wrought Iron Railway Bars.*

The next enquiry, is, whether the resistance is greater upon wrought than upon cast iron rails. As in the case of the cast-iron, when first introduced, the wrought-iron rails were made far too slight; and observation shewed, that, to a certain extent, the resistance appeared greater than upon cast-iron; and this, as has been shewn, was owing to the bending.

Referring to the experiments, on the comparative resistance of cast and malleable iron rails, these experiments, it will be seen, were made with the surfaces of the rails quite dry, and free from dust; to ascertain the increase of resistance by the occurrence of any extraneous matter on the rails, the surfaces were watered pretty freely. The number of vibrations, before attaining a state of rest, when dry, was 540 and 570 respectively, and, when watered, 375. Upon wrought-iron rails, when dry, with a less extent of vibration, the number of oscillations was 404 and 412, while, when chalked, the number was 230. With cast-iron, when oiled, under the same circumstances, the number was 290; and, when still more copiously oiled, the number was reduced to 244.

The result of all these experiments is, therefore, that no increase of resistance, above that on cast-iron, takes place upon wrought-iron rails; and that the resistance is a minimum, when the rails are quite dry, and free from any extraneous matter.

CHAPTER IV.

ON THE FORMATION AND CONSTRUCTION OF RAILWAYS.

§ 1.—*Formation of the Line of Railway.*

In the early stage of the construction of railways, little or no care seems to have been taken, to level the surface of the ground, so as to form the best line of road between the two extremities. Horses being then exclusively used, casual undulations were levelled down, but the general line of railway does not appear to have been laid out, with a view of obtaining the best gradients for the road which the country afforded. The only principle acted upon seems to have been, that the line should be so formed, as that a horse should take down a certain determinate load. If, therefore, any particularly steep place existed, where that load could not be overcome, it was levelled down to such an extent, as to enable the horse to take the load fixed upon; and that was laid down as the guide, by which the other parts of the line were laid out; it being deemed sufficient, if a horse could take, upon the other parts of the line, the same load which it could do upon the steeper or more inclined portions. When mechanical power was applied, a different system was required;—it then became necessary to lay out the line of railway, suitable for the different kinds of motive power, intended to be used upon it, consistently with the facilities which the nature of the country afforded.

It is not our intention, however, in this chapter, to enter upon the consideration of the principles of laying out a line of railway, between any two places, with reference to the motive power intended to be used upon it. We shall reserve that consideration, until we have ascertained the capabilities of each description of motive power; by which we may be enabled, to elicit some general principles for our guidance, in determining that very important question. We shall, therefore, in this place, pass over the consideration of the proper levels, or gradients, to be observed in forming a line of railway between two points or places, and confine ourselves to a detail of the mode of forming the railway, supposing the line and gradients previously determined upon; which detail will comprise the execution of the earthwork, laying down the rails, and accomplishing the various other descriptions of work, requisite to form a complete railway.

§ 2.—*Earthwork. Excavating and Embanking.*

Let A, B, C, *Fig.* 1, *Plate V.*, represent a section or the outline of the country, over which the railway is to pass, and *a*, *b*, *c*, *d*, *e*, the level, at which the railway is to be formed. All those parts of the section which are above the line *a*, *b*, *c*, *d*, *e*, to the extent of the width required for the railway, will, therefore, require to be cut through, excavated, or levelled down; and those portions which are below that line, will require to be embanked or levelled up. The portions A and C, will, therefore, have to be cut down, and the portion B, raised up or embanked. The portions of railway, *a b*, and *c d*, of the section, are, consequently, called *excavations*, or *cuttings;* and the portions *b c*, *d e*, *embankments*, or *embanking*. Where, therefore, a trifling variation in the general inclination of the line, or of the gradients, is not of great importance, it is very advisable, that the line should be so laid out, that the quantity of earth obtained from the excavations or cuttings should be equal to, but not exceed, the quantity required for filling up, or forming the embankments; or, that the quantity of earth, or material, required for the making embankments, should not be greater than what is to be obtained from the excavations or cuttings. If this is not the case, it then becomes necessary, if the embankment does not require the whole of the earth obtained from the cuttings, to lay the surplus earth upon the land or ground adjoining the line of railway, where it is not required, which is called laying it to spoil; or, where there is an excess of embanking, or deficiency of excavation, to make a cutting out of other land, (called "side-cutting,") for the express purpose of filling up the embankment; in both of which cases the expense of the formation of the road, is increased to the extent of what is required for the accomplishment of these superfluous operations. There is, however, an exception to this, in cuttings or embankments of great lengths. Cases may occur, where the distance between the cutting and embankment is such, that the expense of conveying the earth, from one part of the line to another, is greater than the increased expense of making an express excavation, alongside the line of railway, or near the embankment, for the purpose of forming the embankment; and of depositing the earth from the cutting, which ought to have formed the embankment, upon waste ground alongside such cutting, or of depositing it to spoil. These are, however, cases to be judged of by the engineer of the work, and are entirely questions of comparative expense, between the one mode and the other.

§ 3.—*Width of the Railway at the Formation Level.*

Fig. 2. is a cross section of an *excavation* or cutting, and *Fig.* 3. a cross section of an *embankment; a b*, being the original surface of the ground, and *g h* the *formation level*, or extreme depth of the excavation; the *formation level*, being the foundation whereon the superstructure of the railway is to be raised. The first question, therefore, to determine is, the width at the formation level, as by this the whole of the operations are guided; and this depends upon two considerations, first, the width between the rails; and, next, the width between the two lines, if the railway is intended to be a double line.

§ 4.—*Width between the Rails.*

The first public railway, of any extent, which was executed, was the Stockton and Darlington railway, the engineer being Mr. George Stephenson. The width, between the rails, of that railway, was made four feet eight inches and a half, taking the Killingworth colliery railway as a standard. The Liverpool and Manchester railway, also constructed by Mr. Stephenson, was formed of the same width; and it was then made a standing order of the legislature, that, in all public lines of railway, the width, between the rails, should be four feet eight inches and a half; and in some railway bills, the breadth of the rails, or outside width, was, also, stipulated; that of the Newcastle and Carlisle railway, in 1829, being required, by the act, to be five feet and one inch, between the outside edges of the rails. The London and Birmingham; Grand Junction, and other railways, connected with these; are all constructed of the width of four feet eight inches and a half. In 1836, this standing order was suspended, and there is now no standard of width whatever, in any of the railway bills, which pass the legislature; and it is, therefore, left to the discretion of the railway companies, or their engineer, of what width the railway shall be constructed. The Great Western railway has been made seven feet wide, between the rails, by the engineer, Mr. Brunel, jun.; and the railways recently constructed, and now in operation, in Scotland, are five feet six inches wide; some of the old railways being four feet six inches. It is impossible to conceive the confusion, which may be the result of this departure, of the legislature, from a standard width for all railways; especially if railway companies, and engineers, follow the dictates of their own opinion, without reference to the general convenience of the public. The delay, expense, and inconvenience, of changing from a line of railway, of one width, to another of a different width, where despatch, and rapidity of travelling, is the great characteristic of the system, must be inconceivable. It is due to the public, that a full and comprehensive enquiry should be instituted, by the legislature, to determine the proper width, now to be adopted; not only with reference to all railways to be made in future, but, likewise, with reference to those already made; and when a conclusion is come to, and the best width, under all the circumstances, determined upon, it should be made a standard, in all railway bills, and should not be allowed to be departed from, under any pretence whatever.

Without presuming to determine upon so important a question, on which there is a great difference of opinion, amongst engineers; we shall, for the present, assume the width between the rails to be four feet eight inches and a half. The breadth, of the bearing part of the rails cannot vary much; about two inches and a half, seem to be the width agreed upon by almost, if not all, the engineers of the different lines of railway in England. The width between the outside of the rails will, therefore, be five feet one inch and a half; or five feet one inch, if the breadth of the rail itself, be two inches and a quarter.

§ 5.—*Width between the Two Lines.*

The next consideration is, the width between the two lines of railway. Upon the Liverpool and Manchester, the width was made the same as that between the rails, viz., four feet eight inches and a half. On the Newcastle and Carlisle railway, it is made the same. On the London and Birmingham railway, and the Grand Junction railway, the width is six feet; the latter width seems, certainly, preferable, upon great lines of railway; but experience has shewn, that no great inconvenience is felt upon lines of the lesser width. In the drawings of *Plate V.* the width is six feet.

§ 6.—*Width on the Outside of the Rails.*

The next question to determine is, the width required on the outside of the rails, or between the rails and the edge of the embankment, or side of the excavations. This is, to a great extent, determined, by what is necessary to keep the blocks firm, to preserve the stability of the rails, and to effect the passage of the engines and carriages along the railway with every possible security. On private railways, and upon some of the public railways, where economy of construction has been a primary object, a width of three feet and a half, from the rails to the outer edge of the embankments, or footpath, of the excavation, or from *n* to *k*, or *o'* to *l*, in *Figs.* 2 and 4, has been found sufficient to secure adequate firmness and stability to the blocks and rails; four feet, in any case, we should deem quite sufficient, to effectually accomplish these objects, viz., the stability of the blocks and rails.

But there is another very important object to effect,—the width necessary to secure the safety of the engines, and carriages, passing along the railway; and which is more difficult to determine, without going into the subject, in a speculative point of view. If we were to appeal to the experience upon the Liverpool and Manchester railway, and upon the Newcastle and Carlisle railway, where the radius of the curves, upon the latter, is less than will, in all probability, be made upon any of the railways now in formation; (that railway having been laid out before locomotive engines arrived at the perfection they have now attained, and with a view of using horses upon it,) we should say, that four feet is quite sufficient, to secure the safety of the passengers and goods.

On approaching a narrow embankment, at a rapid rate, the general impression is, that the engine will *run* over the side of the embankment, and *drag* the train of carriages over it. Nothing can be more fallacious, for, if the engine was, by any accident, to run off the rails, it would not *drag* the carriages after it. If it goes over at all, the carriages will *push* the engine, but the engine will not *drag* the carriages over, for this very simple reason; if the engine does run, or is thrown off the rails, a diminution of its speed immediately takes place; and, there being no such check to the carriages, their inertia carries them forward against the engine, *pushing* it on until the whole train is stopped. In approaching the question, we must, therefore, consider it with reference to that mode of action; and, likewise, with reference to the immense tangential force, inherent in an engine and train of carriages, moving at so rapid a rate.

Supposing an engine thrown off the rails, the wheels have then to run upon the loose coating of the road, the resistance of which, to the wheels, is very great, and which we may safely state as being equal to one fifteenth of the weight. The distance the train will run, before stopping, after being thrown off the rails, will, therefore, depend upon the resistance, and the velocity with which it was moving, when thrown off the rails. The formula, $s \frac{v^2}{64 p}$ will shew the space, s, in feet, the train will pass over before stopping, v being the velocity in feet, per second, which the train was moving at, and p the resistance to the wheels, which we have called one fifteenth of the weight. An engine and train, therefore, travelling at the rate of twenty miles an hour, and being thrown off the rails, will run about 210 feet, or seventy yards, before stopping; but if the same train is running at the rate of twelve miles an hour, it will become at rest in about seventy-six feet, or twenty-five yards.

Upon a straight line, the tangential force will cause the train to keep along the line of the road, and there will not be any great danger of its being diverged four feet in 210 feet, supposing four feet to be the width, on the outside, between the rail and the edge of the embankment. But in a curve it is different, the direction of the tangent then tending to cause the train to run towards the side of the embankment. It will, in this case, therefore, depend upon the radius of the curve, what distance the train would run before reaching the side of the embankment; and whether it would reach the side within the distance of 210 feet, or seventy yards, in the one case, or seventy-six feet in the other.

The versed sine A F, of a curve, the radius of which is represented by C E, and the sine by E F, is $AF = CE - \sqrt{CE^2 - EF^2}$. On curves, the radius of which is 1200, 1800, and 2400 feet, the versed sine, or distance of the tangent from the curve, in 210 feet, will be eighteen, twelve, and nine feet respectively; which would be the position of the train, if, when moving at the rate of twenty miles an hour, it was projected from the curve in a straight line. But if the train was moving at the rate of twelve miles an hour, seventy-six feet being the length it will run before stopping, or of the tangent, the distance from the rail on the curve of the shortest radius, or 1200 feet, will only be about two feet and a half.

We see, therefore, that three and a half, or four feet breadth on the outside of the rails, which appears to be sufficient to keep the blocks firm, is likewise sufficient to prevent all risk of the trains running over the side of the embankment, when the velocity is kept below twelve miles an hour, and the curves of not less a radius than 1200 feet; but, that, when the velocity is increased to twenty miles an hour, if no other obstacle occurs to prevent the train from running over the embankment, than the mere resistance of the wheels, upon the coating of the road, four feet on the outside of the rails are not sufficient. There are, however, other safeguards, which operate to change the direction of the trains, from the tangential course they would otherwise pursue, and divert them to that of the line of the road, or of the rails. A small depth only of road material being spread above the top of the blocks, when a train is thrown off the road, and the wheels have to run upon this material, they sink into it, and meet with the blocks, which act very powerfully in stopping the trains, or of keeping them in the direction of the road. Should, however, the wheels overtop the blocks, they then meet with the rails, which presents an obstacle, standing at least five or six inches above the surface of the road; which the momentum of the train cannot raise the wheels over, and which effectually prevents it from running any further out of the line of direction of the road. If, therefore, the width on the outside of the rails be such, as that, when the wheels on one side of the carriages are within the line of the rails, the opposite wheels do not reach beyond that width, or to the edge of the embankment, the train cannot by possibility run over the embankment. We, consequently, come to this conclusion, that, where the speed is not greater than twelve miles an hour, and the radius of the curves not less than 400 yards, a width of three and a half or four feet on the outside of the rails, or from *n* to *k*, or *o′* to *l*, is sufficient; but that, when the speed is increased to twenty miles an hour, or upwards, the width should, at least, be equal to the distance between the rails of the railway.

Upon the London and Birmingham; and the Grand Junction, the width on the outside of the rails is five feet, the distance between the rails being four feet eight inches and a half. On some of the railways, a mound of earth, shewn by the dotted lines at *i k*, *l m*, *Fig.* 3, is raised about two feet high above the level of the road upon the embankment; which acts as an additional, and, we should say, an effectual, security against any danger that can possibly arise, from the trains being thrown over an embankment.

We have gone into this part of the subject rather fully, it being very desirable, in an economical point of view, in the construction of railways, that no greater width should be taken, than what is, absolutely, necessary; at the same time, the safety of the passengers requires, that the width should be such, as to effectually guard, so far as human care can, against any accident.

Supposing the width, between the outside of the rails, to be five feet one inch; between the two lines, six feet; and the breadth on the outside of the rails, five feet on each side; we have, then, the width of the entire road, at the level of the rails, or, between *k* and *l*, *Figs.* 2 and 3, *Plate V.*, twenty-six feet two inches. The only remaining questions for consideration, are the slopes, *g k*, *h l*, required for the filling of the road, and the width required for the drainage of the excavations. The depth of the filling is two feet, or two feet three inches, and a slope of one foot horizontal, to one foot perpendicular, is found to be sufficient; although, in some cases, on the embankments, it is made the same slope as that of the embankment, which would be, for the two slopes, *i k*, *l m*, four feet six inches, in the former case; and six feet nine inches, where the slopes are one and a half to one; or nine feet, where the slopes are two to one.

The width of the drainage, *c g*, *h d*, *Fig.* 2, will vary, according to the quantity of water required to be conveyed off; but one foot and a half on each side, at the formation level, is generally found sufficient.

§ 7.—*Width of Excavations.*

We have, then, the width of the excavations at the formation level, as follows:—

	ft.	in.
Two lines of railway, including rails,	10	2
Width between the two lines, - -	6	0
Do. on the outside of rails, - -	10	0
Do. required for the slopes, - -	4	0
Do. for the drainage, - - -	3	0
	33	2

which will be the width, *f i′*, *c d*, *Fig.* 2, *Plate V.*

§ 8.—*Width of Embankments.*

And for the embankments, or *g h*, *Fig.* 3, which require no width for drainage, three feet less, or thirty feet two inches. Where mounds are raised on the embankments, as shewn by the dotted lines in *Fig.* 3, the width, *i k*, *l m*, is two feet on each side, requiring thirty-four feet two inches, where the slope of the filling is one to one; or, thirty-six feet, where the slope is one and a half to one; and thirty-eight feet, where the slope is two to one. The mode of calculating the quantity of earth contained in any cutting, or embankment, has been published: and tables constructed by Mr. Bidder; more elaborate tables have likewise been made the subject of a publication, by Mr. Macniel.

The filling of the Grand Junction railway, is two feet three inches; and on that line, where the slope of the embankments is one and a half to one, the width, at the formation level, is thirty-seven feet; and, where two to one, thirty-nine feet four inches.

§ 9.—*Slopes of the Excavations, and Embankments.*

Having now ascertained the width, at the formation level, it is next necessary to determine the angle to be given to the slopes, *s s*, of the excavations and embankments. These depend, in some degree, upon the depth of the excavation, or height of the embankment; in the former, when the material is sand, gravel, chalk, or gravelly clay, a slope of one and a half horizontal, to one perpendicular, is quite sufficient; and in excavations, up to thirty or forty feet, this slope has been found to stand very well. In some descriptions of clay, such as the plastic clay of London, and clay of a similar nature, a slope of one and three-fourths, or two to one, is necessary. In all the excavations on the Newcastle and Carlisle railway, through a district sixty-two miles in length, the slopes are made one and a half to one, and they have been found to stand quite well. The sand cutting through the Cowran Hills, on that line, is 110 feet deep, and it is interspersed, in some places, with thin layers of clay, and, yet, it has stood quite firm, with a slope of one and a half to one. The embankments are generally made, with the same slope, as that of the excavations; and it is presumed, that, with whatever slope the excavation will stand, the embankment formed of the material from such excavation will require, but will stand with the same angle of slope, as that of the excavation.

On all the modern railways, the slopes are covered with a layer of soil, which is procured from the base of the embankments, or from the top of the cuttings; this layer of soil is spread over the face of the slope about six inches thick, or of the thickness which the soil from those places will yield. It is of great importance to the security of the slopes, that the soil should be laid on as soon as possible, after the excavation is made, or the embankment consolidated; and sown with grass or clover, or both, to get a turf upon it before the slopes are affected by the action of the weather. By doing so, slopes will often stand, where, without the soiling and turf, or when exposed to the action of the weather, they will not stand; $s\,s$, in *Figs.* 2 and 3, shew the soil laid upon the face of the slope.

In these drawings, we have shewn the slope of the excavation to run down to the formation level or bottom of the drain. In some cases, where stone is plentiful, and where there is an excess of cutting, side walls, similar to $e\,f$, *Fig.* 15, are built, to retain the sides of the excavation, the dotted line, $p\,q$ shewing, in that case, the line of the slope. In such cases, stone drains, similar to that shewn at g, are made to still further diminish the width of the railway. The propriety of doing this is, however, entirely a matter of calculation.

§ 10.—*Fencing the Railway.*

rqp, and $p'q'r'$, *Figs.* 2 and 3, shew the mode, generally practised, of fencing the railway. The ditches, $r\,q$, $r'\,q'$, are mostly made four feet wide at top, and one foot and a half wide at bottom, and of such a depth as will carry off the water; and the mound, $p\,q$, $p'\,q'$, about the same section, and about two feet high, being formed from the excavation of the ditch.

The ditches, $r\,q$, $r'\,q'$, are, of course, intended to carry off all the water, and effect the drainage of the adjacent lands; the ditches, $c\,g$, $h\,d$, *Fig.* 2, being to carry off all the water which falls, or is brought into the excavation, or line of railway.

§ 11.—*Coating the Railway, or, forming and draining the Foundation for the Blocks.*

We now come to a most important part of the construction of railways, viz., forming a foundation for the blocks, and laying down the rails. The line having been formed to the proposed inclination longitudinally, it is then levelled transversely, or a little convex, with a rise of three or four inches in the middle, so that the water may fall towards the ditches on each side. But, as the material constituting the base of the railway, in the excavations, and embankments, will, in a general way, be gravel, clay, or other earth, which would retain the water, and which the blocks would sink into when subjected to the action of the carriages upon them; it is necessary to cover these surfaces over with some material, which will allow the water to drain off from the bottom of the blocks, and which will likewise form a sufficiently firm foundation for the blocks to rest upon. This is generally done by a layer or coating of sandstone, or other stone, broken into small pieces, and spread upon the line of formation of the railway. 1, 2, *Figs.* 2 and 3, or *a a*, *Fig.* 12, shew this layer of stone, with the blocks resting upon it. This broken stone, therefore, serves as well for a firm foundation for the blocks, as for a drain to carry off the water. The thickness of coating, or broken stone, laid on, is generally nine to twelve inches, the stones not being larger than will pass through a ring two and a half inches in diameter; but when the blocks are set upon this as a foundation, a little sand, or stone broken extremely small, is put upon the larger sized coating, to make the block bear more firmly. When the railway is laid down, it is then filled up between the blocks, and on each side, to the level of about three inches above the top of the blocks;

with small gravel, sand, marl, or any material of that kind, which will consolidate sufficiently hard, around the blocks, to keep them steady and firm. In some cases, the under coating is not spread across the whole width of the formation, but only sufficiently wide to act as a support and drain to the blocks, the remainder of the width being filled up with gravel or sand.

Where good sandstone coating can be obtained, nine to twelve inches are found quite sufficient, generally, to keep the blocks and road effectually free from water; but, where good coating cannot be obtained, or where the width of the road is very great, it is, therefore, necessary to have recourse to a different mode of drainage. In these cases, a stone, or brick drain, is carried along the middle of the line; with similar cross drains running from it into the side ditches, at certain intervals. *Figs.* 4 and 5 will shew the manner in which this is done. *Fig.* 4 being the plan, and *Fig.* 5 an elevation, *a b*, are the centre drains; and *e f*, *e f*, the cross drains, running from the centre drain into the side ditches, *c d*, *c d*. These drains may either be made with bricks or stone, as may be found most economical, the dimensions varying from four to six inches square. Similar drains are formed on the embankments, the side drains, in this case, running down the slopes, to carry off the water to the side ditches. The necessity for these drains depends, however, much upon the nature of the subsoil of the excavations, and the material forming the embankments.

§ 12.—*Setting the Blocks.*

The drainage having been effected, and the under coating having been all spread upon the line, the next operation is, setting the blocks.

On all the excavations where stone blocks can be had at a moderate cost, and on the embankments which are sufficiently consolidated, stone blocks are, decidedly, the best support for the rails; but, upon high embankments made of clay, and which are constantly settling down, it is found most advisable, in the first instance, to lay down wooden sleepers, stretched across from one rail to the other. *Figs.* 3 and 4 exhibit both modes; A B represent stone blocks; and C D, wooden sleepers. The stone blocks now laid down are never less than two feet square, by one foot thick; and they are generally laid down diagonally, as shewn in *Fig.* 4. The reason for laying them thus, is, that they act with greater effect transversely, in steadying the rails; and the workmen can have access to all the four sides, to put the block right in case of displacement, which cannot so well be done, when the blocks are laid at right angles to the line of road. Setting the blocks is of great importance, as upon its being well done, depends the permanent stability of the road. The old method was, after having spread the bottom of the excavation, or top of the embankment, over with a layer of ashes, or small stones, or gravel, to place the blocks upon this, with the chairs and rails attached to them; workmen were then employed to push the ashes, or sand, underneath the blocks, with narrow shovels, at the same time beating upon the upper side of the blocks with heavy mallets, until the rails were at the proper level. In this manner of setting the blocks, it will be seen, that no firmer seat, or greater solidity could be given to the foundation, than what was effected by the blows of the mallets upon the blocks; which having little effect in compressing or consolidating the foundation, when the carriages came to run upon the rails, the blocks immediately sunk down, and it required the workmen to be constantly pushing ashes or sand underneath, to raise them to their proper level, until they came to a permanent seat; or, in fact, until the seats of the blocks became sufficiently firm to resist the weight of the carriages passing over them, or until the carriages had no effect in depressing the blocks.

In laying down the Liverpool and Manchester railway, Mr. Stephenson adopted a plan, by which, in setting the blocks, the foundation was, in the first instance, compressed and consolidated to such an extent, that the weight of the carriages had no effect in causing the blocks to yield. This was done by the impact of the blocks themselves, the principle being, in setting the blocks, to employ a force, weight, or impact, upon the foundation whereon they were to rest, *greater* than the weight or effect imposed by the action of the carriages upon that foundation; and, consequently, the latter could have no effect in further compressing the foundation, and causing it to yield, or be depressed. To effect this, he made use of the block itself, by successively lifting it up, and allowing it to fall upon the seat, whereon it was intended permanently to rest. The block was raised by every operation to such a height, as that the impact or blow upon the coating or foundation, when let fall, was much greater in effect than the direct weight or pressure of the carriages.

This system of setting is, however, entirely subverted, if the foundation, whereon the coating is laid, be not perfectly firm and solid. The least subsiding or sinking of the foundation, renders all this care, of effecting a firm seat for the blocks, useless. Upon excavations well drained, it may be adopted with complete effect; and if well done, and if the blocks are sufficiently large, they require very little care in keeping right afterwards. Upon well consolidated embankments also, this plan of setting can be practised with like effect; but in yielding embankments, made of clay, and before they become perfectly consolidated, the whole expense of thus setting the blocks is rendered useless by the least yielding, which destroys the foundation, which so much care and expence have been bestowed to form.

The mode which Mr. Stephenson used for thus setting the blocks, is as follows; and the same plan is now practised in setting the blocks, upon all the modern railways. A lever, about twenty feet long, is fixed upon a portable stand, the lever being sufficiently strong to lift one of the blocks, but otherwise very flexible; the stand is about five feet high, the fulcrum of the lever being placed at such a distance from one end, that a man can readily lift one of the blocks. A chain fixed to the short end of the lever is fastened to the chair of the block; it is thus lifted or jerked up, about a foot high, and then let fall upon the coating, and this is repeated a great many times; another man, at the same time, throwing underneath the block, sand, or fine gravel, until the successive blows effect a solid and firm foundation, and the block is firmly seated upon the coating of the road. At each of the times when the block falls, the attendant, by proper squares and sights, causes it to fall on the proper place, and, at last, to be firmly seated; not only level transversely, but, also, correctly ranging, with the longitudinal level, or general inclination of the road.

In this manner, the blocks are all set, along the whole line of road, or along certain lengths, before the rails are keyed to the chair; but the blocks, being set perfectly parallel with the general inclination of the road, and properly level transversely, and the chairs being all of the same height, when the rails are keyed down, they, of course, form a perfectly correct line of road. It need scarcely be added, that, when the blocks are once seated, they should not, on any account whatever, be moved in the least degree; for the least movement, in any direction, must destroy the seat, which has been accomplished with such trouble, by the mode of setting.

Blocks of stone are, as before stated, universally used, where the ground is firm; that is, in all the excavations, and on the embankments, where perfectly consolidated. In some instances, blocks are used in the latter case, where the embankments, though not perfectly consolidated, are not likely to subside very much; but it is evident, the same care in setting the blocks is not necessary. Where the ground is not firm, and wooden sleepers are used, they are generally made to reach the whole length, from side to side, between the rails; and to such a distance beyond, that both rails can be placed upon the same sleeper. This is the more necessary, where the foundation is liable to subside; inasmuch as it preserves the proper width between the rails, even if both sides of the railway are not upon the same level, and which is often the case, upon yielding embankments. These wooden sleepers, are mostly made of larch fir; and for railways, four feet eight inches distant between the rails, from eight to ten feet long, eight to ten inches broad, and about five inches thick.

When the blocks are thus set, or sleepers laid, as the case may be; the space between the blocks, and on the outside of the rails, is filled up to about three inches above the top of the blocks, or about the same depth below the top of the rails.

A B, *Fig.* 4, is a plan, shewing one side of a double line of railway, laid with stone blocks, and C D, the other side, laid with wooden sleepers; the shaded parts, *a b*, *c d*, *c d*, and *e f*, *e f*, shewing the drains, *Fig.* 3, shewing the section of the blocks, and wooden sleepers.

§ 13.—*Seating the Chairs upon the Blocks.*

A seat is, first of all, made upon the top of the block, perfectly level, and in the same plane as the base of the block, upon which the chair is to be set. *Fig.* 6, *Plate V.*, shews the mode generally adopted to fasten the chair to the blocks. Holes are drilled into the stone, about two inches in diameter, into which oaken plugs are driven, shewn at *a b*, *Fig.* 6; these plugs are then bored with a three-eighth inch auger; and the chair, having been properly seated upon the top of the block, an iron pin, shewn at *c d*, is driven, through the hole of the chair, into the wooden plug, and which, having a head, as shewn in the figure, fastens the chair to the sleeper.

The rough nature of the blocks, almost renders it impossible to get a level and uniform seating for the chair; and recourse has been lately had to a thin piece of felt, interposed between the chair and block, which, when the chair is firmly pressed, by the pin, to the block, fills up all the interstices, and makes a more firm seat, than could be done without this expedient.

The chairs have generally only two holes, and two pins to fasten them to the blocks. *Fig.* 7, shews a chair with four pins, for fastening it to the block. Mr. Story has laid down some of this description, with four pins, on the Stockton and Darlington railway. *Figs.* 6 and 7, shew a plan and section of the chairs, intended by him, for the rails of the Great North of England railway.

Fig. 8, shews a plan, by Mr. Daglish, for fastening the chair to the block. Two holes, *b b*, of two inches diameter each, are drilled two inches upwards, from the bottom of the block; through the remainder of the thickness of the block a hole is drilled, three quarters of an inch in diameter; two bolts of that size are put through these holes, with the heads downwards, the other ends of the bolts passing through the chair; keys are driven through the ends of the bolts, which wedge the chair upon the block, and which can be tightened at any time. The only disadvantage of this mode, is, that if any accident happens to the bolt, it cannot be replaced, or repaired, without removing the block.

In all the old railways, the plan of fastening the chair to the block, was by means of an oaken pin; and this plan has been adopted, upon the Newcastle and Carlisle railway; and so far as the experience of between two and three years enables us to judge, it seems likely to answer quite as well, if not better, than the plan shewn in *Fig.* 6. In the latter plan, the iron pin is only kept in its place, by the compression of the wood against the pin; but we find, that, by boring out the hole, in the middle of the plug, the wood is much shattered, and it is still more split in driving the pin. There remain, therefore, only detached pieces of the wood, to act against the pin, to keep it tight; and we accordingly find, that most of the pins, first used on the Liverpool and Manchester railway, have all worked loose. *Fig.* 9 shews the mode adopted on the Newcastle and Carlisle railway. The wooden pins are three quarters of an inch in diameter, and six inches long; the hole drilled in the block, is scarcely three quarters of an inch in diameter; when, therefore, the plug is driven, it sustains considerable compression. The hole in the chair is an inch deep, bevelled upwards, or three eighths of an inch larger diameter on the upper than the under side; the plug having an enlarged head, as shewn in the figure, to keep the chair firmly in its place. These plugs are all engine-turned, and made octangular, and of old oak, or the heart of the oak, well dried; when well driven, they cannot be forced out again, the ragged nature of the blocks, and the expansion of the plugs, securing them within the block, quite tight and firm. The objection, which most naturally suggests itself, against this plan, is, the probable decay of the plug within the chair. We find, however, plugs remaining quite good, upon the old railways, which have been in use upwards of twenty years. Little doubt can, therefore, exist as to their durability within the blocks; and the heads being cut off, level with the top of the hole of the chair, and covered with tar, if made of good oak, they will be found very durable.

§ 14.—*Keying the Rails to the Chairs, and Form of joining the Rails at their Ends.*

In Chapter II. we have given, in describing the different forms of rails, the mode of uniting them at the joints, and of keying the rails to the chairs. For the particular plans, of joining all the various kinds of rails and chairs, we refer the reader to that chapter; our object, in this place, being, to enquire into the effect, in practice, of the different modes of keying the rails to the chairs, and of joining the ends of the rails to each other.

We have stated that, at the first introduction of railroads, the rails were all made with square joints, or square ends; and that, subsequently, they were made so that a portion of the end of one rail overlapped a similar portion of the next rail, forming what is called, an overlap joint; the latter mode being adopted to avoid the shocks, or blows, which the carriage wheels might meet with, by the end of one rail projecting above that of the other, and which the square end joints present, when the blocks are out of order.

Professor Barlow, made an experiment upon the Liverpool and Manchester railway, to ascertain the effect to a train of waggons, passing over a joint displaced, or out of order, with the end of one rail rising above the plane of the other. He applied a deflectometer, or instrument shewing the amount of deflection of the rail, when the engine and train passed over it, compared with a rail, with a joint displaced, or with its end rising above that of the preceding rail; and found the force of concussion fifty per cent. greater, with the bad joint, than with a perfect joint.

The following is the experiment alluded to; a bad, or open joint, was selected, the deflectometer applied to the block, and the shock measured by the instrument; the rail was then taken up, and relaid, so as to make the joint, as close as usual, having the opening the same as the other end, and the effect was again taken. The result, with the Swiftsure engine was —

	Bad joint.		Replaced joint.	
Disturbance - -	·043		·032	great speed.
Ditto - - - -	·030		·016	
Ditto - - - -	·031		·022	
Ditto - - - -	·023		·015	
Mean disturbance	·031	Mean	·021	

We see, therefore, how important it is, that the mode of joining the ends of the rails, should be such as to prevent the end of one rail, from rising above the plane of the other. With square ends, when the blocks are displaced, this is unavoidable; we must, therefore, either rely upon the size of the blocks, and the mode of fixing them, being such as that no displacement will take place, or contrive such a joint as will allow of a block being displaced, without destroying the parallelism of the rails. We have gone, somewhat largely, into this part of the subject, when treating on the plan of setting the blocks; but we find, in practice, that it is extremely difficult to form such a foundation for the blocks, as will not occasionally yield, and produce the displacement of the rails. The plan of half-lapped joints, if the principles on which that plan is based could be fully carried into effect, in practice, would, to a very considerable extent, remedy, if not entirely remove, the evil; but there are great obstacles, in working out that theory, in practice. In the first place, in forming a half-lapped joint, by simply cutting or splitting the rail into two equal parts at the ends, the middle rib and base are so reduced in thickness, that, in practice, we find them laminating, or becoming crushed; it is, therefore, essential, in the construction of such a rail, either that the middle rib and base should be entirely set to one side, so as to preserve a sufficient thickness of iron to resist the pressure; or, that a portion of iron should be welded upon the end of the half lap, to form an adequate base to prevent its being crushed. These, and especially the latter, it will be seen, increases the cost of the rails, and therefore, in some cases, may be considered an important objection; and, in the next place, it is difficult, unless very great pains are taken, in the construction of the ends of a half-lapped joint, to form it in such a manner, as that, when a block is displaced, one end shall not be raised above that of the other; as it requires to be a little rounded at the extreme end of the half lap. There can be no doubt, however, if the funds of any railway company will allow of the more perfect mode of manufacturing this description of rail; and it be the intention to form a perfectly smooth line of railway, that the plan of forming the joints, in such a manner, effects that object better than rails with square ends. Sometimes, instead of making the half lap parallel, the ends of the rails are cut diagonally; but this forms a joint, with all the objections of the crushing at the ends, and does not completely obviate the shocks, by one end being raised above the other.

In considering the subject of the best form of joining the ends of the rails, we must not omit taking into account, the effect of the expansion and contraction of the rails, by the variation of temperature. We have seen, in § 6, Chap. III., that this amounts to about the fifteenth part of an inch, in a rail fifteen feet in length. Supposing the chairs and blocks to remain firm, this will be equal to the thirtieth part of an inch, at each end of every rail; and therefore, if the rails were laid down at the maximum degree of temperature, the open space between the ends, with a square joint, would amount to the fifteenth part of an inch; and would, therefore, present a shock to the carriage wheels in passing. In this case, the extent, which the half-lapped ends of the rails of that description of joint would have to slide against each other, would be the same distance, or the fifteenth part of an inch, when the temperature was at the lowest. This is, supposing the ends of the rails to be allowed to slide within the chair.

On referring to Chapter II., it will, however, be seen, that almost all the modes of fastening the rails to the chairs, is upon the principle of their being immoveably keyed thereto, and, therefore, when perfect, no allowance is made for the variation of length, by the increase or diminution of temperature. This seems to imply, that it is the universal opinion of engineers, that no regard should be paid, in forming the joints, to the effect of the expansion or contraction. In laying down the railway however, the practice is, to keep the ends of the rails about a sixteenth of an inch separate; if the rails are laid in the medium temperature of the year, we find that in summer, the ends become quite close together, and in winter, they again open; although the principle of keying, is that of an immoveable joint.

According to the experiments of Barlow, a bar of iron is extended the one ten thousandth part of its length, by every ton of direct strain, per square inch of section. Now, suppose the railway bar to be of a sectional area equal to five square inches, this would be five tons per one ten thousandth part of an inch extension; and as we see the contraction between the maximum and minimum temperature, is equal to the fifteenth part of an inch, or, in a fifteenth feet bar, equal to the two thousandth part of the length of the bar, or five times that which the strain of one ton would effect; we find, therefore, that the strain upon each chair by the keys, if firmly fixed, would be equal to twenty-five tons. Any mode of keying the rails to the chairs, upon the principle of firmly securing the one to the other; would, therefore, impose such a strain upon the chair and rails, as would have considerable effect in breaking the former, and of diminishing the tensile force of the latter. In practice, therefore, when such a mode of keying is adopted, and when a space of about one sixteenth of an inch is left between the rails, it appears that the expansion in summer extends the ends, so as to become quite close, and, if then keyed, we are convinced, that the rails are permanently lengthened by the action of the key, and the motion of the wheels upon the rails; and that the action of the temperature operates more in expanding, than in contracting, the rail; and hence, we find, in summer, the rails twist and bend as they become lengthened by the expansion, and in winter, the ends become partially opened by the contraction, but not to the extent which the temperature would produce, if there were not a certain degree of compression acting upon them previously. No doubt, the imperceptible, slow, but powerful effect of the heat, added to the tremour and motion occasioned by the wheels; produces a working of the keys, and they thus yield and become loose, and allow the rail to accommodate itself to the expansion or contraction, produced by the variation of temperature.

If, therefore, in practice, we find a constant motion in the joints of the rails, by the action of the weather, and that no plan of keying hitherto adopted, can or, perhaps, ought to produce an immoveable joint; it would appear, that the only mode of preventing the shocks and blows incident to the opening of the joints, and to produce a perfectly smooth railway, would be to have recourse to the adoption of half-lapped joints, so that they could slide longitudinally, to counteract the effect of the expansion and contraction. But to produce such a joint, which would not crush or yield to the pressure of the wheels, it is necessary, we find, to incur a considerable expense in its formation. At the same time, we think it right to observe, that in a well-constructed railway, with large blocks, well laid, and with heavy rails, a comparatively smooth and level railway can be formed with square joints; and that on almost all the modern railways, such a joint is used.

§ 15.—*On Curves, on the Line of Railway.*

Where the line of railway is perfectly straight, it is scarcely necessary to observe, that the rails should be laid perfectly horizontal, or in a plane with the gradient of the line longitudinally, and perfectly level transversely; but where there are curves on a line, the level transversely will require some consideration. That property in all bodies to continue their motion in a straight line, gives to the carriages upon railways, a tendency to move in a tangential direction; and hence, on approaching a curve or change in the direction of the line of railway, the carriages have a tendency to move in the direction of the tangent to the curve; and they are only kept upon the rails, or along the line of the curve, by the action of the flanch of the wheels, against the side of the rails. The wheels, which act against the rails, are the flanches of the wheels, which travel on the outside rails of the curve, and their flanches act against the inside of those rails.

All the wheels now used on railways, especially where curves occur on the line, are constructed, so that the outside rim is conical, or is enlarged in diameter next the flanch; when, therefore, the carriages are passing round a curve, the wheels being connected together by the axle, forms, as it were, a conical roller, running upon the rails with different radii; the larger radii being on the outside curve of the rail. This increase in the diameter of the wheel, running on the outside, compensates, to a certain extent, for the increased length of the outer curve of the rail; and if the radius of the curve, is not less than the line which the two wheels of unequal radii would describe, the wheels will travel along the line of the curve without rubbing against the flanches. But, if the curve is more acute than such a line, then the flanches of the wheels, are the only guides to keep the carriages on the rails.

The degree of cone, generally given to the tire of the carriage wheels, is, to make the diameter, next the flanch, one inch larger than the diameter next the outside of the tire; the breadth being three and a half inches. In practice, it is likewise usual to keep the wheels at such a distance from each other upon the axles, that when travelling upon a straight line, the flanches on each side are about one inch from the rail. Supposing the wheels three feet diameter, which is the general size, the curve which such wheels would describe, beforethe flanches would rub against the rails, is thus found. The extreme lateral motion, generally given to the wheels upon the rails, is from one and a half to two inches, the difference of diameter on the whole breadth of three and a half inches is one inch; therefore, suppose the extent of lateral motion, before the flanch rubs against the rail, to be 1·05 inch, then $\frac{1{\cdot}05}{3{\cdot}5} = {\cdot}3$, the difference of diameter in 1·05 inches; consequently, when the flanch is just rubbing against the side of the rail, one of the wheels is traversing a circle 36·3 inches in diameter, and the other, a circle equal to 36 inches. Now, the line which these wheels would describe, the width between the rails being fifty-six inches, would be a curve with a radius of 565 feet, viz., as ·3 : 36 :: 56 : 565 feet; and as this is a curve of a less radius than any which ought to occur upon a railroad, we find that a cone of an inch, in the breadth of three and a half inches, given to carriage wheels of a diameter equal to three feet, is sufficient in all ordinary curves upon a railroad, to prevent the wheels rubbing against the inside of the rails.

We have now to consider, the effect of the centrifugal force of carriages, passing round curves of different radii.

As before stated, the tendency of carriages passing around the curves upon a railway, is to keep a tangential course; this is capable of being measured, and is a certain force, depending upon the velocity of motion, and the radius of the curve, the formula being well known.

Let w = the weight of the carriages,
r = the radius of the curve in feet,
v = the velocity of the carriages in feet per second,
g = the accelerating force of gravity, or the velocity which a body would acquire in falling a second of time.

Then the fractional part of the weight of the carriage, representing the centrifugal force, will be $G = w + \frac{v^2}{gr}$.

Thus, suppose the velocity of the carriage to be fifteen miles an hour, or twenty-two feet per second, and the radius of the curve 500 feet,

$$\text{then } G = w + \frac{22^2}{32+500} = \frac{1}{33}w.$$

If, therefore, we elevate the outside rail of the railway, to such a height, above the inner rail, that we give to the axles of the carriages resting upon the two rails, such an inclination as will produce upon the carriages a gravitating force towards the centre of the curve, equal in amount to that of the centrifugal force outwards; there will neither be any tendency in the carriages to upset, or to press the wheels against the rails. Thus, upon the curve above named, if the outside rail be elevated to such a height above the inner rail, as will give to the axles of the carriages, such an inclination as, together with the difference of diameter of the wheels, where running upon the rails on the curve, will be equal to the one thirty-third part of the breadth between the rails, when the carriages travel at the rate of fifteen miles an hour; the gravitating force inwards will counteract that of the centrifugal force outwards, in passing round the curve.

Let w=the width of the railway, and s=the surplus of elevation given to the end of the axle of the wheel, on the outside of the curve, in inches, $d-d'$=the difference of diameter of the two wheels, where running upon the rails in traversing the curve; then $s = \frac{V^2w}{gr} - \frac{1}{2}d - \frac{1}{2}d'$=the height, in inches, which the outside rail of the curve, should be elevated above that of the inner rail, to counteract the effect of the centrifugal force of the carriages passing round the curve.

We must now find the value of $d-d'$, which will vary as the radius of the curves. To accomplish this, we have to obtain the difference of diameter of the two wheels, which, in the breadth, w, of the railway, will cause the wheels to describe a curve, the radius of which is r. Supposing the wheels thirty-six inches in diameter, $=D$, this will be $\frac{D\,w}{r}$; consequently, we have

$$s - \frac{V^2w}{gr} - \frac{1}{2}\frac{D\,w}{r}.$$

When, however, we once determine, and lay down the rails suitable for a given velocity, and the carriages move at a slower rate, the force of gravity will overbalance that of the centrifugal, and the effect will be, a tendency of the carriages to press the flanches of the wheels against the inside rails of the curve; and, on the contrary, if they move at a greater velocity, the tendency will be, to press the flanches against the outside rails. As the slower trains are generally more heavily laden, and when, consequently, any increase of friction will have a more powerful effect upon the moving power, than with lighter trains travelling at a quicker rate; it will be advisable, that the elevation of the outside rail, should not be greater than to compensate for the centrifugal force, at the slower rate of travelling with heavy trains.

The following Table will shew the elevation to be given to the outside rail, of different radii, above that of the inner rail of such curve; so that the whole amount of centrifugal force, is balanced by that of the gravity of the load, towards the inside of the curve.

TABLE I.

Description of waggon, and width of railway.	Radius of the curve in feet.	Surplus of elevation in inches, the velocity in miles per hour being,		
		10 miles.	15 miles.	20 miles.
Diameter of waggon wheels 3 ft.; width of railway 4 ft. 8 in.; inclination of the tire of the wheel ½ inch in the breadth, viz. 3½ inches.	250	1·16	3·04	5·67
	500	·58	1·52	2·83
	1000	·29	·76	1·42
	2000	·15	·38	·71
	3000	·10	·25	·47
	4000	·07	·20	·36
	5000	·06	·15	·29

§ 16.—*Plan of crossing Streets, and Turnpike Roads.*

Having thus described the mode of executing a railway on ordinary ground, the plan of drainage, and the coating and laying the railway; we shall now describe the plan of crossing streets and roads. *Fig.* 10 is a section, and *Fig.* 11, *Plate V.*, a plan, of crossing a street, or public highway, near a town; *a a a*, &c. is masonry, forming the foundation whereon the railway is to be laid, and the drains, *b b*, for carrying off the water, and acting, likewise, as a receptacle for the dirt. The blocks *c c*, are placed upon the masonry, and upon the blocks, and attached to the chair, is a frame of cast iron, inclosing the rails, as shewn in *Fig.* 11, *r r* being the rails, *e e*, *e e*, the cast-iron frame, with the cross ribs, *l l l*, &c. Between the rails, *r r*, and the sides, *e e*, of the iron frame, there is just sufficient width for the flanch of the wheels of the carriages to pass along; and being open underneath to the drains *b b*, except where covered by the blocks *c c*, and chairs *ff*, *Fig.* 11, all the dirt falls down into the drains, and keeps the rails entirely free for the passage of the carriages.

The stones *g g*, *g g*, are penned close against the outer sides of the iron frame, and on a level with the top of it; so that, when carts, or other carriages, cross the rails, they are not subjected to any jolt. Between the stones *g g*, the road is paved in the ordinary way, and which, resting on the solid masonry, is kept very firm and level.

Fig. 12 shews the manner of passing common roads, where the passage is not very great. In this case, the masonry is not required, the blocks *c c* are set, as in the common way, upon the coating *a a*; a cast-iron frame, similar to that before described, and shewn in *Fig.* 11, is laid upon the blocks, for the purpose of protecting the rail, from the wheels of the carriages crossing the road; but in this case, there is no drain or receptacle for the water and dirt, as in the former cases, any dirt falling into the cavity, against the rails, being taken out by the attendants, when necessary. The road may be either paved on the surface, against the frame-work, or covered with broken stones, or with the common material of the road; in the latter case, however, the iron frame-work, as shewn in the drawing, must be of larger dimensions, to prevent its being broken by the wheels of the carriages.

§ 17.—*Mode of passing yielding Ground, or Mosses.*

We have thus described the different modes of executing, and laying down railways upon ordinary ground. It would be going beyond the proper sphere of a work of this kind, to attempt to offer plans to meet difficulties in extraordinary cases, the intention being, rather to describe what has been done, than to devise plans for executing unforeseen difficulties. The modes of passing yielding ground, mosses, or bogs, adopted by some engineers, may, however, be described in this place; and the Chat Moss, on the Liverpool and Manchester railway, being the most extensive moss yet passed over, we shall give the plan adopted by Mr. Stephenson, for carrying the railway over this moss.

This moss is of considerable extent, comprehending an area of about twelve square miles, being of so soft and spongy a nature, that cattle cannot walk upon it, and an iron rod sinks with its own weight. The depth varies from ten to thirty-five feet, resting on clay and sand. The distance which the railway was to be carried over it, was upwards of four miles and a half, an undertaking which required some degree of nerve to contemplate. It is necessary to premise, that, in carrying the railway across the moss, the level required, that it should, in some places, be twelve feet above, in others, nine feet below, and to vary from these, to level with the original surface of the moss. We have, therefore, three distinct operations, viz., *embanking* the railway above; *forming a cut below;* and forming the road *level with* the moss.

Embanking the railway above the moss. There is another moss, of considerably less extent than this, over which the railway passed, and which, at one end, was terminated by an extensive cutting of clay and gravel. As an embankment, of four feet in height, had to be formed over this moss, the materials from the excavation were used for this purpose. The moss was about twenty feet deep, and it was soon found, that as the materials were successively laid upon the moss, the whole mass gradually sunk; and when the embankment was finished, although the actual level of the railway was only four or five feet above the original surface of the moss, the quantity of the metal deposited would have formed, on ordinary ground, an embankment twenty-four or twenty-five feet high; with such materials, therefore, (clay and gravel,) it would have been impossible to form an embankment over Chat Moss. The quantity required, and the consequent expense, would have been enormous. Mr. Stephenson had recourse, therefore, to the moss itself, for materials to form the embankment, which, by its inferior specific gravity, would not sink to such an extent as gravel and clay. In its natural state, the moss was unfit for this purpose, but drains were cut, five yards apart, which laid the moss between the drains dry, and rendered it excellent material for the purpose. With this material, embankments were formed upon part of the moss, and it was found to require only about four times the quantity of material, that would have sufficed for sound ground, and the road appears in quite as good order, as in any other part of the line.

Forming a cut below the level of the surface of the moss, was accomplished entirely by draining; the drain was cut along the line of the railway, eighteen inches to two feet deep, which laid dry that portion of the moss between them. About twelve inches in thickness, thus dried, was excavated at a time; and it was, in that manner, successively drained and excavated, until the proper depth was obtained. The permanent road was then formed in the manner hereafter described.

Laying down the road upon the surface of the moss. Drains were first of all cut on each side of the line, and lateral ones, where necessary, to carry off the water. By this means, a certain depth of moss on the top was partially consolidated, and formed a layer or surface of dry moss, of considerable tenacity; upon this, hurdles, nine feet long, and four feet broad, wickered with heath, were laid down transversely. In many places, only one layer of hurdles was required; but when the moss was very soft, two layers were used. Upon this, was laid about two feet of ballast, or gravel, to form the permanent road; and wooden sleepers, stretching across each line of road, were used to lay the rails upon. The stability of the road, therefore, depends solely upon the tenacity of the materials, supported by the buoyancy of the moss. When we consider, however, the area of base thus firmly united and bound together, and the support which even so spongy a substance as the moss must give to so extensive a platform; it is natural to suppose, that the impression made upon so great an area, by the pressure of so inconsiderable a proportion of the whole weight as that of a train of carriages, must be slight indeed; and we find, that, since the opening of the railway, the passage of the traffic over the moss proves that the road is exceedingly stable. It may be necessary to remark, that the surface of the moss is higher than that of the country bordering its edge.

Figs. 13 and 14, *Plate V.*, shew this mode of forming a railway over a moss; *a a* are the hurdles, or wickered foundation, which may either be single, or two or three layers, according to the tenacity of the moss; *b b* is the coating of sand or gravel, resting upon the wicker work, small branches of trees, brushwood, or furze, being laid down upon the hurdles; upon this gravel, either longitudinal sleepers, *c.c*, are laid down, with transverse sleepers, *d d d*, laid upon them, or transverse sleepers, without the longitudinal ones, according as the moss may require.

The longitudinal sills, *e e*, are then laid along the transverse sleepers, upon which the chairs and rails are laid down in the usual way. A moss has been passed, in the manner shewn in the above figures upon the Garnkirk railway, near Glasgow, by Messrs. Grainger and Miller.

The drainage is effected in the same manner as shewn in *Fig*. 4, side drains, *c d*, *c d*, being cut, to consolidate the surface of the moss, and carry off the water from the surrounding country; and centre and cross drains, *a b*, *e f*, to effect the drainage of the road. *x*, *Fig*. 14, shews one half of the centre drain.

§ 18.—*Construction of Passing Places, and Turn Tables.*

Having thus given a description of the various modes of cutting, embanking, and forming the superstructure of railways, and of laying down the rails; we shall now proceed to give an outline, and shew the various modes of laying down single and double lines of rails, with the different kinds of crossings, and rails required for carriages passing each other, or from one line to another.

In almost all the private lines of railway in the neighbourhood of Newcastle-upon-Tyne, and other districts of Great Britain, one main line of road is laid the whole distance; with short lengths of double road at certain intervals, and proper passings between them, for the carriages going in one direction, to pass the others returning in the opposite direction.

In public lines, and for general traffic, especially where slow and quick travelling trains are to work, it is almost necessary to have double lines of road laid the whole distance. Quadruple lines, being so extremely expensive, will only be resorted to in extraordinary cases, or near the termination of extensive lines of railway.

The same description of passing places, will suffice for a quadruple, as for a double line of railway; we shall, therefore, divide the subject into two kinds:—double lines of railway, with the kinds of crossings required for them;—and single lines, with their crossings.

Fig. 25, Plate III., represents a double railway, with crossings, from one line to the other, for the carriages to pass each other, or for a quick train to pass one moving at a slower rate. A A′ is one line, along which the carriages travel in the direction shewn by the darts, or from A to A′; B B′ being the other line, whereon the carriages travel in the opposite direction, or from B′ to B, those two lines are supposed to extend the whole length of the railway. When the goods to be conveyed, are to travel at the same, or nearly at the same, rates of speed, perhaps few, if any, passings will be required from one road to the other; but, when it is intended for the conveyance of passengers also, or for the transit of light goods, at a swifter pace than that which it is deemed advisable to convey heavy goods; then it will be necessary to have certain passings, so that the carriages moving slow, can cross to the other road, and allow those moving faster to pass them, when the former can again pass upon the same road again, and so proceed.

It may, however, be remarked, that, wherever it can be done, it is very advisable to have as few passing places as possible; as there does exist, upon the best constructed crossings, a certain degree of danger to trains passing rapidly along, from a possibility of neglect on the part of the attendants, and of the rails getting out of order.

Thus, suppose a train of heavy goods travelling along the road A towards A′, and another train of light goods, or passengers, coming in the same direction; the heavy train can then pass along the crossing *a b*, into the road, B B′, until the lighter train has passed, when it can again resume its former line, by proceeding along the crossing, *c d*. In like manner, a light train of carriages, proceeding along the line B′ B, encounters a heavy train, travelling in the same direction; by the proper signal, the heavy train proceeds along *f e* into the line, A′ A, until the other train passes, when it again gets into its former track, by passing along *d c*. In this manner, when the road is pretty straight, (which, in public lines, should always be the case,) and upon very long lines, the carriages may never be interrupted by each other; as, if engines are used, the weights they take being large, there will not be a great number upon the road at once, and the heavy trains making a point of giving way to those proceeding at a swifter rate, those travelling with passengers and light goods, may be very little interrupted.

Figs. 26, 27, and 28, *Plate III.*, shew single lines, with different kinds of crossing places, for the carriages to pass each other. In *Fig.* 26, A A′ is the main line, extended the whole distance, along which the carriages travel, in both directions; B B′ is a siding or passing place, for the carriages, going in opposite directions, to pass each other; this kind of siding is used when the goods are all conveyed in one direction, where the distances are short, the motion slow, and where, perhaps, the necessity for the carriages passing each other is not very frequent. In this kind of railway, the carriages will always continue along the main line of road, A A′, unless diverted into the passing place, B′ B, by a moveable rail, or switch, which will be hereafter described, the attendant having to put it into the proper position whenever the carriages are required to pass into the line B B′. Thus, if a train of carriages, coming along the main line, in the direction A A′, is likely to meet another train coming in the opposite direction, then the attendant puts the moveable rail into the proper position; the empty train proceeds along A′ B′, and the carriages pass each other, when the empty carriages resume the main line again, by passing through B A.

This form of siding is much, or, indeed, almost invariably, used in all the railways, where the goods are to be conveyed in one direction only, the empty carriages being the returning load; such as the conveyance of coals, from the coalpits to the shipping places.

In this case, the loaded carriages always keep the main line uninterruptedly, the empty carriages passing into the siding; the moveable rail being placed on that end of the crossing, towards which the empty carriages are proceeding, or at A′.

This arrangement is, however, very inconvenient, requiring the constant precaution of the attendant to put the switches in their proper places, whenever the carriages are to pass each other. It is true, the loaded carriages passing on the main line are not interrupted, the projecting ledge of the wheels, always displacing the switches from their position in contact with the rail, into that which allows of the free passage of the carriages, without interruption. *Fig. 27, Plate III.,* shews a mode of obviating the inconveniences of the moveable rail, by a particular form of laying the road; by which the carriages are enabled to pass each other, without the danger of meeting, and where no moveable rail or switch is required. In this plan of passing, A A′ represents the main line, with the carriages proceeding in the direction of the darts, and B′ B the line, along which the carriages pass in the opposite direction.

The carriages having always a tendency to continue moving in a straight line, will, in passing along from A towards A′, keep the road A A′, there being no switch to divert them into the road A B; and, in like manner, the carriages proceeding in the opposite direction, B′ B, will keep that road, there being on that line no switch to divert the carriages along B′ A′; the two trains will thus proceed into the different lines A′ and B, and, passing each other, will join the main line again, the former by the road A′ B′, and the latter by the road B A.

This form of passing, will be very useful upon lines, where any neglect of placing moveable switches in the proper place, might occasion many inconveniences; and it is, therefore, much used for underground railways, where the passing places are very frequent, and where the expense of keeping attendants at all the passing places, would be very great.

This form of crossing, though obviating the use of switches, is objectionable, from the curves, or bends, in the line at each passing place, and which the loaded carriages must necessarily make, whether there be any carriages to pass or not. Upon some of the private lines, and upon the Killingworth railway in particular, switches of a particular description are used, by which the main line of way is not obliged to be diverged, as in the last mode, and by which the loaded carriages always traverse the main line, and the empty carriages are also obliged to pass through the siding, when necessary.

This is effected by a spring switch, applied at 1′, *Fig.* 26, which, opening to the wheels of the loaded carriages, and allowing them to pass freely along; acts against the wheels of the empty carriages, and always diverts them into the passing place, A′ B′. This form of switch, which was at first worked by a weight, is now worked by two springs, as shewn in *Fig.* 3, *Plate IV.*

Fig. 28, *Plate III.* shews another form of passing place, by which the carriages, passing in opposite directions, are made to diverge equally on each side, and which is used where the traffic is nearly equal, in both directions; A *a b*, being the route in one direction, and A′ *c d*, the route for the carriages proceeding in the opposite direction.

We shall now explain the different forms of crossing rails, employed to divert the carriages into the various passing places previously described.

Figs. 1 and 2, *Plate IV.* shew the point and switch rails, and *Fig.* 29, *Plate III.* the crossing rail, almost universally used on all the private railways in the north of England; and which are generally applied to the kind of passing place or "siding," *Fig.* 26, *Plate III.* The point rails A, *Fig.* 1, *Plate IV.* are placed at A, *Fig.* 26, *Plate III.*; and the point rails B, *Fig.* 2, *Plate IV.* at A′, in the same passing place. When the loaded carriages pass from A towards A′, *Fig.* 26, *Plate III.*, they keep along the straight rails, *a a*′, *b b*′, there being nothing to divert them from that course, or turn them into that of *c c*′, *c c*′. Again, the empty carriages, or those passing from A′ towards A, will continue along the rails *d d*′, *e e*′, if the switch rail, *g g*, remain as shewn in the figure; but, when placed in the position of the dotted lines, the carriages are diverted along the rails, *g g*, *f f*, into the passing place, B′ B. We see, therefore, that it depends upon the switch rail being in the position shewn in the figure, or as shewn by the dotted lines, whether the carriages, traversing the direction, A′ A, keep along that line, or are diverted into the line, B′ B. When this switch, or point, is worked by hand, it always remains open; and it only requires the attendant, to place it in the position of the dotted lines, to divert the carriages into the passing place; or not to interfere with it, to allow the carriages to keep the main line. On the Killingworth railway, this switch was always kept shut, or in the position of the dotted lines, by a weight acting upon it; in which case the returning carriages were obliged always to pass through the line B′ B, the loaded carriages, passing from A to A′, pushing the switch open. In this form of point rail, it will be observed, that the ends of the point rails, at *c c* and *f*, are some distance from the general line of the rails; in quick travelling, this break in the continuity of the rails causes a considerable jolt, when the carriages pass over them. To obviate this defect, on the Killingworth railway, I made the point rails on both sides to work upon a joint, as shewn in *Fig.* 3, *Plate IV.* *a a′*, *b b′*, are the rails of the main line A A′, as in the former figure; *c c′*, *c c′*, the line of rails passing into the siding, B B′. When these switches are in the position shewn in *Figure* 3, the wheels of the carriages pass along the rails, *a a′* and *b b′*, without any break in the continuity of the rails, the same as along *a a′*, *b b′*, *Fig.* 1. The carriages returning in the opposite direction, on the main line, have likewise the same continuous rail to pass along. In coming out of the passing place, B′ B, the carriages travel along the rails, $c'c$, $c'c$; the wheels of the carriages, in this case, open the point rail b', and shut the point c, which thus present an uninterrupted and continuous bearing to the wheels. The same effect is accomplished at the other end, A′, of the passing place, by similar point rails reversed, the point rail at 1, being always shut, and that at 2, constantly open; the rail at 1, thus diverting the carriages, passing in the direction A′ A, into the passing place, and being opened by the wheels of the carriages, passing in the other direction, from A towards A′.

The same kind of points, either common, as in *Fig.* 1, or moveable, with springs, as in *Fig.* 3, is required at the ends A and B′ of the passing place, *Fig.* 27; the points at 1 and 4 being always open, and the points at 2 and 3 always shut, against the rail.

Fig. 28, is a plan of passing place, where a single line of public railway is used, and which may be worked without manual labour; and this kind of passing place, having been in use, for some time, upon the Newcastle and Carlisle railway, we can speak with some confidence, to its answering the purpose, better than any other kind of passing place we have yet seen. In this, the spring points, shewn in *Fig.* 3, *Plate. IV.* are used; at 1 and 4, *Fig.* 28, *Plate III.* the point rails always remain open, and at 2 and 3, always shut; the wheels of the carriages being deviated, by the closed point, at 2, into the passing place, *a b*, and, on joining the single line again, the wheels open the point 3, at the same time closing, and passing along 4, into the single line. The wheels of the carriages, travelling in the opposite direction, meeting with the closed point, 3, they pass into *c d*; opening the point 2, and closing 1, in passing into the single line at A. *Figs.* 5 and 6, *Plate IV.* shew the spring for working these switches, or points; *a*, *Fig.* 5, represents the rails, *a a′*, *Fig.* 3; *b*, the moveable rail, *b b′*, and *d*, a stud, to prevent the point from moving too far outwards. A spiral spring is enclosed within a small cast-iron tube, or cylinder, with a gland, *g*, at one end, which can be taken off at pleasure; a stud, *e*, is fastened to the moveable rail, *c*, and is projected downwards, through a longitudinal hole, into the box, shewn at A B, *Fig.* 3, and is thus capable of moving back and forwards, from the rail, towards *d*. A cap, or plate of iron, shewn at *f*, nearly fills the inside of the box, and a bolt proceeds from this cap within the spring, and is screwed to the stud, *e*, upon the rail.

The action of the spring, retained at one end by a circular ring, cast upon the box, shewn at *h*, *Fig.* 5, and acting against the cap, *f*, at the other end, is communicated, through the bolt, to the moveable rail, *b*, and keeps it firmly against the rail, *a*; and, when the rail is moved outwards, towards *d*, the spring acts powerfully in moving it back to its original position. When the spring slackens, by taking off the gland, and screwing the bolt, and cap, *f*, against the spring, it is tightened.

Fig. 6, though of a precisely similar principle, acts a little differently. In this case the moveable rail is required to be constantly open, or against *d*; the spring, therefore, acts against the stud, *e*, at one end, and the gland, *g*, at the other, and, consequently, constantly keeps the rail, *c*, against *d*, and when it is pushed towards *a*, by the wheels of the carriages, the spring immediately acts, to push it back to *d*. This spring is tightened by merely screwing the gland, *g*. Both these iron cylinders, with the springs, are fastened down to the blocks by pins, in the usual way, as shewn in the drawings.

This description of point rails, acting in this manner, will not, however, do for the double line, *Fig.* 25. As in this case, the carriages are only to be deviated *occa-*

sionally into the passing places; the point rails must, therefore, be worked by hand, the mode of doing which will be described hereafter.

Fig. 4, *Plate IV.* is a plan of point rail adopted by Mr. Stephenson, on the Liverpool and Manchester railway. About nine feet of the rails, on each side of the railway, are made to move upon a cast-iron framing, which is placed upon the blocks by the chairs, 1 1 1 1 and 2 2 2 2; the two ends, *a c*, of the rails, constituting the single way, rest upon the cast-iron frame at one end; and the four ends, *b b′*, *d d′*, of the rails forming the main line, and the rails leading into the passing place, at the other end of the cast-iron frame.

These loose rails, which are united by a rod, *e*, work upon a joint at one end, as shewn in *Fig.* 4, and move back and forwards, to join either of the ends of the rails, *b d*, or *b′ d′*, at the other end; the rails, *a b*, *c d*, forming the main line of way A A′, *Fig.* 25, *Plate III.*; and the rails, *a b′*, *c d′*, *Fig.* 3, forming the line of way, *a b*, *Fig.* 25, leading into the other line, B B′. When, therefore, these moveable rails are in the position shewn in *Fig.* 4, the carriages must necessarily travel into the passing place; and when put into the position shewn by the dotted lines, they continue along the main line of railway. The same kind of moveable rail will be required at the several points *b*, *c*, *d*, *e*, and *f.* This kind of sliding rail is much used in the depôts, and at the termini of railways.

Fig. 31, is another kind of sliding rail, lately used upon the Liverpool and Manchester railway. The rails of this are the same as in the common points, *Fig.* 1, *Plate IV.* but are placed upon a cast-iron frame; two short lengths of rails, *e f*, *e′ f′*, moveable on a joint at the ends, *e e′*, likewise work back and forwards upon this frame, and are fastened together by a bar of iron, *g*.

When these moveable rails are placed in the position shewn in the figure, the carriages must necessarily pass along the rails, *a*, *b*, *c*, *d*; and if placed in the position shewn by the dotted lines, they must then travel along the rails *a b′*, *c d′*.

We have stated, that the two moveable rails, *a c*, *Fig.* 4, *Plate IV.*, are worked back and forwards by hand; this is accomplished in the following manner. A hollow cast-iron stand, *s s′*, *Figs.* 4 and 7, is set upright upon a large stone block, *g*, which is firmly fixed in the ground; the stand being fastened upon the block by pins, driven through the holes, 3 3 3 3, a vertical spindle or shaft, *n*, works in a socket at the lower end, and within the cap, *h h′*, at the other. Upon this spindle, near the bottom, a horizontal sheave, *r*, is fixed on a false centre, with an iron ring working round its periphery, and forming what is called an eccentric motion; a handle, *i*, is fixed to the top of the spindle, by which it is turned round; and a rod, *f*, proceeds from the ring, which works round the eccentric sheave, and is fastened to the rail, *c d′*, and by the rod, *e*, to the sliding rail, *a b′*. When, therefore, the eccentric sheave, *r*, is in the position shewn in *Fig.* 4, the rails, *c d′* and *a b′*, are drawn into the position shewn in the figure; and when the handle is turned, and the eccentric sheave is in the position shewn by the dotted lines, the rails are put into the position, *a b*, *c d*. The spindle and eccentric being enclosed by the cast-iron stand, nothing but the handle is exposed, and this works on a joint at *h′*; when not used, it is bent down into the position shewn by the dotted lines, and may be secured by a lock at *k*.

The same plan of eccentric motion is applicable, and is used for moving the sliding points, *bb′*, *c c′*, in *Fig.* 3, *Plate IV.*, or for working the sliding rails, *e f*, *e′ f′*, *Fig.* 31, *Plate III.*

Having explained the mode of passing the carriages from one line to another, we have now to explain the plan adopted where the one rail crosses the other, as at *x x′*, &c., *Figs*. 25, 26, and 27, *Plate III.* *Fig*. 29, *Plate III*., shews the common plan of doing this, which consists of the rails, *a b*, *b′ a′*, raised upon a cast-iron plate, with openings, at the crossing of these rails, at *c*, for the flanch of the wheels to traverse. Keeping in mind that the flanch of the carriage wheels, traverses the inside of the rails; suppose this rail applied to the crossing at *x′*, *Fig*. 26, the carriage wheels, in travelling from A towards A′, pass along the rails, *a c a′*, of *Fig*. 29; while in travelling from A′ to B′, they pass along the rails, *b′ c b*. The same description of rail answers for the crossing at *x*, except that it is reversed, the end, *b′ a′*, being turned towards A; and in all the crossings marked *x′*, in *Figs*. 25, 26, 27, and 28, the rail is laid down as shewn in *Fig*. 29, and, where marked *x*, reversed, or with the end, *a′ b′*, towards A A. In this crossing plate, there is a liability of the wheel running off the road, when at the point, *c*; thus the flanch of the wheel, being on the inside of the rails at *x′*, *Fig*. 25, the carriages are kept upon the rail by the flanch running along the inside of the rail, *c x′*, or *b′ b*, *Fig*. 29; but between the rail *b′* and the point *c*, the continuity of the line of the rail is broken, and there is nothing to keep the wheel upon the rail; the outer side of the iron plate, *Fig*. 29, shewn by the part shaded light, is, therefore, raised above the level of the top of the rails, to prevent the wheels from running off. The great disadvantage of this rail is, the jolt to the wheels of the carriages, in passing from the rails *a′* and *b′*, to the point *c*; the point *c* wearing down so very soon, from the breadth of bearing being so very narrow on that part of the rail.

To obviate this objection, I had a form of crossing made upon the Killingworth railway, which was described in the second edition of this work, and which was worked by a weight. This description of crossing rail is shewn in *Fig.* 30, *Plate III.*, worked by a spring. *a a′*, and *b b′*, are the two lines of rails, as in *Fig.* 29, but reversed; and instead of the two rails, *a′ b′*, being fixed, with a space between them for the flanch of the wheel to pass, as in *Fig.* 29; in this case, as shewn in *Fig.* 30, they are two moveable rails, *a′ c*, and *b′ d*, and are kept constantly pressing against the point, *x*, by springs.

These rails are placed upon an iron frame, A A. B B, is a cast-iron cylinder, or box, containing a spiral spring, similar to those previously described in *Plate IV.*, and shewn on a large scale in *Fig.* 32, *Plate III.* The sliding rails, *a′ c*, *b′ d*, are connected with the spring, by studs, *s s*, *Fig.* 32, passing through an oblong hole on the top of the pipe, *e f*, *Fig.* 30; which allows the rails to move outwards, and which prevents the dirt from falling into the box. This hole is covered by a piece of tin plate, sliding over the top of it; *b′ d*, *a′ c*, *Fig.* 32, shew portions of the rails, *x* being the point rail; B B are the glands filling the cylinder, and capable of being screwed inwards, against the springs. It will be seen by this drawing, that the springs, abutting against the glands at both ends, are continually acting upon the rails *b′ d*, *a′ c*, to press them against the middle rail *x*; and, when necessary, the glands are screwed up to tighten the springs, and cause them to act with the required force against the middle, or point rail, *x*.

When the carriages traverse this crossing, the wheels have a continuous rail to travel upon, and, therefore, the jolt occasioned by the break in the rail at *c*, *Fig.* 29, is obviated, and, likewise, the liability of the wheels running off the rails; there is, therefore, no necessity for the raised ledge on the outside of the rail. Thus, when the wheel traverses the rail $a a'$ towards a', the whole weight of the carriage is upon that rail, and the rail $b' d$ is at liberty to move outwards, which is done by the flanch of the wheel pushing against the end d; the same takes place with the rail $a' c$, when the wheel travels on the rail $b b'$. Suppose, likewise, the carriages going in the opposite direction, or from b' to b, in this case the weight of the carriages is upon the rail $b' d$, while the opposite one, $a' c$, is quite at liberty; the latter is, therefore, pushed out, and the wheel proceeds on the straight line $b' b$; there is, consequently, no risk of the wheel traversing the wrong direction. As a further preventative, however, and to avert the least possibility of such an occurrence, a rail is sometimes laid parallel to, and on the inner side of the main line of rails, immediately opposite to the crossing rail, as shewn at 5, 6, *Fig.* 26. This rail, being laid only of such a distance from the main rails, as to allow the flanch of the wheels to pass; effectually prevents the least possibility of the wheels taking the wrong direction, in passing over the crossing rail, *Fig.* 30.

The description of passings, from one line of railway to another, thus described, runs obliquely across the line of rails; at such an angle, as not to produce any considerable shock to the carriages in passing, or to throw the wheels from off the rails, or twist the framework of the carriages. The angle should, in some degree, depend upon the rate of speed it is intended to pass along. Upon the private colliery railways, where the rate of speed is not more than eight miles an hour, the angle is generally between 6° and 7°; but upon public lines of railway, where the speed is great, a less angle than 2°, or 2½°, should not be adopted.

In *Fig.* 26, the length required from the point rail, 3, to the crossing rail at *x*, is fifteen yards in the former case, and forty-two yards in the latter; and this will be the same in all the other crossings, in *Figs.* 25, 26, and 27. In *Fig.* 28, the same angle will only require half the length; or, when the length is the same, the angle will only be half that in the other figures. At the depôts, or termini of railways, where many lines are required, and where the ground is generally valuable, and the space limited, these kinds of crossings would be very inconvenient, or, indeed, quite inapplicable; and, therefore, an entirely different description is necessary.

Let 1 1′, 2 2′, and 3 3′, *Fig.* 8, *Plate IV.*, be different lines of railway; on each of these lines, as shewn in the figure, circular turn-tables are placed, upon which the carriages are run; and these turn-tables, turning round with great facility, the carriages can be run upon any other line of railway, either at right angles, or at any other angle, with the line of railway from that on which they are traversing.

Figs. 9, 10, 11, and 12, shew the most improved turn-table, or plate, used at the termini of railways. This consists of a circular table, turning round upon rollers; rails being laid upon this table, of the same width as those of the road, it is turned so that the ends of the rails upon the table, are placed opposite the ends of the rails of the road, into which the carriages are to be conveyed. Thus, suppose a carriage on the line 2 2′; it is run upon the table in the direction, 5 6; the table is then turned round, with the carriage upon it, until the carriage is standing in the direction 5′6′, when it may be run into the line 10 10′; or if, when it is upon the next table, and in the direction 8 8′, it is turned round into the direction 9 9′, it may then be run back into the line 3′3, or into the same line on the other side of the turn-table. The table on the line 11′, is shewn turned into the proper position, for running the carriage into the oblique lines, 4 or 4′.

These tables are thus constructed:—Suppose *o o*, *Figs.* 10 and 11, to be the surface of the ground whereon the rails of the railway are laid, a circular hole is dug out, of sufficient depth to receive the table; around this, large stone blocks, *a a*, similar to the railway blocks, are placed; upon these blocks, eight cast-iron chairs, represented at *b b b*, &c., *Fig.* 9, are placed, and pinned down; a circular ring of cast iron, *c c*, is laid within these chairs, about two inches and a half broad at top, and a little bevelled; this ring is laid perfectly horizontal, and upon it the small bevelled rollers, *g g g*, &c. revolve; the arms, 1, 2, 3, 4, acting as axles to them, and around the ends of which they turn freely. These arms pass through a ring of iron near the extremity, which keeps the rollers constantly in their proper position; the arms are fastened in the centre to a ring of iron, *f*, which turns freely round the spindle, *f′*, *Fig.* 11. The turn-table rests upon these rollers, which are for the purpose of causing it to turn round, as freely as possible. *Fig.* 12, shews the frame-work of the table; *h h h*, &c. are the outer rim; *i i i*, the arms; and *m m*, the inner rim, which is of the same diameter as the ring of iron, *c c c*, and which rests on, and turns round upon, the periphery of the rollers, *g g g*. The table is kept in its place by the vertical spindle, *f′*, fixed upon the table at *e*, and turning with it upon the rest, *e′*.

The table, it will, therefore, be seen, turns round this rest as a centre, and, revolving upon the periphery of the rollers, it moves round with very little friction. It is not intended that the spindle, *f′*, should support any part of the weight of the table, the use of it being solely to prevent any side motion. The outer ring, *h*, of the table, projects above the level of the arms, *i i*, and the inner part of the ring, *h′ h′*. Within this outer ring, a platform of timber is laid, resting upon, and fastened to the arms, *k k*, the bolt holes being shewn in the figure; upon this platform the rails of the road are placed. *n n*, *Fig.* 11, shews the timber, the upper side of which is level with the top of the outer ring, *h h*. A circular ring, *o o*, of cast iron, or of mason work, is laid around the outer circle of the table, upon which the rails rest; and which abut against the ends of the rails, laid upon the turn-table.

We have said that the top of the turn-table is covered with timber, on which the rails forming the railway is laid; in many cases the top is formed of cast-iron, the rails being raised a little above the surface of the cast-iron plate.

CHAPTER V.

CONSTRUCTION OF CARRIAGES ADAPTED TO RAILROADS.

§ I.—*Coal Waggons, and Wooden Wheels.*

It is very obvious, that the form of carriages for railroads, will depend, in a great measure, upon the nature of the goods to be conveyed in them; different kinds of goods, and various species of traffic, requiring different descriptions of carriages. There are, however, some parts of the carriages common to all the varieties, viz. the wheels, the axles, and the bearings, in which the axles run. We shall, therefore, at first, describe the different forms of wheels, and axles, or other parts, which, the nature of the road requires, should be always of the same form and construction; and then give drawings, of some of the different kinds of carriages used on railroads.

The body of the carriages, or, as they were termed, "waggons," used at the first introduction of railways, was, (and still remains, where employed in conveying coals,) in the form of the frustum of a pyramid, or in the shape of a hopper, being much broader and longer at the top, than at the bottom. The railroads, almost universally, descending towards the depôt, the fore-wheels were made of greater diameter than the hind-wheels, according to the angle of the road, the object being, to keep the framing, or body of the waggon, in a horizontal position. The end of the waggon, resting on the large wheels, was also made to project considerably farther, beyond the perpendicular line of the axles of the front, than the hind-wheels; so that the centre of gravity of the load was not midway between the wheels, but much nearer the large wheels than the smaller, and, consequently, a greater weight was laid upon them, than upon the latter. This form of the waggon has gradually given way to wheels of the same size, and the body of the carriage is square, and placed equally upon the two axles, as shewn in *Figs.* 1, 2, and 3, *Plate VII.*

The wheels were, for a long period, made of wood, composed of one entire piece, or of two or three pieces, fastened together. The mode of making the latter, was, by joining the pieces together by wooden pins, and securing them by flat slips of iron, in the shape of an *s s*, nailed upon the line of the joining. The periphery of the wheels was hewn into the proper shape, by the workmen, with a projection on one side, to keep them upon the rail. The axles were made of wrought iron, and fixed firmly into the centre of the wheels, and, consequently, turned upon the bearing with the wheels. From the very probable inaccuracy of the workmanship, it is not likely the periphery of the wheels would be perfectly circular, which would cause considerable jolting, or an undulatory motion, to the load, and thus increase the draught.

§ 2.—*Cast-iron Wheels.*

It seems uncertain at what precise period cast-iron wheels were first introduced. In a Dictionary of Arts and Sciences, published in 1754, a drawing is given of a cast-iron wheel, used upon carriages to convey stones from a quarry near Bath, said to be "a great improvement in some carriages and waggonways, made use of at the coal-mines, near Newcastle;" from whence we may suppose, that cast-iron wheels had not been used at the latter place at that period. How long after this they were adopted, we cannot learn; but in 1765, two wooden and two cast-iron wheels were mostly in use, the wooden ones being retained for the application of the brake, or convoy.

Great reluctance was shewn, even down to a very recent date, to relinquish the employment of wooden wheels; many objections were urged against cast-iron,— their liability to break, to cut the rails, their insufficiency to present an adequate hold to the brake. At first, sufficient attention does not appear to have been paid, to avoid the contraction, in cooling of cast-iron wheels, and they frequently broke in pieces. Increased knowledge of the properties of cast iron, and of the utility of that kind of wheel, soon, however, produced a general acquiescence in their use. When cast-iron rails came into use, the wooden wheels could no longer be used, so that the introduction of the former would accelerate the discarding of the latter; and, therefore, in 1767, the date of the introduction of cast-iron rails, we may suppose wooden wheels were little used.

A B C, *Fig*. 1, *Plate VI.*, shews the form of the cast-iron wheels, for an edge rail; *f f*, is the nave; *a a*, the rim; and *b b*, the spokes. The rim is made sometimes nearly, or often quite, cylindrical, with a projection at one side, called the flanch, to keep the wheel upon the rail; *c* is a square hole, through the nave, for the axle.

This is the form which was generally used for edge rails, for many years after their introduction, the whole being cast in one piece; the spokes being about half an inch thick, and four inches broad; the rim, one inch thick, and the flanch, one inch deep. For the plate rail, the spokes were tapered away, from the nave, to about two inches broad, forming a rim of that breadth, perfectly cylindrical, to run upon the rails; or, in some cases, the middle portion, between the nave and rim, was cast of one entire piece, with circular holes, to make it lighter.

A very formidable objection to the use of iron wheels, was, that the rails, especially when their surfaces were narrow, tended to form, or wear an indented groove around their rims; which groove, when of moderate depth, not only caused considerable friction, but was liable to break the rails by a side pressure. The edges, also, of the top of the cast-iron rail, suffered much by the action of the sides of the groove thus formed, and were frequently broken off, on the interior side, for the whole length of the rail. To remedy this, the breadth of the surface of the rails was increased, which diminished the evil to a certain extent; but the expense of repairs was still considerable.

§ 3.—*Cast-iron Wheels, Case-hardened.*

A complete remedy was, however, effected a few years ago, by what is called, "case-hardening" the rim of the wheels. This is done by placing a massive ring of cast iron, around the mould for forming the casting of the wheel; and running the metal, which forms the exterior surface of the rim of the wheel, against this cold cylindrical piece of iron. The rapid abstraction of heat by the cold iron, produces such a degree of compactness, and hardness, to the superficies of the wheel in contact with the cold iron, that the file has no effect upon it, and this hardness effectually prevents the action of the rail from wearing the wheel into grooves.

Previous to this, the cost of wheels was a very serious charge, in the annual repair of the carriages; but the wheels now, when properly case-hardened, and where the speed is moderate, work for many years without wearing away. Several, which have been in use for eight years, are still in good order; and, from their appearance, are likely to remain so for a considerable time to come. The operation of case-hardening was, at first, attended with great difficulty; the rapidity, with which the cold iron caused the rim to cool, produced an unequal contraction of the metal, in all the several parts of the wheel, and made them frequently fly in pieces. The rim, being first cooled, would not yield to the contraction of the spokes in cooling; and, therefore, when the spokes cooled, if the contraction did not cause them to separate immediately, it left such a tension upon them, that the shocks they received, when brought into use, soon made them crack, and thus rendered the wheel useless. Many plans were devised to remedy this, in some, the rim was made considerably thicker than the spokes, that the spokes might cool more rapidly, and thus compensate for the more rapid cooling of the rim by the iron ring; the spokes, in this case, being more numerous.

The plan now mostly used, where the wheel is entirely formed of cast iron, is, to cast the nave in two pieces, as is shewn in *Fig.* 1, *Plate VI.*, *e c e*, being the division; two hoops of wrought iron, *i i*, *i i*, being laid around the nave, to secure it.

In Messrs. Losh and Stephenson's patent, to which we have before alluded, there is described a mode of forming the wheels, with wrought-iron spokes, in such a way as to yield to the unequal contraction, occasioned by the case-hardening of the wheels.

A B C, *Fig.* 2, *Plate VI.*, represents the form of their wheel; *c c c c c c*, are the arms, which are of flat malleable iron, dovetailed at the ends. The iron arms being laid in the mould, the cast iron is run around them, and thus forms one entire wheel; the contraction in the cooling, draws the dovetailed spokes firmly into the rim and nave; and, by the use of a little borax, an union is formed, between the wrought and cast iron, which produces a degree of combination, that prevents the possibility of their working loose. The spokes were first made straight, as shewn in the drawing, and were six in number, but experience has since shewn that a greater number is preferable; and they are, also, now made of a slightly serpentine form, so as to yield to the contraction of the rim in cooling. In this wheel, the nave is cast entire.

This system of case-hardening the rim of the wheels, as before stated, has been found to be of very great utility, reducing the wear and cost to a comparatively trifling amount. The hardness, certainly, renders them more liable to crack, or break, by sudden jerks or blows; but this tendency is partly overcome, by the rims being made a little thicker now than formerly; the malleable-iron spokes also tend, in a certain degree, to obviate this objection.

It has been urged, against case-hardened wheels, that their hardness makes them liable to cut the rails; this might apply to narrow rubbing surfaces, but cannot have any application to one surface, rolling over another, when the hard surface is the rolling one, and also the broader. We have often examined, very carefully, their action upon the rails, but could never find any tendency in them to cut the rails; whereas, when the common wheels are indented, on the surface of the rim, they are very liable to injure the rails, from the periphery, thus grooved, breaking the sides of the bearing surface of the rails off, and leaving only the middle section. This may be seen, on all those railroads upon which the common wheels have been long used.

The universal adoption of case-hardened wheels, on all the railroads where a slow rate of travelling is practised, in preference to the common wheels, is, however, the best criterion, which can be adduced, of the general belief of their superiority.

We are also inclined to think, that casting the wheel against a perfectly cylindrical piece of iron, tends to form it more perfectly cylindrical, than casting in the ordinary way, and this will likewise lessen the resistance, arising from the undulatory motion, produced by the imperfect circular form of the rim.

§ 4.—*Cast-iron Wheels, with Wrought-iron Tires.*

The very great rapidity of travelling, which is now adopted upon public railways, causes the subject of wheels, to be a most important object in railway travelling. The rapid motion, very materially, increases the liability of case-hardened wheels to break, not only from the brittle nature of the material, but, also, by the friction of the wheels upon the rails, at such great velocities, heating and expanding the rims, and thus causing them to crack, and fly to pieces; and various plans have, therefore, been devised, to obviate this objection.

The wheels of the locomotive engines, up to 1826, were formed of common cast iron, the case-hardening being deemed objectionable, as diminishing the adhesion upon the rails. Finding the wear of those wheels very great, I had a rim, or tire, of wrought iron, put upon one set of wheels, of one of the Killingworth engines. This tire was made by the hammer of the workman, and, not being of uniform thickness, produced considerable resistance to the engine. The experiment was, however, pursued a sufficient length of time to prove, that, with regard to common cast iron, the wear was very much less. The trial being so very satisfactory, the Bedlington

Iron Company were induced to erect a pair of rollers, to roll them by machinery, by which means, a uniformity of thickness was preserved. Since that time, the use of malleable iron tires has gradually increased, and is now adopted upon all the public lines, where rapid travelling is practised, not only for engine wheels, but also for the common carriages.

In forming this wheel, the nave and spokes were the same as the common, or case-hardened wheels, but the rim was cylindrical, without the flanch. The rim was then turned, to clear it of all sand, or loose particles, and to make it perfectly cylindrical. The tire, being previously turned into a cylindrical shape, and welded, is then heated to a certain degree of temperature, and the contraction in cooling, causes it to embrace the rim of the wheel sufficiently tight, to prevent it from coming off; experience having shewn, that, when the carriages do not travel at a velocity, which heats the tire, such a mode of laying them on is sufficient.

At very rapid rates of travelling, for locomotive engine wheels, and for the wheels of passenger carriages; cast-iron spokes and rims, have not been found of that degree of safety, as to ensure perfect confidence in their use. Mr. George Stephenson, therefore, on the Liverpool and Manchester railway, adopted cast-iron naves, with wooden spokes and rim, on which the wrought-iron tire was laid. Square boxes are cast in the nave, to receive one end of the spokes, the other ends being inserted into the fellies, in the same manner as in coach wheels. A thin wrought-iron rim is laid around the fellies, upon which the outside, or flanched tire, is laid. This description of wheel ensures perfect safety, but the expense of construction is very considerable.

Mr. George Stephenson has obtained a patent for a wheel, with cast-iron nave and rim, and hollow ~~cast-~~ wrought-iron spokes; A B C; *Fig.* 3, *Plate VI.*, represents this form of wheel. The wheel in this plate shews the dimensions of one of the engine wheels, those for common carriages being made lighter. This wheel differs little from those previously described, except that the spokes are made of hollow wrought-iron tubes, or what is called "gun-barrelled spokes." These spokes are laid into a mould, and the cast iron forming the nave and rim, is run around them in the usual way; but a composition of borax is applied, upon the ends of the tubular spokes, for the purpose of causing a more perfect union between the wrought and cast iron; and the spokes, thus united, are found, in practice, not to work loose. The nave is cast of one entire piece, and the rim is cast cylindrical; the latter is then turned, and a tire of wrought iron, with a flanch rolled upon it, is laid upon the cylindrical rim of cast-iron.

These wheels, being much less expensive than the wheels with wooden spokes, have been extensively used upon the public railways, where rapid travelling is practised. There still, however, exists the objection to the rim being formed of cast iron; and though the risk of breaking is greatly obviated by the adoption of wrought-iron spokes, and the malleable-iron tire, still there is certainly some risk, resulting from the use of cast iron [redacted] as a rim for wheels, which are to travel at very rapid rates of speed. The rim is, generally, made very heavy, to still further guard against the risk of breakage; notwithstanding which, cast iron, used as a rim for such very rapid rates of travelling, as from twenty to thirty miles an hour, is certainly objectionable.

Messrs. Jones, of London, have a patent for a kind of wheel with wrought-iron spokes and rim, which is much used for heavy carriages, on the common roads, and which has been tried, in some places, on railways. The rim and spokes of this wheel are of wrought iron, and the nave of cast iron; the spokes are formed of round bars, screwed at one end, and dovetailed at the other; holes are made through the rim, which are bevelled outwards, and into which the dovetailed spokes are inserted; holes are cast in the nave of the wheel, through which the other ends of the spokes pass; this end of the spoke is screwed downwards into the nave, thus screwing the dovetailed ends into the rim of the wheel. The spokes, therefore, do not rest upon or within the nave, as in other wheels, but are suspended around the rim; the nave, and, consequently, the axle and carriages, are, therefore, suspended from the rim, the spokes being in a state of tension, and not of compression, as in the ordinary wheels. These wheels have not, however, been much used on railways.

§ 5.—*Wrought-iron Wheels.*

Mr. William Losh, of Walker, has produced a wheel, with wrought-iron spokes and rim, which has been very extensively used on railways, both public and private, being of such a construction, that economy is combined with safety. This wheel was the subject of a patent, in August 1830, previous to the introduction of which, no more perfect wheels had been used, than those with cast-iron rims, hooped with wrought iron.

A B C, *Figs.* 4 and 5, *Plate VI.*, shew different forms of these wheels. The spokes are formed of flat iron bars, one end of which is cast into the nave, in the same manner as shewn in *Fig.* 2. In the wheel, *Fig.* 4, the spokes are a little bent; but this is not necessary, as they may be made quite straight. The outer ends of the spokes are bent, according to the different modes of construction, into a circle, so as, when joined together, they form a circular rim, on which the flanged tire is laid. Thus, in *Fig.* 4, the end of the spoke *a*, is bent at 1, in the manner shewn in the drawing; and from 1 to 2 forms a portion of the inner rim, the spoke, *b*, forming a continuation from 2 to 3, and so on, until the circle is complete; the end of the spoke 1, resting on the elbow-bend of the end 2 of the spoke *b*, and the end of *b* resting upon the elbow-bend of the spoke *c*. This is shewn more distinctly, on a larger scale, at D. When, therefore, the bent spokes are thus laid upon the ends of each other, they form a circular rim; the tire is then heated, and laid upon the rim, and, when cooled, the contraction of the iron presses the ends of each spoke firmly upon the elbow-bend of the next spoke, and thus forms a perfect wheel. The under side of the outer tire is rolled concave, with a slight bead, or projection, on each side, shewn at *d d*, in B, *Fig.* 4. The expansion of the rim, or tire, when hot, allows the inner rim, or spokes, to pass within the projecting bead; and, when the tire contracts, it secures the inner rim firmly within the side beads.

A B C, *Fig.* 5, is another form of this description of wheel, which is called the sector-spoked wheel, each spoke being a sector of a circle. In the construction of this wheel, the ends of the bar of iron, forming the spokes, are inserted into the nave, in the usual manner, being first moulded into the form shewn in the drawing, and the other ends bent into the form of a ~~section~~, as sector shewn in the drawing; and, being laid against each other, forms a continuous circle, or rim, upon which the flanched tire is laid, as before described. This construction of the spokes forms a very firm and complete wheel. There are many other modifications, in the construction of this description of wheel, described by the patentee; but those shewn in *Figs.* 4 and 5, have been mostly used. This kind of wheel, being formed entirely of wrought iron, except the nave, and the intermediate rim being of wrought iron, it is peculiarly adapted for railways, where the rate of travelling is very great, as there is no risk of breakage, if the material be of good quality; and if the velocity is so very rapid, that the tire becomes heated, and expands, the elasticity of the spokes is quite sufficient to counteract any effect of this kind, and to preserve the stability of the wheel. They have been, almost exclusively, used on the recently made carriages on the London and Birmingham, Grand Junction, and Liverpool and Manchester railways. Several modifications of this form of wheel, have been attempted; but as these are, generally, more in the shape of evasions of the patent, than improvements in the construction of the wheels, we do not conceive it necessary to describe them; more especially as few, if any, have been, as yet, used by the different railway companies.

§ 6. *Form of Axles, and Bearings.*

The axles, and plan of bearings, or chairs, come next under consideration. For many years after the introduction of cast-iron wheels, the axles, wheels, and plan of bearing were uniformly of one description, for carriages on edge-rail roads. *Figs.* 1 and 2, *Plate VII.*, shew an improved form of the waggons, now almost exclusively used for the conveyance of coals on private railways. The wheels are all of the description shewn in *Fig.* 1, *Plate VI.*, with a square hole in the nave, into which the ends of the axles are wedged; the bearings are all within the wheels, and consist of a cast or wrought iron chair, secured to the framing of the carriage by bolts, with a semicircular bearing for the axles. In the early stage of railroad mechanism, the chair, or bearing, was made extremely narrow, not more than one inch and a quarter in length, and in breadth not equal to the diameter of the axles. It was made thus, under an impression, that the narrowest bearing produced the least friction. Subsequent experience has shewn this to be quite erroneous, and experiments will be hereafter given, which shew this, in a very conspicuous point of view. The length of the bearings is now never less than three inches, but more frequently greater.

Fig 4, *Plate VII.*, shews an improved plan of this kind of bearing, which is much used, for carriages of the description of *Figs.* 1 and 2; *a a*, are the bolts which secure the chair to the framing of the carriage, *b b*, the upper part of the chair, with a semicircular bearing, *e*, representing the end of the axle. Until recently, the lower side of the axle was exposed, and the dust of the railroad operated very injuriously to the progress of the carriages; a cap, *d*, is now fastened by the bolts, 1 1, to the upper part of the chairs, which protects the axle from the dust of the road. The oil is applied to the upper side of the axle, through the hole, 2; and there are two modes of securing a continual supply of oil, or other lubricating matter, to the axle. When oil was used to lubricate the axles of the carriages, on the Liverpool and Manchester railway, the plan introduced by Mr. Stephenson, was a tin box, containing the oil, placed upon the frame-work of the carriage, from which a piece of cotton wick proceeded, and which was inserted down the hole, 2, *Fig.* 4; and which, acting as a syphon, kept up a continual supply to the axle. The other plan, which was first introduced by Mr. Booth, was, to use such a description of lubricating matter, as would melt with a moderate degree of heat. This was placed in a box, in the frame-work of the carriage, immediately above the bearing of the axle, with a hole to communicate therewith; the lubricating matter was, therefore, constantly in contact with the axle; and when the latter became in the least degree heated, for want of oil, the heat produced a fresh supply.- Mr. Booth has a patent for a kind of lubricating substance of this description, which consists of a solution of the common washing soda of the shops, in the proportion of half a pound of the salt to a gallon of pure water; to one gallon of this solution, three pounds of good clean tallow, and six pounds of palm oil are added; or, instead of the mixture of palm oil and tallow, ten pounds of palm oil, or eight pounds of firm tallow. The whole mixture is heated to about 200° or 210° of Fahr., and well stirred, or agitated, until the composition is cooled down to 60° or 70° of Fahr., and has obtained the consistency of butter, in which state it is ready for use.

The kind of bearing, previously described, is used where the wheels are on the outside of the frame-work of the carriage, or where the bearing is on the inside of the wheels. In many carriages, and especially those for the conveyance of bulky goods, it is necessary to have a greater width of frame-work, than that which can be obtained within the wheels; and, hence, it is necessary to elevate the frame-work of the carriage above the wheels, and increase its width; in which case the bearings are placed on the outside of the wheels. Independently of the increased accommodation which such a form of carriage presents, there are other considerations, which make a bearing outside the wheels, preferable to one within the wheels. In the latter case, the size of axle is necessarily large to resist the shocks, as well as the direct weight of the load; and when the wheels are of large diameter, the twist upon the axles is very considerable. With inside bearings, therefore, the chair, or semicircular bearing, cannot be of less diameter than the size of the axle; but outside bearings not being subject to the twisting of the wheels, the diameter of the axle, at the bearing, can be made much less; and, if we suppose the same resistance acting on the surfaces in both cases, the friction should be in the direct ratio of the diameter of the axle at the points of bearing, and, consequently, greater with the inside than outside bearing. Carriages carrying about four tons of goods, and with three-feet wheels, require axles, at least, three inches and a quarter in diameter, which must be the size of the bearings inside the wheels; whereas the outside bearings may be reduced to two inches, and thus diminish the resistance considerably.

Figs. 5, 6, and 7, *Plate VII.*, shew a plan of axle and bearing on the outside of the wheels; *a* is that part of the axle, on which the nave of the wheel is fixed; *b b*, shewing a part of the nave, and *c* the end of the axle, which constitutes the bearing portion; in this bearing, the axle diminishes in diameter in three divisions. *Fig.* 8, is another plan, which is more generally adopted, than the preceding. *Fig.* 6, shews a section of the bearing, or chair, through the middle; this chair consists of a cast-iron box, 1, 2, 3, 4, in two pieces, separated at 4′, and fastened together by bolts, the holes of which are shewn at 5, 6, on the plan *Fig.* 7; one of the bolts is shewn by the dotted line, *d*, *Fig.* 6. The extreme end of the axle, it will be seen, is increased in diameter, for the purpose of preventing the chair from sliding outwards, and, therefore, it necessarily causes the chair to be made in two pieces; *i e*, *i e*, are the upper and lower brass parts, which rest on the axle, and surround it, and which are enclosed by the cast-iron chair, 1, 2, 3, 4. A cavity, or chamber, at *f*, is cast in the chair, to contain the oil, or other lubricating matter, which, in the middle, is open to the upper side of the brass bearing; the oil being communicated to the axle by the two holes, shewn in the drawing. This chamber is covered, at the top, by a lid, 2 *g*, by which it can be filled with oil at any time. The spring, shewn at *g g*, *Figs*. 6 and 7, rests upon the chair, and is fastened to it by the same bolts which fasten the chair together, as shewn at *g d*, *Fig*. 6. *Fig*. 7, which is a plan of the bearing, shews the spring, *g g ; 5* and 6 being the bolt-holes for fastening the chair together, and also fastening the spring upon the chair. The middle compartment is the chamber, which contains the oil, with the hole through the brass of the chair, to lubricate the axle; the two side compartments, shewing that part on which the springs rest, with the bolt-holes, for fastening the springs to the chair. Vertical guides, similar to those shewn at *f f*, *Fig*. 10, are fastened to the side of the frame of the carriages; and the grooves, *h h*, *Fig*. 7, are cast for the guides to work in. *Fig*. 9, shews a plan of bearing, used on the carriages for the Newcastle and Carlisle railway, and is a vertical section, through the middle of the chair; *e*, being the upper side of the brass, and *e'*, the under part. This chair is put together in two parts, meeting in the middle of the axle, and bolted together by two bolts on each side, as shewn at 1 1, *Fig*. 4. In this bearing, the spring does not rest upon the back, or upper side of it, as in *Fig*. 6; but the spring is placed above the frame of the carriage, as shewn in *Fig*. 10, with a bolt, 2', passing through the frame, and resting on the upper side of the chair, by which the spring is acted upon by the inequality of the road. This bolt, resting upon the middle of the chair, prevents the possibility of a chamber in the middle for the oil, and there are, therefore, two chambers for that purpose, one on each side of the part whereon the bolt rests; with two holes, 1 1, communicating with the brass of the bearing, and axle, for the oil to pass to the bearing part of the axle.

In the plan of bearing, *Figs*. 6 and 7, the guides are fastened to the outside of the framing of the carriage, and work within the grooves, *h h*, *Fig*. 7. In the plan, *Fig*. 9, the guides are made nearly the whole breadth of the chair, and work within the projecting parts, 3 3, 4 4, of the chair, *Fig*. 4. *f f*, *Fig*. 10, shew this plan of guides; one cheek of the guide, shewn by the dotted lines, projects upwards, on the inside of the frame, to steady it; and it is bolted upwards to the frame, by the bolts, *a a*, *a a*. The dotted lines, 3 3, 4 4, *Fig*. 9, represent the cheeks of the chair, within which the guides slide up and down; that part of the bearing on each side, projecting a little, as seen at *c*, in *Fig*. 10, and effectually acting as a guide for the chair to slide up and down. To secure the stability of the carriages, and counteract the twisting of the framing at the curves, it is very important, that the guides should be fixed, so that no working should take place, in the oscillation of the carriages, from one side to the other. Besides the bolts, *c c*, a stay, *b*, on each side, also passes between each guide, with a cross bolt between each side-stay, at *b*; a diagonal stay at each end, at *d d*, is also placed to steady the guides, and which likewise acts as braces to support that part of the framing of the carriage, which projects beyond the wheels.

The springs in *Fig*. 10, it will be seen, are placed above the frame of the carriage; that is done for the purpose of keeping the platform of the carriage as low as possible. If the springs were placed below the framing, or were made to rest upon the chair, as in *Fig*. 6, it would raise the frame, 4 4, so much higher, as would be equal to the thickness of the spring. Another disadvantage of having the spring below the frame, is, that it increases the depth of the guides; and, of course, renders them weaker in resisting the side shocks, or twisting of the curves.

The bolt, 2′, *Fig.* 9, passes through a hole in the frame of the carriage, and rests against the under side of the middle of the spring.

On all these bearings, it will be seen, that the end of the axle is increased in size, or that a collar is laid around the axle, so as to make it larger in diameter, than that part whereon the chair rests; this is done for the purpose of steadying the guides, or to prevent them from extending outwards, or in breadth. This has been found to be quite necessary, as some were tried upon the Newcastle and Carlisle railway without this collar, the guides and chairs of which, could not be kept at the proper width. We may here remark, that all these bearings are upon the principle of the wheels being fixed to the axle, and turning with them; which is the reverse of what is universally used on the carriages upon turnpike roads, where the wheels turn round upon the axle. In railway carriages, however, the depth of the flanch, to keep the wheels upon the rail, is only one inch; and it is necessary that no vibration of the wheel should exist, otherwise its liability to get off the rail would be greatly increased. In all bearings, similar to those used on common roads, some vibration exists, especially when they are a little worn; and the following trial will shew that the least vibration is injurious:—On the Newcastle and Carlisle railway some carriages were constructed, with the axles fitted into the nave of the wheel, in the same way as if they were to turn round with the wheels; except that, instead of the axles being keyed to the nave of the wheel at both ends, one of the wheels on each side was not keyed to the axle, but was left at liberty to turn round it, for the purpose of trying the effect upon the curves; a groove being cut around the axle, in which the end of a pin worked, to prevent the wheel from working off. Although the hole through the nave of the wheel was bored out, and the axle turned, and made to fit as accurately as possible, still there was a trifling vibration of the wheel, when it turned round the axle, and this small vibration was sufficient to cause the carriages to run off the rails occasionally; the axles were then keyed to the wheel, and no such occurrence took place. From this experiment, it would appear, that it is quite essential to the safety of railroad travelling, that the wheels of the carriages should be fixed to the axles, and turn round with them. We are aware, that upon some railroads, though principally upon plate rails, the wheels are loose upon the axles; but on plate rails, the liability to run off the rails, is much diminished by the great height of the upright ledge; and upon those of the edge rails, the flanch of the wheels is made very deep, and the carriages travel at a slow rate.

Having thus described some of the different plans of bearings, we shall reserve, for another part of the work, our enquiries into the best form and dimensions of the bearing part of the axle, to produce the least friction; and shall proceed to describe the different kinds of carriages for coals, heavy goods, and passengers, used upon the different railways.

§ 7.—*Modern Coal Waggons, or Carriages.*

Figs. 1, 2, and 3 shew the plan of waggons or carriages, used in the north of England for the conveyance of coals. The reason why they are made of this shape, is, that the coals are discharged out of the bottom of the carriage; and, therefore, it is necessary to have them narrower at the bottom than at the top, or in the shape of a hopper, that the coals may run out. In some of the railways in the south of England, and in Scotland, the coals are laid upon a waggon with a square body, the coals being in this case, lifted out by hand or by shovels; but, in the neighbourhood of Newcastle, this mode is too slow an operation; for the large quantities required to be constantly shipped. *Fig.* 1, is an elevation; *Fig.* 2, a plan; and *Fig.* 3, an end view. The framework consists of the two side frames, or soles, A A, A A, as they are called, fastened together by the four cross sheths, B B B B, and the bolts, *a a*. Upright sheths, *b b b b*, are placed upon the side frames, and cross sheths, as shewn in the figures; and are made of wrought iron, rolled into the proper shape for the purpose. The lower ends of the upright sheths are bolted to the framing, A A, A A, by screw-bolts, that part, passing through the framing, being bevelled upright; when screwed down, they are fixed firmly into the timber. The top framing is also iron, rolled for the purpose, the side sheths being rivetted to the top frame; the ends and sides are then clead with deals, which are sometimes bolted to the upright sheths, but more frequently rivetted to them with small bolts.

The upright sheths, and top framing, are sometimes made of timber, and either clead with thin sheet iron, or deals. The bottom, which consists of deals fastened together by the cross sheths, *c c*, *c c*, is hung upon two iron cross bars, *e f*, *e f*, working upon eye-bolts at the ends, *e e*, and is hung upon clasps at the ends, *f f*, for the purpose of being opened with facility, when the clasps are struck off. The waggons are dragged by means of a short chain, with a double eye at each end, attached to the middle bar, *g g*, and fastened to the two cross sheths, B B; the end of the bar, *g g*, passes into the double eye, and is secured by a bolt, as shewn in *Fig.* 3. A chain is not, however, always used; sometimes a bar of iron is substituted, which is fastened in the same manner. To add to the breadth of the ends of the side frames, A A, A A, and prevent the ends from passing each other, on the curves of the road, a piece of wood, *i i*, is bolted to the inside of the side frame, and secured by hoops, *k k k k*, passed around the ends. The break, or brake, is fastened to the side frame by a cast-iron stud, bolted to the framing, and shewn by the dotted lines at *o*, *Fig.* 1. A wrought-iron pin is keyed into this stud, on which the brake, or lever, *m n r*, works, the pin at *o* acting as its fulcrum. The part, *m n*, is a flat bar, to which pieces of wood are bolted on each side, for the purpose of nailing on the wooden brakes, *p p*, which press against the wheels. These brakes were formerly called "convoys," and were made of wood entirely; the pieces, *p p*, being called "breasts," and composed of beech. The end, *r*, is kept up by a bolt, when not used; and before self-acting planes were established, another lever, acting upon the end *r*, was applied, to increase the power. The dimensions of the waggons, here described, are such as carry about fifty-five cwt. of coals; or, by heaping a little, nearly three tons.

§ 8.—*Truck for the Conveyance of general Merchandise.*

Fig. 10, *Plate VII.*, is a side view or elevation; *Fig.* 11, a plan; and *Figs.* 12 and 13, end views of a truck, or platform carriage, for the conveyance of general goods on public railroads. The main framing consists of the four longitudinal frames, 11, 22, 33, 44, which are fastened together by the three cross sheths, 55, 66, 77;

these sheths are mortised into the frames 11 and 22, and bolted to them by bed-bolts, and are likewise more firmly bound together by the long bolts, *5′5′*, *6′6′*, *7′7′*. This framing is still further strengthened, and prevented from twisting, by the diagonal braces, 88 and 99. It may here be remarked, that the inner longitudinal frames, 22 and 33, are not applied, except where carriages similar to those of *Figs.* 1, and 3, are to travel upon the same railway, or where carriages are used, with the bearings inside the wheels. In these cases, the inner frames are necessary to abut against the ends, *k k*, of the other carriages, unless the whole train be coupled together by inflexible bars, and thus prevent the ends of the carriages from abutting against each other. When the inner frames, 22 and 33, are not used, the diagonal braces must extend to the outer frames, 11 and 44. Upon this main frame, the upper framing, *i i*, *k k*, is raised, for the purpose of forming a platform, on which the goods are to be placed, and which is thus constructed:—Upon the outer frames, 11 and 44, and also resting upon the cross sheths, 55, 77, the cross sheths, *l l*, *m m*, are laid at each end, an end view of which is shewn in *Fig.* 12. Four cast-iron boxes, *r r r r*, are bolted down to the side frame, 11 and 44, on each side, shewn on a larger scale in *Figs.* 14, 15, and 16; *Fig.* 14, being an elevation; *Fig.* 15, an end view of the inner side; and *Fig.* 16, a plan. Upon the cross sheths, *l l*, *m m*, and the cast-iron stands, the longitudinal sheths, *i i* and *k k*, are bolted; another longitudinal sheth, *o o*, (broken off in *Fig.* 11,) is laid upon the cross sheths, 5, 6, and 7, and bolted to them; four cross sheths, *n n n n*, resting in the middle upon the last-named sheth, and with their ends upon the cast-iron stands, *r r r r*, as shewn in *Figs.* 11, 13, and 16, are then placed across, and bolted to the lower cross sheths.

This frame-work is then covered with planks, shewn in *Fig*. 13, and made with a little depression in the middle, for the goods to lie more securely. It will be seen also, for the same purpose, that the outside longitudinal sheths, *i k*, project a little above the level of the cleading of the platform. At each end, a piece of timber, *s s*, *Fig*. 12, is laid across, and which is likewise raised a little above the level of the platform. The iron bar, by which the carriage is dragged, is shewn at *e e*, *Fig*. 11, and as it reaches the whole length of the carriage, and as all the cross sheths are bolted to this bar, it gives additional strength to the frame-work.

These carriages, which are generally denominated "trucks," are used for almost all the different descriptions of goods carried upon railroads; and as they present, upon a railroad, four feet eight inches in width, a superficial surface of platform of seventy-five square feet, a considerable quantity of very light goods can be placed upon them. They generally carry about four tons weight, and by increasing the dimensions of the platform, this may be increased.

§ 9.—*Common Passenger Carriages.*

Figs. 1 and 2, *Plate VIII.* shew the elevation and plan, of the frame-work of a carriage for the conveyance of passengers, the same figures being used to refer to the same parts, as in the previous drawings of the truck carriages; 11, 22, 33, and 44, *Fig*. 2, are the longitudinal sheths; and 5 5′, 5″, 6 6′ 6″, 7, the cross sheths. The same inner longitudinal sheths, 22 and 33, are put in this drawing, as in that of *Fig*. 11, *Plate VII.*; but these may be omitted, when carriages are not used on the same railway, with inside bearings, or where such carriages do not travel in the same trains with the passenger carriages. 88, 99, are the cross stays; the cross sheths are mortised into the longitudinal sheths, secured with bed-bolts, and likewise with cross bolts, as shewn in the drawing. The springs of this carriage, are placed above the frame-work similar to the trucks, as shewn in *Fig.* 1; but they may be placed below, without altering the construction of the frame-work at all, it being merely necessary to raise the framing of the carriage a little higher. In the drawing, *Fig.* 1, the spring is shewn the same as for the truck carriages, but for passenger carriages of a better class, the springs are made much longer, and sometimes double or grasshopper springs. In this carriage no upper or raised platform is required, as on the truck carriages; that part of the wheels above the frame-work, runs underneath the seats, as shewn in the drawing. *Fig.* 1, is an open carriage, or what is called the *second class* of passenger carriages; *t t t t t t*, are the seats; w w w, the doors. A canopy is raised upon iron uprights, and covered, to shelter the passengers from the rain, and also from the small particles of coke, thrown out of the chimney of the engine; *x o y u*, shews the brake for stopping the carriage, which, where it presses against the wheel, is hung upon the inside of the outer sheth at *y*; the lever, *x v o*, works upon the fulcrum at *v*. When, therefore, the end, *x*, is moved outwards, it presses the brake, *y u*, against the wheel, by the connecting rod, *o i*. This is what is called a single brake, but the lever being very powerful, it is generally found sufficient. This is one of the varieties of the open passenger carriages; there are, however, many different forms, according to the fancy of the engineer; the figure shewn in the drawing is, however, a very comfortable and economical form of open carriage.

§ 10.—*First Class, Passenger Carriages.*

Figs. 3, 4, and 5, *Plate VIII.*, shew a plan of close, or first class carriage, for the conveyance of passengers. The framing of this carriage is precisely the same as that for the open carriage, described in *Fig.* 2, the letters referring to the same parts. *Fig.* 4, is a cross section, shewing the construction of the interior of the carriage; *t t t t*, being the seats; and B, the space below the seats; *r r*, the stands for the springs. In some of these carriages, the seats are divided into four compartments, as shewn in *Fig.* 4, with arms for the comfort of the passengers. The seats, and back, and the whole of the inside, are lined with cushions, and some of them are fitted up in the first-rate style of coach-building.

In the carriages shewn in the plates, the main framing is a solid piece of oak; in most of the carriages used on the Liverpool and Manchester, and also the Grand Junction or Birmingham railways, the side framing consists of two pieces of timber, kept apart two or three inches by studs, and secured by bolts. The latter mode of constructing the framing of the carriages, is for the purpose of applying a particular description of buffing apparatus, which will be hereafter described. In these carriages, the brake is worked different from the common passenger carriages, the guard sitting upon the top of the carriage. $a' a''$, *Figs.* 2, 3, and 4, is an upright rod, worked by the handle, a'; this rod works a small pinion, *b*, and large wheel, b', on the axle of which is a small pinion, working into the toothed rack, c', fixed to the horizontal rod, $c' c''$. This rod lays hold of a lever, or arm, fixed upon the shaft, $e' e'$; and upon this shaft is another lever, communicating with the two arms, *f f*, *Fig*. 3. When, therefore, the handle, *a'*, is turned, the combination of wheels moves the rod, *c' c'*, back and forwards, by means of the toothed rack; and if it is drawn in the direction of the dart, the lever on the shaft, *e' e'*, presses the two arms, *f' f'*, downwards, and, consequently, presses the brakes, *u u*, against the wheels; and the handle being turned so as to work the rod in the opposite direction, the brakes are drawn upwards, and, therefore, drawn from against the wheels. The combination of wheels is for the purpose of increasing the power of the handle, *a'*, which could not otherwise be made of sufficient power, without being inconveniently long.

In *Fig*. 6, *Plate VI*., another plan of working the brake is shewn. In this plan there is a separate brake to each wheel, and not a double one, as in *Fig*. 3, *Plate VIII*. 1 *Fig*. 6, *Plate VI*., is the handle, and pinion, working into the large wheel, 2, on the axle of which is a small pinion, working the two-toothed racks, 3 and 4. Two axles, 5 and 6, are fixed to the frame of the carriage; on each of these axles an arm is firmly fixed, projecting downwards, and upon these arms the brakes, which act against the travelling wheels of the carriage, are fastened. Upon the same axles, at 5 and 6, other two levers, or arms, are fixed, both of them projecting upwards. When, therefore, the handle is turned towards the left, the rod 3, and arm 5, are pushed forwards, and, consequently, that brake is pressed against the wheel; while, at the same time, the rod 4, and arm 6, are pulled in the opposite direction, and that brake is pressed against the other wheel; and when the handle is turned in the other direction, the brakes are taken from against the wheels. There are several other modes practised, of applying brakes to the wheels of the carriages, which it is unnecessary here to describe.

§ 11.—*Mode of coupling Carriages, or Buffing Apparatus.*

In railway travelling, the engines are necessarily very powerful, and, consequently, several carriages are dragged at a time; and these were generally fastened to each other, either by a chain, or by a bar of iron. If by the former, the inertia of one waggon, by any change of motion, is independent of the other; and, therefore, when the engine puts the first carriage in motion, it is done by a jerk, or sudden pull, and so on throughout the whole train, as each carriage is successively put in motion; and, consequently, a succession of jerks is felt by the passengers, as each carriage is put in motion. Again, when the train is stopped, or the speed slackened, the inertia of each carriage causes it to strike against the preceding one, and a succession of blows, or shocks, is felt, as each carriage successively strikes against that which precedes it; and thus the passengers are continually subjected to a succession of jerks, or shocks, whenever any change of motion takes place. When the carrriages are fastened together, by an inflexible bar of iron, the succession of jerks, or shocks, is obviated, the carriages being prevented striking against each other, and only one jerk, or blow, is felt, when the entire train is either stopped, or put in motion; but, in this case, unless the engine be more than sufficiently powerful, to drag the train forward, when in motion, at a certain velocity, it will be incapable of putting the whole mass of carriages, from a state of rest, into motion, without very considerable delay. If the carriages are not fastened together by an inflexible bar, but by a chain, this allows each carriage to move a short distance, before the next is put in motion; then each carriage is put into motion in succession, and the inertia is subdivided into as many efforts as there are carriages.

Whether, however, the changes of motion of the train of carriages, is effected as one mass, or in separate carriages; every change produces either a jerk, or a shock, or both, and these are greater, the more rapid the rate of travelling, and it required some contrivance to obviate this inconvenience. The most obvious was a spring, by which the blow, or jerk, was not instantaneously transmitted to the other carriages, but gradually, and through the elasticity of the springs. Upon the Liverpool and Manchester railway, which was the first where rapid travelling was begun, and where the necessity first existed, the carriages were fitted up with springs in the following manner.

Fig. 6, *Plate VI.*, shews the plan used on that railway; an elliptic spring, *d d*, is placed horizontally in the middle of the frame of the carriage, the back of which rests against the stop at *c*, and the two ends rest against the stops at *d d*. The dragging chain, *b*, is fastened to the middle of the spring, by the rod, *b b′*; and the dragging chain, *f*, is fastened to the ends, *d d*, of the spring, by the two diagonal rods, *e′ e′*.

Buffer heads, or cushions, stuffed with hair, or some other elastic substance, *g g*, *h h*, are placed at the ends of the outer side frames of the carriage. The rods, upon which the buffer heads, *g g*, are fixed, passing through the ends of the side frame of the carriage, and these side frames being constructed of two pieces, kept apart by studs, the rods pass within the frame, through the rests, *d d*, and press against the ends of the elliptic spring, *c*. These rods are shewn by *g' g'*, *Fig*. 6. The connexion of the two buffers, *h h*, with the spring, is more complex. Two levers, *i i*, are fixed upon the frame, to one end of each of which the buffers are connected by the rods, *l l;* the other ends of the levers being connected, by a short link, to the ends, *d d*, of the spring. The connecting rods, *l l*, running in an oblique direction from the line of the buffer heads, the latter is kept parallel with the frame by a rod, sliding through the guides, *k k*. A similar apparatus is fixed to each carriage of the train, part of one of which is shewn in the plate.

When, therefore, a carriage is dragged in the direction of the two darts, the jerk occasioned by the pull of the engine is resisted, or neutralised, by the chain *b*, and rod *b'*, *Fig*. 6, *Plate VI*., acting against the spring at *c;* the carriage being, in fact, put into motion by the ends of the spring, *c*, acting against the rests at *d d*. The carriage, B, is then put in motion by the ends, *d d*, of the spring, acting through the diagonal rods, *e' e'*, to the chain, *f;* and the same apparatus, being fixed to the carriage B, it will be seen, that each carriage is put in motion by the action of two springs, viz. that upon the carriage itself, and also by the spring upon the carriage next preceding it. The chain, *b*, it ought to be remarked, is attached to a spring upon the tender, so that this carriage, also, is acted upon by two springs. The above contrivance effectually operates to prevent the blows or jerks to the carriages, by a sudden *increase* of velocity, or when the train is put in motion. We shall now explain how it operates against shocks, or blows, occasioned by any sudden *diminution* of velocity, or when the train is stopped. When a train is stopped, or the velocity is diminished, the inertia of the carriage, immediately following the engine, causes it to run against the tender frame, and each carriage to strike against that next before it, or the buffers, *n n*, to strike against the buffers, *h h*. When the buffers, *h h*, are struck against, they are pressed forward, and act against the ends, *d d*, of the spring, through the rods, *l l*, and cross heads, *i i;* at the same time, the buffers, *n n*, or, which has the same action, the buffers, *g g*, act, through the rods *g′ g′*, against the ends, *d d*, of the spring. Thus, either in pulling, or pushing the carriages; or in any variation or change of velocity, the spring, *a a*, acts to prevent any jerk, or blow, to the body of the carriage, and any unpleasant shock to the passengers. Several other methods have been adopted of applying similar elliptic springs. In some cases another elliptic spring has been applied to the back of *d d*, in the middle of the frame, in which case the dragging chain, *f*, and buffer heads, *h h*, work precisely the same as the chain, *b*, and buffer heads, *g g*, on the other end of the carriage; and this, indeed, seems to be a better application than the one in the drawing, as the cross heads, *i i*, and the oblique rods, *e e* and *l l*, are done away with, and the force applied more direct from the dragging chains and buffers to the springs, than in the other plan.

The wood engraving, *Fig.* 1, opposite, will shew this mode of applying the springs; *a a* and *a′ a′*, will be the two springs, placed back to back against the cross sheth, *s s*. At *d d*, in this plan, there would be rests, as in *Fig* 6, *Plate VI.;* and the rod, *b b′*, would be applied to the spring, *a a;* and the rod, *f f′*, to the spring, *a′ a′*. The carriage would, in this plan, be dragged by the rests, *d d*, through the intervention of the spring, *a a*, in one direction, and by the rests, *d′ d′*, through the spring,

Fig.3

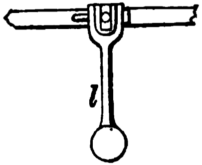


Fig.2.

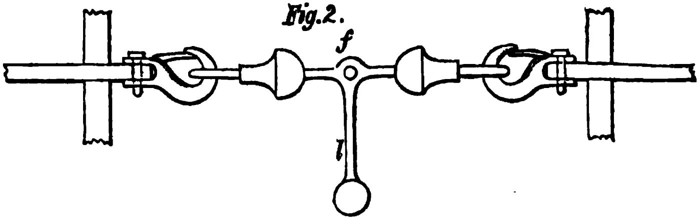
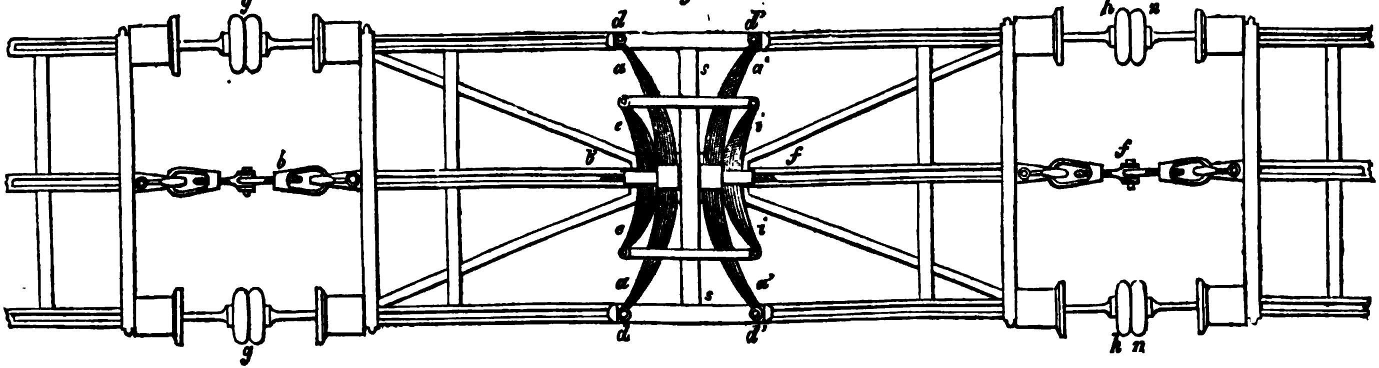


Fig.1.



a′ a′, in the other direction. There are other two smaller springs shewn in the drawing, but, in this case, we suppose there are none. All the buffers will then act direct against the ends, *d d* and *d′ d′*, of the springs. This is a much less complicated mode of application, than the preceding.

A modification of this plan, or, rather, an extension of it, is used upon some railways. Two other springs, *e e*, *i i*, are fixed upon the frame, independent of the long transverse springs, and the coupling or dragging chains are fixed to these. The carriages are dragged by those small springs, and the buffers, alone, made to act against the large springs; there being, in this case, no rest at the ends of the large springs, the ends of the rods of the buffers acting directly against the ends of the springs.

And it will be seen, that if rests are used at *d d* and *d′ d′*, and if each of the two springs are fastened together in the middle; that the dragging chains will act upon one large, and both small springs at once. Other modifications of this application of these springs, in the middle of the carriages, might be described, but which the ingenuity of the reader will readily supply. Another modification of this plan, but differently applied, has been, to fix each of the long elliptic springs near the ends of the carriage, or between the first and second cross sheths of the frame, or, indeed, in some cases, in front of the cross sheth; the side frame being, in this latter case, lengthened, to allow for the elliptic projection of the spring. In these two cases, the drag-chain is affixed directly to the middle of the spring, and the buffer ends directly to the ends of the spring; and in these cases, the objection of the great length of rods, *g′ g′*, pushing against the spring, is obviated.

This apparatus is, however, rather expensive; the springs, rods, levers, and bars of the first carriages, having to bear the resistance of the entire train, require to be very strong; and from the number and lengths of the rods, especially those of the plan in *Fig.* 6, they are liable to get twisted, and put out of order; and likewise, when all the carriages are not loaded alike, they will not be all in the same line, and, consequently, the buffer heads will not strike each other in the centre of the buffer, but above, or below, accordingly as they are loaded; and, consequently, the blows being oblique, considerable strains, and twists, will be thrown upon the buffer rods, and render them liable to get out of order.

To obviate these objections, Mr. Bergin, of Dublin, contrived a different kind of apparatus, which has been applied by him, with great success, to the carriages on the Dublin and Kingstown railway. *Fig.* 7, *Plate VI.*, is a representation of this plan of buffer apparatus. A A A A, are plates of sheet iron, three inches apart from each other, three sixteenths of an inch thick, and fastened together by rivets. These plates rest upon turned bearings, on the middle of the axles, and are fixed to the iron frame, C C C C, which rests against, but is not attached to, the framework, and cross sheths, B B B, of the carriage. D D D D, are hollow tubes; part of the framing, C C C C. A strong iron rod, E E, passes from one end of the frame to the other, to the ends of which the buffer heads, F F′, are fixed, and to which the dragging chains are also attached. This rod, being turned round, passes through the hollow tubes, D D D D, resting upon the rollers, shewn by the dotted lines at *r r r r*, by which it moves back and forwards, very freely. Around this rod, the spiral springs, shewn in the drawing at 1, 2, 3, 4, are placed;

these springs rest, or abut against, the hollow tubes, D D D D, not being allowed to pass within them. Two collars at *a a*, are fastened to the rod, E E, moving with it, and against which the other ends of the springs rest, or are attached. The whole of this apparatus resting on the axles, and not being attached to the frame-work of the carriage, does not partake of the rise and fall of the carriages, when subjected to different loads; the oblong holes, shewn at B B B, in the sheths, allowing the apparatus to move up and down. The buffer heads, and rods, E E, of all the carriages of the whole train, are thus kept in the same line, or parallel with the level of the rails of the railway, the wheels being presumed to be all of the same size. Suppose the carriages dragged forward in the direction of the upper arrow, the collars, *a a*, compress the springs, 1 and 3, and which, acting against the boxes, D D, and cross frames, B B, gradually put the carriage into motion; and if the carriage is to be moved in the opposite direction, the collars, *a a*, compress the springs, 2 and 4, which act in a similar manner, to put the carriage into motion. The rod, E E, being attached to the next carriage by the drag-chains, and by similar rods, it will be seen, that the springs of one carriage are entirely independent of the other, the direct resistance of the whole train being upon the rod, E E, and the other connecting rods of the several carriages; the irregularities of motion being compensated by the springs of each of the carriages individually, and all at the same moment, when the velocity is increased. When the motion is diminished, or the train stopped, the concussion, or blow, is neutralised in the following manner:— If the buffer, F, strikes that immediately preceding it, the springs, 2 and 4, are compressed, and the body of the carriage gradually brought into the change of motion, or state of rest, as the case may be; and the buffer, G, striking against the buffer, F′, is met by the elasticity of the same parts of the spring. When the carriage is moved in the opposite direction, or in that of the lower arrow, the action is precisely the same; only that the springs, 2 and 4, are compressed by any increase of velocity, and the springs, 1 and 3, by a diminution, or when the train is stopped.

Fig. 8, *Plate VI.*, shews a plan of buffers, by Mr. Blackmore, and applied to the carriages on the Newcastle and Carlisle railway, likewise shewn in *Fig.* 2, *Plate VIII.* 1 1, is the side frame of the carriage, and *5 5′ 5″*, 6 6′ 6″, 7, the cross sheths of the framing. Two cast-iron hollow tubes, A A, are fastened to the cross sheths by bolts. An enlarged cross section of the mode of doing so, is shewn in *Fig.* 9, *Plate VI.*, *55* being the sheths, and A the tube; the latter is put together in two pieces, as shewn in *Fig.* 9, for the purpose of inserting the spiral springs. *Fig.* 8, is a section through the middle of the box, or tube; a rod, B B, and C C, passes through each of these tubes, to which the buffer heads, F and G, are attached; a collar is fixed upon the rods at D and E. When, therefore, the carriage is dragged in the direction shewn by the upper arrow, the spring resting against the end, H, of the tube, gradually puts the carriage into motion; and, if there are other carriages attached to the rod, C, the spring acting against the end, I, of the box, drags the other carriage into motion, and so on throughout the whole train. When the carriage is moved in the opposite direction, a similar action takes place. In the case of a diminution of motion, or when the train is stopped, and the buffer heads are brought into action, the springs, acting against the opposite ends of the box, are compressed, and gradually bring the carriages to a state of rest. By having the diameter of the rod, B B, a little larger, from H to B, and K to B, and likewise within the rest at D, forming a shoulder at those places; and by having a moveable collar, acting against the shoulder, and embracing the end of the springs, then both compartments of the springs are brought into action at the same time. Thus, when the buffer, F, is drawn outwards, the collar at D, acting against the shoulder of the rod, compresses the spring against H, and the same with the collar, K, which presses the spring against the rest, D; then, if the buffer be forced inwards, the loose collars at H, and on the right hand side of the rest at D, acting against the shoulder of the rod, compress the springs against the rest, D, and the end of the box at K, while the rod moves through the loose collars on the left side of the rest at D, and at K. *Fig.* 10 shews, on a large scale, the buffer head, with the ring, to which the dragging chain is attached.

Both these last-described buffers, act in the middle of the carriage in dragging, and also when the carriages strike against each other, and are liable to the objection of the carriages rising and falling with the inequality of load; and although the object of Mr. Bergin's patent, was to obviate the oscillatory motion of the carriage, yet the action of both dragging and pushing the carriages, in the middle of the sheth, has been objected to by some engineers, as producing the effect, which it was the object of the patent to obviate.

It will be seen by *Fig.* 6, *Plate VI.*, that the carriages are dragged by the middle of the sheths, and the buffers are applied at each side, and that the ends of the buffers do not meet against each other, but that a certain space is allowed by the drag-chain. It has been found in practice, that unless the ends of the buffers are perfectly square with the body of the carriage, or with the line in which the carriage is moving, and especially in going round curves; that the buffers on one side, striking against each other, throw the carriage into an oblique direction, and produce a continued oscillatory motion. Mr. Henry Booth, of Liverpool, produced a new plan of applying the buffers, for which he obtained a patent in January 1836.

The wood engraving, opposite page 218, shews this plan, which consists of keeping the buffer heads constantly in contact with each other, by the springs acting upon them with a certain degree of pressure. This is accomplished by shortening the drag-chain, and fixing upon them draw-screws, to produce the necessary pressure against the buffer heads. Upon the drag-chains, *b f*, are placed screws, working within two long links, or shackles, the sockets of which are spirally threaded to receive the screw-bolts. These screws are worked by a short lever, *l*, upon which a ball is placed, to prevent the lever from turning round; but, in practice, this is not found necessary.

Fig. 2, is a view of the chain, and screw shackles, on a scale double that of *Fig.* 1, or one inch to a foot, and *Fig.* 3, is a cross section of the lever.

The drag-chains being placed upon the hooks of the bars of the carriages, the screw is turned until the buffer heads are brought together; when the screw is turned round two or three times more, until their ends, pressing against the springs of the carriage, produce a pressure against each other, equal to about a fourth or fifth of the elasticity of the springs. This plan is adopted on the Liverpool and Manchester, the Grand Junction,

and the London and Birmingham railways, and appears to answer all the expectations of the patentee; who states, that "it gives to a train of carriages a com-
" bined steadiness and smoothness of motion, at rapid
" speeds, which they have not, when the buffers of
" each carriage are separate from those of the adjoining
" carriage."

CHAPTER VI.

DESCRIPTION OF THE DIFFERENT KINDS OF MOTIVE POWER USED ON RAILROADS, AND THE DISPOSITION OF THE ROAD FOR THEIR APPLICATION.

§ 1.—*Different Kinds of Motive Power used at various Periods on Railroads.*

In the early periods of the history of railroads, horses were exclusively used; the disposition of the general line of the road, into proper or uniform degrees of inclination, seems then to have been an object of little moment. Most of the railroads, descending in the direction the goods were to be conveyed, afforded an easy draught to the loaded carriages, and the descent was never so great, but that the empty carriages could be drawn up the acclivities. In some of the deep ravines, mounds of earth were thrown up, and some sudden and abrupt acclivities partially levelled; but trifling undulations do not appear to have been noticed. The horses, therefore, would, along the same line of road, be frequently subjected to very fluctuating degrees of draught. Upon some of the old waggonways, the horse was sometimes very heavily strained, and his action was, at other times, not at all required. When the waggons reached some of the more rapid declivities, it was the custom to unhook the horse from the fore part of the waggon, and cause him to follow behind, the waggons running of themselves. The horse thus followed, until he arrived at a part of the road, where the waggon would no longer run down; he was then again fastened to the waggon, until he arrived at another declivity, where his action was not required; and it was no uncommon thing, to find him thus changed several times in the course of his journey. The only motive power, for a long time after the introduction of railways, was horses, and so long as the wooden rail continued in use, the general load was from two to three tons, including the weight of the carriages. The only guide, in the formation of the road, appears, then, to have been to enable the horse to drag that weight, and the road was sloped accordingly. It is interesting, to trace the gradual advancement towards the present state of improvement, from the old roads, to those successively formed, at the different steps of their progress; and the quantity of goods conveyed, at different periods, exemplify it, in a very distinct manner. While the wooden rails without plates continued, the road followed, almost always, the undulations of the surface, except to avoid steep ascents; and where there was a separate road for the empty carriages, the latter invariably did so. No attempts seem to have been made, to avail themselves of the action of gravity down the steep planes; and the most disastrous effects were occasionally produced, by the waggons running "amain," down the steep declivities. A brake, or convoy, being used, to regulate their descent, this brake was pressed by the man with more or less force, according to the declivity of the road, or the velocity with which he wished the waggons to descend. In wet or damp weather, the wheels, by licking up the dirt and mud from the rail, became so slippery, that the action of the brake was almost destroyed; and the attendant having thus no power over the loaded carriage, it frequently got away, destroying every thing in its course, perhaps killing the horses that happened to be upon the declivity, and was, finally, dashed to pieces at the bottom. These accidents were not uncommon, and the destruction caused by them, and the narrow escapes which the men themselves frequently experienced, are in the recollection of many now living. To obviate this inconvenience, in wet weather, boys and men were employed, strewing ashes upon the rails down the steep declivities, or, as they were termed, "runs," to cause the brake to take effect; and, in some states of the weather, where very steep declivities occurred, the work was obliged to be stopped entirely.

Frequently, on these very steep descents, for many days the work was laid off, on account of the weather; a sudden shower of rain occurring, when any of the waggons were upon the declivity, set the whole away; and men were stationed to draw ropes, as booms, across the line of road, to stop their progress. If the ropes could be drawn across before the momentum became very great, the damage was less; but if they broke the ropes, then the most disastrous effects followed. When the double wooden way came into use, plated with iron, and where occasional ascents intervened, more care was taken in forming the road, and a horse was enabled to take a chaldron waggon, containing fifty-three hundred weight of coals, exclusive of the weight of the empty waggon; still, however, the evil occasioned by the waggons "running amain," down the steep declivities, remained.

When cast-iron wheels were introduced, the hind-wheels of the waggon were still made of wood, that the brake might be enabled to take a better hold, in regulating the descent. The brake, for a long time, only acted upon the hind-wheels, and, in that case, I suppose, they found it necessary to retain the wooden wheels, to secure sufficient hold. After, it was prolonged beyond the fulcrum, and made to act upon both wheels, the effect being doubled; we presume they found its action, upon the cast-iron wheels, sufficiently powerful, on such descents as they traversed, to secure the proper hold, and the wooden wheels were, therefore, relinquished.

The next improvement being the adoption of iron rails, the load of the horse was increased, to nearly double the quantity heretofore taken upon the wooden rail, and this also led to a complete change in the formation of the road. By the substitution of iron rails, the resistance was so much diminished, that the brake could no longer afford security to the waggons descending steep hills; and recourse was obliged to be had to other modes of descending them, and restraining the velocity of the waggons. It is supposed, that those circumstances led to the adoption of, what is called, the "self-acting inclined plane," on which the surplus gravity of the loaded waggons was usefully employed, in dragging the empty ones up the plane.

The prevailing means of draught then were, horses upon the level, or slightly descending, or ascending, lines of road; and self-acting planes, upon the steep declivities.

Afterwards, when the steam engine became the prevalent moving power, for almost every other mechanical purpose, its action was employed upon railroads, in dragging the waggons up ascents, on the line of road, by means of a rope, extending from the engine to the waggons.

And, lastly, the power of locomotion was given to the steam engine; and it was, in that manner, applied to drag the waggons, along the more level parts of railroads, without the intervention of a rope.

Having thus given a brief outline of the various species of motive power, successively employed in transporting goods along railroads, we shall now describe them under their respective heads, viz.:

1. Horses.
2. Gravity, acting as self-acting planes.
3. Steam engine, fixed, with ropes.
4. Steam engine, with locomotion.

§ 2.—*Horses.*

Any description of this species of power would be quite superfluous. Of all quadrupeds, the horse is the best adapted for use, as a moving power, especially in the way that his muscular action is here employed. In dragging carriages upon a railroad, we can always adapt the line of draught, to the direction of his muscular force, so that the greatest effect is thrown upon the line of traction.

When a horse makes an effort to drag a carriage, he bends his body forward, and throws that part of his weight upon the collar, which is required to overcome the resistance of the carriage; and the muscular force of his legs is employed to keep up his action, and to move his body forward. His effort, then, is resolvable into two parts, viz., the action upon the load, and that required to urge his own body forward. No very satisfactory experiments have yet been made, to ascertain the precise amount of each; or what proportion the constant exertion, which a horse is capable of bestowing upon the load, bears to his own weight.

Dr. Desagulier states the effect at 200 lbs., moved at the rate of two miles and a half an hour, for eight hours a day; or 200 lbs., twenty miles a day. Mr. Smeaton found his performance less. Mr. Watt states it at 150 lbs., moving two miles and a half an hour.

Assuming, therefore, 150 lbs. as the amount of a horse's power, at that velocity which should be kept up in conveying goods along a railroad, and that a moderately sized horse will weigh about 10 cwt., or 1120 lbs.; we are aware, that, occasionally, he may be able to exert considerably more power upon the load, but it must be at the expence of time, and should not, therefore, enter into the calculation. Taking, however, this assumption as our datum, we may reckon his muscular exertion divided into eight parts, seven of which are required to urge his own weight forward, and one, that of the load. Now, if the acclivity of the road be so increased, until the gravity of the horse's own weight amount to that proportion of his power, which he is capable of exerting upon the load, then the muscular effort will be the same, in both cases. He is capable of exerting, upon the load, a force equal to the seventh part of his own weight; therefore, the angle of inclination will be about 8° 15′; or, upon an ascent of one in seven, the exertion required, to overcome the gravity of the horse's own weight, is equal to the force which he is capable of bestowing upon the load, on a level plane.

In laying out a railroad, therefore, with a view of employing the motive power of horses, all ascents, in the direction of the load, should be carefully avoided; the diminution of the power of the horse being so very great, that very little effective power will be left, for the action upon the load. Even on moderate acclivities, the road should, if the level, between the two ends of the line, will not admit of a moderate inclination; be divided into successive platforms, separated by short ascending planes, upon which some other species of power should be employed.

§ 3.—*Gravity. Self-acting Planes.*

The first introduction of inclined planes, whereon the gravity of a heavy body downwards, was employed to assist, or effect, the moving of a less heavy body up a plane, inclined to the horizon; appears to have been upon canals, where the weight of the loaded boats, lowered down, was made to draw the empty boats up a sloping plane, from one level to another.

In the year 1788, Mr. Reynolds completed, at the Ketley iron works, an inclined plane, formed of a double iron railroad, by which a loaded boat, in passing down a frame, constructed for the purpose, drew up the boats, which were empty. Since that time, many inclined planes have been made upon railroads, for the purpose of drawing up the empty carriages, by the gravitating power of the loaded carriages down the plane. On public, and other railroads, where the quantity of the goods to be conveyed is fluctuating, and is, or is likely to be, the same in both directions, this species of power cannot be resorted to.

It is only where a preponderance of goods has to be conveyed in one direction, and where, upon any declivities occurring in the line of road, that preponderance is capable of overcoming the gravity of the returning carriages, that the action of gravity can be used to advantage.

It will, therefore, be of importance, in the subject of railroad conveyance, to ascertain upon what declivities, with a given preponderating load, this power is available.

The object of all such inclined planes being, to convey down a certain quantity of goods, in a given time, and to do this with the least expenditure of power; in forming a railroad, therefore, with a view of using this species of traction, it is not only necessary that the descent of the plane be such, as to give a preponderance to the loaded carriages, over those which are empty, but such a preponderance as will cause them to descend, and drag up the empty carriages, with the requisite velocity.

If we give to the plane a greater inclination than requisite, we expose the rope and carriages to an unnecessary strain, and, consequently, to additional wear and cost; and if the inclination be not sufficient, the proper performance will not be accomplished.

Art. 1.—*Theory of Inclined Planes.*

We shall, therefore, first of all, endeavour to develope the laws which govern bodies descending inclined planes; and, afterwards, give such practical illustrations as, we trust, will render the subject a matter of easy calculation to those interested.

The phenomena of falling bodies is now well known, and the laws by which they are governed, in descending inclined planes.

The force with which a body is accelerated down an inclined plane, is, to the whole gravitating force of the body falling freely, as the height of the plane, is to its length, or as the sine of the inclination of the plane.

Let H = the height of the plane.
L = its length.
W = weight of the descending body. Then the gravitating force of the body down the plane, which may be expressed by G, will be $G = \frac{W \cdot H}{L}$ (1). Or, making I the inclination of the plane, we have $G = W \sin. I$.

If we make $r = 16\frac{1}{2}$ feet, the space which a body will descend in a second, by falling freely, and $t =$ the time in seconds, then $\text{s} = \sin.\ \text{I}\ rt^2$, or $\text{s} = \frac{\text{G}}{\text{W}} \times rt^2$ (2), and $t = \sqrt{\frac{\text{s}}{\text{G}r}}$;—or $t = \sqrt{\frac{\text{s}}{\sin.\ \text{I}\ r}}$ (3).

For instance, if the height of the plane be equal to the thirty-sixth part of its length, or the descent be one inch in a yard, then, (by th. 1.) the force, by which the body is urged down the plane, will be equal to the thirty-sixth part of its weight; and (th. 2.) the space, which it will describe in the first second of time, will be the thirty-sixth part of $16\frac{1}{2}$ feet, or $5\frac{13}{36}$ inches; and, by the laws of falling bodies, the spaces passed over, being as the squares of the times, the space described, at the end of any other time, will be equal to the square of that time, multiplied by $5\frac{13}{36}$ inches; and the time of descending the plane, will be equal to the square root of the length in inches, divided by $5\frac{13}{36}$ inches.

This will be true, when the body descends the plane, by *sliding*, and without friction; but as, in practice, the carriages are generally placed upon wheels, which *roll* down the plane, and none are without friction, we must, therefore, make allowances for these causes of retardation; otherwise the result, in practice, will not accord with the theorem.

If a wheel, A, roll down an inclined plane, making G the centre of gravity, O the centre of oscillation, and S the point of suspension; then, the force, which accelerates the centre of gravity down the plane, will be that part of the accelerating force of gravity expressed by $\frac{\text{SG}}{\text{SO}} \times \frac{\text{H}}{\text{L}}$; or $\text{G} = \frac{\text{SG}}{\text{SO}} \sin.\ \text{I}$ (4). The friction of carriages, moved on railroads, will be afterwards shewn not to differ, materially, from a uniform resistance; we may, therefore, express the resistance, opposed by friction, to the body moving freely down the plane, by F, and consider the gravitating force, diminished in amount, equal to F, or to the force opposing the free motion of the body down the plane, by the resistance of friction. Hence, retaining the former symbols, we have $\mathrm{S} = \frac{\mathrm{SG}}{\mathrm{SO}}$ sin. $\mathrm{I} - \mathrm{F} \times r t^2$ (5), and, consequently,

$$\mathrm{F} = \frac{\mathrm{SG}}{\mathrm{SO}} \text{ sin. } \mathrm{I} - \frac{\mathrm{S}}{r t^2} \ (6).$$

The above formula, is on the supposition, that the entire body rolls down the plane; but, in the case of wheel carriages, the wheels only roll down, while the body of the carriage, travels at the same rate of speed as the centre of gravity, G. Let W = the weight of the body of the carriage, w = the weight of the wheels:

$$\text{Then } \mathrm{G} = \frac{(\overline{\mathrm{W} + w.} \frac{\mathrm{SG}}{\mathrm{SO}}) \text{ sin. I.}}{\mathrm{W} + w} \qquad t = \sqrt{\frac{\mathrm{S}}{\mathrm{G} - \mathrm{F} \times r}}$$

$$\mathrm{S} = \mathrm{G} - \mathrm{F} \times r t^2. \qquad \mathrm{F} = \mathrm{G} - \frac{\mathrm{S}}{r t^2} \ (7).$$

Or, as it may be more convenient to express the resistance in lbs., the following notation may, for practice, be retained:—

$$\mathrm{F} = \mathrm{W} + w \text{ sin. } \mathrm{I} - \frac{(\mathrm{W} + w \frac{\mathrm{SO}}{\mathrm{SG}}) \times \mathrm{S}}{r t^2} \quad (8).$$

and consequently $t = \sqrt{\frac{(\mathrm{W} + w \frac{\mathrm{SO}}{\mathrm{SG}}) \times \mathrm{S}}{(\mathrm{W} + w) \text{ sin. } \mathrm{I} - \mathrm{F} \times r}}$ (9).

We can thus determine the friction, F, of any carriage or waggon, by the formula (8), by causing it to descend a plane of a known declivity, and ascertaining the space passed over in a given time; the difference between the space actually passed over, and that which the carriage ought to have described, in descending freely, will be the diminution by the effect of friction, and will be a correct estimate of its amount.

This applies to a body, or a system of bodies, descending an inclined plane, opposed only by their own friction and inertia; but, in practice, the principal use made of this species of motive power is, in employing the preponderance of a descending train of loaded carriages, to drag the returning empty carriages up the plane. The gravitating force of the descending train of carriages is then, not only opposed to their own inertia, and friction, but also to the inertia, friction, and gravity, of the ascending train of carriages; and if, as must always be the case, the motion of these trains, is effected by means of a rope, passed over a roll, or wheel, at the top of the plane, and over small sheeves, upon the whole length of the plane; we must, therefore, in applying the previous theorem to practice, take all those resistances into consideration.

Let W' represent the inertia of the ascending train of carriages, rope, wheel at the top, and sheeves upon the plane.

F' = the friction of the descending train of carriages, the friction of the ascending train, their gravity, and the friction of the rope, wheel, and several sheeves upon the plane. And $G = W\frac{H}{L}$, the gravitating force of the descending train, or moving power.

$$\text{Then } S = \frac{G - F'}{(W + w\frac{SO}{SG} + W')} \times r\,t^2 \quad (10).$$

$$t = \sqrt{\frac{(W + w\frac{SO}{SG} + W') \times S}{G - F' \times r}} \quad (11).$$

$$\text{Thus } F' = G - \frac{(W - w\frac{SO}{SG} + W') \times S}{r\,t^2} \quad (12).$$

The preceding expression of W', is composed of the weight of the descending carriages, and inertia of the wheel and sheeves; the former is readily known, but the force required, to overcome the vis inertiæ of the latter, and give them the proper velocity, will depend much upon the form of the different sheeves, &c. In any system, revolving round an axis, passing through the centre of gravity, the resistance, which each particle opposes to a change in its angular motion, is, as the square of the distance from the centre of motion. In order, therefore, to find the force necessary to put the sheeves, &c. into motion :—

Let Q = the quantity of matter, or weight of *the body ;* S R = the distance of the centre of gyration, from the axis of motion ; and S D = the distance from the axis, at which the force is applied to communicate motion to the sheeve ; then $\frac{\text{W. SR}^2}{\text{SD}^2}$ supposed to be placed at the distance S D, from the centre of motion, will represent the same resistance to angular motion, as if the weight of each particle was multiplied into its distance from the axis.

It is not, perhaps, necessary to pursue the enquiry with that minuteness, as to ascertain, either by experiment or calculation, the distance S R; if we take $\frac{\text{W. SR}^2}{\text{SD}^2} = \cdot 5$, W being 1, it will be sufficiently near for practice. If, therefore, $a =$ the inertia of the ascending train, $= a' + a'' \frac{\text{SO}}{\text{SG}}$; a' being the weight of the body of the carriage, and a'' that of the wheels ;

$b =$ the weight of the rope ;

$c =$ the inertia of each wheel or roll, and c' that of the sheeves, = half their weight ;

Then $\text{W}' = a + b + c + c'$.

And if F = the friction of the descending train;
f = the friction of the ascending train;
g = their gravity;
φ = the friction of the rope, sheeves, &c.

$$\text{Then } \mathrm{F}' = \mathrm{G} - \frac{(\overline{\mathrm{W}+w\,\frac{\mathrm{SO}}{\mathrm{SG}}} + \overline{a+a'\frac{\mathrm{SO}}{\mathrm{SG}}} + b + c + c') \times \mathrm{S}.}{r\,t^2}$$

Consequently $\mathrm{F}' = \mathrm{F} + f + g + \varphi$; and, therefore, having the friction of the carriages, and their gravitating force, the friction of the rope, &c., will be $\varphi = \mathrm{F}' - \overline{\mathrm{F} + f + g}$ (13).

In the application, therefore, of the inclined plane, to practice, it will be requisite, as before stated, that the quantity of work should be done with the least cost; and this will be accomplished, when the descent of the plane is such, as will perform the work required, without laying any unnecessary strain upon the rope employed for the purpose. This can be effected, either by employing a commensurate number of carriages upon, or by giving additional elevation to the plane.

Any body, or system of bodies, placed upon a plane inclined to the horizon, will, if the gravitating tendency of the body down the plane exceed its friction, begin to descend, and its motion will be accelerated, according to the laws of falling bodies, and will pass down the plane in a certain time; and this will be the same, whatever be the number of carriages. But, if we employ this system of bodies, or train of carriages, to drag up a certain number of empty carriages, by means of a rope, we shall require a certain preponderance of gravitating force, to accomplish it in a given time. We can, therefore, either increase the number of carriages, until the aggregate sum of their gravitating forces amount to this preponderance; or, we can, by elevating the plane, increase each individual gravitating force, until we acquire the same preponderance.

If we are restricted, as to the number of carriages that can be conveyed down at a time, we must then, necessarily, have recourse to the latter method; but, if no such restriction exists, we can then give to the plane that elevation, which will perform the work with the best effect. The proper inclination of planes cannot, however, be found without a perfect knowledge of all the circumstances attending their mode of action; such as the friction, the wear of ropes, &c. We shall, therefore, pass over these considerations at this time, and refer to them again, when we shall have detailed the experiments made to ascertain these *facts*; and shall now proceed to describe the mode of action, of self-acting planes upon the railroads, in the neighbourhood of Newcastle, where their use has been very extensive.

Art. 2.—*Description of Apparatus for Self-acting Planes.*

Fig. 1, *Plate IX.*, represents a ground plan of the wheel, w w, of a self-acting plane, round the rim of which the rope winds, by which the loaded carriages drag the empty ones up the plane. The wheel is generally of cast iron, about six feet in diameter, with six spokes, and a grooved rim, for the rope to wind upon; the groove being only of sufficient width to hold the rope within it, as the wheel moves round, consequently, the rope, when in action, only passes round one half of the wheel, from *a* to *b*.

At the top of the plane, a square hole is dug, the sides of which are lined with masonry, the top being nearly upon the same level as the railroad; the wheel is then placed between two frames of timber, the upper of which, *a b* and *c d*, are shewn in the drawing. They are kept steady by the diagonal braces, *e e*. The carriages on which the axle runs are placed on the front of these frames, the upper one at *g*, and the other immediately below it, on which the ends of the axle that sustains the wheel rest, and on which it is at liberty to run freely round.

At the top of the inclined plane, a certain space of ground, for about twenty or thirty yards, (varying according to the number of carriages run down at a time,) is made level, on which the loaded carriages remain, until they are to be lowered down, and on which the empty ones stop, after their passage up the plane; at the end of this level platform, and furthest from the top of the plane, the wheel is placed, a little below the surface of the rails, and, being covered over, the rails are laid down upon it, as shewn by the dotted lines. The plane is then formed into a proper slope, between the platform, or level, at the top, on which the wheel is placed; and the lower extremity, where a similar flat, or piece of level road, is made, for the descending train of waggons to land upon. The slope is either uniform, or such as the nature of the ground will permit. Sometimes it is necessary to make considerable bends, or curves, in the line of the road; but, whatever be the form or length of the slope, it must always be terminated at each end by these level platforms. The narrower parallel lines, in the drawing, will shew the rails as laid down upon the platform; the wheel being placed below the level of the rail, and the square hole being covered up, the rails pass over upon the cover. In the drawing, the rails are broken off at *k k*, the cover being removed, to shew the wheel.

The plane wheel being placed below the surface of the rails, it is fixed, with a little inclination upwards, so that the rope may lead to the surface. From this, to the bottom of the plane, small horizontal sheeves are placed, for the rope to run upon, as well to keep it from dragging along the ground, as to diminish its friction. S S, *Fig.* 1, shews one variety of these sheeves, and G another variety. In the first of these, the periphery, on which the rope runs, is flat, and it is not intended that the rope should rub against the sides, while in the other plan, the rope fills the whole of the periphery whereon it runs. The former plan was adopted, to prevent the rubbing action of the sides of the sheeves against the rope, but the latter is the plan now, almost universally, used. G is an end view, H a side view, and I and K, different parts of the same sheeve. These sheeves are fixed to stone blocks, or wooden sleepers. I I, is a plan, and K, an elevation, of the stands on which the sheeves are fixed, and by which they are placed upon the stone blocks; I is a cast-iron frame, with socket holes, 1 2. The inner side of the socket projects upward, as shewn at 3 3, in figure K; to these the wooden uprights, 5 5, are bolted, the lower ends of which pass within the sockets, 1 2. A diagonal hole, equal in breadth to the diameter of the axle of the sheeve, is cut from the side of the wooden upright, 5 5, terminating in the middle, and the axle being placed within this, it runs upon this stand, as seen in *Fig.* G. The holes, 4 4, are cast in the base of the stand, for pins to fasten the stand to the blocks. In H, two braces, *b b*, are shewn, but they are seldom used; these sheeves are placed perfectly vertical, where the line of road is straight; but in the curves, they are placed at angles with the horizon, in proportion to the radius of the curve.

The dimensions of the sheeves are generally eleven inches, with wrought-iron axles, of about three quarters of an inch in diameter, and they are placed upon the plane at intervals of from eight to ten yards distant from each other; the intention being, that they should be of such a height from the ground, and at such distances, as that the weight of the rope, between each sheeve, should not cause it to drag upon the ground.

The dotted line, A A, *Fig.* 1, may be supposed to represent the one end of the platform, and the top of the plane. Three rails, *r r′ r″*, are laid from this part down the plane, of the requisite width between each rail, for the carriages to run upon, so that both the ascending and descending trains pass upon the middle, and upon one of the outer rails, and they are continued to where the one train of waggons has to pass the other. The three rails are then made to branch into four, in the same manner as from A A to B B′, so as to form two distinct lines of railway; and they are thus continued for such a distance, as to allow the ascending and descending carriages to pass each other. These four rails, then, converge into two, or a single line, of road, as shewn at C C, and are so continued to the bottom of the plane, so that the parallel lines, as shewn in the drawing, will represent a complete passing, in the middle of the plane. The empty, or ascending carriages, will be at C C, when the loaded carriages are at A A, and they will pass each other near D′ E′.

The plan of laying down the rails, and the mode of action of this description of plane, will be best seen, on reference to *Fig.* 2, *Plate X.* Suppose the plane wheel, W, placed at W, instead of the two rolls, A B;

then that figure represents the rails, of an entire self-acting plane; W being the level platform at the top, W′ the same at the bottom, and E the passing place, on the middle of the plane, C and D being the top and bottom of the plane; the loaded and empty carriages passing, alternately, down opposite sides of the plane.

When used for passing boats, from one level to another, upon canals, and, also, on several railroads, a double line of road is laid, from top to bottom of the plane, as shewn in *Figs.* 5 and 8, *Plate X.*, with a double line of rollers, or sheeves, and, in some cases, three rails, the entire length of the plane, as in *Fig.* 4; but the reader will perceive, that, in most cases, the one above described will answer precisely the same purpose. In very short planes, the obliquity of the road, in passing from a single to a double line, will cause a retardation to the carriages, and, also, additional friction to the rope; but upon long planes, this is scarcely felt, and the cost of a double road, the whole distance, would be considerably greater.

When the slope of a plane is not uniform, descending more rapidly in some parts than in others, or when the descent is so great, as to give more than a requisite preponderance to the moving power, a brake is applied to the periphery of the inclined wheel, to equalise, or regulate, the velocity of the carriages down the plane; and, in many instances, men traverse the plane with each train of waggons, and apply the brake, or convoy, of the carriages, to check their velocity, when required. The brake, upon the inclined wheel, will be perceived to have no power, in checking the velocity of the carriages, more than what is equal to the hold the rope takes, upon the wheel, in passing round its semi-periphery; for, if the excess of gravity, of the loaded carriages, above what is required, to overcome the whole retarding forces, be greater than the hold of the rope, the wheel may be completely stopped, and the rope slide round the wheel, which, in some instances, might be attended with danger. Such a wheel, as described in *Fig.* 1, *Plate IX.*, cannot, therefore, be used, where the excess, or preponderance, of gravity, is such, as to make the rope slide round the wheel, when the brake is applied.

Many other plans of employing gravity, as a moving power, have been resorted to, by different persons. In very steep places, horizontal rolls, similar to A B, *Fig.* 2, *Plate X.*, have been used, where the descending train unwinds the rope, from one barrel, and, at the same time, winds the rope upon the barrel of the returning carriage; which rope is again, in its turn, unwound by the descending train. In such a combination, the brake can be employed with any degree of force thought proper, as the rope and barrel are one machine, and the rope cannot move round, without moving the barrel round also.*

Fig. 3, *Plate IX.*, shews a method of acquiring an increase of friction, upon the wheel, at the top of the plane, where the preponderance of gravity is such, as to cause the rope to slide round the wheel, shewn in *Fig.* 1. This, it will be seen, is effected by causing the

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* The first self-acting inclined plane, erected near Newcastle-upon-Tyne, was by the late ingenious Mr. Barnes, on which the descending train of waggons drew up, out of a pit or well, sunk to the summit, a plummet of considerable weight, which plummet, in its descent, drew the empty carriages up the plane.

rope to cross, in front of the wheel, by the horizontal sheeves, *a a*, by which the rope nearly encircles the entire periphery of the wheel. In this case, the wheel is a little inclined, from the horizontal, so that the ropes may cross each other.

Skeleton waggons, loaded with metal, are sometimes made use of, to overhaul, or drag, the rope down the plane, by which the empty waggons were drawn up; and, also, at the same time, to drag the rope up the plane, by which the descending train was lowered, for the purpose of allowing the descending train always to pass down the same line of road, and the ascending train to travel up a different road, each having a separate rope. We do not see, however, that this mode can be of advantage, except under very peculiar circumstances; for the moving power, in this case, is subjected to a resistance, equal to double the amount of the friction, of the rope; and the rope is, also, subjected to a similar excess of strain, above what exists in the common form of plane, where the loaded carriages always pass down that road, which the empty ones traverse upwards, and *vice versâ*. The mode by which the carriages are made to pass from one line to another, upon the self-acting plane, is, at once, simple and effective, and is done without the aid of manual labour.

The rails laid down in *Fig*. 1, *Plate IX.*, represent, as before stated, an entire passing place. Thus, the rails between F and G, *Fig*. 1, shew the plan of causing the carriages to pass between F and G, *Fig. 2*, *Plate X*. The ledge, or projecting flange, which directs the wheels of the carriages upon the rails, is upon the inner side of the rim of the wheels, and, consequently, travels on the inner side of the railroad. When the rails diverge into four, and thus form two separate roads, as from A A to B B, *Fig.* 1, *Plate IX.*, two rails are made to join into one, as shewn in the figure; and the carriages, in the different tracks, pass into the double road, without the least obstruction, as will readily be seen on inspecting the drawing; keeping it always in mind, that the projection, which guides the wheels, traverses against the inside of the rail. Again, in passing from a double line into the single one, viz., along the road, B B, towards A, it will be perceived, that the carriages will be inclined to traverse that track only; but, in passing from a single line into a double one, as from C C′ to *m m*, and *n n*, some contrivance is necessary, to direct the carriages into the proper track. For this purpose, rails, moveable on a centre, as shewn at *g g*, *Fig.* 2, *Plate IV.*, are used; which, being made to block up, as it were, the opening into the wrong road, and, at the same time, to act as a check, to direct the wheels into the proper one, perform the desired effect. Thus, suppose a train of waggons to have passed down *m m* to C, then the moveable rail, "switch," or "pointer," *f*, will be thrown out from the rail, into the position shewn in the drawing; and the opposite one, *f′*, will be pushed close against the inner side of the opposite rail, as also shewn in the drawing. Then, on the return of the next train of carriages, which will be the ascending ones, they will pass up the same side, *m m*; for the rail *f′* will prevent them from passing up the other, and this, the reader will perceive, is the track they ought to pass up, being that which the loaded carriages descended. The ascending train passing up D′ D, the descending train will, of course, pass down to E E′. When it arrives at the moveable rails, or switches, it will put them into the reverse position; *f* will be pressed against the inner side of the rail *c*, and *f′* will be thrown out, by the flange of the wheel, into the position of the dotted lines, after the descending train has passed; which, it will be perceived, is that position, which is required to direct the returning carriages into the road E E′, up which they are to pass.

Gravity being a moving power so very economical, it is of the utmost importance, that its aid be extended to every situation, and in every case where its application is available. Friction being the great obstacle, in the extension of its application, it is desirable, that every means be tried to exterminate it, as much as possible.

The plan drawn in *Fig.* 1, *Plate IX.*, will, we are inclined to imagine, be found to be a mode of application, by which the annihilation of friction has been effected, to as great an extent as by any plan yet devised. It has this to recommend it, that it has been very extensively used, in a district where almost every means has been resorted to, in the economy of conveying goods, and where every other plan has yielded to its adoption, when the diminution of friction became an object. The simplicity of the construction of this kind of wheel, and the manner of placing it, concealed from injury, and sheltered from the weather, are, also, circumstances which recommend it, in addition to the consideration of diminishing the friction. Barrel-rolls, where the rope winds upon itself, have been used, as before stated, when the excess of preponderance rendered it necessary; but, these requiring double ropes, the other plan is, on that account, superior.

The amount of friction being always proportionate, to the extent of rubbing surface, by placing the rope upon sheeves, and causing it to pass down the plane, along their peripheries; we diminish it, in the ratio of the diameter of the sheeves to the diameter of the axle. Hence, the larger the diameter of the sheeves, the better, provided the weight of the sheeves is not thereby increased. It is also necessary, that the surface of the sheeves, whereon the rope traverses, when running, is always of the same radius; for, if the rope runs upon a surface not every where the same distance from the centre of motion, it must experience a rubbing, from the different velocities of the surface of the sheeves at the different radii; the velocity of the rope in every part being the same, similar to a flat surface, rolling along the periphery of a conical sheeve. In some of the sheeves, shewn in the drawing, the surface, whereon the rope runs, is quite flat, with side flanches, to keep the rope on; but the width will appear greater than requisite, being on an enlarged scale. The general width is, from three to four inches, and the diameter, where the rope runs, from eleven to twelve inches; and the weight about twenty-one to twenty-five pounds. In the other plan, for the purpose of reducing the weight, the surface, where the rope runs, is made concave, nearly equal to the size of the rope, and the weight is, generally, about twenty pounds, the diameter being about twelve inches.

The limit in the application of self-acting planes will be, when the preponderance of the gravitating force, of the descending train of carriages, is not sufficient to drag the ascending carriages up the plane, with the requisite velocity, and always upon descending lines of road.

§ 4.—*Steam Engines, fixed upon Ascending Planes.*

The preceding planes, as before stated, are, necessarily, descending planes; down which the goods are supposed to be conveyed, and up which only the empty carriages, or a very small portion of returning carriages of goods, are supposed to ascend. In the construction of general lines of road, extending from place to place, distant from each other, and between which the face of the country is, perhaps, uneven, undulating, and hilly, we cannot always divide the line into platforms, or stages, with descending planes; when we traverse such lines, we frequently meet with acclivities, which cannot possibly be avoided, up which the loaded carriages must be conveyed. Also, in public lines of road, where the traffic is, perhaps, the same in both directions; or, even, though the preponderance may be in one direction, where loaded carriages occasionally have to pass and repass, it is necessary, that a passage should, at all times, be afforded to the transit of goods. We shall, therefore, now describe the means which have been employed; to surmount such ascents, with the loaded carriages, or to traverse such general lines of road.

We have previously described the action of two kinds of motive power, viz., *horses, and gravity.* The former has been explained, to be limited in action to very inconsiderable acclivities; the latter, to declivities solely. The kind of power, which is the subject of this section, will be applicable to all other inclinations of road; whether they be level, ascending, descending, or undulating. It will not here be attempted to point out the particular degree of inclination, or elevation, which should be observed, in surmounting the summit of a hill; nor how far it may be advisable to divert the line, to obtain a certain inclination of plane, or to avoid such a rising ground. That part of the subject will be, more properly, discussed, when we are fully acquainted with the expences of surmounting different acclivities.

We shall, therefore, first of all, describe the different methods of surmounting those ascents, which occur in some of the principal railroads that have come under our observation; and, afterwards, compare the effect on different planes, with each other, by which we may be able to deduce some practical data, for the guidance of engineers, in laying out the most advantageous line, or the most beneficial inclination of planes, across the country, through which a railroad is to be carried.

The practice of dragging boats upon canals, from one level to another, to save lockage water, by means of sloping planes, has long been in use; but the introduction of steam engines, to drag carriages up ascending planes, upon railroads, is comparatively recent. Mr. S. Cooke, in 1808, erected an engine upon Birtley Fell, in the county of Durham, to draw the loaded carriages of the Urpeth Colliery, across the Durham and Newcastle turnpike road, up a steep ascent; and, since that time, they have been much used upon the railroads in the neighbourhood of Newcastle.

The following are the different kinds of planes with which we are acquainted, and the manner of surmounting them.

Art. 1.—*Descending Planes, with sufficient Gravity to enable the Carriages to drag a Rope after them.*

Descending planes, or inclinations, where the gravity of the carriages, which have to pass downwards, *is sufficient* to drag the rope after them; by which rope, the returning train, is drawn up by a steam engine.

This kind of plane, may be formed of a *single*, or *double* line of road. If *single*, one train of carriages only is in action at a time, and one rope only is used; the descending train drawing the rope out from the engine, upon the plane, to which the ascending carriages are attached, and they are thus drawn up by the engine. If *double*, then there is a double line of road, or one similar to a self-acting plane, with a passing place in the middle; the descending train of carriages passing down on one side, while, at the same time, the ascending train is drawn by the engine up the other. In this latter case, if there be any excess, or preponderance of gravity, in the descending carriages, beyond what is requisite to drag the rope down the plane; this preponderance comes in aid of, and assists the engine, in dragging the ascending carriages up the plane.

The above kinds of planes, are principally used in private railroads, or, on those where the quantity of goods, descending the plane, is considerably greater than the quantity ascending; and where the transit can be regularly carried on, and the rate, at which the goods are to be conveyed, is no object; as it will readily be seen, that there must be as great a number of descending trains of carriages, as will drag the rope out as many times, as there are ascending trains to be brought up, and that the nature of the traffic is such, as will allow of the trains to be thus, alternately, passed up and down; the descending train waiting, until the ascending train is brought up, or, *vice versâ.*

These inconveniences may be modified, by erecting powerful engines, to drag up a great number of carriages at a time, if there is not an adequate number to descend; or skeleton carriages, loaded with metal, or other heavy substances, might be made use of, to drag, at all times, the rope down the plane. But both these latter modes, throw a great and unnecessary strain upon the rope; and, perhaps, should only be resorted to on extraordinary occasions.

In the use of this plane, retaining the same notation, as for the self-acting plane; then the inclination of the plane, or number of carriages, taken down at a time, to accomplish the descent in the time, t, must be such as that

$$\mathrm{G}+\tfrac{1}{2}\,b\ \sin.\ \mathrm{I}=\mathrm{F}'+\frac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{c'}{2})\ \mathrm{S}}{r\,t^{2}} \quad (14).$$

$$\text{or, }\sin.\ \mathrm{I}=\frac{\dfrac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{c'}{2})\ \mathrm{S}}{r\,t^{2}}+\mathrm{F}+\varphi}{\mathrm{W}+\tfrac{b}{2}} \quad (15).$$

$$\text{And } t=\sqrt{\frac{(\mathrm{W}+w\tfrac{\mathrm{SO}}{\mathrm{SG}}+b+c+\tfrac{1}{2}\,c')\ \mathrm{S}}{(\mathrm{G}+\overline{\tfrac{1}{2}b\ \sin.\ \mathrm{I}}-\mathrm{F}')\times r}} \quad (16).$$

And the power required to drag the returning carriages, up the plane, in the time, t, will be

$$\mathrm{P}=\mathrm{G}+\mathrm{F}+\varphi+\overline{\tfrac{1}{2}\,b\ \sin.\ \mathrm{I}}+\frac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{1}{2}\,c')}{r\,t^{2}} \quad (17).$$

$$\text{and } t=\sqrt{\frac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{1}{2}\,c')\ \mathrm{S}}{\mathrm{P}-(\mathrm{G}+\mathrm{F}+\overline{\varphi\ \tfrac{1}{2}\,b\ \sin.\ \mathrm{I}})\times r}} \quad (18).$$

Art. 2.—*Where Goods are to be conveyed on a Descending Plane, the Inclination of which is* not sufficient, *to enable the Descending Carriages, to drag the Rope after them.*

Suppose the plane formed of two separate lines of road, or with three rails, branching out in the middle into two separate lines; where the ascending and descending trains pass each other, and a wheel, similar in every respect to that previously described, in the self-acting plane, is placed at the bottom of the plane. Each train is thus furnished with its separate roll and rope, and a rope passing round the wheel, at the bottom of the plane, is attached to the other, or opposite end of the trains, to that to which the rope worked by the engine is attached. When, therefore, one train is drawn up the plane towards the engine, the rope attached to the other end of the train, passing round the wheel at the bottom, drags the descending train down the plane; and thus the carriages are drawn, alternately, up and down the plane, whatever be the inclination. It will readily recur to the reader, that it is not necessary, for the action of this kind of machinery, that the plane have any specific degree of inclination, as lines perfectly horizontal may be traversed by the same mode; and it need not be restricted to isolated planes, but any distance may be worked, in the same manner, by a series of such machinery.

The formula for this kind of plane will be, when the plane has any degree of inclination,

$$\mathrm{P}=[g+\mathrm{F}+\varphi+f+\frac{(\mathrm{W}\overline{+w\frac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\frac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\frac{1}{2}c')\times \mathrm{S}}{r\,t^2}]-\mathrm{G}\,(19).$$

$$\text{and } \mathrm{t}=\sqrt{\frac{(\mathrm{W}\overline{+w\frac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\frac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\frac{1}{2}c')\times \mathrm{S}}{\mathrm{P}+\mathrm{G}-g+\mathrm{F}+\varphi+f\times r}}\quad(20).$$

And, where the plane is horizontal, G and g vanish, and consequently

$$\mathrm{P}=\mathrm{F}+\varphi+f+\frac{(\mathrm{W}\overline{+w\frac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\frac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\frac{1}{2}c')\times \mathrm{S}}{r\,t^2}\quad(21).$$

$$\text{and } t=\sqrt{\frac{(\mathrm{W}\overline{+w\frac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\frac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\frac{1}{2}c')\,\mathrm{S}}{\mathrm{P}-(\mathrm{F}+\varphi+f)\times r}}\quad(22).$$

Art. 3.—*Double Plane, with an Engine on the Summit.*

When a hill is to be passed, the opposite sides of which, form planes of sufficient inclination, to enable the descending carriages, to drag the ropes after them, an engine is placed upon the summit. In some cases, when the traffic is not great, a single rope roll and rope are used; the train, on the one side, is drawn up, and, passing underneath the rope roll, descends the opposite plane, unwinding the rope from the roll; and when the train reaches the bottom, the rope being then attached to the returning train, it is drawn up, passes the engine, and descends the opposite plane, and, in this case, a single line of road only is necessary, (No. 1.) In other cases, where the traffic is greater, by proper passing places at the top, one train is made to ascend one side of the hill, while another descends on the opposite side (No. 2.); or both sides are furnished with double lines, and both are worked at the same time (No. 3.); and if the inclination is not sufficient, to enable the descending trains to drag the ropes after them, wheels are placed at the bottom, with ropes working round them, as before described, (No. 4.)

In these planes, for No. 1. the power required to drag the carriages up either plane, will be the same as (theorem 17), the time being (theorem 18); and the degree of inclination, necessary to cause the carriages to descend the plane in the time *t*, will be (theorem 15). In the case No. 2, for the descending train of carriages, let

$$\mathrm{G}+\overline{\tfrac{1}{2}b\ \mathrm{sin.\ I}}-\mathrm{F}'+\frac{(\mathrm{W}\overline{+w\frac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\frac{1}{2}c')\times\mathrm{S}}{r\,t^2}=\mathrm{P}'\ (23),$$

and P, per formula (theorem 17), for the ascending train.

Then P P, the power required to drag the ascending train up the plane; at the same time that another train of carriages is passing down the opposite plane.

And for the plane No. 3, the formula (theorem 19,) will represent the power required for each plane; and if the plane is horizontal, as No. 4, then the formula (theorem 21,) will apply.

Art. 4.—*Successive Engine, Planes from one End of the Line to the other.*

By forming the whole line into a succession of engine planes, and employing fixed engines, reciprocating with each other, to convey the goods the whole distance. This is done, by dividing the whole line into stages of certain lengths, at each end of which stages, a fixed engine is erected. Each of these engines, being provided with proper machinery, (hereafter to be described), drags a train of carriages, by means of ropes attached to one end of the train, from the opposite end of the stage, towards itself; and, at the same time, a rope being attached to the other end of the train, it drags that rope from off the roll of the engine, at the other end of the stage, which rope is afterwards employed in dragging back the returning carriages. Each engine is, therefore, provided with two rope rolls, one of which is dragging the carriages towards the engine, while the rope is unwound from off the other roll, by being attached to the other end of the train, dragged along by the engine; and by reversing the process, the carriages are similarly dragged in the opposite direction.

The engines, in this manner, form a series from one end of the line to the other; reciprocating with each other, and has been made the subject of a patent, by Mr. B. Thompson, then of Ayton Cottage. This mode is not confined to a single line only, where the carriages are dragged, alternately, backwards and forwards, between the engines; and where each train, when it arrives at the end of the stage, is obliged to remain there, until the remaining carriages traverse the plane. A double line may be used, when a continued, and uninterrupted transport may be effected, except the stops, by changing, at the respective engines.

The formula, for this mode of working, when the plane is single, will be, where W and a represent the weight of the respective trains,—

When the plane is quite horizontal,

$$\mathrm{P}=\mathrm{F}+\varphi+f+\frac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{S,G}}}+a'\overline{+a''\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{1}{2}c')\times\mathrm{S}}{r\,t^2}\ (24).$$

$$\text{and } t=\sqrt{\frac{\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{1}{2}c')\times\mathrm{S}}{(\mathrm{P}-\mathrm{F}+\varphi+f)\times r}}\ (25).$$

When the planes are not horizontal, then

$$\mathrm{P}=(\mathrm{F}+\varphi+f+\frac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{1}{2}c')}{r\,t^2}\pm g)\pm\mathrm{G}(26).$$

$$\text{and } t=\sqrt{\frac{(\mathrm{W}\overline{+w\tfrac{\mathrm{SO}}{\mathrm{SG}}}+a'\overline{+a''\tfrac{\mathrm{SO}}{\mathrm{SG}}}+b+c+\tfrac{1}{2}c')\,\mathrm{S}}{(\overline{\mathrm{P}\pm\mathrm{G}})\overline{\pm g+\mathrm{F}+\varphi+f}\times r}}$$

G and g will be plus, or minus, according to the inclination of the plane.

Art. 5.—*Description of the different Engine Planes.*

We shall now attempt, with the aid of the drawing, *Fig. 2, Plate IX.*, to describe, more particularly, the mode of action of the different planes, above enumerated; but, first of all, we must premise, that steam is the motive power employed, though it is not absolutely necessary, that it should be so. Water, animal, or even manual labour, might, and may, in particular cases, perhaps, be employed, with advantage, on a small scale; where the ascents are trifling, and the transit of goods, comparatively small; but, as our object is, to illustrate the different modes, upon extensive lines, where the traffic is considerable, and celerity the great desideratum, we shall suppose, that the motive power is either steam, or water.

The reader will find a very able account of different methods, of overcoming short ascents, by means of animal power, described by Mr. Scott, in the Transactions of the Highland Society, vol. iv.; as also other matter on railroads, worthy of perusal.

It will not be necessary to give a drawing of either a steam engine, or a water-wheel, whichever be made the source of motive power; as the construction of these is now so well understood, and their mode of action described in so many publications, that the reader will here feel no loss from the want of them. We shall, therefore, suppose, that *a b*, *Fig.* 2, *Plate IX.*, represents the shaft communicating the action of the moving power to the machinery; which may be the shaft of a steam engine, or a water-wheel, as the case may be. If the former, *a c* will shew the crank, and *d e* the fly-wheel; *f* is a cog-wheel, fixed upon this axle, and gives motion to the rope rolls, A B, by means of the cog-wheels, *g h*. These rolls are, alternately, thrown out of geer, or engaged or disengaged, from the action of the cog-wheels, by any of the common methods of disengaging machinery. The axles of the rolls are turned smooth, so that when the axles are fixed, the rolls are at liberty to turn, or revolve, freely round upon the axles. For the purpose of engaging and disengaging the rolls from the machinery, two levers are fixed upon fulcrums, at *i i*, one end of which constitutes the handles, the other end passes between, but does not touch, (when the machinery is in action,) the two parallel flanches, fixed upon the side of the roll; but which, when moved backwards and forwards, in the line of the axle, throws the projections of the clutches *k k*, either within, or clear of each other; and, consequently, either engages or disengages them from the action of the moving power. Similar clutches are placed upon the other end of the roll, in the interior, to equalize the twist upon the axle, but which are not shewn in the drawing. These rolls are placed upon the bearings, *l l*, &c., resting on a frame of wood, upon the wall of the building; and are elevated sufficiently high, for the carriages to move along the railroad immediately underneath, without touching; the whole of this apparatus being covered over, to preserve it from the action of the weather.

There are various other modes of applying the power of a steam engine, and of fixing the rope rolls; sometimes these rolls are placed below the surface of the rails, the ropes being carried over sheeves, in the manner shewn in the self-acting plane. In other cases, the steam engine and rolls are placed by the side of the railway, and the ropes are led into the proper direction by sheeves. We shall now describe the several modes, of applying the fixed engines to the different planes.

No. 1.—In the mode, No. 1, where the transit is not greater than requires a single road, and the plane is for the purpose of conveying the carriages from a lower to a higher level; a single roll A, *Fig.* 1, *Plate X.*, only is requisite, with a single rope, *r r*, reaching from one end of the plane to the other, and passing over sheeves similar to *s s*, *Fig.* 1, *Plate IX.* The sketch, *Fig.* 1, *Plate X.*, will shew the line of way, necessary for the operation of this kind of plane. A, represents the rope roll, placed at such a height above the rails, as will allow the carriages to pass underneath it. Should this, however, not be convenient, the railway is made to diverge, so as to pass on one side of the engine-house; or the engine is placed on one side of the railway, with sheeves to lead the rope into the proper direction. Suppose the loaded carriages at *a*, the rope roll is then thrown into geer, as previously described, and, the engine being set to work, the carriages are drawn up the plane, until they arrive at the top, at B; they then pass into the road *b*, which is made quite level, where they are stopped, and, the rope being disengaged, they are taken away by other means. A train of carriages are then ready, we may suppose, to pass down the plane, these having been previously brought into the passing place, *c*, which is made with a slight inclination, in the direction of the arrow, and there stopped by a scotch; the rope is then attached to them, the roll thrown out of geer, and the scotch struck out, when they descend the plane, dragging the rope after them, until they land upon the horizontal platform, *d*.

The rope is then detached from these, and fastened to another train of carriages, standing on the road *a*; the roll is thrown into geer, the engine set to work, and the train thus dragged up the hill as before.

When the transit of goods is such, that a single road is not adequate, then the transit is performed by means of a double road, by which the carriages are drawn up, and pass down, at the same time; and this may be effected, either by laying two separate lines of way, from the top to the bottom of the plane, or in such manner as described in the self-acting plane. It will not be necessary to explain the former mode of action, each train keeping its separate line of road. *Fig. 2, Plate X.*, will shew the plan of laying the rails down in the latter mode. Two rope rolls, A B, are used, placed upon the shaft of the machinery, and firmly fixed to it, or continually in geer. These rope rolls are placed in a line with the respective roads, up which they are to drag the carriages; the roll, A, in a line with the road, *a*, and the roll, B, in a line with the road, *b*, so that the ropes, passing upon the centre of the road, *a*, will correspond with the middle of the roll, A, and the rope of the road, *b*, with the roll, B. When the excess, or preponderance of the loaded carriages, is nearly adequate to drag the empty carriages up the plane, then the construction is almost precisely similar to that of the self-acting plane. Either a wheel, similar to *Fig*. 1, *Plate IX*., is placed horizontally, or a like wheel fixed perpendicularly to the axis of the engine, which, being turned by the engine, is thus made to drag the carriages up the plane. This latter mode of operation cannot, however, be carried into effect, where the resistance of the carriages upon the plane is greater than the friction, or hold the rope takes upon the groove of the wheel; for, in that case, the wheel would be turned round, without moving the rope, or affecting the ascent of the load. In the case of the self-acting plane, and the above mode, the rope only passes over half the circumference of the wheel; but when this is insufficient to move the carriages, the friction is increased by crossing the ropes, or causing each rope to pass down the opposite side of the plane, to that which the centre of the wheel, on which they wind, is in a line with. Thus, in *Fig*. 1, *Plate IX*., if the rope, D′, be made to pass round a horizontal sheeve, placed at S, on the opposite side, and the rope, E′, round a similar sheeve on the other side, then the ropes would nearly embrace the whole of the circumference of the wheel, and, consequently, increase its adhesion to the periphery. An additional strain is thus, doubtless, thrown upon the rope by this horizontal sheeve, but this, also acting upon the rope embracing the wheel, tends to increase the hold which it takes upon the periphery. Where the latter mode can be applied, especially without having to resort to the expedient above named, it is of considerable advantage over a double line of road, as it precludes the necessity of having two ropes, which, with rolls, where the rope winds upon itself, as in *Fig. 2, Plate X.*, is indispensable. In both these cases, however, whether the rolls, A B, *Fig. 2, Plate X.*, or the single wheel, *Fig. 1, Plate IX.*, be employed; the formation of the road, and mode of laying the rails, for the carriages to pass each other, are the same as previously described.

No. 2.—On this description of plane, the action does not materially differ from that last described; only, the ropes must be double, and must, necessarily, wind upon barrel rolls, similar to A B, *Fig. 2, Plate IX.* The road may either be formed of two separate and distinct lines of road, from top to bottom of the plane, or in the manner shewn in *Fig. 3, Plate X.*, where A B, are the rope rolls, worked by the engine, and C, is a horizontal sheeve, placed at the other extremity of the plane; D E, represents two trains of carriages in action upon the plane. Three ropes, each equal to the length of the plane, are used; one, represented by *a a*, is attached at one end to the rope roll, A; another, represented by *b b*, is attached to the rope roll, B; and the third, *c c c*, called the "tail rope," passes round the sheeve, C, and is attached, at one end, to the train, D, and, at the other end, to the train, E. The action of this plane, with the aid of the drawing, will be readily understood. Suppose the rope roll, A, in geer, and the roll, B, out of geer; if the engine is set to work, the roll, A, being in geer, will wind the rope, *a*, upon it, and will, consequently, drag the train of carriages, D, towards the engine. The rope, *c c c*, being attached to the opposite end of this train of carriages, passing round the sheeve, C, and being fastened to the end of the other train of carriages, E, will, consequently, drag the latter train down the plane, or towards C, and unwind the rope from off the rope roll, B. When the trains, D and E, arrive at the top and bottom of the plane, respectively, they are taken away, and other sets of carriages substituted, a crossing being near at hand for the purpose; this being done, the engine then drags the train, on the side, E, up the plane, the tail rope of which, passing round the wheel, C, as before, drags the train on the side, D, down the plane, and so on, alternately. The wheel, C, is placed below the level of the railway, and is, in every respect, the same as that of the self-acting plane, *Fig.* 1, *Plate IX.*

The above mode of transit is not confined to an isolated or single plane; by an extension of similar planes, any distance may be traversed. *Fig.* 4, *Plate X.*, will shew the mode of effecting this, by a continuation of the same machinery. A B, are the rope rolls of the engine, similar to those of the single plane, last described, dragging the carriages back and forward, by means of the tail rope, working round the wheel, C, and the rope wheels, E F, dragging the carriages, by means of the tail rope passing round the wheel, D. The darts will shew the direction, which the different trains of carriages are traversing at the same time. Thus, let the engine, by means of the roll, A, be dragging the train, *a*, toward itself, the tail rope will, at the same time, be dragging the train, *b*, in the opposite direction; when it arrives at *e*, the switch, or point, is put in, to cause it to take the way, *f*, where it stops. Meanwhile, the other engine, by the roll, E, is dragging the train, *c*, towards itself, and the train, *d*, by the tail rope, in the opposite direction.

When the train, *c*, arrives at the engine, the train, *d*, arrives at *g*, where it stops; the respective trains are then at *f* and *g*. The ropes are then fastened to the proper carriages, and *f*, proceeds through the passing place, *h*, into the road, *d*, drawn by the roll, F, and *g*, proceeds right forward up the road, *e*, dragged by the roll, B, while the train, *a*, is dragged towards C, by the tail rope, and is stopped at *f*; the train, *c*, crossing at *h*, into the road, *g*, where they are ready for another operation, as before. By a continuation of these, it will readily occur, that any distance may be traversed, even if partially undulating.

In some parts of the line, it might happen, that the descent from the engine, to the end of the plane, might be such, that the gravity of the carriages would enable them to drag the rope after them. In this case, the wheel, C or D, and the tail rope, might be dispensed with, and resumed again on other parts of the line, upon planes, where the descent was not adequate for such an effect.

In this species of transit, it will be observed, that ropes, three times the length of the plane, are required, though only twice the length is in operation at once.

No. 3.—When a hill occurs in the line of road, the summit of which can be formed into a short platform, and the declivity on each side is such, as to give the carriages sufficient gravity to drag the rope after them, the mode of operation, shewn in *Fig.* 6, *Plate X.*, is resorted to. If the traffic is not considerable, or not greater than will require a single line of road, a single rope roll, A, is used, capable of being thrown out of geer, or attached to the shaft of the engine, at pleasure, as shewn in *Fig.* 2, *Plate IX.* A short length of road, immediately underneath the rope roll, is branched into four rails, *a b*, and *c d*. These two roads are made to descend, in opposite directions, the road, *a b*, from *a b*, to *c d*, and the road, *c d*, from that point to *a b*. Suppose the roll, A, attached to the shaft, by clutches, a train of carriages, *f*, is dragged up the plane, D; when they arrive at *a b*, the rope, whereby they have been dragged up, is detached; the train then runs of itself towards *c d;* during which the rope is attached to the other end of the train, the rope roll is thrown out of geer, and, when the carriages pass *c d*, they descend the plane, E, dragging the rope after, until they arrive at the level platform, F, at the bottom. Another train of carriages is then attached to the rope, the roll struck into geer, and the train is dragged up the plane, to *c d*, where, from the descent of the road, it runs of itself to *a b*, and descends the opposite plane. The rope having been, during the passage of the train from *c d* to *a b*, detached from one end, and fastened to the other, and the rope wheel struck out of geer, the train runs down, until it arrives at the level platform, C, when it is detached from the rope, and another substituted. When the traffic is greater than can be carried on in the above manner, two rope wheels are used, and the road underneath the engine is made to branch, into two separate roads, distinct from each other, as shewn in *Fig.* 7, *Plate X.* In this case, one train of carriages can be made to descend one plane, while another train is dragged up the opposite plane by the engine; or, if the traffic is still greater, the engine is furnished with two sets, or four rope rolls, and the plane is either formed of two distinct lines of road, or such as are shewn in *Fig.* 2, *Plate IX.*, which will represent one of the planes, the other plane being laid in a similar manner, with proper passing places at the top; viz., four distinct roads, two descending in one direction, and two in the other, as shewn in *Fig.* 6, *Plate X.;* or with three lines of road at the top, the two outer ones for the loaded, and the middle one for the empty carriages. Both these planes can then be worked at the same time, and thus an uninterrupted traffic kept up. And if the inclination is not sufficiently great, to enable the descending carriages to drag the ropes after them, a wheel, such as before described, in *Fig.* 3, *Plate X.*, with a tail rope, can be resorted to; when the formation of the road on each plane will be, in every respect, similar to *Fig.* 4, *Plate X.*

No. 4.—We have, in the preceding cases, shewn the different modes of conveying goods, over isolated hills, or on portions of a line, presenting particular undulations; we are now to consider the whole line, worked by a system of fixed engines, alternating with each other, by means of ropes. This is accomplished by dividing the line into stages, of a convenient length, at the ends of each of which engines are fixed. Each engine drags the carriages, from the opposite end of the stage, towards itself, and, at the same time, unwinds a rope from the roll of the next engine, at the other extremity of the stage, for the purpose of enabling the last-named engine to drag the carriages, in the opposite direction, and thus to keep up a constant transit.

This mode of conveyance may be carried into effect, either by means of a single, or double, line of railway. *Fig.* 7, *Plate X.*, will shew the operation, by a single line of road, which may either be supposed to be one extremity, or an intermediate station of the line, at which an engine is erected. The line is divided into stages, of suitable lengths, about a mile and a half each, as B C, &c., at which places similar engines are erected. If the first stage, A B, rises towards B, with such an inclination, that the carriages, in descending to A, have sufficient gravitating force to drag the rope after them, then it is not necessary to erect an engine at the extremity; but, if this is not the case, then an engine, with a single, or double, rope roll, must be erected at A. At the other stages, B C, &c., the engines must have two rope rolls, capable of being disengaged, from the action of the engine, at pleasure, similar to those shewn in *Fig.* 2, *Plate IX.* At the extremity of the stages, the single line of railway is made to branch into two separate lines, *a b*, *c d*, the former descending from *a b* to *e*, and the latter from *c d*, to *f*. The mode of operation is as follows:—D will represent a train of carriages, passing in the direction A B, while another train is conveyed in the same direction, B C, on the next plane. The rope rolls, *m*, *n*, *p*, may be supposed out of geer, and the rolls, *o*, *q*, in geer, or attached to, and turning round with, the shaft of the engine. The engine, B, is, therefore, by means of the roll, *o*, dragging the train of carriages, D, towards itself, and is, at the same time, unwinding a rope, *g*, attached to the other end of the train, from off the roll, *m*, of the engine, A. On the other stage, the engine, C, is dragging the train, E, towards itself, and also a rope from the roll, *n*. In this manner, the train, D, arrives, at the engine, B, and the train, E, at the engine, C, where they are stopped; other trains may be supposed to be in readiness, to which the ends of the ropes, *g* and *i*, are attached. The rolls, *m*, *n*, and *p*, are then struck into, and the rolls, *o* and *q*, out of geer. The engines, A and B, being set to work, drag, by means of the ropes *g* and *i*, the train of carriages to A, and B, and, with them, the ropes *h* and *k*; which ropes are again used, to drag the carriages in the opposite direction, and so on, alternately.

This mode of operation is practised, when the line of road is nearly level; but if any declivity occur, which gives the train of carriages a greater gravitating force than what is necessary, to drag the rope, then the rope rolls, instead of being struck out, are always kept in geer; by which means the excess of gravitating force, assists the engine in dragging the carriages along the other stage. If such an inclination occurs throughout the whole length of the stage, the tail rope is dispensed with altogether; but if it be only a casual descent, it is retained, to drag the carriages over the other parts of the stage.

It will be observed, that, in this mode of operation, the train of carriages, on arriving at the engine, is obliged to be stopped, until the train, proceeding along the other stage, arrives. This is a source of great delay, effecting only an average speed of transit equal to half the rate, at which the carriages travel, between the stages; or, to effect a general average rate of travelling of four miles an hour, it will be necessary that the carriages, while in motion, should travel at the rate of eight miles an hour. There is, also, by this mode of working the engines, obliged to be a train of carriages always standing at the end of each stage; which requires, for effecting the transit of a certain quantity of goods, a considerable number of carriages, more than what is required, if the transit was uninterrupted.

There is another mode, however, of working the trains, which, though requiring more powerful engines, obviates part of these objections. This is, by causing both the trains of carriages to be dragged towards an engine at the same time, and, in returning, to be both dragged from that engine, at the same time, by the engines at the other end of each stage. Thus the engine, B, drags the trains, D and E, towards itself, and both arrive at *c d*, and *a b*, at the same moment. The ropes are then detached, the carriages, by the descent of the roads, as before described, respectively run, of themselves, from *c d*, to *f*, and from *a b*, to *c*. The rolls are then thrown out of geer, the rope, *g*, is attached to the end of the train, E, and the rope, *h*, to the other end; and, in like manner, the rope *i* is fastened to the one end of D, and the rope, *k*, to the other end. The rolls, *q*, *m*, being thrown into geer, the carriages are dragged to the other end of the stage. By this mode, it will be perceived, that the carriages do not stop, but merely pass each other at the engines. The engine has, however, both trains of carriages to drag at the same time, and cannot have the assistance of the gravity of the other train of carriages, if there happen to be any preponderance above what is required to drag the rope; and, likewise, the carriages being dragged towards the engine, it is loaded with the resistance of both trains, while, in returning in the opposite direction, the engine stands idle. Both modes have, therefore, their advantages and disadvantages, and may be used as occasion requires. This mode of transit may, perhaps, be more effectively employed, where the traffic is such that requires a double line of road, as, in this case, no delay, more than what is required to change the carriages, occurs.

We come now to describe the different modes of conveyance, by means of fixed engines, upon double lines of railway. *Fig.* 5, *Plate X.*, will shew a scheme of performing this, recommended to the notice of the directors of the Liverpool and Manchester railway, in the report of Messrs. Walker and Rastrick, and said by the latter to be struck out by him. A, B, C, represent the engines at the end of three stages; each of those engines is furnished with four rope rolls, similar to those shewn in *Fig.* 2, *Plate IX.* D, E, F, G, may be supposed to be four trains of carriages; D and F, proceeding in one direction, and E and G, in the other. *a*, *b*, *c*, *d*, shew the rolls of the engine A; *i*, *k*, *l*, *m*, those of the engine C; while those of the engine, B, are not drawn, that the direction which the carriages take may be more easily shewn. Double crossing places are made at each station, as will be seen in the plate, to enable the carriages to pass from one road to the other. D, shews the train of carriages which the engine, B, is dragging towards itself, and with it a tail rope, from the roll, *c*, of the engine, A; which tail rope is to be used in dragging the train, G, along that plane, after it passes the engine, B. In like manner, G, is the train which the engine, B, is dragging towards itself on the other plane, and with it a tail rope from the roll, *k*, of the engine, C; by which rope the latter engine drags the train, D, along, after it passes the engine, B. The engines, A and C, are, at the same time, dragging, by the rolls, *a* and *m*, the trains, E and F, towards themselves; and also, by the rolls, *d* and *i*, trains from the other planes, towards their respective stations. When the train, D, arrives at G, the ropes are disengaged, and the train proceeds to *o*, where it stops. Meanwhile, the train, G, arrives at *e*, where, the ropes being disengaged, it proceeds to *p*, where it likewise stops; at the same time the train, F, has arrived at the station, C, and the train, E, at the station, A. The engine, A, has meanwhile, by the roll, *d*, dragged another train, I, to that station; and the engine, C, by the roll, *i*, a train, H, to its station. The darts at the station, B, will shew the position of the trains, which will suffice for the other stations, as the operation is the same in each. When the train, G, arrives at *e*, the rope by which it was dragged is detached, and also the tail rope from the roll, *k*. The tail rope of one of the rolls of the engine, B, is then attached, and, also, the rope which dragged the train, D, to that engine. The engine, A, then drags the train, G, through the crossing, *p q*, and along the road to the station, A. In like manner, on the ropes being attached, the train, D, is dragged by the engine, C, through the crossings, *o n*; the rope which C dragged from the roll, *k*, being attached. The operation is the same at all the other stations, in every one of which, it will be seen, that the carriages are obliged to pass from one line of road to the other, at each of the stations; so that each of the lines of double road becomes, alternately, between the stations, the route for the carriages passing in both directions.

The inconvenience, delay, and risk, attending the carriages thus passing from one line to the other, and travelling, in both directions, upon different parts of the same line of road, confine the use of this mode of transit, exclusively, to private lines of road; upon public lines, it would produce inexplicable, and irremediable, confusion. Upon public lines, where fixed engines are obliged to be used, to surmount steep declivities, some mode of application, different from any of those previously described, therefore became necessary. On the Liverpool and Manchester railway, which terminates, at the Liverpool end, at a high level, it was necessary to apply a fixed engine, to drag the goods up from the low level, or station, near the docks, to the higher level; or where the locomotive engines could be used, the length of the plane being 2250 yards, and the inclination, 1 in 22.

The plan adopted by Mr. Stephenson was, by an endless rope, passing over a sheeve, fixed upon the main, or crank, axle of the engine. *Fig.* 8, *Plate X.*, will shew the plan of effecting this mode of transit; a double line of road is laid the whole distance, and, at the bottom of the plane, a sheeve, B, is fixed horizontally, and similar to C, *Fig.* 3; *e* and *f* represent the rope passing round it. At the top of the plane, a horizontal wheel, A, is fixed, worked by two engines, one on each side of the railway; and this wheel has two grooves on its periphery, for the rope to wind round. Tracing the rope from *e*, as shewn in the drawing, it passes round the wheel, A, crosses between that wheel and another wheel, *a*, passing over the side of the latter, then around *b*, and, leading past *a*, crosses again; and, winding around A, upon the other groove, leads down the road, to the train, at *f*, and so round the wheel B. By passing the rope twice around A, sufficient adhesion to its periphery is obtained, to drag the carriages up the plane. To give additional pressure to the rope, upon the grooves of the wheels, and to equalize the tension of the rope, as well as to keep it constantly stretched, a vertical wheel is attached to the axle, *c*, of the wheel, *d*, over which a rope passes, with a heavy weight attached; a well is sunk, to a certain depth, within which this weight ascends, and descends, as the tension of the rope becomes greater, or less, or as the rope becomes shorter, or longer, by any variation of humidity to which it is exposed.

By this plan, the carriages ascending the plane always travel on the same line of road, the descending carriages traversing the other; and the trains are thus always ready to be conveyed along the proper line, by the locomotive engines; all crossing from one line to the other is, consequently, obviated.

Upon the new tunnel for passengers, at the same end of the line, a different mode of applying the use of an endless rope has been adopted. Two engines are erected, one on each side of the railway, one of which is sufficient to work the plane, and the other is kept, as a spare engine, in case of accident. A horizontal shaft reaches across the whole width of the two lines of railway, which can be connected with, or disengaged from, each engine, at pleasure, or worked by both, if necessary. Upon this shaft, and in the centre of one of the lines of railway, a grooved wheel, nineteen feet and a half in diameter, is placed vertically. The rope, which constantly ascends the plane, passes over the upper side of this wheel, around the under side, and is brought nearly to the top side again, by a small sheeve, four feet in diameter, being placed in front of the large wheel. The rope thus embraces nearly the entire circumference of the large wheel, and the adhesion, thus obtained, is sufficient to drag from eighty to ninety tons of carriages, and passengers, up the plane, without any slipping of the rope; the plane being 2200 yards in length, with an inclination of about 1 in 100. After the rope passes over the small sheeve, in front of the shaft wheel, it is then taken round a horizontal wheel, placed upon a carriage, running back and forwards, upon a railway, to which the stretching apparatus, described previously, is affixed. After passing round this horizontal wheel, the rope is then directed into the centre of the other line of railway, by two other horizontal sheeves, whence it passes down the plane, and over two horizontal sheeves, at the bottom, into the centre of the ascending line of railway; which it traverses, and passes over the large wheel, upon the crank axle, as before stated. In working this plane, the descending carriages are not attached to the rope, the descent being such, as to allow of their being taken down by the brakes, on the carriages, with safety. But this mode of application does not preclude the descending carriages being affixed to the rope; indeed, if they were, and if there was a surplus of gravitating power, the descending carriages would assist the engine, in dragging up the ascending train.

On the Brandling Junction railway, upon a short plane, 792 yards in length, and with an inclination of 1 in 22·9; where the great bulk of the traffic is up the plane, and where, consequently, the gravitating force of the ascending carriages is very great; I have adopted a plan of obtaining adhesion, which may be carried to any extent that may be required, however steep the planes are. A B, *Fig.* 15, *Plate VI.*, is the crank axle of the engine, working the plane; upon this axle the wheel, G, is fixed, on the periphery of which there are three grooves. Another wheel, C D, is placed a little distance from the former, which has, likewise, three grooves on its periphery; this wheel is not placed quite vertical, but at such an angle therefrom, as that each groove, on its *upper side*, leads to one of the grooves on the crank-axle wheel, while the same groove, on the *under side*, leads to another groove on the crank-axle wheel; or, the angle at which the wheel, C D, is placed from the perpendicular, is such as to be precisely equal to the breadth of one of the grooves on the crank axle, as shewn in the drawing. Thus the rope, *a b*, which is the ascending rope, passes alongside the sheeve, C D, over the wheel, G, and then leads into the first groove, on the under side of the wheel, C D, around that groove, *d*; which, it will be seen, leads to the upper side of the second groove of G, then to the under side of the second groove of C D, over the upper side of the second groove of that wheel, and the upper side of the third groove of G; and from thence around the third groove of C D, from whence it passes, by the side of G, around the horizontal sheeve, E, and so down the plane; at the bottom of which it passes over two sheeves, which lead to the centre of the ascending line. The horizontal sheeve, E, is placed at some distance from the engine, for the purpose of allowing for the stretching of the rope; the sheeve, E, is placed upon a frame, moveable on a railroad, and the stretching weight is attached to the sheeve, E, as before described. As the number of grooves, on the wheel upon the crank axle may be increased, at pleasure; by this method, any degree of adhesion may be obtained, without any unequal strain being thrown upon the rope. We have, in the preceding description of the different modes of conveying goods, or working lines of railway by fixed engines, we trust, explained the manner, by which the conveyance of goods may be effected, over any kind of country, whether flat, hilly, or undulating; and whether the line be divided into successive platforms, or levels, with ascending or descending planes; or, whether the line be stretched, at once, across the country, without regard to any particular degree of inclination. Either one or other of these modes, or their various modifications, will comprehend means for securing a regular and constant transit.

§ 5.—*Locomotive Steam Engines.*

The steam engine, for many years subsequent to its discovery, was solely employed in lifting or raising water, by means of pumps; Savary, Newcomen, Beighton, Desagulier, and other eminent men, successively contributed their aid to its improvement, and its advancement in utility; still it was cumbrous, heavy, unwieldy, and complicated, and its use confined within narrow limits. It was in this state that Mr. Watt found it, and to his enterprising genius, the world is indebted, for one of the most useful machines ever given to commerce and the arts. Its action was no longer confined to a rectilinear motion, or that of pumping water; but, through his assiduous exertions, converted into a rotatory motion, and applied to almost every manufactory.

So early as the year 1759, steam appears to have been thought of, as a motive power to wheel carriages. In a note to the last edition of Robinson's "Mechanical Philosophy," Mr. Watt states: "My attention was first directed, in the year 1759, to the subject of steam engines, by the late Dr. Robinson, then a student in the University of Glasgow, and nearly of my own age. He, at that time, threw out an idea of applying the power of the steam engine to the moving of wheel carriages, and to other purposes; but the scheme was soon abandoned, on his going abroad." Mr. Watt, it appears, soon after made an experiment with steam, acting by its expansive force, but relinquished the idea of constructing an engine upon this principle: "I, however," says he, "described this engine, in the fourth article of my patent, in 1769; and again, in the specification of another patent, in the year 1784, together with a mode of applying it to the moving of wheel carriages."

For many years subsequent to this, the improvement of the steam engine, acting by condensation, seems to have wholly occupied the scientific world; and the use of steam, acting by its elastic force alone, was entirely abandoned or neglected. Mr. Hornblower had a patent, for the application of steam, acting both by its expansive force, and by condensation; but it is to Messrs. Trevithick and Vivian, that we owe the introduction of the steam engine, acting solely by the expansive force of the steam. In March, 1802, they obtained a patent for the application of that species of power, to propel carriages upon railroads.

Mr. Woolf, a short time after, made a series of experiments, to develope the law of action of steam, at different degrees of elasticity, which he explained, in his patent of June 7, 1804.

Art. 1.—*Trevithick and Vivian's Engine.*

Messrs. Trevithick and Vivian, in the specification of their patent, gave a drawing of their engine, applied to move a carriage upon the common roads, which may be seen in the fourth vol. *Rep. Arts. 2d Series*, p. 241. The carriage there delineated resembles, in form, the common stage coaches, used for the conveyance of passengers; a square iron case, containing the boiler and cylinder, is placed behind the large, or hinder, wheels of the carriage, and is attached to a frame, supported from the axles of those wheels. The cylinder was in a horizontal position; and the piston-rod was projected backwards and forwards, in the line of the road towards the front of the carriage. Across the square frame, supported by the wheel of the carriage, an axle was extended, reaching a little beyond the frame on each side; this axle was cranked in the middle, in a line with the centre of the cylinder, and a connecting rod, passing from the end of the piston, turned this axle round, and produced a continued rotatory motion of it, when the piston was moved backwards and forwards in the cylinder. Upon both ends of this axle, cog-wheels were fixed, which worked into similar cog-wheels upon the axle of the wheels of the carriages, so that, when a rotatory motion was produced in the cranked axle by the piston-rod, the rotatory motion was communicated to the axle of the larger, or hinder, wheels of the carriage; and these wheels being fixed upon, and turning round with the axle, gave a progressive motion to the carriage. Upon one end of this axle was fixed a fly-wheel, to secure a rotatory motion in the axle, at the termination of each stroke.

The fore wheels of the carriage were of the usual form, which, turning to different angles with the body of the carriage, directed its motion upon the road; and, in cases where abrupt turns of the road required sudden changes in the direction of the carriage, the toothed or cog-wheels, on either side, could be thrown out of geer, and the opposite wheel made to drive the carriage into the proper obliquity of the road.

Upon the periphery of the fly-wheel, a brake was attached, to regulate the descent of the carriage down steep hills. The contrivances, to effect the requisite motions of the various parts of this machine, are extremely ingenious; and, considered as the first attempt of the application of steam to carriages, upon common roads, it is entitled to great commendation.

The many objections to its application, upon public turnpike roads, would, we presume, operate in preventing the patentees from carrying it into practice, in the manner described in their specification; they, therefore, it appears, directed their attention to its use upon railroads.

Two years after the date of this patent, we find, that Mr. Trevithick made an engine in South Wales, which was tried upon the Merthyr Tydvil railroad. The engine is stated to have had an eight-inch cylinder, with a four-feet six-inches stroke, and " drew after it, upon the railroad, as many carriages as carried ten tons of bar-iron, from a distance of nine miles; which it performed without any supply of water, to that contained in the boiler at the time of setting out; travelling at the rate of five miles an hour."

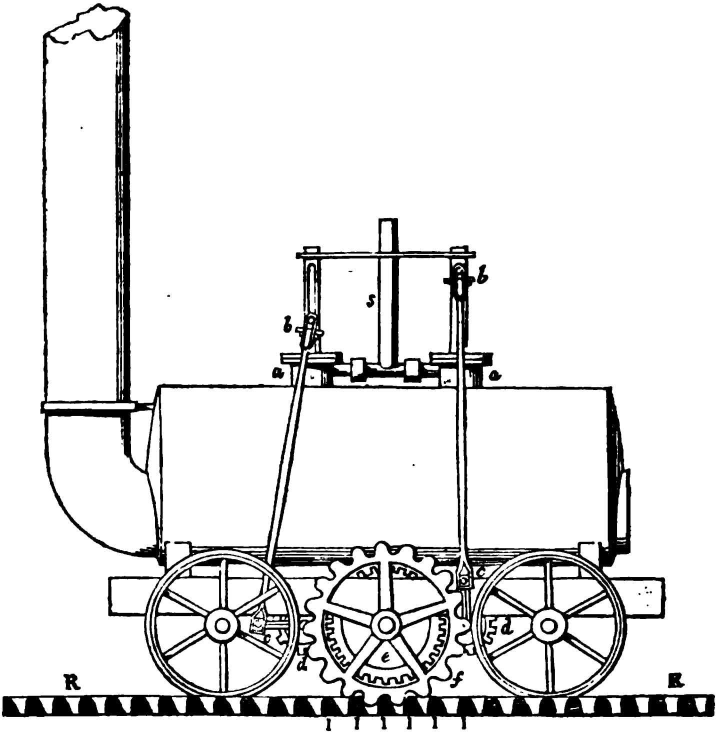
As there is no account given of the inclination of the road, we cannot judge of the real performance of the engine. It had, it appears, only one cylinder, and, from what we can learn, did not materially differ, in construction, from that previously described, except in the form of the carriage.

The great obstacle, to the introduction of steam carriages upon railroads, at that time, was the supposed want of hold, or adhesion, of the wheels upon the rails, to effect the locomotion of the engine. Messrs. Trevithick and Vivian, in their patent, recommended making the external periphery of the wheels rough or uneven, by using projecting heads of nails, bolts, or cross-grooves; or, in case of a hard pull, to cause a lever, bolt, or claw, to project through the rim of one, or both of the wheels, driven by the engine, to take hold of the ground. But it will appear obvious to any one, that this mode of remedying one defect, would be the means of producing another; for any projections, would not only cause considerable resistance to the progressive motion of the engine, but would also tend to injure the rails of the road.

Art. 2.—*Blenkinsop's Engine.*

To obviate these defects, Mr. Blenkinsop, of Middleton colliery, near Leeds, in 1811, obtained a patent for the application of a rack, or toothed rail, stretched along the whole distance to be travelled; into which cog-wheels, turned by the engine, worked, and thus produced a progressive motion, in the carriages.

No. 1.



The annexed drawing, No. 1, will convey a pretty correct idea of the mode of action, of this kind of engine. R R, represents a portion of the rails, constituting the railroad, on the side of which were cast the semicircular protuberances, or projections, 1 1 1, &c. These semicircular teeth projected, from the side of the rail, two or three inches, thus forming a longitudinal toothed rack, which was extended the whole length of the road. *a a*, are the cylinders, placed within the boiler. The action was communicated, by the pistons, to the connecting rods, *b b*, which transferred the motion to the cranks, *c c*, turning axles, attached to the inside of the frame of the carriage. Upon the axles, on which these cranks were fixed, were also fixed the pinion-wheels, *d d*, which were turned round by the cranks; these two pinion-wheels communicated with a larger cog-wheel, *e*, in such a manner, that both contributed in producing a rotatory motion in it. The action of this cog-wheel, *e*, extended to the outside of the frame of the engine, and upon the end of it was affixed the larger toothed wheel, *f*, which was thus turned round by the large cog-wheel, and, consequently, by the action of the engine; and the teeth of this cog-wheel, being made to correspond with, and lay hold of, the toothed projections, on the side of the rail, a progressive motion of the carriage was thereby effected. The steam, after performing its office, in the cylinder, was allowed to escape into the atmosphere, through the pipe, *s*. The boiler was cylindrical, and heated by a circular tube passing through it, terminated, at one end, by the chimney. The toothed or rack rail, was only laid on one side of the road, the other being common rails. The cog-wheels were varied in size, according to the different velocity with which it was required to travel.

By the use of this rack-rail, Mr. Blenkinsop's engine was enabled to ascend acclivities, which Mr. Trevithick's engine, from the want of adhesion, could not surmount. Mr. Blenkinsop, soon after the date of his patent, erected some of those engines, and employed them upon the Middleton colliery railroad, in conveying coals to Leeds, where they were used for several years; but it having been since proved, that the adhesion of the wheels was sufficient, to accomplish the progressive motion, the rack-rail has been abandoned.

The engine, erected by Mr. Trevithick, had one cylinder only, with a fly-wheel, to secure a rotatory motion in the crank, at the end of each stroke. An engine of this kind was sent to the North, for Mr. Blackett, of Wylam, but was, for some cause, or other, never used upon his railroad, but was applied to blow a cupola, at an iron foundry, in Newcastle. Mr. Blackett, however, had, in 1813, an engine of this kind made, and set upon his railroad, which worked by the adhesion of its wheels upon the rails. Still, the supposed want of adhesion formed the great obstacle to their introduction, and the attention of engineers was directed, to obtain a substitute for this supposed defect.

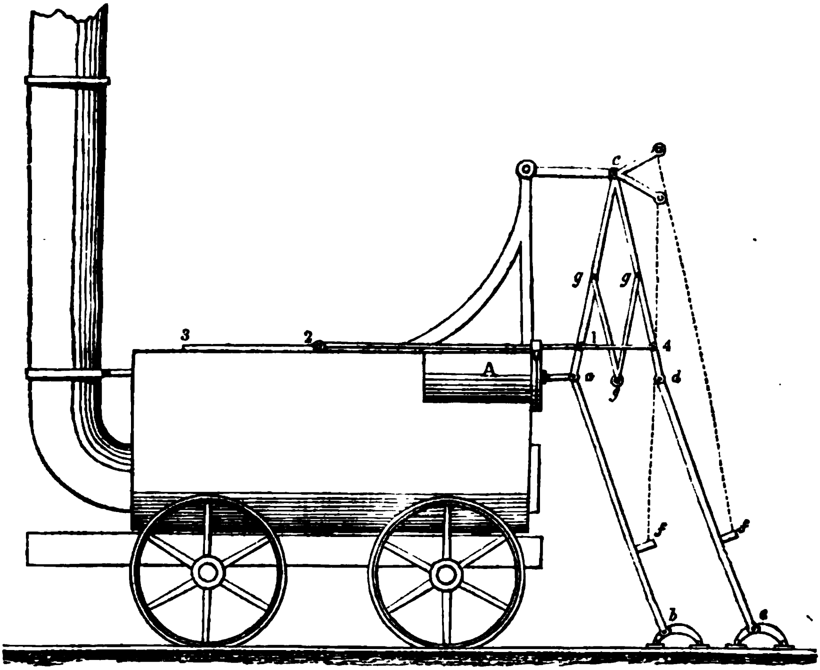
Art. 3.—*Chapman's Engine.*

In December, 1812, Messrs. William and Edward Chapman obtained a patent, for a mode of effecting the locomotion of the engine, by means of a chain, stretched along the middle of the railroad, the whole length, properly secured at each end, and at proper intervals. This chain was made to wind partly round, or to pass over, a grooved wheel, turned by the engine, of such a form, that the wheel could not turn round, without causing the chain to pass along with it. When this wheel was turned round by the engine, as the chain was fastened firmly at the end, and could not be drawn forward by the wheel, the carriage was, therefore, moved forward, in the line of the chain and road. The carriages, containing the goods, were attached to the engine carriage, and thus conveyed along the railway. At intervals of every eight, or ten, yards, the chain was secured, by means of upright forks, into which it fell, when left at liberty; this was for the purpose of taking off the strain, from the chain, when more than one engine was travelling by it. The chain was prevented slipping, when the grooved wheel was turned round, by friction rollers pressing it into the groove. Mr. Chapman had one of his engines tried upon the Heaton railroad, near Newcastle, but it was soon abandoned; the great friction of the chain, and also its liability to get out of order, operated considerably against it.

Art. 4.—*Brunton's Engine.*

In 1813, Mr. Brunton, of Butterley iron works, also obtained a patent for a mode of accomplishing the locomotion of the engine, without the aid of the adhesion of the wheels upon the rail, of which, as it displays great ingenuity, we have given a drawing.

No. 2.



No. 2, is a side view of the engine. The boiler was nearly similar to that of Mr. Blenkinsop, cylindrical, with a tube, passing through it, to contain the fuel. The cylinder, A, was placed on one side of the boiler; the piston rod projected out behind, horizontally, and was attached to the leg, *a b*, at *a*, and to the reciprocating lever, *a c*, which is fixed at *c*. At the lower extremity of the leg, *a b*, feet were attached, by a joint, at *b*. These feet, to lay a firm hold upon the ground, were furnished with short prongs, which prevented them from slipping, and were sufficiently broad, to prevent their injuring the road.

On inspecting the drawing, it will be seen, that when the piston-rod is projected out from the cylinder, it will tend to push the end of the lever, or leg, *a*, from it, in a direction parallel to the line of the cylinder; but as the leg, *a b*, is prevented from moving backwards, by the end, *b*, being firmly fixed upon the ground, the reaction is thrown upon the carriage, and a progressive motion given to it; and this will be continued to the end of the stroke. Upon the reciprocating lever, *a c*, is fixed, at 1, a rod, 1, 2, 3, sliding horizontally backwards and forwards upon the top of the boiler. From 2 to 3 it is furnished with teeth, which work into a cog-wheel, lying horizontally; on the opposite side of this cog-wheel a sliding rack is fixed, similar to 1, 2, 3, which, as the cog-wheel is turned round by the sliding rack, 2, 3, is also moved backwards and forwards. The end of this sliding rod is fixed upon the reciprocating lever, *d c*, of the leg, *d e*, at 4. When, therefore, the sliding rack, shewn in the drawing, is moved forward in the direction 3, 2, 1, the opposite rod, 4, is, by the progressive motion of the engine, moved in the contrary direction, and the leg, *d e*, is thereby drawn towards the engine; and, when the piston-rod is at the farthest extremity of the stroke, the leg, *d e*, will be brought close to the engine. The piston is then made to return in the opposite direction, moving with it the leg, *a b*, and also the sliding rack, 1, 2, 3; the sliding rack, acting on the toothed wheel, causes the other sliding rod to move in the contrary direction, and with it the leg, *d e*. Whenever, therefore, the piston is at the extremity of the stroke, and one of the legs is no longer of use to propel the engine forward, the other, immediately on the motion of the piston being changed, is ready, in its turn, to act as a fulcrum or abutment for the action of the moving power, to secure the continual progressive motion of the engine.

The feet are raised from the ground during the return of the legs toward the engine, by straps of leather or rope, fastened to the legs, at *f f*, and passing over friction sheeves, moveable in one direction only, by a ratchet and catch, worked by the motion of the engine. The feet are described of various forms in the specification, the great object being to prevent them from injuring the road, and to obtain a firm footing, that no jerks should take place at the return of the stroke, when the action of the engine comes upon them; for this purpose, they were made broad, with short spikes, to lay hold of the ground.

In a communication to the editor of the *Repertory of Arts*, vol. 24, the patentee gives an account of an experiment, made with one of those engines, which he termed his mechanical traveller. The boiler was of wrought-iron, five feet six inches long, three feet in diameter; the step was twenty-six inches long, the piston-rod having a stroke of twenty-four inches; the weight of the whole forty-five cwt. "The machine being placed on a railway, I first ascertained the power necessary to move it at the rate of two miles and a half in an hour, which I found to be eighty-four pounds. I then applied a chain to the hinder part of the machine,—by which, as the machine moved forward, a weight was raised at the same time and rate, and found, that, with steam equal to forty, or forty-five, pounds pressure on the square inch, the machine was propelled at the rate of two miles and a half per hour, and raised perpendicularly 812 lbs. at the same speed; thus making the whole power equal to 896 lbs. at two miles and a half per hour, equal to six horses nearly."

About this time, Mr. Blackett had considerably improved his engines, and, by experiments, had ascertained the quantity of adhesion of the wheels upon the rails; and proved, that it was sufficient to effect the locomotion of the engine upon railroads approaching nearly to a level, or with a moderate inclination. His railroad was a plate rail, and would, consequently, present more friction, or resistance, to the wheels than an edge rail; and, on that account, the amount of adhesion would be greater than upon the latter rail. Still the credit is due to Mr. Blackett, for proving that the locomotion could be applied by that means alone.

The first attempt of Messrs. Trevithick and Vivian failed, and though this was, no doubt, owing to the imperfect construction of the engine, yet it appears that the cause was partly, if not wholly, attributed to the want of adhesion to obtain locomotion; and hence, we find the engineers alluded to, attempting to produce locomotion by other means; Mr. Blenkinsop, by means of a cog-rail; Mr. Chapman, by the chain; and Mr. Brunton, by means of moveable legs.

Art. 5.—*Blackett's Engine.*

It was, however, a question of the utmost importance, to ascertain, if the adhesion of the wheels of the engine, upon the rails, were sufficient to produce a progressive motion in the engine, when loaded with a train of carriages, without the aid of any other contrivance; and it was by the introduction and continued use of them, upon the Wylam railroad, that this question was decided; and it was proved that, upon railroads nearly level, or with very moderate inclination, the adhesion of the wheels alone was sufficient, in all the different kinds of weather, when the surface of the rails was not covered with snow.

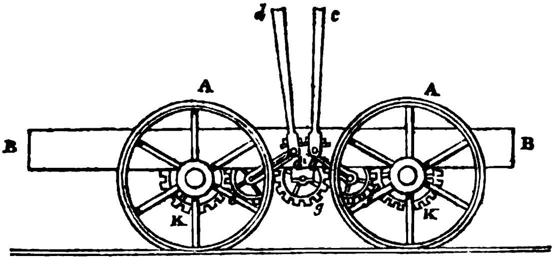
Mr. Hedley informs us, that they first tried, by manual labour, how much weight the wheels of a common carriage would overcome, without slipping round, upon the rail; and, having found the proportion it bore to the weight, they thence ascertained, that the weight of the engine would produce sufficient adhesion to drag after it, upon their railroad, a requisite number of waggons.

The first engine applied upon the Wylam railroad, had only one cylinder, with a fly-wheel, to regulate the action of the crank; but it was found to be very troublesome, and its action very uncertain. When the engine was stopped, and the crank and connecting rod in the same line, the power of the cylinder had then no effect, in turning the crank round; and the engine had to be moved by levers, applied to the spokes of the fly-wheel, until the crank formed such an angle, with the connecting rod, that the engine got sufficient power to produce a rotatory motion, and propel itself forward. This occasioned frequent delays, and the irregular action of the single cylinder, produced jerks in the machinery, and had a tendency to shake the machine in pieces; for some time, however, the whole of the coals, was taken down the railroad by this kind of engine.

Art. 6.—*Stephenson's Killingworth Engine.*

In the early part of the year, 1814, an engine was constructed at Killingworth colliery, by Mr. George Stephenson, and on the 25th July, 1814, was tried upon that railroad. This engine had two cylinders, each eight inches in diameter, and two-feet stroke; the boiler was cylindrical, eight feet long, and thirty-four inches in diameter; the tube, twenty inches in diameter, passing through the boiler.

No. 3.



No. 3. will shew the manner by which the power of the engine was communicated to the wheels, and the locomotion effected. A A, are the wheels of the carriage, supporting the engine; B B, the frame of the carriage, on which the boiler was fixed; *a b*, and *c d*, connecting

rods, similar to *b c*, *b c*, No. 1, transferring the motion from the piston to the crank. *b c*, and *d f*, are the cranks which turn the two cog-wheels, *e f*; the cranks are placed in such a position, with respect to each other, that when one of them is perpendicular, or in a line with the connecting rod, the other is horizontal, and at right angles to it; and this arrangement is continually secured, by the interposition of another cog-wheel, of the same size, and working into the other cog-wheels, *e* and *f*.

Two larger cog-wheels, K, and K, are fixed upon the axles of the carriage-wheels, which, when the small wheels *e*, and *f*, are turned round, by the rotatory motion of the crank, are, also, turned round, and, with them, the wheels of the engine.

The wheels of the engine being thus turned round, upon their axis, the friction, or adhesion, of the rims, against the rails, preventing them from turning, or sliding, round upon the rail, would, necessarily, cause them to roll forward, and thus produce a progressive motion in the engine.

If the power required to produce, or the resistance opposed to, the progressive motion of the wheels, were greater than the friction, or adhesion, of the exterior surface of the periphery of the wheels, upon the rail, the wheels would then slide round, and the engine would stand still; but so long as the former does not exceed the latter, the wheels will always roll forward, along the rails, and effect the progressive motion of the engine.

In this engine, the small cog-wheels, *e*, *g*, *f*, were each twelve inches in diameter, and the cog-wheels, upon the axles of the travelling wheels, twenty-four inches in diameter; so that the cranks made two revolutions, for one revolution of the engine wheels.

This engine was tried upon the Killingworth colliery railroad, July 27, 1814, upon a piece of road with the edge rail, ascending about one yard in 450; and was found to drag after it, exclusive of its own weight,

eight loaded carriages, weighing, altogether, about thirty tons, at the rate of four miles an hour; and, after that time, continued regularly at work.

The application of the two cylinders, rendered the action of the engine regular, and secured the continual progressive motion; thus remedying the imperfection, caused by the irregular action of the single cylinder, and fly-wheel.

When the engine had been at work a short time, it was soon found, that sufficient adhesion existed upon the edge rail, to perform the requisite traction to the load. At first, grooved sheeves were fixed upon the hinder travelling wheels of the engine, and similar grooved sheeves upon the fore-wheels of the convoy carriage, containing the coals and water, with an endless chain, working over each, to procure the adhesion of the wheels of the convoy carriage, in addition to the adhesion of the engine wheels; but, on trial, it was not found necessary to resort to the aid of this contrivance, as the adhesion of the engine wheels alone was found sufficient, to produce the desired effect.

The communication of the pressure upon the pistons to the travelling wheels, by the cog-wheels, produced great noise, and, in some parts of the stroke, considerable jerks; each cylinder alternately propelling, or becoming propelled by, the other, as the pressure of one, upon the wheels, became greater or less than the pressure of the other; and, when the teeth became at all worn, caused a rattling noise. If any play, or space, existed between each tooth of the cog-wheels, the transition of this power, from one side of the teeth to the other, always occasioned a jerk; and this became greater, as the teeth became more worn, and the space, or play, between each tooth increased.

To obviate this, became desirable, and Mr. Stephenson, in conjunction with Mr. Dodd, took out a patent for a method of communicating the power of the engine, directly, to the wheels, without the aid of these cog-wheels. The patent was dated Feb. 28, 1815, and consisted of the application of a pin, upon one of the spokes of the wheels that supported the engine, and by which it travelled upon the railroad; the lower end of the connecting rod being attached to it by, what is termed, a ball and socket joint, and the other end of the connecting rod being attached to the cross-beam, worked up and down by the piston.

a b, No. 4, page 292, represents the connecting rod, the end, *a*, attached to the cross-beam, and the end, *b*, to one of the spokes of the wheel, A. In like manner, the end, *d*, of the connecting rod, *c d*, is attached to the beam of the other piston, and *c*, to a pin, fixed in the spokes of the wheel B. By these means, the reciprocating motion of the piston, and connecting rod, is converted, by the pin, upon the spokes, acting as a crank, into a rotatory motion; and the continuation of this motion secured, by the one pin, or crank, being kept at right angles to the other, as shewn in the drawing.

To keep one of the engine cranks always at right angles to the other, the patentees had two methods:—to crank the axle on which each of the wheels was fixed, with a connecting rod between, to keep them always at the same angle, with respect to each other; or, to use a peculiar sort of endless chain, passing over a toothed wheel, on each axle. This endless chain, at first, consisted of one broad and two narrow links, alternately, fastened together at the ends with bolts; the two narrow links being on the outside of the broad link. Consequently, the distance they were separated laterally, would be equal to the breadth of the broad link, which was, generally, about two inches, and their length three inches. The periphery of the wheels, fixed upon the axles of the engine, was furnished with cogs, projecting from the rim of the wheels, about an inch, or one and a half inches. When the wheel turned round, these projecting cogs entered between the two narrow links, thus, having a broad link between every two cogs, and resting on the rim of the wheel; these cogs, or projections, caused the chain to move round with the wheel, and completely prevented it from slipping round upon the rim. When, therefore, this chain was laid upon these two toothed wheels, one wheel could not be moved round without the other moving round at the same time with it; which thus secured the proper angles to the two cranks.

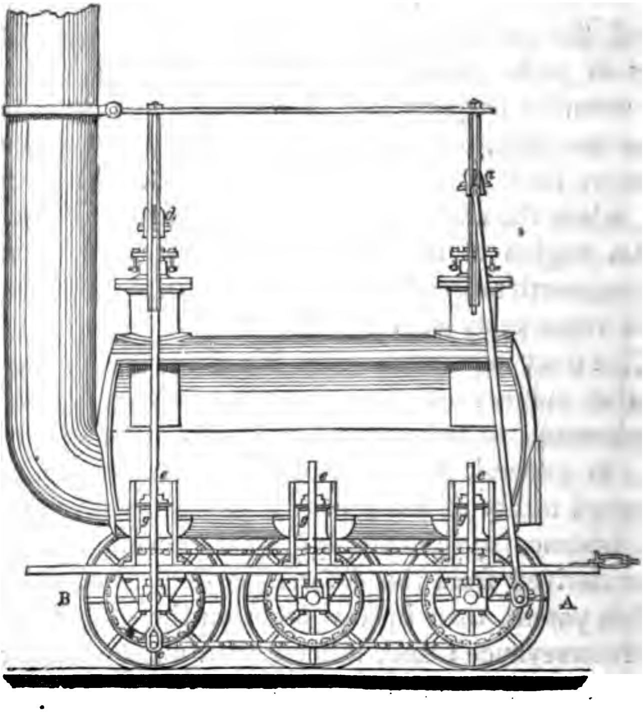
This mode of communicating the action of the engine, from one wheel to another, is shewn in the drawing of No. 4, page 292; the wheels A, and B, having each projecting cog-wheels, round which the endless chain passes. This contrivance entirely superseded the use of the cog-wheels, and was without the jolts or jerks incident to them; for, when the chain got worn by frequent use, or was stretched, so as to become too long, one of the chairs of the axle was made to move back to tighten it, until a link could be taken out, when the chair was moved to its former situation.

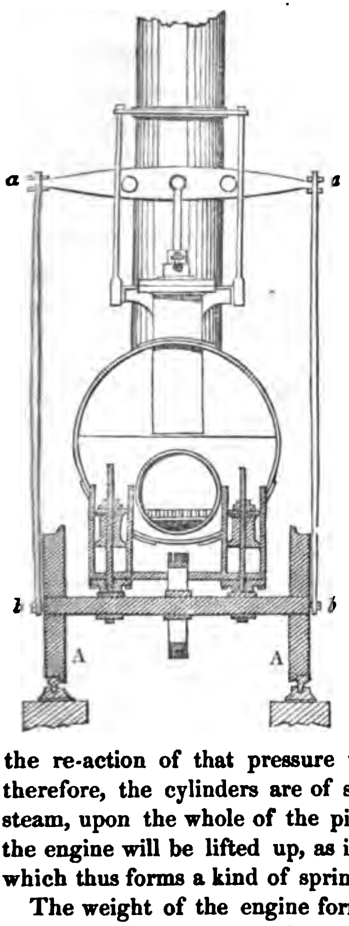
An engine of this construction, was tried upon the Killingworth railroad, on March 6th, 1815, and found to work remarkably well.

The next improvement by Mr. Stephenson, was part of the subject of the patent of Messrs. Losh and Stephenson, so often mentioned previously. Considering, in general, the disappointments met with in the eventual utility of most of the patents, this appears a rare instance to the contrary; more general benefit has been derived from the different contrivances, exhibited in this patent, than in any other on the subject of railroad conveyance; and, indeed, than many on any other subjects, and it certainly confers great credit upon the patentees. This improvement being very minutely described, in the specification of their patent; and the advantage derived being very judiciously, and very clearly stated, we shall give it in their own words:—

"In what relates to the locomotive engines, our invention consists in sustaining the weight, or a proportion of the weight, of the engine upon pistons, moveable within cylinders, into which the steam or water of the boiler is allowed to enter, in order to press upon such pistons; and which pistons are, by the intervention of certain levers and connecting rods, or by any other effective contrivance, made to bear upon the axles of the wheels of the carriage, upon which the engine rests."

No. 4.





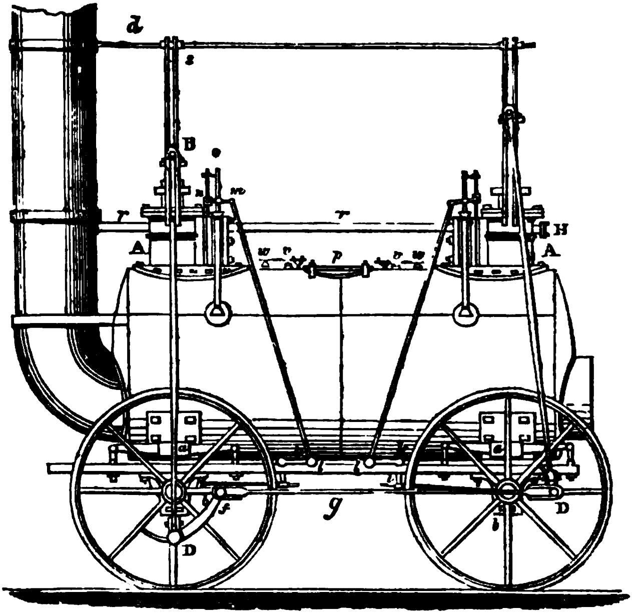
e e e, No. 4, shew the cylinders placed within the boiler, one side of which, in the drawing, is supposed to be removed, to expose them to view. They are screwed, by flanches, to one side of the boiler, and project, within it, a few inches, and are open, at the top, to the steam, or water, in the boiler. *g g g*, are solid pistons, filling the interior of the cylinders, and packed, in the common way, to render them steam tight. The cylinders, in the figure, are drawn, as cut through the middle, to shew the pistons. The cylinder is, also, open at the bottom, and is screwed upon the frame, of the engine. The pistons are furnished with a rod, in a similar way to other pistons, inverted and securely fixed to it; the lower end of which, passes through a hole in the frame, which supports the engine, and presses upon the chair, that rests on the axis of the wheels, on which the carriage moves. The chair has liberty to move up, and down, with the piston-rod. When, therefore, the steam presses upon the piston, the weight is transmitted, to the axle, by the piston rod; and the re-action of that pressure takes as much weight off the engine. If, therefore, the cylinders are of sufficient area, so that the pressure, of the steam, upon the whole of the pistons, is equal to the weight of the engine, the engine will be lifted up, as it were, or entirely supported by the steam, which thus forms a kind of spring, of the nicest elasticity.

The weight of the engine forming one great obstacle to its introduction where the rails were weak, it was of the utmost importance to find out some remedy. Mr. Chapman, in his patent for the application of a chain, described a plan of placing the weight of the engine upon two frames, supported by six or eight wheels; and the Wylam engines, being heavier than the rails would bear, were placed upon eight wheels; but the complication attendant on so many wheels, and the unwieldy nature of such a length of framing, formed altogether so many objections, as to render them almost useless, as a species of moving power.

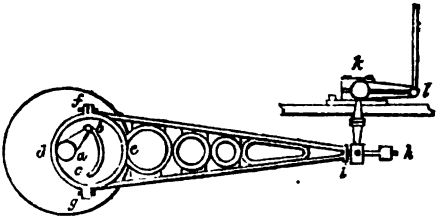
The application of the steam-bearing cylinders, divided the weight equally upon the four wheels, and, if necessary, upon six wheels, as shewn in No. 4, page 292; and thus caused one frame to be sufficient, and, consequently, simplified their construction proportionably.

Having thus given a sort of historical account of the introduction of the locomotive engine, its gradual and successive improvements up to a certain date, and, in doing so, described many of the detached parts entering into its construction; we shall now proceed to describe the whole combined, as forming an engine, long in use upon the Killingworth railroad, which, though inferior in neatness to those now in use upon the public lines of road, forms a very useful and economical description of engine.

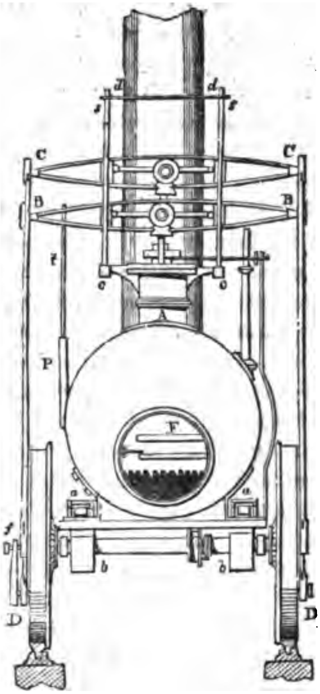
No. 5.



No. 5,
page 298.



No. 6.



Nos. 5 and 6, represent a side and end view of one of the engines used upon the Killingworth Railroad.

The boiler is of malleable iron, cylindrical, with hemispherical ends. A cylindrical tube passes through the boiler, within two inches of the bottom; in one end of this tube the fire is placed, and the other end is terminated by a chimney. The grate, whereon the fire is laid, is placed rather below the middle of the tube, and reaches about four feet within it, resting, at the further end, upon a narrow partition of brick, closing up the lower side of the tube below the bars. F, No. 6, shews the fire door, which, at the tube end of the fire, closes up the upper side of the tube; thus forcing the air through the fire in the usual manner. In some of the engines, this tube, instead of passing through the boiler, is made to return, and pass out at the same end as the fire grate. The boiler rests upon a square frame of wood, or iron, supported by the springs, *a a*, two on each side. The chairs on which the axles of the engine rest, are either of brass or cast iron, four inches in length, and reach to the semi-circumference of the axle; they are, as shewn in the drawing, made to slide up and down within the guides, *b b*, and the action of the springs is communicated to them by a pin, passing through a hole in the frame of the engine; one end of the pin resting on the back of the spring, and the other on the upper side of the chair or bearing. The wheels are thus made to yield to any inequality of the road. The cylinders are placed vertically, and partly within the boiler, as shewn at A A, in the drawings. They are lined on the inside with sheet copper, the piston-rods work through stuffing boxes, in the usual way, and are attached to the cross beams, B B, and C C; sometimes formed of a solid piece of wrought iron, and at times of the form represented in No. 2. The rectilinear motion of the piston-rod is secured by the slides, *s, s, s, s*, fastened to the projecting arms, *e c*, cast upon the top of the cylinder, and kept perpendicular by the braces, *d d*.

The connecting rods, B D, and C D, are attached to the ends of the cross beams, by ball and socket joints; and at the other end, by similar joints to a pin, fixed upon one of the spokes of the engine wheels at D D. To strengthen this spoke, the two adjoining spokes are connected with it by a circular piece of metal joining the three spokes.

To secure a continued rotatory motion of the whole, the arrangements of the pistons are such, that when one is at the top or bottom of the cylinder, the other is at half stroke; and thus, either the one or the other, is constantly in effective action. Thus, as shewn in the drawing, while the spoke forming the crank of one is perpendicular, the other is horizontal. This position of the pistons, with respect to each other, was, as previously stated, secured by an endless chain passing over cog-wheels, fixed upon the axles of the engine. In the old engines, this chain consisted of flat links; but they were subsequently made of a circular, and flat link alternately. The teeth or projections of the wheel, protruding themselves between the flat links, and the round links falling into the circular cavities between each projecting tooth:—The advantage of this form of link was, that the circular links were at liberty to move round; and by thus continually presenting a different surface to the teeth of the wheel, the wear was equalized. The friction of this chain was comparatively trifling, the links, falling as it were, into their places, without sliding, occasioned little wear, and consequently little friction.

However good in other respects, this chain had its defects, and it has been superseded, by the cranks and connecting rod, represented in the drawing. By continued working, the chain was apt to stretch, and a contrivance was resorted to, of the removal of the chairs from each other, to tighten the chain; but, as this could only be done at certain periods, the chain was frequently getting slack. When this took place, and when the full power of one of the cylinders was applied upon one pair of wheels, while the other connecting rod was upon the centre, and therefore not capable of acting at all upon the other wheels, the rotation of the latter depended upon the action of the chain; if the chain was, therefore, slack, it occasioned a slipping of the wheel, until the links of the chain laid hold of the projections of the wheel in the direction in which the chain was moving round; and this slipping alternately occurred by each of the wheels in succession, as they became the predominant moving power. Such a slipping being injurious to the rails, the chain was laid aside, and the connection effected in the following manner. The pins fixed upon the spokes of the wheel, to which the connecting rod is attached, are projected outwards; upon one of these pins, on each side, a crank, D *f*, is fixed, within which the connecting rod of the pistons work, as shewn in No. 6. This crank is placed in such a position, that, with respect to the axle of the wheels, the two ends are at right angles with each other; the extreme end of which partakes of precisely the same motion, and is always parallel with the pin at the end of the connecting rod of the other cylinders. A rod, *f g* D, fixed at one end of the crank, and at the other, to the pin in the wheel of the other cylinder, thus connects the whole together, and keeps the pistons always in the same position with respect to each other. This rod being keyed fast at each end, effectually prevents any partial slipping of the wheels, unless the whole partake of the same motion.

The wheels, as shewn in the figure, are four feet diameter; the naves, and spokes, are made of cast iron, the former being rimed out, to fit the axle, which is fastened to it, by means of iron keys. The axles are of wrought iron, three inches and a half in diameter, and are turned perfectly round, where the chair rests upon them, and also at the extreme end, which passes into the nave of the wheel. The rim was formerly of cast iron, the whole of the wheel being cast in one piece; experience having, however, proved the rapid wear of cast iron, in 1827 I had a rim, or tire, of wrought iron, put upon one set of the Killingworth engine wheels; and since that time similar tires have been extensively used, not only for locomotive engine wheels, but, also, for the wheels of common carriages, on public railways. When these tires are laid upon the cast iron wheels, the periphery of the wheels are turned, and the tires are laid on at that temperature, which causes them to embrace the rim sufficiently tight, to prevent them coming off. Experience having shewn, that when the carriages do not travel at a velocity that heats the rim, such a plan of laying on iron tires is sufficient. At great rates of travelling, wooden spokes, and fellies, have been used by Mr. Stephenson, and entirely wrought-iron wheels, by Mr. Losh, on which the wrought-iron tires are laid; these tires, in all cases, being rolled into the form suitable for travelling upon the edge rail.

The steam is communicated, from the boiler, to the cylinders, through a passage, the area of which is regulated by the sliding lever, or handle, *l*, No. 5, which, of course, restricts the quantity, and regulates the velocity, of the engine. The steam is admitted to the top, and bottom, of the piston, by means of a sliding valve, which, being moved up and down, alternately, opens a communication between the top, or bottom, of the cylinder, and the pipe, *r r*, that is open into the chimney, and turns up within it.

The steam, after performing its office within the cylinder, is thus thrown into the chimney, and the power with which it issues being proportionate to the degree of elasticity; and the exit being directed upwards, it accelerates the velocity of the current of heated air accordingly.

The action of the steam engine is now so well known, that it will not be necessary to describe the mode, by which the rectilinear motion of the piston, is converted into the rotatory one of the wheels, and the progressive motion of the carriage thereby affected; a slight inspection of the drawing will convey to those having the slightest knowledge of machinery, the manner in which it is done, as nothing can be more simple and effective.

The sliding, or steam valve, is opened and shut, at the proper periods, by the following contrivance; *a*, No. 5, page 294, represents the axle, of the travelling wheels, of the carriage; *a b*, is a lever fastened upon, and turning round at the same time with it; *b c*, is a circular opening in the eccentric circle, *d e*, within which a pin, attached to the end of the lever, *a b*, is at liberty to move; this eccentric circle is loose, upon the axle of the carriage, and is only turned round, when the pin, at the end of the lever, *a b*, arrives at *b* or *c*, according to the direction, in which it is moving. A circular hoop, or strap of iron, fits the circumference of the eccentric motion, connected to the lever, *f g h*, which is moved backwards, and forwards, as the axle, and eccentric ring, turns round. As this lever is moved, its motion is communicated to the arm, *i k*, as shewn in No. 5 also, and through it, by the lever, *k l*, and rod, *l m*, to the cross head *m n*, and so to the rod, *n o*, of the sliding, or steam valve, which, as the carriage is moved forward, is thus worked, up and down, to open and shut the communication between the two sides of the cylinder and the boiler, at the proper periods.

Before the application of this mode, the measure was effected by a square box, or tumbler. It seemed to me, from the irregularity of the noise, caused by the exit of the steam into the atmosphere, that the changes were not made at the proper time of stroke, and I applied this as a sort of experimental plan, by which, on altering the screws, *h*, and *i*, the steam could be thrown into the cylinder at any time of stroke. I soon found that there was a certain time, at which the opening into the cylinder should be made, when the effect was the greatest; and, as the common tumbler did not effect this at the same period of stroke, when the carriage was moved in both directions, I retained this mode of working the slides permanently.

It will be seen, that the rod, *i*, moves through the head of the lever, *k i*; by this contrivance, the rod moves a considerable distance without moving the slide at all; and, therefore, enables us to use an eccentric of a much larger diameter, and, therefore, the slide is moved much quicker than with a smaller eccentric.

p, No. 5, is the man-hole door, to have access into the interior of the boiler; v, is the safety valve, to allow the steam to escape, when the elasticity becomes too great. It is loaded with the weight, w, corresponding with the pressure of steam, which it is found requisite to retain within the boiler.

The boiler is supplied with water by means of a small forcing pump, P, fixed to the side of the boiler, and worked by the rod, *t*, attached to the cross-beam of the engine. The diameter of this pump is very small, that the quantity of water injected shall not reduce the temperature of steam in the boiler, so as to be injurious, and check the regular supply of steam to the cylinder. The quantity of water required not being great, it is pumped in at proper intervals, when the draught is not heavy, and when the pressure, or elasticity of the steam, is not required to be very powerful.

When the engine is used for travelling, the boiler is inclosed within a wooden covering, consisting of thin narrow deals, to prevent the radiation of heat; if this is not done, the wind has great effect in reducing the temperature, by the rapid abstraction of heat.

The water and coals, required for the regular wants of the engine, are carried in a convoy-carriage, attached to the engine. The size of this, and the quantity carried, will, of course, depend upon the length of the stages the engine has to travel, or the convenience of obtaining them.

The train of carriages moved by the engine is most frequently attached to the convoy-carriage; but the engine can, also, drive the carriages in the front, by propelling them forward; but this is very liable to drive the carriages from off the road, especially when curves in the line of road occur.

Such was the form of engine which, with trifling modifications, was used until the year 1829; the maximum practical performance of such an engine, weighing, with tender, about ten tons, being equal to convey forty tons, at the rate of six miles an hour; the evaporating power being equal to about fifteen gallons of water per hour.

Art. 7.—*Liverpool experiments.*

In the spring of the year 1829, the Liverpool and Manchester railway had made considerable progress towards completion; and it became necessary that the Directors should determine as to the power that should be employed upon it, for the conveyance of merchandise, &c. They had previously, in the year 1828, appointed a deputation of their body, to visit the railways in the counties of Northumberland and Durham, where the different varieties of motive power were most extensively practised. The deputation accordingly visited the most improved railways in that district, and returned without being able to decide upon which kind, was the most advantageous to their interests.

The only conclusion which they came to, appears, according to Mr. Booth*, to have been, that, from the great amount of traffic anticipated upon the line, horses were inapplicable. The contest then being between locomotive, and fixed engines, the Directors, in order to determine which of the two were the most suitable for this purpose, resolved to employ two practical engineers; who were to visit the Darlington and Newcastle railways, carefully to examine the working of the two species of mechanical power, and report to the Board of

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* On the Liverpool and Manchester railroad, p. 69.

Directors, which, under all the circumstances, was the best description of moving power to be used. For this purpose they fixed upon Mr. Walker, of Limehouse, and Mr. Rastrick, of Stourbridge; who made a tour through all the railways in the North, and reported to the Directors the result of their observations. Messrs. Walker and Rastrick have subsequently published their reports, which, though separate, were substantially the same; the result of which was, that at the period of their enquiry, (March 1829,) the following Table, given by Mr. Rastrick, will shew the power of the different locomotive engines employed on the railways which they visited.

TABLE I.

Of the absolute Quantity of Work done by five different Locomotive Engines, when reduced all to the same Standard, of 5, 8, and 10 Miles per Hour. The Carriages proportioned to the Goods, in the same Ratio as they are proposed for the Liverpool and Manchester Railway, and also of the Work that the Ten-horse Engine proposed by Mr. J. Walker, and myself, will be capable of doing:

ENGINES.	RAILROADS.	IN SUMMER.												IN WINTER.											
		At 5 miles per hour.				At 8 miles per hour.				At 10 miles per hour.				At 5 miles per hour.				At 8 miles per hour.				At 10 miles per hour.			
		Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weigt.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.
		tons	tons	tons.	tons	tons	tons	tons.	tons	tons	tons	tons.	tons	tons	tons	tons.	tons	tons	tons	tons.	tons	tons.	tons	tons.	tons.
Engine on six 4-feet wheels, made by Timothy Hackworth	Stockton and Darlington	47¾	23¾	15	86½	26	18	15	54	18¾	9½	15	43¼	40¾	20¼	15	76	21¾	10¾	15	47½	15¼	7¾	15	38
Engine on four 4-feet wheels, worked by James Stephenson	Stockton and Darlington	34⅔	17⅓	12	64	18⅔	9⅓	12	40	13⅓	6⅔	12	32	28¾	14½	12	55¼	15	7½	12	34½	$10\frac{4}{10}$	$5\frac{2}{10}$	12	$27\frac{6}{10}$
Engine on four 4-feet 2-inch wheels, under Mr. N. Wood's care	Killingworth Colliery	38	19	10½	67½	21	10½	10½	42	15½	7¾	10½	33¾	31¼	15¾	10½	57½	17	8½	10½	36	12	6¼	10½	28¾
Engine on four 3-feet wheels, under the care of Mr. T. Wood	Hetton Colliery	24¼	12	10½	46¾	12½	6¼	10½	29¼	8⅔	4⅓	10½	23½	19⅔	9⅚	10½	40	9⅔	4⅚	10½	25	6⅓	3⅙	10½	20
Engine on four wheels, rack rail, under the care of Mr. Blenkinsop	Middleton Colliery, near Leeds	22¼	11	6¼	39½	12¼	6⅛	6¼	24⅝	9	4½	6¼	19¾	19¼	9½	6¼	35	10¼	5⅛	6¼	21⅝	7½	3¾	6¼	17½
Ten-horse Engine, proposed by J. Walker, and J. U. Rastrick	Liverpool and Manchester	33	16½	10½	60	18	9	10½	37½	13	6½	10½	30	27⅓	13⅔	10½	51½	14½	7¼	10½	32¼	10¼	5	10½	25¾

From the above Table it will be seen, that the assigned performance of the engines proposed for the Liverpool and Manchester railway, was nearly the same as previously deduced in the first edition of this work; and, therefore, we find, that up to this time no material improvement had taken place.

The reporters state, that their estimate of the powers of the engines, was formed upon those in actual use; that great improvements were making in them, and Mr. Walker especially states, "that in estimating the question generally, it is fair to anticipate others; and it is true that improvements in the stationary system may also be expected, but not to the same extent, as in locomotive engines."

Notwithstanding this report of the above gentlemen, the Directors did not feel themselves able to come to a decision on the subject; a leaning in favour of locomotive engines existed, Mr. Booth says, in a majority of the Directors, provided they could be constructed of adequate power, and at a less weight than the engines hitherto in use, which were generally seven or eight tons in weight; and if they could be made to conform with the stipulations of the Railway Act, by not throwing off any smoke. Mr. Harrison, one of the Directors, had, as stated by Mr. Booth, been for some time of opinion, that the excitement of a reward, publicly offered, would be the most likely mode of effecting their object; and in this opinion his brother Directors ultimately coincided. Accordingly, on the 20th of April, 1829, they resolved on offering a premium of £500, for the best locomotive engine, subject to certain stipulations and conditions.

Considering the very important conclusions, which have resulted from the competition, induced by the offer above noticed, the very rapid improvement which it produced in these engines, forming not only a new era in *their* history, but in the importance of railway communication in general; we shall make no apology, in giving a brief outline of the proceedings, and of the various improvements effected by this competition of talent.

The conditions, on which the Directors offered the premium of £500, were as follow:—

Railway Office, Liverpool, 25th April 1829.

STIPULATIONS and CONDITIONS, on which the Directors of the Liverpool and Manchester Railway, offer a Premium of £500 for the most improved Locomotive Engine.

1st, The said engine must "effectually consume its own smoke," according to the provisions of the railway act, 7 Geo. IV.

2d, The engine, if it weighs six tons, must be capable of drawing after it, day by day, on a well-constructed railway, on a level plane, a train of carriages of the gross weight of twenty tons, including the tender and water-tank, at the rate of ten miles per hour, with a pressure of steam on the boiler, not exceeding fifty pounds per square inch.

3d, There must be two safety valves, one of which must be completely out of the controul of the engine-man, and neither of which must be fastened down while the engine is working.

4th, The engine and boiler must be supported on springs, and rest on six wheels, and the height, from the ground to the top of the chimney, must not exceed fifteen feet.

5th, The weight of the machine, *with its complement of water* in the boiler, must, at most, not exceed six tons; and a machine of less weight will be preferred, if it draw *after* it a *proportionate weight*; and, if the weight of the engine, &c. do not exceed *five tons*, then the gross weight to be drawn need not exceed fifteen tons, and in that proportion for machines of still smaller weight; provided that the engine, &c. shall still be on six wheels, unless the weight (as above) be reduced to four tons and a half, or under, in which case, the boiler, &c. may be placed on four wheels. And the company shall be at liberty to put the boiler, fire-tube, cylinders, &c. to a test of a pressure of water, not exceeding 150 pounds per square inch, without being answerable for any damage the machine may receive in consequence.

6th, There must be a mercurial gauge affixed to the machine, with index-rod, shewing the steam pressure above forty-five pounds per square inch.

7th, The engine to be delivered complete for trial at the Liverpool end of the railway, not later than the 1st of October next.

8th, The price of the engine, which may be accepted, not to exceed £550 delivered on the railway; and any engine not approved to be taken back by the owner.

N.B.—The railway company will provide the *engine tender*, with a supply of water and fuel, for the experiment. The distance within the rails is four feet eight inches and a half.

Subsequently, the 6th October, was fixed upon for the day of trial; and, to assist the Directors in coming to a correct decision on the merits of the different engines, Mr. Rastrick, of Stourbridge, Mr. Kennedy, of Manchester, and myself, were appointed judges on the occasion.

On the day appointed, the following engines were entered for the prize:—

Mr. Robert Stephenson, - -	Steam Engines	The Rocket.
Messrs. Braithwaite and Erickson,		The Novelty.
Mr. Timothy Hackworth, - -		The Sans Pareil.
Mr. Burstall, - - - -		The Perseverance.

Mr. Brandreth (Horse Machine, the Cycloped).

And the following regulations were issued from the railway office:—

"The engines to be ready at ten o'clock on Tuesday morning. The running-ground will be on the Manchester side of the Rainhill Bridge.

"The load attached to each engine, will be three times the weight of the engine.

"No person, except the Directors and Engineers, will be permitted to enter or cross the railroad.

"Liverpool, 5th Oct. 1829."

The part of the railway, on which the trials were fixed to be made, was at a place called Rainhill; being a level piece of road on the top of the Whiston and Sutton inclined planes, about two miles in length.

The original stipulations of the Directors containing no regulations as to the mode of trying the powers of the different engines, the judges determined, that in order to ascertain the comparative merits of each, they should be subjected to the following practical test. And, in consequence, a card, containing the following regulations, was distributed to the different competitors.

LIVERPOOL AND MANCHESTER RAILWAY.

The following is the ordeal, we have decided each Locomotive Engine shall undergo, in contesting for the Premium of £500 at Rainhill:—

The weight of the locomotive engine, with its full complement of water in the boiler, shall be ascertained at the weighing machine, by eight o'clock in the morning, and the load assigned to it shall be three times the weight thereof. The water in the boiler shall be cold, and there shall be no fuel in the fire-place. As much fuel shall be weighed, and as much water shall be measured and delivered into the tender-carriage, as the owner of the engine may consider sufficient for the supply of the engine, for a journey of thirty-two miles and one half. The fire in the boiler shall then be lighted, and the quantity of fuel consumed for getting up the steam shall be determined, and the time noted.

The tender-carriage, with the fuel and water, shall be considered to be, and taken as part of the load assigned to the engine.

Those engines that carry their own fuel and water, shall be allowed a proportionate deduction from their load, according to the weight of the engine.

The engine, and the carriages attached to it, shall be run by hand up to the starting-post, and as soon as the steam is got up to fifty pounds per square inch, the engine shall be set upon its journey.

The distance the engine shall perform each trip, shall be one mile and three quarters each way, including one-eighth of a mile at each end, for getting up the speed, and for stopping the train; by this means, the engine, with its load, will travel one and a half mile each way, at full speed.

The engine shall make ten trips, which shall be equal to a journey, of thirty-five miles, which shall be performed, at full speed, and the average rate of travelling shall not be less than ten miles per hour.

As soon as the engine has performed this task, (which will be equal to the travelling from Liverpool to Manchester,) there shall be a fresh supply of fuel and water delivered to her; and as soon as she can be got ready to set out again, she shall go up to the starting post, and make ten trips more, which will be equal to the journey from Manchester, and back again to Liverpool.

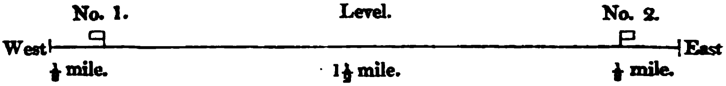
The time of performing each trip shall be accurately noted, as well as the time occupied in getting ready to set out for the second journey.

Should the engine not be enabled to take along with it sufficient fuel and water for the journey of ten trips, the time occupied in taking in a fresh supply of fuel and water shall be considered, and taken as part of the time in performing the journey.

J. U. Rastrick, C. E., Stourbridge,
Nicholas Wood, C. E., Killingworth, } Judges.
John Kennedy, Manchester,

Liverpool, 6th Oct. 1829.

The ground was then marked out according to the diagram below.



And the mode of conducting the experiment agreeably to the conditions, was as follows:—One of the judges was stationed at the post, No. 1, and the other at the post, No. 2. The engine, when ready, started off from the extremity of the stage, and when it arrived at the station, No. 1, the time was taken; it then proceeded on until it arrived at the station, No. 2, when the time was again taken. The velocity was then checked, and when it arrived at the end of the stage, was stopped, and set in motion in the opposite direction; and when it again passed the station, No. 2, the time was marked, and the engine proceeded at full speed, until it arrived at the station, No. 1, when the time was again recorded. By this method, the time occupied in traversing the 1½ mile stage at full speed, and also the time occupied at each end, was ascertained.

The first two or three days were occupied in preparing the engines for the contest, and in shewing their powers to the numerous company assembled on the occasion; after which, it was determined, to avoid confusion, that each engine should be tried separately, and on different days.

Art. 8.—*Experiments with the Rocket Engine, Mr. Stephenson's.*

The "Rocket," being first ready, was put upon trial, and having got a proper supply of water, was weighed, and found to be four tons five cwt.; the load affixed agreeably to the resolutions of the Directors, was therefore three times that weight, or twelve tons fifteen cwt., viz.:—

	Tons	cwts.	qrs.	lbs.
Engine - - - - - -	4	5	0	0
Tender, with water and coke -	3	4	0	2
Two carriages, loaded with stones	9	10	3	26
Whole mass in motion -	17	0	0	0

The engine was then taken to the extremity of the stage, the fire-box filled with coke, and the fire lighted; the water in the boiler being quite cold, the time occupied in raising the steam until it lifted the safety valve, loaded to a pressure of fifty pounds per square inch, was fifty-seven minutes. Immediately the steam was at the above pressure, which was at $10^{h}\ 36'\ 5''$, the engine started from the west extremity of the stage, and arrived at the same place, after performing ten trips, or thirty-five miles, precisely at $1^{h}\ 48'\ 38''$. The following Table will shew the time occupied in performing the respective trips, and also the time lost at each end of the stage.

EXPERIMENT I.

Observations.	No. of Trips.	Time in getting up and stopping the speed of the Train.	Time taken when the Engine passed the Post No. 1.	Time in coming up from Post No. 2 to No. 1.	Time n going down from Post No. 1 to No. 2.	Time taken when the Engine passed the Post No. 2	Time in stopping and getting up the speed of the Train.	Observations.
H. M. S.		H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	
Started 10 36 50	......	0 1 25	10 38 15	....	0 7 43	10 45 58	....	
							0 2 14	
	1	....	10 54 55	0 6 43	....	10 48 12	....	
		0 3 42						
Stopped to oil.		....	10 58 37	....	0 7 8	11 5 45	....	
							0 4 35	Greased the Pistons.
	2	....	11 18 42	0 8 22	....	11 10 20	....	
		0 2 28						
		....	11 21 10	....	0 7 52	11 29 2	....	
							0 2 45	
	3	....	11 39 50	0 8 3	....	11 31 47	....	
		0 2 55						
		....	11 42 45	....	0 6 7	11 48 52	....	
							0 2 20	
	4	....	11 58 15	0 7 3	....	11 51 12	....	
		0 2 27						
		....	0 0 42	....	0 6 31	0 7 13	....	
							0 2 27	
	5	....	0 15 45	0 6 5	....	0 9 40	....	
		0 2 5						
		....	0 17 50	....	0 5 55	0 23 45	....	
							0 2 53	
Stopped to take in six buckets of water, equal to 19 imperial gallons.	6	....	0 35 20	0 8 42	....	0 26 38	....	
		0 4 5						
		....	0 39 25	....	0 5 55	0 45 20	....	
							0 2 35	
	7	....	0 55 30	0 7 35	....	0 47 55	....	
		0 2 24						
		....	0 57 54	....	0 5 40	1 3 34	....	
							0 3 14	
	8	....	1 13 45	0 6 57	....	1 6 48	....	
		0 3 25						
		....	1 17 10	....	0 5 18	1 22 28	....	
							0 4 2	Took in 16 Imperial Gallons of Water.
	9	....	1 33 35	0 7 5	....	1 26 30	....	
		0 2 15						
		....	1 35 50	....	0 4 12	1 40 2	....	
							0 2 1	
H. M. S. Stopped at 1 48 38 From the time of starting till noon 1 23 10	10	0 1 23	1 47 15	0 5 12	....	1 42 3	....	
		0 28 34		1 11 47	1 2 21		0 29 6	
Total time 3 11 48				+			0 28 34	
			Time in going 30 miles at full speed - -	2 14 8		Time in starting, stopping, and going 5 miles -	0 57 40	

One half of the assigned performance having been completed, and the supply of water exhausted, the engine was then run down to the watering station, and took in a fresh supply of water, which, having done, it then ran back to the west end of the stage, took in some coke, and again started upon its journey. The time occupied in doing all this was 14′ 34″, and the precise time of starting, upon the second journey, was 2ʰ 3′ 12″. After performing the assigned number of trips, as shewn in the following Table, the engine arrived at the west end of the stage, at 5ʰ 0′ 21″, the steam being found to be at the same elasticity as at starting, and the same quantity of water in the boiler.

EXPERIMENT II.

Observations.	No. of Trips.	Time in getting up and stopping the speed of the train.	Time taken when the Engine passed the Post No. 1.	Time in coming up from Post No. 2 to Post No. 1.	Time in going down from Post No. 1 to Post No. 2.	Time taken when the Engine passed the Post No. 2.	Time in stopping and getting up the speed of the train.	Observations.
H. M S.		H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	
Started 2 2 12	……	0 1 38	2 4 50	………	0 6 15	2 11 5	………	
							0 2 8)	
	1	………	2 20 45	0 7 32	………	2 13 13	………	
		(0 2 25						
		………	2 23 10	………	0 5 57	2 29 7	………	
							0 2 23)	
	2	………	2 38 50	0 7 20	………	2 31 30	………	
		(0 2 30						
		………	2 41 20	………	0 5 17	2 46 37	………	
							0 2 59)	
	3	………	2 55 48	0 6 12	………	2 49 36	………	
		(0 2 47						
		………	2 58 35	………	0 7 6	3 5 41	………	
							0 3 40)	Greasing waggons.
	4	………	3 16 8	0 6 47	………	3 9 21	………	
Took in 1 cwt. 0 qr. 2 lbs. of coke.		(0 2 41						
		………	3 18 49	………	0 6 5	3 24 54	………	
							0 2 11)	
	5	………	3 33 38	0 6 33	………	3 27 6	………	
		(0 2 48						
		………	3 36 26	………	0 5 51	3 42 17	………	
							0 2 32)	
	6	………	3 52 7	0 7 18	………	3 44 49	………	
		(0 2 2						
		………	3 54 9	………	0 6 9	4 0 18	………	
							0 2 29)	
	7	………	4 10 33	0 7 46	………	4 2 47	………	
		(0 2 18						
		………	4 12 51	………	0 5 23	4 18 14	………	
							0 3 38)	Took in 16 imperial gallons of water.
	8	………	4 30 11	0 8 19	………	4 21 52	………	
		(0 2 13						
		………	4 32 24	………	0 5 25	4 37 49	………	
							0 2 6)	
	9	………	4 46 27	0 6 32	………	4 39 55	………	
		(0 1 57						
		………	4 48 24	………	0 3 44	4 52 8	………	
							0 2 10)	
H. M. S. Stopped at 5 0 21	10	0 0 45	4 59 36	0 5 18	………	4 54 18	………	
Total time occupied in this experiment - 2 57 9		0 24 4		1 9 37	0 57 12		0 26 16 0 24 4	
			Time in going 30 miles at full speed - -	+ 2 6 49		Time in starting, stopping, and going 5 miles -	0 50 20	

On examining the foregoing experiments, we find the following result:—

		h.	m.	s.			
At full speed	30 miles in	2	14	8	equal to	$13\frac{4}{10}$	Miles per hour.
	30 miles in	2	6	9		$14\frac{3}{10}$	
Ends of stage	5 miles in	0	57	40	equal to	$5\frac{2}{10}$	Miles per hour.
	5 miles in	0	50	20		6	

Maximum velocity in performing one trip	1st journey, $19\frac{1}{7}$ 2d journey, 20	Miles per hour.
Minimum velocity in performing one trip	1st journey, $11\frac{4}{11}$ 2d journey, 13	Miles per hour.

The greatest velocity attained, being in the last eastward trip, which was performed in 3′ 44″, being at the rate of $29\frac{1}{9}$ miles per hour.

The quantity of fuel put into the fire-box for getting up the steam, was - - - - - - -	222 lbs.
Deduct remaining, when the steam was at 50 lbs. per square inch - - - - - - - -	80
Consumption of fuel in getting up the steam	142 lbs.

The quantity of coke consumed by the engine, in performing the two experiments, was 1085 lbs., which, for 70 miles, is

Including the engine and tender -	0·91 lbs.	per ton, per mile.
Exclusive of ditto - - -	1·63 lbs.	

The quantity of water used, was 579 gallons, or 92·6 cubic feet; consequently the consumption of fuel was $11\frac{7}{10}$ lbs. of coke, for each cubic foot of water evaporated; the evaporating power of the engine being about 18·24 cubic feet of water per hour.

On examining these experiments, it will be seen, that the eastward trips were invariably performed in less time, than those of the opposite direction. In going east, the engine *dragged* the carriages after it, while in travelling west, the carriages were *pushed* before the engine; as the road was said to be perfectly level, we can only attribute the difference of effect, to the disadvantageous action of pushing the carriages, instead of dragging them; and as in the practical application of this mode of conveyance, these engines will always drag the carriages after them, if the plane be perfectly horizontal, we ought, perhaps, to take the performance of the eastward trip, as the work done, which will be as follows:

	h.	m.	s.		
1st journey,	1	2	21, or 14½	miles per hour, or average	
2d journey,	0	57	12, or 15¾	15 miles per hour.	

It would, however, be assigning a performance greater than the experiment would warrant, to take the above as the performance of the engine; for although the above was the effect at full speed, and though, undoubtedly, a great loss of effect was also occasioned by the stops at each end of the stage; yet it should not be lost sight of, that during the time the engine was stopped at each end of the stage, there was no waste of steam, and the evaporation in the boiler was going on all the time, not with that rapidity which would take place had the engine been working, but still such as the exhausting power of the chimney could effect. Perhaps, therefore, under all the circumstances, the real performance of the engine, compared with what it would have been, had the distance been travelled right forward; should be the seventy miles travelled in the observed time occupied between the inner stations, and half the time at each end. This would make the performance seventeen tons, including the engine, or nine tons and a half, exclusive of the engine, conveyed seventy miles in about five hours, or at the rate of fourteen miles per hour. And this would give the evaporation of water, 114 gallons per hour, and the consumption of coke, 217 lbs. per hour.

Art. 9.—*Experiments with Hackworth's engine, the Sans Pareil.*

The next engine brought forward for trial, was the "Sans Pareil."

It was the original intention of the judges, to have ascertained the time, and quantity of fuel necessary to raise the water in the boiler, to the temperature equivalent to the elasticity of fifty pounds per square inch; but when this engine came to the starting post, it was found, that Mr. Hackworth had been running it back and forward, to ascertain if some leaks in the boiler (which had delayed its trial for some days), had been effectually stopped, and the water being consequently warm, no measure could be taken either of the fuel, or the time required to raise the steam to the necessary elasticity. The engine was, therefore, put on its trial, and this part of the enquiry omitted.

When the requisite quantity of water was put into the boiler, and the engine placed upon the weighing machine, it was found to weigh four tons, 15½ cwt. On perusing the conditions issued by the Directors, it will be seen, that if any engine should be more than four tons and a half weight, it was to be placed upon six wheels; the weight of the "Sans Pareil," therefore, excluded it from competing for the prize; but on further consideration, the judges determined to put the engine through the same trial, as if it conformed with the proposed conditions, to ascertain if the performance was such, as would enable them to recommend this point to the favourable consideration of the Directors.

The weight of the engine, and the load assigned agreeably to the conditions, were as follow, viz.

	Tons	cwt.	qrs.	lbs.
Engine - - - - - -	4	15	2	0
Tender, with water and fuel - -	3	6	3	0
Three carriages, loaded with stones	10	19	3	0
Total mass in motion -	19	2	0	0

Having had a sufficient quantity of fuel supplied, and the steam raised to the regulated elasticity, the engine was brought up to the starting post, and proceeded on its task in a similar way to the Rocket.

The following Table will shew its performance.

EXPERIMENT III.

Observations.	No. of Trips.	Time in getting up and stopping the speed of the train at west end.	Time taken when the Engine passed post No. 1.	Time in coming up from post No. 2. to post No. 1.	Time in going down from post No. 1. to post No. 2.	Time taken when the engine passed post No. 2.	Time in stopping and getting up the speed of the train at east end.	Observations.
H. M. S.		H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	
Started at 10 10 21	......	0 1 9	10 11 30	....	0 5 9	10 16 39	....	
							0 2 6	
	1	....	10 26 22	0 7 37	....	10 18 45	....	
		0 2 12						
		....	10 28 34	....	0 6 3	10 34 37	....	
							0 2 1	
	2	....	10 43 46	0 7 8	....	10 36 38	....	
		0 2 11						
		....	10 45 57	....	0 6 8	10 52 5	....	
							0 2 11	
	3	....	11 1 37	0 7 21	....	10 54 16	....	
		0 2 35						
		....	11 4 12	....	0 5 34	11 9 46	....	
							0 1 52	
	4	....	11 18 12	0 6 34	....	11 11 38	....	
		0 2 35						
		....	11 20 47	....	0 5 39	11 26 26	....	
							0 1 55	
	5	....	11 35 17	0 6 56	....	11 28 21	....	
		0 2 40						
		....	11 37 57	....	0 6 1	11 43 58	....	Oiling carriages, and repairing forcing pump.
							0 4 11	
	6	....	0 55 21	0 7 12	....	11 48 9	....	
		0 2 54						
		....	0 58 15	....	0 6 22	0 4 37	....	Took in 3 imperial gallons of water.
							0 2 34	
One of the waggons got loose.	7	....	0 15 12	0 8 1	....	0 7 11	....	
		0 3 31						
		....	0 18 43	....	0 5 31	0 24 14	....	Took in 8 gallons of water, and examined forcing pump.
							0 3 18	
H. M. S. Stopped at 0 27 32	8	....	....	....	....	0 27 32	....	
Time till noon - 1 49 39		0 19 47		0 50 49	0 46 27		0 20 8	
Total time, 2 17 11				+			0 19 47	
			Time in going 22 miles and a half at full speed - -	1 37 16		Time in starting, stopping, &c. -	0 39 55	

In traversing the eighth trip to the west, the pump that supplies the boiler with water got wrong, which, checking the supply, the water in the boiler got below the top of the tube, and melted the leaden plug, inserted for the purpose of preventing accidents in such a case, and put an end to the experiment.

So far as this experiment was conducted, the following performance was effected:—

		h.	m.	s.			
At full speed	$10\frac{1}{2}$ miles in	0	50	49	equal to	$12\frac{4}{10}$	Miles per hour.
	12 miles in	0	40	27		$15\frac{5}{10}$	
Ends of stage	$1\frac{7}{8}$ miles in	0	19	47	equal to	$5\frac{7}{10}$	Miles per hour.
	2 miles in	0	20	8		6	

Maximum velocity (in one trip) $16\frac{1}{2}$ miles per hour.
Minimum ditto - ditto $12\frac{1}{2}$ ditto.

The greatest velocity attained, being in the 5th trip, going east, the $1\frac{1}{2}$ miles being traversed in 3′ 59″, which is at the rate of $22\frac{2}{3}$ miles per hour.

The whole distance traversed by the engine was $27\frac{1}{2}$ miles, and the consumption of coke was 1269 lbs.,

which is { including the engine and tender, 2·41 lbs. / exclusive of - ditto - 4·2 lbs. } per ton per mile.

The quantity of water used, was 274 imperial gallons, or 43·84 cubic feet; and, consequently, the consumption of coke was 28·8 lbs. for each cubic foot of water evaporated; the evaporating power being equal to 24 cubic feet of water per hour.

Making the same allowance, as in the case of the Rocket, for the loss of effect at the ends of the stage, the performance would be nineteen tons and a half, or eleven tons, exclusive of the engine and tender, conveyed at the rate of about fifteen miles per hour; and the evaporation of water nearly 150 gallons per hour, and of coke, 692 lbs. per hour, or, 28·8 lbs. for each cubic foot of water evaporated.

The owners of the "Novelty," not having had any opportunity of trying that engine upon a railway, previous to its arrival at Liverpool, it was found, when placed upon the road there, that some alteration of the wheels was necessary. This, together with the lateness of its arrival, and the occurrence of some trifling casualties in starting, produced considerable delay; and it was not until the 10th that the engine could be put upon its trial.

Art. 10.—*Experiments with the Novelty, Messrs. Braithwaite and Erickson's Engine.*

It had been previously determined by the judges, that it should be tried on the Monday, in order to give the owners more time to perfect the different alterations, but, at the urgent request of Mr. Braithwaite, it was brought out on the Saturday.

This engine, as will be afterwards shewn, differs from the previous ones, in the water and fuel being carried on the same wheels as the engine, and not on a separate carriage; and as the weight to be dragged was to be three times the weight of the engine only, and not of engine and water tank; it was determined by the judges, that the load assigned to this engine, in order to place it on the same footing as the others, should be the same proportion of useful load, compared with the weight of the engine, that the useful load taken by Stephenson's engine, bore to its weight; leaving both engines to carry the fuel in their own way.

The weight of Stephenson's engine was 85 cwt., and the load taken, (exclusive of tender and water,) was 191 cwt. Messrs. Braithwaite and Erickson's engine, (exclusive of water tank) weighed 61 cwt. Therefore as 85 : 191 : : 61 : 137 cwt., the load assigned to the "Novelty."

The weight of the whole train in this experiment, was, therefore, as follows:

	Tons	cwts.	qrs.	lbs.
Engine, with water in the boiler -	3	1	0	0
Tank, water, and fuel - -	0	16	0	14
Two carriages, loaded with stones	6	17	0	0
Gross weight in motion -	10	14	0	14

The engine was then brought up to the place of starting, and the fuel having been previously weighed, the fire was lighted, and the time in getting the steam up to an elasticity of 50 lbs. per square inch, was 54′ 40″. The quantity of fuel delivered to raise the steam was 66 lbs., but as we had no means of ascertaining what was left in the fire, no account could be had of what was actually consumed.

The engine then started to traverse the stage in a similar way to the others, and the following Table will shew its performance, as far as conducted:—

EXPERIMENT IV.

Observations.	No. of trips.	Time in getting up and stopping the speed of the train at west end.	Time taken when the engine passed the post No. 1.	Time in coming up from post No. 2. to post No. 1.	Time in going down from post No. 1. to post No. 2.	Time taken when the engine passed the post No. 2.	Time in stopping and getting up the speed of the engine.	Observations.
H. M. S.		H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	
Started 11 0 28	......	0 1 20	11 1 48	....	0 5 36	11 7 24	....	
							0 2 34)	
	1	....	11 16 38	0 6 40	....	11 9 58	....	
	......	0 1 20	....	0 6 40	0 5 36 0 6 40	....	0 2 34	
				Total time	- 0 12 16	distance 3 miles.		

When the engine arrived at the post, No. 1, in returning, it was found that the pipe conveying the water from the forcing pump to the boiler had been burst open; occasioned, Mr. Erickson said, by the cock which opens or shuts the communication from the pump with the boiler, having been accidentally shut while the pump was working. This being repaired, it was too late to go on with the experiment this day, but the engine, (according to a statement by Mr. Vignoles, published in the Mechanics' Magazine,) with a calculated weight of ten tons six cwt. and one quarter, traversed the eastward trip of one mile and a half in four minutes thirty-nine seconds, being at the rate of seventeen miles and a half per hour, and the westward trip in five minutes fifty-four seconds, being at the rate of fifteen miles an hour. The loaded carriages being detached, the engine made a trip with passengers, going at the rate of between twenty and thirty miles an hour. Two or three days being allowed to get the engine into complete working order, (as many as Messrs. Braithwaite and Erickson requested,) it was again, on the 14th, put upon its trial.

On the arrival of the judges at Rainhill at the appointed time, they found that several parts of the engine having been taken to pieces, were not put together, and a considerable time elapsed before this was done; to prevent unnecessary delay, therefore, no account was taken of the quantity of fuel necessary to raise the steam to the proper degree of elasticity. The engine being ready, made a trip to see if every thing was right, and then came up to the starting-post. It was then set off upon its task in the same way as the others, and the following Table will shew its performance.

EXPERIMENT V.

Observations.	No. of trips.	Time of getting up and stopping the speed of the train at West end.	Time taken when the engine passed the post No. 1.	Time in coming up from post No. 2. to post No. 1.	Time in going down from post No. 1. to post No. 2.	Time taken when the engine passed the post No. 2.	Time in stopping and getting up the speed of the engine.	Observations.
H. M. S.		H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	H. M. S.	
Started 1 25 40	....	0 1 23	1 27 3	....	0 11 8	1 38 11	....	Stopped on road down to post No. 2.
							0 2 39	
	1	....	1 46 25	0 5 35	....	1 40 50	....	
		0 1 19						
Boiler joint blew out and stopped the engine above the bridge at 2 1 45		....	1 48 44	....	0 6 14	1 54 58	....	
							0 1 7	
	2	....	....	....	....	1 56 5	....	
				0 5 35 +	0 17 22			
					0 5 35			
				Total time -	0 22 57	distance 4½ miles.		

In returning westward, the second trip, some of the joints of the steam generator gave way, and put an end to the experiment; after which, Mr. Erickson declared to the judges his wish to withdraw from a further competition for the prize.

No conclusion whatever could be formed from these experiments, of the power of this engine; none of the experiments were continued sufficiently long to shew the quantity of steam which could be raised in a given time, or the fuel required to generate it.

The "Perseverance," of Mr. Burstall, having met with an accident in its conveyance to Liverpool, and having been found, on trial, not to be adapted for the purposes of the company, this gentleman, in a very handsome manner, withdrew from competing for the prize.

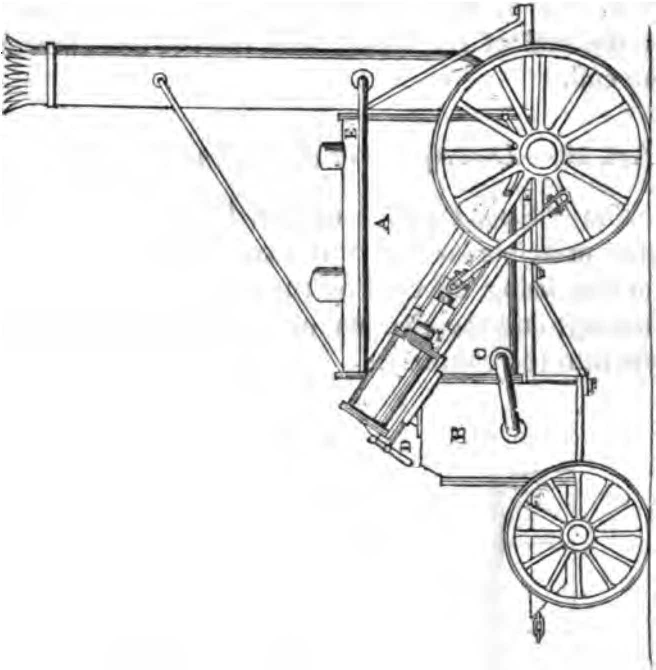
The prize was then awarded to the "Rocket," of Mr. Stephenson, as having performed all the conditions and stipulations required of the competitors.

We shall, in the first place, give a brief sketch of the construction of the different engines, and then offer a few remarks on the important improvements, to which these experiments have led.

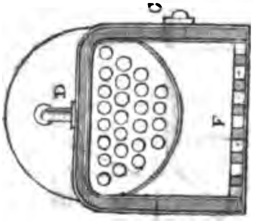
Art. 11.—*Description of the "Rocket" Engine.*

The "Rocket" engine, of Mr. R. Stephenson, shewn in the engraving, No. 7, opposite, differs from the locomotive engines previously described in this work, in the mode of raising steam. The boiler, A, is cylindrical, with flat ends, six feet long, and three feet four inches diameter. To one end of the boiler is attached a square box, or furnace, B, three feet long, by two feet broad, and about three feet deep; at the bottom of this box, the fire-bars, F, are placed, and it is entirely surrounded by a casing, except at the bottom, and on the side next the boiler, leaving a space of about three inches between this casing and the furnace, which space is kept constantly filled with water; a pipe, C, on the under side, communicating with the boiler, supplies it with water; and another pipe, D, at the top, allows the steam to pass off into the boiler. The upper half of the boiler is used as a reservoir for steam, the lower half being kept filled with water. Through the latter part of the boiler, copper tubes reach from one end of the boiler to the other, shewn in No. 8, being open to the fire-box, at one end, and to the chimney at the other. In the boiler of the "Rocket," there were twenty-five tubes, three inches in diameter. The cylinders were placed, one on each side of the boiler, as shewn in the drawing, and worked one pair of wheels only; were eight inches diameter, with a stroke of sixteen inches and a half; diameter of large wheels, four feet eight inches and a half. A slight inspection of the drawing will shew that the principle of generating steam by this engine, is the *exhausting power of the chimney*, which is aided by the impulse of the steam

No. 7.



No. 8.

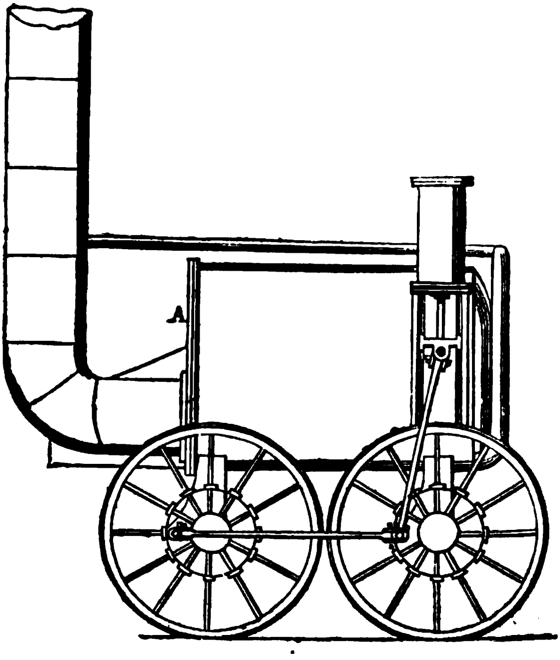


from the cylinders, being thrown into the chimney by two pipes, E, one from each of the cylinders. The area of surface of water, exposed to the *radiant heat* of the fire, was twenty square feet, being that surrounding the fire-box or furnace; and the surface exposed to the heated air or flame from the furnace, or what we shall call *communicative heat*, 117·8 square feet; the area of the grate-bars being six square feet. The end view, No. 8, will shew the disposition of the tubes in the end of the boiler, with the fire-box surrounding the end.

Art. 12.—*Description of the "Sans Pareil" Engine.*

The "Sans Pareil," of Mr. Hackworth, is of the same principle as the "Rocket;" the combustion of the fuel being effected by the *exhausting power of the chimney*, and the ejection of the steam from the cylinders into the chimney.

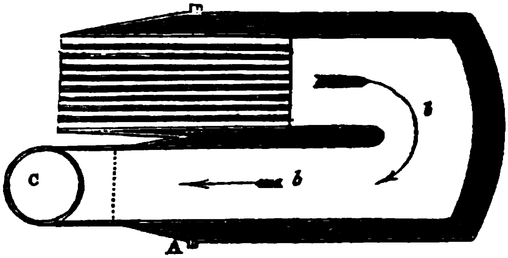
No. 9.



The accompanying sketch, No. 9, will shew the form of boiler, which is cylindrical, four feet two inches in diameter, with one flat, and one hemispherical end, and six feet long. The cylinders were placed one on each side of the boiler, and immediately above one of the pairs of wheels; the other two wheels being connected with them by side rods. Cylinders, seven inches; length of stroke, eighteen inches; diameter of wheels, four feet and a half.

The steam is generated by means of a double tube, as shewn in the sketch, No. 10, passing nearly from one end of the boiler to the other, and then returning; the fire-grate and chimney being thus both at the same end of the boiler, A, No. 10, shews the grate-bars, *b b*, the tube, and C, the chimney. The tube projects, from the end of the boiler, about three feet; and at the fire end a semi-circular casing surrounds the top of the tube, to the extent of the whole three feet, but at the chimney end the casing extends only two feet. This was for the double purpose of obtaining an area of heating surface, and to allow sufficient air to pass through the fire-grate, which tubes placed entirely within the boiler do not possess. At the fire end the tube was two feet in diameter, tapering away to fifteen inches, the diameter at the chimney; the length of grate-bars being five

No. 10.

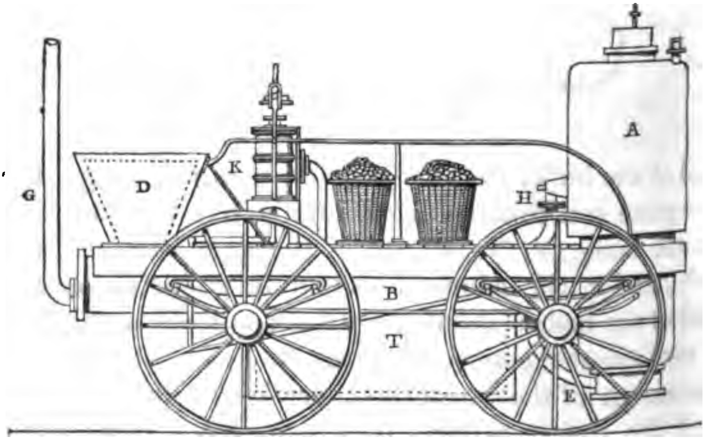


feet. The area of surface of water exposed to the direct action of the fire or *radiant heat*, was, therefore, 15·7 square feet; and to the *communicative* power of the heated air and flame, 74·6 square feet, the area of the fire-grate being ten square feet.

Art. 13.—*Description of the "Novelty" Engine.*

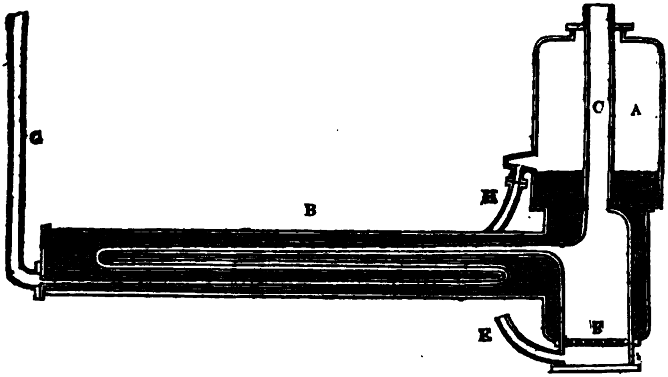
Messrs. Braithwaite and Erickson's engine, the "Novelty," is of a different principle, the air being driven or *forced* through the fire by means of a bellows. The accompanying drawings will shew the general construction of this engine, and more particularly the generator, or mode of raising the steam, which constitutes its prominent peculiarity. In the sketch, No. 11, A is the generator, the lower part of which is filled with water, and the upper part is a chamber for the steam; connected with this is the horizontal generator, B, which being placed below the top of the water in the upright generator, A, is constantly filled with water. A tube, C,

No. 11.



passes through the upright generator from top to bottom; near the bottom it is, as shewn in No. 12, increased in diameter, for the purpose of receiving the fire-grate, F; the fuel being supplied from the top, it is kept air-tight by sliding shutters. The bottom of this tube, containing the fire-grate, is closed, and the supply of air is effected by the bellows, D, worked by the engine, and communicated through the pipe, E. The air, after passing through the fire, is made to traverse through a winding tube, (shewn in the separate drawing, No. 12,) within the horizontal generator, and to

No. 12.



pass into the atmosphere through the pipe, G. K is the cylinder, working one of the pair of wheels, by means of a bell crank, the others being connected, when necessary, by a chain similar to the old engines.

No. 12, will shew the mode of generating the steam more particularly. A is the upright generator; C, the inner tube; F, the fire-grate; B, the horizontal generator; H, a pipe through which the steam from B passes into the steam chamber, A. From C, the inner tube or pipe, *e e e*, passes nearly to the end of B; returns, and then passes out at the opposite end, through which the heated air is forced. E, is the pipe from the bellows, conveying the air underneath the grate bars, to produce the necessary combustion of the fuel. The action will be readily understood, the air is forced through the fire with a velocity which causes a rapid combustion of the fuel, and the heated air and flame is forced along the winding tube, *e e e*, into the atmosphere, through the pipe, G. The area of grate-bars, in this engine, is only about 1·8 square feet. The *radiant surface*, about 9·5 square feet; and the area exposed to the heated air, by means of the tube traversing the generator, B, about thirty-three square feet.

Mr. Burstall's engine, not being adapted for the present celerity of railroad conveyance,—nor being of that form which combined lightness with economy of fuel, —it will not, perhaps, be necessary to attempt a more particular description of it; the boiler, consisted of an upright generator, the heated air and flame escaping up the chimney immediately from the fire-place, without any flues to abstract the redundant heat. But we must add, that though its general construction rendered it inapplicable for the use of the company, yet several of the individual parts displayed great ingenuity.

The estimate of Messrs. Walker and Rastrick, of the powers of the engines in use previous to those trials, deduced from the performances of the engines on the several railways they visited, was, that an engine, weighing, with its tender, ten tons and a half, would be capable of taking nineteen tons and a half weight, or a gross load, including the engine, of thirty tons, at the rate of ten miles an hour, on a level railway; or, according to their mode of reckoning, a gross load of twenty tons, at fifteen miles an hour, being only an efficient load, exclusive of engine, of nine tons and a half, with an engine, weighing, with tender, ten tons and a half.

The result of these experiments was, that an engine, weighing, with its tender, only seven tons nine cwt., took a load of nine tons and a half at the same rate of speed; this was very important, as the weight of the old engines was such as to place a limit to their application; they were already of a weight considered to be the maximum, without injuring the rails, and could not, it was supposed, be increased, and consequently could not be made more powerful; a high rate of speed was out of the question, as, even at fifteen miles an hour, the gross load was only nine tons and half; and, therefore, no useful result could be accomplished by such engines, at a rate of speed above ten miles an hour.

To have accomplished, at once, a reduction of three tons weight in the engine, or nearly fifty per cent., and thereby admitting the use of those engines upon roads, where their great weight previously was an insuperable objection, was of itself of very great importance, to the employment of this species of traction; but this was not the whole amount of the benefits derived from this competition of talent; the consumption of fuel was likewise diminished forty per cent. The great improvement, however, was the increased evaporating powers of the engine, by the employment of numerous tubes of small dimensions; thus the Rocket engine, weighing only four tons and a quarter, had an extent of evaporating surface, three times and a half greater than the old engines, weighing seven tons and upwards; and, as it has been previously stated, the power of those engines depending solely upon their evaporating powers, it will at once be seen, what a field was opened out for the extension of the use of those engines. These tubes were used at the suggestion of Mr. Booth, treasurer to the Liverpool and Manchester Railway Company; and nothing since the introduction of those engines, has given such an impulse to their improvement.

The competing engines being limited to weight, the effect was not an increased load at a greater rate of speed, or a greater amount of performance by those engines, beyond the old engines; the effect being, as the quantity of water evaporated per hour, the Rocket only evaporated 18·24 gallons per hour, the old engines 15·92 gallons; therefore, the practical effect, as engines, was nearly the same. But, as an engine weighing only four tons and a quarter, performed the same work of an engine weighing seven tons, it was easy to see, that if the former was increased in weight, its power would be much more than correspondingly increased, as the weight might be added to the boiler, and those parts of the engine by which the power is generated; the wheels, and several other parts not being required to be increased in weight in the same proportion.

Accordingly, we find that, immediately after these experiments, the engines were made of a greater weight, and consequently greater power; this was not done at first, perhaps, to the extent which subsequent experience has proved to be advisable, but the effect of these experiments was, that the railway company were enabled to commence operations, at a rate of speed very much beyond what could have been contemplated by the most sanguine friends to this kind of motive power. The quick trains commenced with a rate of speed equal to twenty miles an hour, and this has since been increased; this was also done with a practically useful load, as, by constructing larger engines, the evaporating power was increased very considerably beyond that of the old engines; and, consequently, they were capable of conveying nearly the same load as the old engines, at an increased rate of speed.

Art. 14.—*Description of the improved Killingworth Engines.*

An improved plan of the boiler of the common engine, has been adopted, at the Killingworth Colliery, by the writer, by which, the evaporating power is very much increased; and which, for private railways, where the load to be conveyed at a time, does not require to be greater than sixty or eighty tons gross, at a rate of eight to nine miles an hour, will be found very economical. *Fig.* 14, *Plate VI.* is a representation of the plan of this boiler; A, is the boiler, which is cylindrical, with flat ends, ten feet long, and three feet and a half, or four feet, in diameter; a short tube, *a b*, *c d*, two feet in diameter, and of a length sufficient for the grate-bars, is placed within the boiler, within about an inch of the lower side of the boiler, and similar to the single tube of the common engine boilers; the grate-bars are laid about two thirds from the top of the tube, leaving sufficient space for the fire above the bars; but as there is not sufficient space below the grate-bars for the requisite quantity of air to support the combustion of the fuel, a hole is cut through the bottom of this tube, and also through the boiler, by which an increased quantity of air is got underneath the grate-bars; a ring of iron, an inch thick, is placed around this opening, and the rivets passing through both the boiler plates, this ring, and the plates of the tube, keeps the boiler water-tight, and also allows a space of one inch of water to surround the inner tube below the grate-bars. This tube being surrounded with water on all sides, the entire radiation of the fire has effect. At the end, *a c*, a flat plate of copper, riveted to the tube, closing the end, and it is made water-tight; the outer end, *b d*, of the tube, passing through the end of the boiler, and being also made water-tight all round its periphery. Tubes similar to those described, as being introduced into the Rocket engine, and now used in all the improved engines, are inserted into the copper plate at the end, *a c*, of the tube, as shewn in the drawing; and pass through the end of the boiler, and are clinched to the copper plate, and end of the boiler, by a mode which will hereafter be more particularly described, when treating of the improved engines. At the end of the boiler, where the tubes pass through, a chamber is fixed, similar to that described in the Rocket engine, on the top of which the chimney is placed.

In this plan, therefore, no fire-box is required, the construction is much more simple, and for private railways where rapid rates of travelling is not required, this plan will produce steam very rapidly, and will be found quite sufficient for the load above stated. It is necessary, however, that the plate at the end, *a c*, of the fire-tube through which the small tubes pass should be of copper, experience having shewn, that neither iron or brass will answer the purpose. From experiments made, and from the daily practice of these engines, we place the evaporating power of a boiler, such as *Fig.* 14, as equal to 280 gallons per hour.

Art. 15.—*Description of the modern Engines for public Railways.*

Having thus given a detailed history of the great improvements made in the locomotive engine, induced by the memorable contest at Liverpool; and, in elucidating the principles of the different engines there exhibited, given such drawings, and explanations, as will convey to the reader a perfect knowledge of the progress of improvement, from the old engines to those at present in use; we shall now proceed to describe, in detail, the construction of some of the most improved engines for public railways.

Boiler, and method of generating Steam.

Fig. 1, *Plate XI.* is an elevation, and *Fig.* 2 an end view, of the interior of the boiler, and other working parts connected therewith; $a\,a'$, $b\,b'$, is the boiler, which is cylindrical, and, generally, three feet in diameter, eight feet long. $a''\,b''$, *Fig.* 2, showing one end; a hemispherical chamber, $a\,c$, $d\,d'$, is attached to the end, $a\,b$, of the boiler, by the corner plates at a and b, which chamber, as shewn in the figures, is a little larger in diameter than the boiler; within this chamber, the square box, $e\,e'$, $f\,f'$, is placed, a little rounded on the upper side at $e\,e'$, and bent outwards at $f\,f'$, so that it can be riveted to the chamber at $d\,d'$, and made steam-tight. Though, in the drawings, the outlines of the chamber and fire-box are only shewn, they are both entirely close on all sides and top, and are only open at bottom, with the exception of the chamber, which is open within the area of the end of the boiler; $g\,g$ are the grate-bars, and h, the fire-door of the fire-box. As these boilers are subjected to a considerable pressure of steam, the flat sides of the chamber, and fire-box, and also the top of the latter, are not calculated to sustain the pressure; bolts are therefore placed around the sides between the chamber and fire-box, as shewn in the drawings, to resist the pressure; and cross bars of wrought iron, $i\,i\,i\,i\,i$, *Fig.* 2, and i, *Fig.* 1, are placed upon the top of the fire-box, and fastened down to it, by bolts screwed on the under side, and keyed on the upper side, as shewn in the drawings. The fire-box is, therefore, entirely surrounded by the water of the boiler, except on the under side, where the grate-bars are laid, and at the opening for the fire-door. The other end, *a′ b′*, of the boiler is closed by a circular flat plate; the lower half of this plate, or end of the boiler, is perforated with holes, to receive one end of the small tubes; and similar holes are perforated in the side of the fire-box, as shewn in *Fig.* 2. *k k*, *Fig.* 1, is a longitudinal view of the tubes, and *k*, *Fig.* 2, an end view. At the other, or chimney end of the boiler, a chamber, *l a′*, *l′ l″*, similar in shape to that of the other end previously described, is affixed, on the top of which the chimney, *m*, is placed; it will, therefore, be seen, that the tubes open at one end into the fire-box, and, at the other end, into the chimney. The chamber on which the chimney is placed, is, of course, close on every side, except that part within the area of the chimney; but there is a door at *n*, for the purpose of giving access to the interior of the chamber, and, more particularly, for cleaning out the inside of the tubes. It will, of course, depend upon the diameter of the boiler, and tubes, what number can be inserted; but, as they are placed near each other, the number is, generally, very considerable. *Fig.* 5, shews, on a large scale, the mode of inserting them into the plates of the boiler, and fire-box; *a b* represents the plate of the boiler, and *e e* the hole, which is bevelled outwards; *c c* is the tube; when the tube is inserted, and hammered out, or enlarged at the extremity to fit the bevel of the hole, a hoop, *f f*, also bevelled on the exterior surface, but parallel on the interior side, is driven within the tube, and hammered, or clinched against the interior of the tube.

As the elasticity of the steam, has a constant tendency to press the plate outwards, a glance at the figure will shew, that the greater the pressure, the more tightly will the tube press against the steel ring, and, consequently, keep it fast; to prevent, however, too great a strain upon the tubes, it is customary to insert two or three stays within the boiler, reaching from the chimney end of the boiler, to the exterior end of the fire-box chamber, as shewn at *o o*, *Fig.* 1. *p*, *Fig.* 1, is the man-hole door, or aperture, for the purpose of admitting a man into the interior of the boiler, when any repairs are necessary; it is made steam-tight by an iron plate, bolted to an upright pipe, with flanches; *q q'*, are two other openings into the boiler, for the safety valves; *q* is for a mitre valve, with a handle, as shewn in *Fig.* 1, *Plate XII.*; the end of this handle, as seen at 1, in *Fig.* 2, *Plate XII.*, is fixed to a spiral spring, with a vernier, 2, working up and down, as the steam is increased or diminished in elasticity; and shewing, by proper graduated marks upon the fixed plate, 2, the degree of elasticity of the steam pressing against the valve; *q'* is another valve, which is covered up, as shewn in *Plate XII.*, so that the engine-man cannot have access to it, to overload it; this safety valve is not loaded quite so heavy, or to so great pressure as *q*; so that when the steam in the boiler becomes of too high a degree of elasticity, it first escapes by this valve, and gives notice to the engine-men to check the intensity of the fire; which is done by a flap, or fan, placed within the chimney, and turned by the rod, *w w*, *Fig.* 1, *Plate XII.*

Fig. 4, *Plate XI.* exhibits the mode of ascertaining the height of the water in the boiler, *d*, is a glass tube, open at each end, and fixed in the two brass cases, *h h*, and attached to the end of the boiler, *a b*, by means of a pipe, which gives a communication between the boiler and the glass tube; *e f*, are two cocks, for opening or shutting off the communication between the boiler and the interior of the tube; *c*, shews the height of the water in the boiler. When the two cocks, *e f*, are open, there being then a free communication from the water in the boiler, through the tube, to the steam in the upper part of the boiler, the water will therefore stand at the same level within the tube at *c′*, as it does at *c*, within the boiler; *g h* is a pipe for carrying off the water within the glass tube, when necessary, and which is done by opening the cock, *g*, and shutting *e* and *f*. The boiler is supplied with water by two force pumps, worked by the engine, and shewn in *Fig.* 1, *Plate XII.* It is necessary to these boilers, where only a very small space can be allotted for water, that the supply be kept up with certainty, and hence a duplicate pump is always used.

The cylinders are placed within the chamber, *l d′ l′ l″*, *Fig.* 1, at the chimney end of the boiler, A, representing one of them; the plan of admitting the steam into the cylinder is by slides, which will be more particularly described hereafter; *r* being the steam chamber, into which the steam is thrown, from the boiler, previous to its admission into the cylinders, by the slides. In these engines, where the boilers are required to be of the least possible dimensions, and where the emission of steam to the cylinders, is so extremely rapid, considerable difficulty was at first experienced in preventing the water from mixing with the steam, and being thus carried into the cylinders, or, what is called by the engine-men, "priming;" the agitation of the water by the motion of the engine, and the rapid evolution of steam, increasing the difficulty; this is now obviated, by placing a chamber, B, on the top of the boiler; the steam-pipe, *c*, being carried nearly to the top of the chamber, to receive the steam, and being funnel-shaped, or spread out at the top, and nearly filling the chamber, the water is thus separated from the steam, and falls back into the boiler, and the steam alone passes into the steam-chamber and cylinders.

The regulator, for increasing or diminishing the supply of steam to the boiler, is placed between the pipe proceeding from this chamber, and the two pipes leading to each cylinder. *Fig*. 8, shews the regulator on a large scale; *c*, is the steam-pipe, leading from the chamber, B, and *s s*, are the two steam-pipes, leading to each cylinder; over the mouth of each of the pipes, *s s*, a disk, or slide, 1 1, moves back and forwards, alternately closing or opening the mouth of the pipes, as they are moved round. These two disks are fixed upon the horizontal rod, 2 2′, *Fig*. 1, by which they are turned round; this rod reaches the whole length of the boiler, and, passing through the opposite end, is turned by a handle, 4, as shewn in *Fig*. 1. It will be seen, that the regulator, *a*, *Fig*. 8, is a chamber, with the pipe, *c*, leading into it from the boiler, and the two pipes, *s s*, leading from it to the cylinders; and that, as the disk is moved round, the communication is either opened or shut, to the cylinders. These disks are, of course, kept tight against the face of the mouth of the pipes, by the pressure of the steam, but spiral springs are likewise placed between the arms of the spindle, or rod, 2 2′, and the brass face of the disk, as shewn in *Fig*. 8, to keep a constant pressure against the face of the pipes. To resist the contraction and expansion of the rod, 2 2′, as well as to make it steam-tight, in passing through the boiler at the handle, 4; a tube, 3 3′, bored out on the inside, passes through the end of the boiler, and is bolted to it at the end, 3′, by a flanch;

the end, 3, of this tube, is conical, into which the rod is made to fit, as shewn in the figure, being pressed steam-tight against it by a spiral screw, fixed within the tube. The rod has a sliding joint at 2', to compensate for the contraction, and expansion, and at the same time allow the disk, at the end, 2, to be pressed tight against the face of the steam-pipes, and the part, 3, steam-tight, at the other end.

As previously stated, in describing the progressive improvement of these engines, the chimney is not of sufficient height or power to create draught of air through the fire, to produce steam sufficiently quick to supply the cylinders, when travelling at rapid velocities; the steam, therefore, after passing through the cylinders, is thrown into the chimney, to create a sufficient draught. *t*, *Fig.* 1, shews the pipe through which the steam is thrown into the chimney; an end view of which is shewn at *Fig.* 11, *v v*, being the pipes leading from each cylinder, into the single vertical pipe, *t*, called the "blast pipe."

For the purpose of giving warning to the passengers, that the engine is about to start, or to persons standing or straying about upon the line of railway; a contrivance has been adopted in the shape of a steam-whistle, which produces a very smart and shrill sound, and which can be heard at a very considerable distance. *x*, *Fig.* 1, *Plates XI.* and *XII.* shews this contrivance fixed to the boiler, within reach of the engine-man. *Fig.* 11, *Plate VI.* shews the construction of this, on a large scale, which consists of a pipe, fastened to the top of the boiler, by the flanch or plate, *a a;* a cock, *b*, is placed in this pipe, which being opened or shut, allows or prevents the steam from issuing through this pipe; when open, the steam passes into the hollow cup or chamber 11, through the apertures of a plate, shewn in the plan, 2 2, and which is placed upon the pipe, at its opening into the bottom of the chamber, 1 1. The steam then passes around the plate 3 3, between its edge and the side of the cup, 1 1, and, striking with great force against the thin edge of the cup, 4 4, produces a most powerful, sharp, and shrill whistle.

Fig. 12, *Plate VI.* is a vacuum valve, for the purpose of allowing the steam to escape out of the boiler, when the pressure is very low, and when the boiler is required to be emptied of steam; they are sometimes attached to the cylinder, and sometimes to the boiler, by the flanch, *a a*; as will be seen, it is a mitre valve, opening inwards, and, consequently, so long as the steam is above the pressure of the atmosphere, the valve is shut, and prevents its escape. There is, however, a spring in the inside of the valve, which is acted upon by the plate, *i*, fixed upon the upright spindle, passing through the top of the valve. Upon this spindle, there is a spiral thread, with a nut on the outside of the valve, at *c*; when, therefore, this screw is turned, the plate, *i*, presses against the spring, and, acting on the valve, forces it down, and then allows the steam to escape. When in use, by causing the spindle to act upon the spring, any degree of pressure is kept upon the valve, and, therefore, when the steam gets below that pressure, it escapes, and gives notice to the engine-man, that the steam is below the proper degree of elasticity.

Fig. 13, *Plate VI.* is a syphon oil cup, for the purpose of keeping up a regular and constant supply of oil to the various working parts of the engine; it is fastened to the parts where required by the screw, *a*, the oil being put into the chamber, *b*, of sufficient quantity to serve a journey, or day's work, of the engine; it is made to feed down upon the bearing by a cotton wick.

Fig. 15, *Plate XI.* is a valve, or ball-clack, which is used for the force pumps supplying the boiler with water. From *a* to *b*, is a pipe, on the top of which, at *a*, it is mitred, and the ball rests upon this mitre; the upper part being open from *a* to *c*.

Mode of admitting the Steam into the Cylinders, and of working the Engine.

Having thus described the form and construction of the boiler, and the manner in which the steam is generated, we have now to explain the mode of transmitting the steam into the cylinders, and the plan of producing the locomotion of the engine. The cylinders, as previously stated, are placed horizontally, as shewn in *Fig.* 1, *Plate XI.*, and in the same plane with respect to each other; A, *Fig.* 1, representing one cylinder, and D, *Fig.* 3, the other. These cylinders are fixed to the frame-work of the boiler, and, being within the chamber, into which the heated air from the tubes is thrown, in its passage to the chimney, they are always kept at a high degree of temperature. 5, and 6, are the pistons, 5 5, being the piston-rod, and 5 9, the connecting rod, of one cylinder; and 6 6, the piston-rod, and 6 10, the connecting rod, of the other; the former represents the connecting rod and crank, in a line with the cylinder, and the latter the crank, at right angles with the line of the cylinder.

The parallelism of the piston-rod is effected generally by the use of slides, as being most convenient for this description of engine; 8 8, *Figs.* 1 and 3, are the stuffing boxes or glands of the cylinders; and *Figs.* 12, 13, and 14, shew the slide-bars, constituting the parallel motion for the piston-rods. *a*, *b*, *c*, *d*, *Fig.* 13, is an end view of the two plates, fixed parallel with the line of the centre of the cylinder, and crank axle. *Fig.* 14 is a plan of the same plates, the upper ones, *c d*, being removed to shew the slide; *e e*, is the cross-bar to which the piston-rod, 6, is attached, as shewn in *Fig.* 12; and to which the end of the connecting rod, 10, is likewise attached, as shewn in *Fig.* 14; this cross-bar is inclosed within the brass carriage, 1, 2, 3, 4, *Fig.* 13, resting on 1, 2, as shewn in *Fig.* 14; and 3, 4, forming the cover; this carriage slides within the parallel plates, *a*, *b*, *c*, *d*, and thus the parallelism of the ends 5, and 6, of the piston-rods, is effected, while the stuffing-boxes, 8 8, and pistons, preserve the rectilinear motion of the other end. One end of the connecting rod, therefore, keeps up an alternating rectilinear motion, and the other, by means of the crank, a continued rotatory motion, by which means the locomotion of the engine is effected. We have said, that the drawings shew one of the cranks in a line with the centre of the cylinder, while the other is at right angles with it; this is necessary to secure a continued and certain rotatory motion to the wheels, and to accomplish this, it is necessary to have two cranks upon the driving axle of the engine. *Figs.* 9 and 10, *Plate XI.* are two views of the axle, upon which the propelling or driving wheels are fixed, which move the engine. This axle is cranked in two places, at E, and F, as shewn in the two drawings; *a a* being the part where the chair rests upon, and *b b*, that part whereon the wheels are fixed. The axle is cranked in such a manner, as that when one crank is horizontal, the other is vertical, and vice versâ, being at right angles with each other; thus, in *Fig.* 9, the crank, E, is horizontal, and F, vertical; and in *Fig.* 10, the crank, E, is vertical, and F, horizontal. The cause of this, as explained previously, being to ensure a continuous rotation to the wheels, by either one or other of the cranks being continually subject to the action of the cylinders and piston rods.

Having thus shewn the manner in which the pistons act, in producing the rotation of the wheels, we now come to a very important part of the mechanism of these engines, viz., the mode of applying or transmitting the steam to the cylinders, and pistons; this is effected by what is called the slide valve. Upon that part of the cylinder inclosed within the chamber, *r*, *Figs*. 1 and 3, *Plate XI*. a face is made quite smooth, on which there are three apertures, *a a′ z*, and *c c′ z*, *a c*, communicating with the bottom of each cylinder, *a′ c′*, with the top, and *z z*, leading to the discharging pipe, *t*; a box, *e e′*, slides steam-tight upon the face of the cylinder over these holes, leading to the top and bottom of the cylinder, and to the discharging pipe; the inside of this box is hollow, and it is just large enough to embrace two of the holes, the middle one, *z*, and one of the others; the remaining one being open to the outside of this box, and consequently to the inside of the chamber, *r*. When this box is therefore moved back and forward, it alternately effects a communication between the steam chamber, *r*, and either one, or the other of the openings, to the top or bottom of the cylinder, and, consequently, with the discharging pipe, *t*. Thus, in *Fig*. 3, the steam chamber, *r*, is open to the bottom, *c*, of the cylinder, and the top, *c′*, is open to the discharging pipe, or recess, *z*; whereas, in *Fig*. 1, the top of the piston is open to the steam chamber, and the bottom to the discharging pipe.

The slide, or box, on the face of the cylinders, is moved back and forward, by means of the following contrivance, four sheeves, or rings, are fixed upon the axle of the driving wheels, upon false centres, and called eccentrics, as G, H, I, K, *Figs.* 9 and 10. In one revolution of the axle, the extent of the rectilinear motion produced by each of these eccentric wheels, is represented by the distance, 1 2, 3 4, which is equal to the distance that the slide, *e e′*, is required to be moved upon the face of the cylinders. A strap, or ring, is therefore placed around the periphery of each of these eccentric wheels, as shewn at L, *Fig.* 3, and likewise in *Fig.* 6, to which a rod is attached, communicating with the cross-head, M N, fixed at R, and by which the slide is moved back and forwards by the rod, P. By these it will be seen, that in every revolution of the axle, and crank, the slide, *e′*, is moved back and forwards, so as to transmit the steam alternately from the top to the bottom of the piston, and the reverse. From the nature of the eccentric, however, the slide, *e e′*, is continually in motion, and, therefore, no sooner are the apertures fully open, than the slide, by moving, commences to shut them again; and, therefore, to prevent any injurious effect, or to secure the free admission of the steam into the cylinders, from the apertures being so diminished, they are generally made sufficiently large, so as to check the force of the steam, when they are partially open or closed.

To give full effect to the steam, the passage communicating the steam to the piston should, perhaps, remain fully open, until the piston arrives at the extremity of the cylinder, or in the position shewn in *Fig.* 1, when the steam should be instantaneously shut off from the one side, and applied as quickly to the other, as is done in some of the fixed engines; this cannot, however, be done by the eccentric motion. There is likewise another important consideration, the engine has alternately to travel in different directions; if, therefore, one eccentric was used for each slide, it would have to be placed in the same position as the crank, to suit the motion in travelling in both directions; and the slide would be moved to the extremity of the face of the cylinder, or be fully shut, when the piston was at the end of the cylinder; full open at the middle of the stroke; and again completely shut, when the piston was at the other end of the cylinder. This sort of motion would cause the steam to be applied to the piston, until it arrived at the extremity of the stroke, and, consequently; the admission would not commence untill some time after the piston begun to move in the opposite direction, and would not be fully open until the piston was at half stroke; when it would again gradually close, until it reached the extremity of the stroke. This, as might be expected, would operate very injuriously to the engine; inasmuch as the full pressure of the steam would be upon the piston to the extremity of the stroke, and very little, if any, steam would be applied to the piston, until some time after the returning stroke; the very reverse of the expansive system, so beneficially applied to high pressure-engines.

As stated, in a former part of the work, experience had shewn, that to obtain a maximum effect, it was necessary that the steam should be entirely shut off before the piston arrived at the extremity of the cylinder, and that it should be open to a certain extent, when the piston commenced its motion, in the opposite direction; or in fact, that, in those engines which travel at great velocity, the expansive system should be carried further than with large fixed engines, and that the steam should not only be shut off from the piston, before it arrives at the end of the stroke, but that the steam should even be applied to the opposite side of the piston, before it reached the extremity of the cylinder; or that the slide should, at the extremity of the stroke, be opened to a certain extent. The extent to which the slide should be open at the return of the stroke, will depend upon the velocity of the piston; in well-arranged engines, one-eighth of an inch has been found to produce the best effect. Mr. Pambour, in his excellent work, has devoted a chapter to this part of the subject, to which we would refer the reader, requiring complete information on this part of the mechanism of locomotive engines.

We have shewn a method by which this was effected, by the eccentric being placed loose upon the axle, by which the axle was moved round to a certain extent, before the slide was moved at all. Upon public railways, where the speed is very rapid, there is some risk attending the use of one eccentric, working loose upon the axle, and two eccentric wheels are therefore now generally adopted, for working each cylinder; each of which is placed in the proper position for moving in opposite directions, and the change is made by a particular contrivance, with the cross heads, M N, working the slides; several engines are, however, yet erected with single eccentrics.

The drawings, *Figs.* 6, 7, and 9, *Plate XI.*, shew the mode of working the slides by double eccentrics. G, H, *Fig.* 9, working one cylinder, and I, K, the other; each of which are placed in the proper position for admitting the steam into the cylinder, at such a period of the stroke, as to produce a maximum effect, when the engine is moving in opposite directions.

We shall afterwards inquire at what periods of the stroke of the piston this should be effected. On attentive examination of the drawings, and of the position in which these eccentrics are placed, so as to produce that effect, it will be seen, that there are four eccentrics, two for each cylinder, one for working the slide, when travelling in one direction, and one for working the same slide, when the engine is travelling in the opposite direction; it is necessary, therefore, when the motion of the engine is to be changed from one direction to the other, that one of these sets of eccentrics should be thrown out of geer, and the other set put into geer; the great difficulty, therefore, is, to change the motion of the slide-rods, from one eccentric to the other, and which is done by the clutches, which embrace the slide-rods, being thrown in and out of geer by particular contrivances.

In some of the engines, one handle is used, for changing the motion of each cylinder, or throwing the slide-rods in and out of geer; this is, however, apt to produce mistakes by the engine-man, and, therefore, plans have been devised, for changing the motion of both cylinders, with one handle. This is done in different ways, by different manufacturers. We shall describe a method, adopted by Messrs. Hawthorn, of Newcastle, which, we know, works very effectively. *Figs*. 6 and 7, *Plate XI*. shew the manner of accomplishing this. I, *Fig*. 6, shews one of the eccentrics, A B, being the ring, embracing the eccentric, and shewing the manner of fixing the rod to it, and which is adjusted to the proper length, by the screw-nuts at A and B; this is the best mode of adjusting the length of the eccentric rods with which we are acquainted, the other eccentrics being fitted up in a similar manner, and being shewn by the dotted lines; *a b c d*, are the four bars, proceeding from the four eccentrics; the ends of these bars are attached to forked clutches, or arms, hanging from the levers, *g g′*, and *h h′*; the end of the bar, *a*, at *s*, to 1 1; *b*, to 2 2; *c*, to 3 3, and *d*, to 4 4. The lower end of these forked arms are made to fit upon the cross-bars, at 5, 6, 7, 8, *Fig*. 7, which is an end view of the cross-head, M N, *Fig.* 3, and which works the rod, P, and slide, *e e′*, back and forwards; the two weigh-bars, 5, 6, *Fig.* 6, are in the position attached to, or resting upon, the cross-bars, 5 and 6, *Fig.* 7. As shewn at *Fig.* 6, these forked rods are hung at their other, or upper ends, from arms, or levers, fixed upon the centres, *g* and *h*; 1 1, and 2 2, being suspended from the lever, *h h′*; and 3 3, 4 4, from the arm, or lever, *g g′*. When the forked arms are thrown into geer, or rest upon the weigh-bars, R S, R M, as 1 1, upon 5, and 2 2, upon 6, *Fig.* 7, and, being attached to the rods, *a b*, of the eccentrics, the arms, N and T, are worked by the eccentrics, and, consequently, the slides, *e e′*, *e e′*, of the cylinders; but, when the forked arms are lifted out from off the weigh-bars, 5 and 6, they move back and forwards, suspended from the end of the levers, as in the case of 3 3, 4 4, from *g g′*, without moving the slides at all. The system of working the slides, therefore, is, that four forked arms attached to, and working continually with, the eccentric sheeves, two for each cylinder, are alternately thrown in and out of geer, as the engine moves in different directions; two only of these forked arms being in action at one time, the two which are resting upon the weigh-bars, 5, 6, or 7, 8, are working the slides of the cylinders, and the other two, which are not resting upon these bars, are inoperative. It is only, therefore, necessary, in order to change the motion of the engine, to lift one set of these forked arms, from off the weigh-bars, 5, 6, 7, 8, and replace them by the other two. We shall now describe how this is effected, *g f* is another arm, upon the axle, *g*, from which the rod, *e*, proceeds, to the handle, H, fixed upon the fulcrum, F, and worked by the engine-man; the lever, *g g′*, is prolonged in the opposite direction, to *i*, to which a pin is fixed, fitting vertically within the oblong hole, in the lever, *h h'*, the prolongation of the lever, *h h'*, from *g*, being shewn by the dotted lines. When, therefore, the handle, H, is thrown back, as shewn in *Fig.* 6, the lever, *g g'*, is raised upwards, and, with it, the forked arms, 3 3, and 4 4; while, at the same time, the lever, *h h'*, is depressed, by the pin, *i*, working in the oblong hole, at *i*, and with it the forked arms, 1 1, and 2 2; and, consequently, by this operation, the two forks, 11, and 2 2, are thrown into geer, or upon the weigh-bars, 5 and 6; while the two forks, 3 3, 4 4, are raised up, or lifted, out of geer, or from the weigh-bars, 7 and 8, *Fig.* 7.

When, however, the handle, H, is thrown forwards, the lever, *gg'*, is depressed, and the lever, *h h'* raised by the pin, *i*, acting in the same manner as before, against the oblong hole; the forked arms 1 1, and 2 2, are, therefore, lifted from off the weigh-bars, 5 and 6, or thrown out of geer, and the forks, 3 3 and 4 4, are depressed or thrown into geer upon the weigh-bars, 7 and 8, *Fig.* 7; N, and T, *Fig.* 7, representing the ends of the arms, N and T, *Figs.* 3 and 1; the slides are thus, by this contrivance, alternately engaged or disengaged from the two eccentrics.

The rods *a*, and *c*, are attached to the eccentrics, I and K, of one engine, and the rods *b*, and *d*, to the eccentrics, H, and G, of the other. The eccentrics, K, and G, being fixed in the proper position upon the axle, for applying the steam to the cylinders at the proper time, when the engine is moving in one direction; and the eccentrics, I, and H, when the motion is reversed, or when the engine is moving in the opposite direction. According to this arrangement of working the slides, and changing the motion of the eccentrics; nothing more is required to reverse the direction of the engine, than to move the handle, H, from one position to the other.

Figs. 1 and 2, *Plate XII.* are a side view and elevation of a locomotive engine complete, the middle wheels, being those to which the steam is applied, and being larger than the others. The figures in this plate have the same reference as in *Plate XI.* The handle, H, for changing the motion of the engine, is a little different from that described in *Fig.* 6, *Plate XI.*, the mode of working the slides being different. *p* is the pipe leading from the water-tank to the force pump, for supplying the boiler with water. We have not shewn the plan of pump, but as the mode of working such pumps are so well known, except shewing the sort of clack generally used, we did not think it necessary to give any plates to illustrate the plan of working these pumps. We may, however, observe, that there are always two pumps attached to each engine, the constant and certain supply to engines of such rapid evaporating powers, being of the greatest consequence. The pumps are worked from eccentrics, on the axle of the wheels of the engine.

We have not given a plan of the tender, for carrying the coke, and water; these are made similar to other carriages in the frame-work and wheels, with a wrought-iron tank, of a quadrangular form, about two feet and a half high, and one foot and a half wide, around the sides of the platform of the carriage, open at the end next the engine, the space within being allotted for the deposit for the coke.

The plan of engine shewn in *Fig.* 1, *Plate XII.* is such as is used for the conveyance of passengers, or where the load to be taken is not great, or where a great amount of adhesion is not required; the driving wheels of this engine are five feet in diameter, calculated for a speed of twenty-four miles an hour. When heavy trains are to be propelled, or where the gradients of the road is such that adequate adhesion is not obtained, four of the wheels are coupled together, by which a greater amount of adhesion is obtained; this is done b projecting the axles of the driving wheels beyond th frame-work of the engine, and cranking the ends; th axle of the other pair of wheels is made to project i like manner, and a horizontal rod between the ends o the crank, connects the motion of the wheels with eac other; and, in some cases, as for the inclined plane on the Liverpool and Manchester line, and also for th Newcastle and Carlisle railway, all the six wheels of th engine are so coupled; the wheels, in this case, bein of less diameter.

In the Great Western railway, which is made seve feet wide between the rails, and on which Mr. Brune proposes travelling at a higher rate of speed, he ha made his driving wheels of a larger diameter; and th Messrs. Hawthorn are now constructing an engine fo that railroad, with driving wheels ten feet in diamete calculated for a speed of forty miles an hour.

Tables of the Dimensions of Locomotive Engines.

We now give tables of the dimensions of severa engines, constructed by Messrs. Stephenson and Co and Messrs. R. and W. Hawthorn of Newcastle upo Tyne.

		* Area of tubes in surface exposed to the contact of heated air.	Chimney.	Wheels.						Dimensions of steamway to cylinder.		Weight of engine.			
a sed he nt ric.	Area of fire grate.		Diameter.	No.	Driving.		Sup-porting.		No.	Length.	Width.	In working trim.		Empty.	
eet.	sqr. feet.	sqr. feet.	ins.		ft.	ins.	ft.	ins.		ins.	ins.	tons.	cwt.	tons.	cwt.
-	7·1	286·66	13	2	5	0	3	6	2	6	1 1/16	—		7	7
94	10·7	366·71	13½	2	4	6	3	6	4	7	1 2/16	—		—	
90	10·15	366·71	13½	2	4	6	3	6	4	7	1 1/16	—		—	
21	9·27	339·36	13½	2	5	0	3	6	4	6	1⅛	—		—	
78	6·0	249·08	13	2	4	4	4	4	2	5½	1	7	2	6	5½
67	5·75	208·51	12	2	5	0	3	6	2	5½	1	—		—	
71	10·32	360·71	13½	2	4	6	4 3	6 6	4	7	1 1/16	—		—	
44	6·73	200·36	12	2	4	6	2	8	4	6½	1	7	3	6	4
15	5·61	197·53	12	2	4	6	2	8	4	6½	1	6	13	5	18½
52	9·5	343·04	13½	2	5	0	3	6	4	6	1⅛	11	6½	9	3
87	6·7	185·79	12	2	4	6	2	8	4	6	1	—		—	
01	7·4	326·63	15	2	4	0	4	0	2	—	—	8	4	7	8¼
94	6·01	206·22	12	2	5	0	3	6	2	—	—	—		10	2
82	8·02	356·44	15	2	4	6	4	6	2	8	1	9	1	7	18
08	6·08	187·75	12	2	5	0	3	6	2	—	—	—		—	
87	6·0	232·84	10	2	4	4	4	4	2	—	—	7	10	6	13
31	5·6	270·23	12	2	4	6	3 2	0 6	4	—	—	7	1	6	8
07	5·1	165·85	11½	2	4	6	3	0	4	—	—	6	12½	5	12
82	4·84	243·70	12½	2	4	6	4	6	2	—	—	7	4½	6	11¼
54	5·73	250·13	12½	2	4	0	4	0	2	—	—	7	5	6	9
72	10·2	339·45	16	2	5	0	3	6	4	—	—	11	17½	9	19½
78	10·2	490·23	17	2	4	6	4 3	6 6	4	—	—	—		—	
78	10·2	531·71	17½	2	4	6	4 3	6 6	4	—	—	—		—	
20	5·4	183·55	11½	2	4	0	4	0	2	—	—	5	12	5	2
19	10·0	313·96	13½	2	5	0	3	6	4	—	—	10	5	9	6½
10	6·01	220·31	12½	2	5	0	3	6	2	—	—	6	11	5	16
14	6·90	291·68	13½	2	4	4	4	4	2	—	—	7	3	8	3
45	10·1	429·05	15	2	5	0	3	6	4	—	—	—		—	
65	8·43	347·81	15¼	2	4	6	4	6	2	—	—	10	11	9	3
70	5·28	247·24	12¾	2	4	6	4	6	2	—	—	7	8	6	11
69	10·2	494·18	15	2	4	0	4	6	4	—	—	11	6	10	6
84	8·29	406·98	15	2	5	0	3	6	4	—	—	—		—	
15	11·0	531·71	15¼	2	6	0	4	0	4	—	—	—		—	
57	9·0	463·74	14¾	2	4	6	4	6	2	—	—	11	12	10	6½
07	6·0	266·85	10	2	5	0	3	6	2	—	—	7	7	6	11½
43	11·29	546·79	19	2	4	6	4 3	6 2	4	—	—	—		—	
71	8·28	392·05	14½	2	5	0	3	6	4	—	—	9	12	—	
01	11·0	567·63	14¼	2	4	6	4 3	6 6	4	—	—	—		—	
26	13·9	641·52	17	2	6	6	4	0	4	—	—	12	12½	11	9
34	8·64	359·50	11½	2	5	0	3	6	4	—	—	—		—	
07	11·0	531·71	14⅝	2	6	0	4	0	4	—	—	—		—	
68	7·86	403·41	12⅝	2	5	0	3	6	4	—	—	—		—	
93	88·32	448·13	12⅞	2	4	6	4 3	6 6	4	—	—	—		—	
302	9·10	432·84	12¼	2	5	0	3	6	4	—	—	—		—	
504	8·91	357·00	11⅝	2	5	0	3	6	4	—	—	—		—	
5	11·1	546·79	15⅝	2	4	6	4 3	6 6	4	—	—	—		—	
10	~~136·0~~	~~54·78~~ 603.87	16⅝	2	7	0	4	0	4	—	—	—		—	

CHAPTER VII.

ON THE FRICTION, AND RESISTANCE OF CARRIAGES MOVED ON RAILROADS.

§ 1.—*Different kinds of Friction.*

In all carriages, moved on railways, or other roads, there is always a certain degree of obstruction, or resistance to their progressive motion, arising from the attrition of their rubbing parts, and the action of the wheels upon the rail; and this retardation is denominated the *friction* of the carriages, and is always greater or less in the proportion which the extent of rubbing action bears to the weight of the carriage. This resistance of wheel carriages is referable to two separate causes:—that arising from the pressure or attrition upon the axles;—and the obstruction to the rolling of the wheels upon the rails or road. In the case of a common sledge, or a body *dragged* along the surface of a plane, the entire weight of the body is referable to the action of attrition, the parts subjected to attrition sliding over each other with the same velocity, as the progressive motion of the body on the plane. On the contrary, if the body be cylindrical, and *rolled* along the plane, no part of it is subjected to the action of attrition; the only resistance (which, when the surfaces are smooth and hard, is very trifling) being that produced by the rolling of the periphery upon the plane.

Suppose a cylinder composed of two concentric circles, one within another, let the interior cylinder be of small diameter compared with that of the outer; if we now cause this cylinder to roll along a plane, upon the periphery of the outer circle, and place the body to be moved, or the carriage, upon the periphery of the inner cylinder; that portion of the resistance arising from *attrition,* will be represented by the weight of the body acting upon the periphery of the inner circle; and that portion arising from *rolling*, the resistance of the periphery of the outer circle upon the plane. And as the velocities of the peripheries of these circles will be in the ratio of their diameters, the velocity of the *rubbing* surface, compared with the velocity of the *rolling* action, will be as the radii of the respective circles. In this case the inner circle represents the axles, and the outer the wheels of a carriage; hence we have two distinct species of friction, viz., the friction of *attrition,* acting upon the axles; and that of *rolling*, acting on the periphery of the wheel: — the degree of resistance opposed to the promotion of the carriage, by the sliding of the axles upon the chairs or bearings which rest on them, is called the *friction* of *attrition;* and the retardation by the action of the periphery of the wheels rolling upon the rails, the *rolling friction*. In all wheel carriages, however, the two species of friction are in action at the same time, and, therefore, where it is not particularly expressed to the contrary, the term *friction* will be understood to comprehend both kinds of resistance combined. It will be afterwards necessary, when treating of locomotive carriages, to speak of that property of bodies in contact with each other, and subjected to pressure; the surfaces of which resist sliding, and which is employed for a mechanical purpose; the employment of such resistance, for that particular purpose, ceasing when the surfaces begin to slide over each other; whereas, in the case of the friction of attrition above mentioned, the action only commences when the bodies slide over each other. We shall, therefore, denominate that force, which, acting upon two surfaces in contact with each other, and which is not sufficient to cause them to slide on each other, as the force of *adhesion.*

There are other species of obstructions presented to the motion of carriages, besides those already enumerated, such as the action of the wind, &c.; but as their effects in retarding motion at moderate velocities are trifling, we shall at present omit noticing their effect, but shall afterwards, when treating of rapid motion, recur to these obstructions.

Let $f =$ the resistance opposed to the free motion of a carriage upon a railroad, by the action of rolling, in parts of the weight W.

$g =$ that by attrition, upon the axles in parts of the weight $W' = f'\frac{d}{D}$.

$D =$ diameter of the wheels.

$d =$ diameter of the axles.

Then the power P, required to move the body over the plane will be $P = \frac{W}{f} + \frac{W'}{f' + \frac{d}{D}}$.

In this case W represents the whole weight of the carriage, and W' that part resting upon the axles; and it follows from this, that the quantity of rubbing action, or that part of the friction of railway carriages, which arises from the attrition on the axles, will be in the inverse ratio of the wheels, or $\frac{W'}{f'\frac{d}{D}}$ while the resistance arising from the action of rolling will be always $\frac{W}{f}$. We have no decisive experiments to prove the value of f with different sized wheels; but as large wheels more easily surmount obstacles than wheels of small diameter, we may suppose the former will always present less resistance.

In constructing wheel carriages, therefore, with a view of diminishing their friction, it would appear that we should make the diameter of the wheels as large, and the axles as small, as possible; but there is a limit to this, independently of the inconvenience of loading and unloading carriages, much elevated by being placed upon very high wheels. The axles must be made sufficiently strong to support the weight placed upon them; and that strength must be increased with the size of the wheels, for the larger the wheels, the greater the leverage to twist and break the axles; but as the tendency to break the axles, increases only in the direct proportion of the diameter of the wheels, while the strength of the axles increases as the cube of their diameter, it will, in all cases, be of advantage to make the wheels of as large a diameter, and the diameter of the axles at the points of bearing as small, as circumstances will permit.

In order to obtain a correct knowledge of the resistance of carriages moved on railroads, it will be necessary, therefore, to ascertain by experiment the values of f and f'. In the former, the sphere of action is confined to the breadth of the rail, which is generally the same in all railroads; but in the latter, and in all rubbing surfaces, it is a subject of the utmost importance, to ascertain, not only the absolute resistance arising from the friction of the axles, but likewise what extent of bearing surface, in proportion to the weight, produces the least friction. The opinions of men of science, on these points, are very various, and the experiments made do not appear to have settled the question satisfactorily. These reasons, therefore, induced us, as well before, as since the publication of the first edition of this work, to make numerous experiments to determine these questions.

§ 2.—*Friction with respect to Weight. Coal Waggons, with inside Bearings.*

It has long been a matter of just regret, that so few experiments have been made, to ascertain the degree of resistance arising from friction to carriages moved along railroads; on a subject of such importance, it is astonishing that, until lately, so little interest should have been excited, comprehending, as it were, the entire basis of the subject. Observations had been made on the weight which a horse could drag by a carriage on a railroad, but, as in this case, no measure of the force exerted by the horse was used, the resistance of the carriage could not be ascertained.

First.—*Grimshaw's Experiments.*

Mr. Grimshaw, of Sunderland, when proprietor of a colliery in that neighbourhood, made a great many experiments on the friction of wheel carriages, with the particulars of which we have been favoured. He laid a few lengths of cast-iron railway down upon beams of wood, and placed upon this railway the carriages used by him in conveying his coals down to the river. He then elevated those beams at one end, until they formed different angles with the horizon, and observed the time the carriages were in descending from one end to the other, when the plane was elevated to different angles. By comparing the spaces actually passed over by the carriage, with the space which gravity would have caused the body to describe in the same time when falling freely, the amount of retardation caused by the friction, was thus ascertained.

The result was as follows:—

> **Loaded carriage, weighing altogether 8522 lbs. friction, equal to 50 lbs., or the $\frac{1}{170}$th part of its weight.**
>
> **Empty carriage, weighing 2586 lbs. friction, 10 lbs., or the $\frac{1}{258}$th part of its weight.**

Mr. Palmer, in the description of his railway, states the result of some experiments, made on the friction of carriages, moved along different kinds of railroads; he makes the resistance considerably greater than Mr. Grimshaw, amounting to the eighty-seventh part of the weight, as found upon the Edge railroad, from the Penryn slate quarries; but, as this must have been owing to some difference in the construction of the railway or carriages, and as Mr. Palmer does not give any detail of his experiments, we are not, therefore, capable of judging of the cause of such an anomaly.

Second.—*Killingworth Experiments.*

Impressed with the importance of knowing the precise amount of resistance opposed to the motion of carriages along railroads, and also the resistance by different forms of carriages; Mr. Geo. Stephenson and myself, in October, 1818, commenced a series of experiments, upon the Killingworth railroad, to ascertain that desideratum.

A spring dynamometer was first used, but we found its action subject to such irregularity, that we were obliged to abandon it, and resort to one of the following construction.

A very heavy pendulum, or leaden weight, was suspended by a rod or arm, from a well-turned and perfectly smooth axle, moving freely upon a brass carriage or chair, which was kept well oiled, and moved with very little friction. A grooved quadrant, accurately formed, was fixed at the extremity of the pendulum, and moved with it. Upon the side of the periphery of the quadrant, a graduated index was fixed, on which were marked divisions, representing pounds. A pointer was secured to the frame of the carriage, in such a manner as to be capable of being adjusted to suit the angle of the road; so that, when the pendulum was perpendicular, the index pointed to the first of the divisions.

When the pendulum was left at liberty, it, of course, assumed a position perpendicular to the horizon, or hung freely down; and, consequently, required a certain force to remove it from that position, which force varied according to the different angles it was made to form, with respect to the horizon; the greatest force, which it would present to any power drawing it out of the vertical position, being when the pendulum became parallel with the horizon.

Knowing the weight of the leaden ball, and the length of the arm of the pendulum, it would have been easy to calculate the scale of divisions representing pounds; but we preferred marking them, by employing known weights, to drag the pendulum out from the perpendicular. To accomplish this, we used a steelyard, made for the purpose, with arms of equal lengths, at right angles to each other; one of which would thus be perpendicular, and the other horizontal. This rested on a pivot, with sharp points, the arms balancing each other with great nicety. From the horizonal arm, known weights were suspended, and from the end of the perpendicular arm, a rope proceeded, which passed round the groove of the quadrant, and was fastened to the leaden ball. The weights were added, pound by pound, and the steel-yard adjusted at each operation; and, as the weights drew the pendulum out of the perpendicular, the divisions were marked on the vernier of the index. The same rope was used in the experiments, that was made use of to adjust the instrument.

This instrument, which was a perfect dynamometer, was firmly fixed upon a carriage, placed upon wheels of such a height, that the rope, leading away horizontally in a tangent from the quadrant, could be fastened to that part of the carriages, to be made the subject of experiment, by which they are usually drawn along the railroad.

The carriage, containing the dynamometer, was placed upon the railroad, and the rope fastened to the carriage, the friction of which was to be ascertained. Manual labour was then applied to the dynamometer carriage, to push it along the railroad, and the rope, being fastened to the waggon, it was drawn forward by the rope of the dynamometer. The distance which the pendulum was drawn out from the perpendicular, by the action of the rope, was therefore the measure of force, or pressure, required to move the waggon forward upon the railroad.

Before recording the pressure indicated by the index, both carriages were put into a certain velocity, and that velocity was kept up, as equable as possible, during the course of the experiments. At first, it was found rather difficult to preserve a state of perfect uniform velocity, the least variation in the force applied to push the dynamometer forward, causing the index to vibrate backwards and forwards. By employing a greater number of men, we accomplished, after successive trials, a regularity of action, which produced the most uniform velocity in the motion; and each experiment was repeated until we were perfectly satisfied of the accuracy of the result.

The degree of force indicated by the dynamometer, was, therefore, that which was required to keep the waggon in motion, or to keep it in a state of uniform velocity, that velocity being first produced by other means.

Experiments made at Killingworth colliery, with the dynamometer, to ascertain the friction or resistance of carriages moved along railroads.

The rails were of cast iron.—Edge-rails of Messrs. Losh and Stephenson, *Fig.* 2, *Plate II.* Flat bearing surface, two inches and a half broad; three feet, nine inches and a half long; the plane, a piece of road selected for the purpose, was quite straight, and with a uniform inclination of .0738 inches in a yard, or one yard in 488. The carriages were the same as used upon the road for the conveyance of coals, and similar in shape to that shewn in *Figs.* 1, 2, *Plate VII.* The wheels were fixed upon the axles, and turned with them; their diameter was thirty-four inches, with a projecting ledge of three-fourths of an inch, to keep them on the road. The body of the carriage rested by a chair of brass or iron upon the axles of the wheels, as explained in the detail of the experiments; the axles being of wrought-iron, two inches and three quarters in diameter, at the bearing.

EXPERIMENT I.

Number of experiments.	Description of carriages.	Resistance up the plane.	Resistance down the plane.	Mean resistance, or friction upon a level plane.	Friction in parts of the weight.
		lbs.	lbs.	lbs.	
1	Loaded carriage, weighing 23½ cwt., and containing 53 cwt. of coals, total weight 76½ cwt. Wheels cast-iron, case-hardened, and had been in use six months. The bearings upon the axles, of cast-iron, four inches broad - - - -	56	22	39	$\frac{1}{219}$
2	Loaded carriage, same weight as the preceding. Wheels cast-iron, but not case-hardened; and were worn considerably. Chairs or bearings, brass, 1½ inches broad	78	48	63	$\frac{1}{136}$
3	Four empty carriages, each weighing 23½ cwt. Three with case-hardened wheels, and one with wheels not case hardened. Same kind of bearings as No. 1. - -	74	32	53	$\frac{1}{198}$
4	Four empty carriages, same weight as the preceding, three with common, and one with case-hardened wheels. Bearings brass, similar to No. 2. - - -	91	49	70	$\frac{1}{150}$
5	Four empty carriages, same weight as No. 3, all with old wheels, not case-hardened, much worn or indented on the rim. Wrought-iron bearings, 1½ inches broad -	112	70	91	$\frac{1}{115}$
6	The preceding twelve empty carriages together - - - - - -	277	149	213	$\frac{1}{147}$
7	* Four empty carriages, and weighing 23½ cwt., all with case-hardened wheels, and cast-iron bearings, similar to No. 1.	72	29	50	$\frac{1}{210}$
8	Four empty carriages, same weight, with case-hardened wheels, and brass bearings, same as No. 2. - - - - -	75	33	54	$\frac{1}{195}$
9	Four empty carriages, same weight, wheels not case-hardened, half worn. Bearings, similar to No. 7. - - - - -	90	48	69	$\frac{1}{152}$
10	Four empty carriages, same weight, wheels same as preceding, or No. 9. Brass bearings, similar to No. 8. - - -	96	54	75	$\frac{1}{140}$
11	Four empty carriages, same weight, case-hardened wheels. Wrought-iron bearings, same as No. 5. - - -	89	47	69	$\frac{1}{152}$

* After the above experiments were performed, there appeared such a variation in the result, between the carriages having different kinds of wheels, and bearings; the following were made to ascertain how much the resistance was affected by each.

A very material difference in the result, will be found in the construction of the carriages, used in these experiments. The carriage No. 1, was of the most modern construction, and the resistance upon a level plane amounted to no more than thirty-nine pounds, or $\frac{1}{219}$ th part of the weight. The carriage No. 2, required sixty-three pounds, or $\frac{1}{250}$ th part of the weight, almost two thirds more; but as the bearings and wheels were different, it was desirable to find to which the variation was attributable.

On comparing No. 8, and No. 10, together, which had the same kind of bearings, but different wheels, it will be seen that in the four empty carriages, there is a difference in the resistance of twenty-one pounds, which must arise from the wheels alone. The whole weight of those carriages was ninety-three hundred weight; therefore, the additional resistance occasioned by wheels, partly worn or indented into a groove around the rim, amounts to nearly the 500th part of the weight. Again, on comparing No. 7, and No. 8, we find the difference nearly the same, amounting to the 550th part of the weight. This proves the great superiority of case-hardened wheels over the common ones; not only in economy, but also in lessening the resistance.

In examining the experiments, there is also another variation in the result, owing to the different kinds of bearings employed. Comparing the resistance of No. 8, with No. 7, there appears a difference of four pounds, which is equal to one pound in each carriage between bearings of cast iron and of brass. The iron bearings are broader than those of the brass, and this will, perhaps, account for the difference; otherwise the brass would most likely have been found to present the least friction, but it at the same time proves the necessity of making the bearings of a certain area, compared with the pressure upon them, and shews that the brass is considerably below that area; inasmuch, as we find that the increased breadth of the cast iron, more than compensates for its inferiority to brass, in diminishing the friction.

We had also an opportunity of subjecting to the test of experiment, another kind of bearing, which for a long period after the introduction of railways was universally used, and we believe is still used in some places.

This is a malleable iron bearing, formed by the hammer of the blacksmith, one inch and a quarter broad. This was the bearing used in No. 11, which, on being compared with Nos. 7, and 8, a difference will be found amounting to nineteen pounds, between that kind of bearing and the cast iron, and fifteen pounds between it and the brass; which is equal to the difference between the common and the case-hardened wheels, and amounting to nearly the 550th part of the weight. This is not the only evil produced by the use of this kind of bearing; it also operates very powerfully in cutting the axles. On being shewn two axles, it is readily distinguishable to which kind of bearing each has been subjected; the axle with the narrow bearing is cut and furrowed, while the other is smooth and even; and it need not be stated the effect which such a cause would produce in the expence, by the destruction of axles.

The reduction of friction, by the introduction of broad bearings and case-hardened wheels is very considerable, and when properly estimated, are of great moment in the economy of railroad conveyance. The two together, amount to the 275th part of the weight of the carriage, or equal to forty-three per cent. of the whole amount of friction.

Third.—*Hetton Experiments.*

The following are some experiments, which I made upon the Hetton Colliery railroad, in December 1824, which, as determining the friction by other methods, will be interesting, as a comparison with the preceding. Length of plane, 1164 feet, perfectly straight, with an uniform and regular descent of one yard in 104,24, or eleven feet, two inches, in the whole distance; edge-rail, of Losh and Stephenson's patent, two inches and a half broad at top. The carriages were allowed to descend freely by their gravitating force, and the space they passed over, ascertained by a stop-watch.

EXPERIMENT II.

Four loaded carriages, each weighing 9408 lbs., with case-hardened wheels, two feet eleven inches in diameter, malleable iron axles, three inches diameter, bearing cast-iron, four inches broad.

Space described, 1164 feet; time, 120 seconds.

Supposing $\mathrm{W} = 8906$ and $w\,\frac{\mathrm{SO}}{\mathrm{SG}}$ (as per experiment) 2095 lbs.; we have by formula 9 (p. 236) $\mathrm{F} = \mathrm{W} + w \sin.\ \mathrm{I} - \frac{\mathrm{W} + w\frac{\mathrm{SO}}{\mathrm{SG}} \times \mathrm{S}}{r\,t^2} = 1574$ lbs.; and $\frac{1574}{4} = 39 \cdot 35$ lbs. the friction of each carriage.

EXPERIMENT III.

Seven loaded carriages, similar to the above, described precisely the same space in the same time, making their friction the same as above—viz. 39·35 lbs.

During the time of performing these two experiments, it was a dead calm, not the least wind; and the rails were dry, and in that state which would present almost the least resistance to the wheels.

EXPERIMENT IV.

Same plane, with one loaded carriage, similar to the preceding: space described, 1268 feet: time of descent, 128 seconds.

By theorem, 9——as before.

F = 41·46 lbs. the friction.

EXPERIMENT V.

Same plane,—same kind of carriage; one loaded carriage, Space described, 1140 feet; time, 125 seconds.

By theorem, 9—Friction, 44·19 lbs.

EXPERIMENT VI.

Same plane,—an empty carriage, similar in form to the preceding, weighing 3472 lbs. Space described, 1206 feet; time, 124 seconds.

By theorem, 9—Friction, 12·73 lbs.

During the time of performing the three last experiments, it was rather windy, and the direction of the wind was partly oblique to the line of the road; which would have the effect of blowing the carriage to one side, and causing the flanch of the wheels to press against the side of the rail, and thus, augment the friction. In these experiments, the rails were in an excellent state, presenting the least possible resistance to the rolling of the wheels. When the rails are quite dry, or quite wet, they present the least; and when partially wet or moist, and catching the dust, the resistance is the greatest; in these three last experiments, they were quite dry.

The following experiments were made with a view of ascertaining the friction of the same carriage loaded with different weights; they were made with the dynamometer previously described.

EXPERIMENT VII.

No. of experts.	Description of carriages.	Resistance up the plane.	Resistance on a level.
1	Carriage with common wheels and cast-iron chairs, four inches broad, wheels 34 inches diameter, axles $2\frac{3}{4}$ inches diameter, weight of the body of the carriage resting upon the axle 12 cwt., and weight of the wheels and axle 11 cwt., loaded with 20 cwt. of iron, upon the same plane as Experiment I.	36	26
2	Same carriage loaden with 40 cwt. of iron	48	34
3	Ditto, loaden with 53 cwt. of iron -	58	40
	Immediately after the above experiments were finished, a smart shower of rain fell, attended with a brisk squall of wind, during which, we availed ourselves of the opportunity of ascertaining the variation in the resistance, by the rails being partly wet.		
4	Same carriage loaden with 53 cwt. of iron	65	47
5	Ditto - ditto - 40 cwt. of iron	52	38
6	Ditto - ditto - 20 cwt. of iron	38	28

§ 3.—*Friction with regard to Velocity. Coal Waggons.*

The following experiments were made with the dynamometer, to ascertain the friction or resistance of carriages, moving at different velocities on a plane rising one in 488.

Experiment VIII.

	Description of carriages, and velocities at which they moved.						
	Loaded carriage, weighing 22½ cwt., with cast-iron bearings, four inches broad, case-hardened wheels, 34 inches diameter; and wrought-iron axles 2¾ inches diameter, containing 53 cwt. of coals, moved at a slow rate of motion - -						56
1	Moved at the rate of	134	feet per minute.	1·52	miles per hour.		56
2		307		3·48			56
3		397		4·51			56
4		140		1·59			56

In prosecuting the above experiments, the carriage and dynamometer were first put into the required velocity; and that velocity was uniformly kept up during time of passing along the plane. Numerous trials were made, to be certain that the result was correct; the dynamometer was pushed along by several men, and the variation from a uniform resistance indicated by the index, was so trifling, that no other record than those in the table could be made. This experiment was made in conjunction with Mr. Stephenson, in 1819.

The following experiments, though made for the express purpose of ascertaining if the friction increased with the velocity, will likewise give the absolute friction. They were made upon a stage, or piece of railroad, selected for the purpose. A perfectly straight plane of the edge railroad, with a uniform and regular inclination, was taken; the declivity of which was such, as would cause the carriages to descend with an accelerated velocity; a carriage was placed upon it, and allowed to descend freely, and the space it passed over in successive portions of time, was marked with the utmost accuracy, in the following manner. Standing upon one end of the carriage, and aided by an assistant, at the end of every ten seconds, I made a mark upon the plane, where the carriage happened to be; and afterwards measured the distance between those marks, which gave the space passed over, in each successive period. The carriage was first put in motion, at the top of the plane, by a slight impulse, only sufficient to overcome its vis inertiæ. The descent of the plane, was one yard in 104; or 134 inches, in 13,968 inches.

EXPERIMENT IX.

No. 1.			No. 2.			No. 3.		
Loaded carriage weighing 9·408 lbs, wheels 35 inches, axles 3 inches diameter.			Loaded carriage weighing 9·408 lbs., wheels 35 inches, axles 3 inches diameter.			Empty carriage weighing 3·472 lbs., wheels 35 inches, axles 3 inches diameter.		
Time of descent.	Space passed over.	Calculated space by formula $s = \frac{G-F}{W} \times rt^2$.	Time of descent.	Space passed over.	Calculated space by formula $s = \frac{G-F}{W} \times rt^2$.	Time of descent.	Space passed over.	Calculated space by formula $s = \frac{G-F}{W} \times rt^2$.
Sec.	Feet.	Feet.	Sec.	Feet.	Feet.	Sec.	Feet.	Feet.
18	25	26	5	2·8	1·9	14	15·1	16·5
28	71·9	63	15	20·4	18·	24	89·	46·2
38	124·6	116	25	54·7	50·2	34	147·8	92·9
48	205·2	185	35	97·	98·6	44	221·	155·6
58	276·5	270	45	158·3	162·8	54	304·2	234·5
68	384·7	371·8	55	234·2	243·2	64	425·	329·3
78	506·1	489·2	65	314·7	339·7	74	487·6	448·3
88	645·5	622·6	75	442·1	452·3	84	595·2	567·8
98	785·3	722·2	85	501·5	581·	94	733·8	677·2
108	939·6	937·9	95	642·1	642·1	104	891·5	869·7
118	1081·6	1119·6	105	800·5	886·5	114	1048·6	104·5
128	1266·5	1318·3	115	965·5	1063·5	124	1205·7	1236·4
			125	1140·4	1256·5			
Friction, 41·45 lbs.			Friction, 44·18 lbs.			Friction, 12·75 lbs.		

It will be seen from the preceding experiments, that the actual space passed over is greater, until a certain period of the time, than the calculated space; which arose from the wind blowing pretty strong in the same direction of the line of the plane, as that on which the carriage was descending, which had the effect of urging it forward until its velocity became equal to that of the wind. In trying the experiment, the pressure of the wind was felt while descending with the carriage, until a certain period, when it appeared quite calm, and this took place somewhere about the end of the 110th or 120th second, where we find the calculated space agree with that actually passed over.

This might be expected, as the calculated space is derived from the descent of the same carriage, during a calm (see Experiment II.) where the space passed over was nearly the same, and, consequently, the effect of the air in retarding the velocity of the one, would be equal to the effect of the wind in accelerating the other; and the result in the two experiments only coincided when the velocities became equal, and when the velocity of the carriage, in the one case, corresponded with the velocity of the wind in the other.

Not having an opportunity of making the experiment upon this piece of road, during a calm, I selected a short distance of the Killingworth railway, with a nearly uniform descent, and embraced an opportunity of trying the experiment when there was scarcely any wind, or at least so little, that it could have no sensible effect, either in retarding or accelerating the velocity of the carriage. The descent of plane was not uniformly the same throughout the whole length, but to ascertain the true result, I took the actual descent at the end of the several spaces passed over.

The following table will shew the result.

EXPERIMENT X.

Loaded carriage weighing 9100 lbs., wheels 34 inches, axles 2¾ inches.

Time of descent.	Space actually passed over.	Descent of plane.	Calculated space on a plane with uniform descent.	Descent of plane if the inclination had been uniform.
Seconds.	Feet.	Inches.	Feet.	Inches.
10	6·	1·	6·6	0·7
20	26·4	3·5	26·4	2·96
30	59·8	7·5	59·4	6·74
40	106·2	12·	105·6	11·8
50	165·	19·	165·	18·3
60	242·8	26·	237·6	26·9
70	326·7	37·	321·4	36·3
80	424·3	46·	422·4	47·1
90	525·3	57·	534·6	58·4
100	635·5	70·	660·	70·6

Friction, 44·62 lbs.

The following Table will shew the result of the foregoing Experiments, on the friction of carriages moving along an Edge Railroad.

TABLE I.

	Reference.			Weight of the carriage in lbs., including wheels and axles.	Weight of the carriage, exclusive of wheels and axles; or weight subjected to rubbing friction.	Amount of friction in lbs.	Ratio of friction to weight.	Friction per ton in lbs.
1	By dynamometer.	Exp. I.	No. 1	8540	7280	39·	$\frac{1}{219}$	10·23
2	Ditto -	- -	No. 7	2604	1344	12·5	$\frac{1}{208}$	10·77
3	Ditto -	- -	No. 8	2604	1344	13·5	$\frac{1}{193}$	11·61
4	Ditto -	Exp. VII.	No. 1	4816	3584	26·	$\frac{1}{185}$	12·10
5	Ditto -	- -	No. 2	7056	5824	34·	$\frac{1}{207}$	10·82
6	Ditto -	- -	No. 3	8512	7280	40·	$\frac{1}{213}$	10·51
7	Ditto -	Exp. VIII.	-	8456	7224	39·	$\frac{1}{217}$	10·32
8	By inclined plane.	Exp. II. -	-	9408	8096	39·35	$\frac{1}{239}$	9·37
9	Ditto -	Exp. III. -	-	9408	8096	39·35	$\frac{1}{239}$	9·37
10	Ditto -	Exp. IV. -	-	9408	8096	41·46	$\frac{1}{226}$	9·91
11	Ditto -	Exp. V. -	-	9408	8096	44·19	$\frac{1}{212}$	10·56
12	Ditto -	Exp. VI. -	-	3472	2160	12·73	$\frac{1}{272}$	8·23
13	Ditto -	Exp. IX.	No. 1	9408	8096	41·45	$\frac{1}{226}$	9·91
14	Ditto -	- -	No. 2	9408	8096	44·18	$\frac{1}{212}$	10·56
15	Ditto -	- -	No. 3	3472	2160	12·75	$\frac{1}{272}$	8·23
16	Ditto -	Exp. X. -	-	9100	7840	39·	$\frac{1}{233}$	9·41

By the above Table, it will be seen, that the least amount of resistance, is equal to the 272nd part of the weight of the carriage, and the greatest equal to the 185th; the average being the 223rd part of the weight, or about ten lbs. to the ton.

§ 4.—*Friction of Carriages, with outside Bearings.*

These experiments were made upon carriages, with bearings inside of the wheels (see *Fig.* 1, *Plate VII.*); and, consequently, the diameter of the bearings large, as compared with the diameter of the wheels, being about a twelfth part. We shall now give some experiments, made upon different descriptions of carriages, which we have been favoured with, by the liberality of the Directors of the Liverpool and Manchester Railway. Many plans of carriages had been submitted to them for adoption on that railway, and the following experiments were made, by Messrs. Hartley and Rastrick, on three descriptions of carriages, submitted to their notice.

These carriages, were the several contrivances of Messrs. Winan, Brandreth, and Stephenson, and were of the following construction.

Mr. Winan's carriage differed from those in common use, by the axles being projected through the nave of the wheels, and made to run upon the interior of the periphery, or inside of the rim of friction wheels. The body of the carriage, No. 1, of the experiments, consisted of a platform, with four cast-iron wheels, each twenty inches diameter, which ran upon the rails; the axles of these projected through the naves, the ends being one inch and a half in diameter, and two inches long; and rolled upon the inside of the rim of four friction wheels, eight inches in diameter; which friction wheels were supported by a journal, one inch in diameter, and one inch and a half long. No. 2, did not differ from this in construction, except that the travelling wheels, were thirty inches in diameter, and not case-hardened.

Mr. Brandreth's carriage was also mounted on friction wheels, but the axles of the travelling wheels in this, ran upon the outside of the rim of the friction wheels, and were kept upon the apex thereof, by guides. The carriage, No. 1, was a platform, resting on four case-hardened wheels, thirty inches in diameter; the axles, three inches in diameter. The two ends of one of the axles rolled upon the apex of the rim of two friction wheels, twelve inches in diameter, and three inches broad on the rim; the other axle rested on the middle upon one friction wheel, similar to the other; this arrangement was for the purpose of causing the four travelling wheels, always to preserve their parallelism with the rails. These friction-wheels run upon bearings, two inches diameter, and two inches and a half long. No. 2, was another carriage, of similar construction, with a body for the loading.

Mr. Stephenson's carriage was of the construction shewn in *Figs.* 5, 6, and 7, *Plate VII.*, consisting of a platform, resting on four travelling wheels, three feet diameter, case-hardened; the axles, as shewn in the drawing, passed through the nave, beyond which they were one inch and three-eighths in diameter, resting upon bearings of brass, three inches and a quarter in length, and supported upon springs.

Knowing that the friction of rolling is less than that of attrition, Messrs. Brandreth, and Winan, expected, by the disposition of a much greater portion of the weight of the working parts, into a rolling motion, than in the common carriages, they would effect a corresponding reduction in the amount of friction.

The experiments given in the following Table, were made upon a part of the Liverpool Railway, wrought-iron rails two inches and a quarter broad on the top, and the experiments were conducted by Mr. Rastrick in the following manner :—The carriages were allowed to run down a descending plane, at the bottom of which, the inclination was in a contrary direction ; the momentum acquired in traversing the descending plane, caused them to run up the ascending plane, until the friction brought them to rest. The difference of level between the two planes, (in the space passed over,) with the distance and time of traversing the two planes, giving the amount of friction.

The annexed Table will shew the result :

TABLE II.

Description of the Carriages.	No.	Inclination of the descending plane.		Time of descent in seconds.	Distance the carriages run, upon ascending plane, before stopping.	Distance on both planes, which the carriages run before stopping.		Friction of the carriages, including the resistance of the air.	
		Length in feet.	Height in feet.			Length in feet.	Height or difference of level, in feet.	In parts of weight.	In pounds per ton.
All these experiments were made with Mr. Winan's carriage, No. 1, weight of which was 16¼ cwt. loaded with stones to 4 tons, except experiment No. 1, which was loaded with stones to 3½ tons. —— Wind scare of carriage, 10 square feet.	1	1467	12	119·75	1166	2633	11·61	$\frac{1}{227}$	9·88
	2			116·75	1433	2900	11·33	$\frac{1}{256}$	8·75
	3	2·220	20	145·50	1865	4085	18·91	$\frac{1}{216}$	10·37
	4			145·00	1989	4209	18·81	$\frac{1}{224}$	10·10
	5			141·00	2711	4931	18·32	$\frac{1}{269}$	8·32
	6	2·604	24	149·50	2957	5561	22 15	$\frac{1}{251}$	8·92
	7			149·50	3221	5825	21·95	$\frac{1}{265}$	8·44
	8	3·364	32	176·00	3877	7241	29·30	$\frac{1}{247}$	9·06
	9			175·00	4013	7377	29·19	$\frac{1}{253}$	8·86
Mr. Winan's carriage, No. 2, weight 13½ cwt., loaded to 4 tons.	10	3·364	32	193·50	2486	5850	30·43	$\frac{1}{192}$	11·65
Mr. Brandreth's carriage, No. 1, loaded with stones to 4 tons. —— Wind scare of carriage, 12 square feet.	11	1·467	12	123·25	1101	2568	11·66	$\frac{1}{219}$	10·21
	12			123·25	1115	2582	11·65	$\frac{1}{222}$	10·11
	13	2·220	20	147·00	1914	4134	18·87	$\frac{1}{219}$	10·23
	14			146·00	2025	4245	18·78	$\frac{1}{226}$	9·92
Mr. Brandreth's carriage, No. 2, loaded with stones to 4 tons. —— Wind scare of carriage, 18 square feet.	15	2·982	28	177·50	2175	5157	26·66	$\frac{1}{193}$	11·58
	16			177·00	2448	5490	26·45	$\frac{1}{205}$	10·91
	17	3·364	32	185·00	2925	6289	30·18	$\frac{1}{208}$	10·75
	18			187·00	2648	6012	30·36	$\frac{1}{198}$	11·31
Mr. Stephenson's carriage, on springs, with 3 feet wheels, loaded to 4 tons. —— Wind scare of carriage, 13 square feet.	19	1·467	12	115·25	1744	3214	11·00	$\frac{1}{292}$	7·67
	20			115·25	1706	3173	11·03	$\frac{1}{288}$	7·79
	21			148·00	2427	4647	18·48	$\frac{1}{251}$	8·91
	22	2·220	20	142·50	2418	4638	18·46	$\frac{1}{251}$	8·92
	23			140·00	2517	4737	18·42	$\frac{1}{257}$	8·71
	24	2·604	24	159·50	3007	5611	22·12	$\frac{1}{254}$	8·83
	25			156·00	3008	5612	22·12	$\frac{1}{254}$	8·83
	26			177·00	3809	7173	29·36	$\frac{1}{244}$	9·17
	27	3·364	32	176·00	3839	7203	29·34	$\frac{1}{245}$	9·17

The portion of railway on which these experiments were made was swept quite clean, and kept free from any extraneous matter, which would have the effect of increasing the friction; when the rails are worn bright by use, they are in a smoother state than any artificial cleaning could make them; therefore, although the experiments were apparently made under advantageous circumstances, we may, perhaps, take them as the average resistance with experimental carriages. During the time of making the experiments, the wind is stated to have been blowing across the line of road; sometimes with a velocity of three miles an hour, and at other times quite calm.

The average friction of Mr. Winan's carriage with twenty inch wheels, is 9·2 lbs. per ton, or equal to the 245th part of the weight; and with thirty inch wheels 11·65 lbs. per ton, or the 192nd part of the weight, which is rather extraordinary. The average friction of Mr. Brandreth's gives 10·63 lbs. per ton, or the 211th part of the weight. Mr. Stephenson's carriage shews the friction to be 8·75 lbs. per ton, or the 249th part of the weight. The anticipated reduction of resistance, therefore, by the friction wheels, does not appear to have been realized; neither does the reduction in the diameter of the axles of Mr. Stephenson's carriage, produce that effect which might have been expected.

Monsieur Pambour of Paris, made a series of experiments on the friction of carriages upon the Liverpool and Manchester Railway, which he published in Paris; and which, as they were made, both with single carriages, and, likewise, in trains of considerable numbers, are very important.

He selected a portion of the Sutton plane on that railway, which is an uniform inclination of nearly one in 100; at the bottom of the plane, the line is nearly level, and by setting off the carriages from a given point on the plane, they ran down, and were again brought to rest by their friction upon the level part of the railway. The following are the gradients of the road on which the experiments were made; stakes were set up at every five chains, or 330 feet, and the table shews the distances, and corresponding descent of level, from the top of the plane on which the experiments were made, to the different stakes, in feet.

Table III.

No. of stakes.	Total distance in feet.	Total descent in feet.	No. of stakes.	Total distance in feet.	Total descent in feet.
0					
1	330	3·47	18	5,940	36·66
2	660	7·07	19	6,270	36·80
3	990	10·62	20	6,600	36·92
4	1320	14·36	21	6,930	37·06
5	1650	18·17	22	7,260	37·14
6	1980	21·77	23	7,590	37·22
7	2310	25·53	24	7,920	37·37
8	2640	28·98	25	8,250	37·34
9	2970	32·07	26	8,580	37·63
10	3300	34·61	27	8,910	37·92
11	3630	35·06	28	9,240	38·14
12	3960	35·19	29	9,570	38·35
13	4290	35·23	30	9,900	38·54
14	4620	35·37	31	10,230	38·67
15	4950	35·71	32	10,560	38·77
16	5280	36·17	33	10,890	38·92
17	5610	36·44	34	11,220	39·02

The mode of conducting the experiments was, by allowing the carriages to descend by their gravity from the stake No. 0, down the plane, and along the level road at the bottom until their friction brought them to rest. Having, therefore, the space described by the carriage from the commencement of its descent, until it assumed a state of rest, and the descent in feet, the friction will be equal to the sine of the plane.

The following Table will shew the experiments made, and the friction of the different carriages.

Table IV.

No. of experiment.	Number and description of carriages.	Total weight of carriages.	Weight of each carriage.	Distance traversed in feet.	Time of descent in minutes.	Total descent in feet.	Friction in parts of the weight.	Friction per ton in lbs.
		tons.	tons.					
1	5 carriages loaded -	31·31	6·26	9,933	10′	38·55	$\frac{1}{258}$	8·69
2	5 carriages loaded -	25·58	5·12	9,324	10′ 20″	38·19	$\frac{1}{244}$	9·17
3	1 carriage loaded -	- -	4·65	7,326	- -	37·16	$\frac{1}{197}$	11·36
4	1 ditto ditto -	- -	5·15	6,663	- -	36·95	$\frac{1}{180}$	12·42
5	1 ditto ditto -	- -	5·20	7,455	- -	37·19	$\frac{1}{200}$	11·17
6	1 ditto empty -	- -	1·85	6,204	- -	36·78	$\frac{1}{169}$	13·28
7	19 ditto loaded -	92·	4·84	10,728	11′	38·85	$\frac{1}{276}$	8·11
8	Jupiter locomotive engine convoy carriage - -	- -	4·50	5,967	- -	36·66	$\frac{1}{163}$	13·76
9	Atlas ditto - -	- -	5·50	7,266	- -	32·88	$\frac{1}{221}$	10·13
10	14 carriages loaded -	61·65	4·40	9,579	- -	35·32	$\frac{1}{271}$	8·26
11	10 ditto ditto - Vesta locomotive engine convoy -	48·72	4·37 5·	10,008	11′ 45″	38·58	$\frac{1}{259}$	8·64
12	24 carriages loaded - Atlas locomotive engine convoy -	110·	4·40 5·50	10,668	- -	38·82	$\frac{1}{275}$	8·15
13	17 carriages loaded - Fury locomotive engine - - Ditto convoy -	94·96	4·78 8·20 5·50	11,262	- -	39·10	$\frac{1}{288}$	7·78
14	20 carriages loaded - Vulcan locomotive engine - - Ditto convoy -	110·14	4·865 8·34 5·50	10,911	12′ 10″	38·75	$\frac{1}{281}$	7·96
15	7 carriages loaded - Leeds locomotive engine - - Ditto convoy -	40·59	7·07	8,175	8′ 30″	37·35	$\frac{1}{219}$	10·23

During the time of prosecuting these experiments the air was quite calm, and the rails in good order, though both it and the carriages were taken in their ordinary working state. At the foot of the plane there were three junctions of lines of road, and the carriages had, consequently, to pass through the crossings, which would increase the resistance. The mean velocity would be about twelve miles an hour, the distance of 10,000 feet being traversed in about ten minutes.

The experiment No. 2, was made with the same waggons as No. 1, but with a less load; in No. 4 the axles were hot at the end of the experiment, shewing a want of oil. All the carriages used in the experiments were with springs.

The following experiments were made upon the Stockton and Darlington Railway, upon waggons, with bearings inside of the wheels, and without springs. They were made in nearly similar circumstances to those on the Liverpool and Manchester Railway, by being allowed to descend an inclined plane, and to run along a level plane at the bottom until they came to rest. They were the common coal waggons; wheels three feet diameter, axles three inches diameter; weight when empty 1·30 tons, and when loaded four tons.

Table V.

No. of experiment.	No. of waggons in each train.	Distance traversed in feet.	Total descent in feet.	Friction in parts of the weight.	Friction per ton in lbs.
1	12	9,552	34·56	$\frac{1}{276}$	8·11
2	4	9,600	34·60	$\frac{1}{277}$	8·07
3	16	10,500	35·04	$\frac{1}{300}$	7·48
4	8	9,894	34·82	$\frac{1}{287}$	7·8

During the time of performing these experiments, the wind was blowing in the direction of the motion, at as great a velocity as that of the mean velocity of the waggons; all the waggons were in good order, especially those in experiments 3 and 4.

The preceding experiments, made on the Liverpool and Manchester Railway, were, with carriages having bearings on the outside of the wheels; the ratio of the diameter of the axles to that of the wheels being, as 1 : 20. In the experiments detailed in Table I. with carriages having bearings inside of the wheels, the ratio is about 1 : 12. If, therefore, the friction was diminished, in the ratio of the diameter of the axles, to that of the wheels, we should have had the resistance of that part of the weight of the carriage, resting on the axle, diminished in the ratio of 20 : 12, in the two sets of experiments. The average resistance of the carriages in Table I. is the 223rd; of Mr. Stephenson's carriage, the 249th; of the single carriages of Mr. Pambour, (viz., experiments 3, 5, and 9,) the 206th; and of the carriages in trains, the 262nd; and of the Stockton and Darlington, the 284th part of the weight.

These results being so very different from the received opinions on the subject, it became extremely desirable that it should be ascertained whence it arose; whether, from any peculiar law of resistance of rolling friction, or of the action of the wheels upon the rails; or if it was occasioned by any variation of friction, by different weights upon the axles; or if the area of bearing on the axles, in any respect caused a variation in the amount of friction.

These desiderata are the more necessary, inasmuch as, unless we know both the actual and relative amount of friction, arising from these different sources, we cannot calculate, " a priori," the resistance of any carriage, loaded with different weights, or having different areas of bearing. Impressed with the importance of determining these correctly, and, before being in possession of Mr. Pambour's experiments, I commenced, in 1830, a set of experiments, comprehending,

1. The resistance of the wheels alone, or the rolling friction.
2. The comparative resistance of the axles, with different insistent weights.
3. The friction of attrition alone, and resistance upon axles of different areas of bearing, and with the insistent weights, varied as much as possible.

To ascertain the resistance of the wheels upon the rails, I took two wheels, connected together by an axle, in the usual way, and loading these wheels with different weights, caused them to descend an inclined plane, perfectly straight; and, by observing the time of descent, ascertained the friction in the same manner, as practised formerly, in the experiments on the resistance of carriages.

By experimenting upon a carriage, and loading it with different weights, and thus varying the ratio of the action of each kind of friction, we might make a near approximation to the amount of each separately; but I preferred the more simple mode of making the experiments on the wheels, and axle, alone, and thus to ascertain the resistance of rolling friction, independently of the resistance of attrition.

The plane, on which the experiments were made, was laid with rails of cast-iron, with half-lap joints, bearing surface, two inches and a half broad, and were in the best possible order; the plane was quite straight, so that the flanch of the wheel did not rub against the rail. The time was observed at each 100 feet, and the following was the inclination from the top:—

Length. Feet.	Descent. Feet.
100	.9958
200	2.027
300	3.0645
400	3.9853
500	4.9228

EXPERIMENT XI.

Weight of wheels and axle - - 595 lbs.
Case-hardened, diameter, 34·5 inches, nearly.
By experiment $s\,o = 26{\cdot}49$ inches; and $s\,G = 17{\cdot}248$ inches.
By formula (6) $F = \frac{s\,G}{s\,O} \sin.\,I - \frac{s}{r t^2}$

Length of plane in feet.	Time of descent in seconds.	Friction in parts of the weight.	Terminal velocity, in feet, per second.
100	34·2	·001181	5·85
200	48·8	·001377	8·20
300	59·6	·001400	10·06
400	70·2	·001441	11·38
500	79·1	·001441	12·51

EXPERIMENT XII.

Weight of wheels and axle, 656 lbs.
Case-hardened, diameter, 34·5 inches, nearly.
By experiment, $s\,o = 26{\cdot}51$ inch.
$s\,G = 17{\cdot}248$ do.
By formula (6) $F = \frac{s\,G}{s\,O} \sin.\,I - \frac{s}{r t^2}$.

Length of plane in feet.	Time of descent in seconds.	Friction in parts of the weight.	Terminal velocity, in feet, per second.
100	34·14	·001157	5·85
200	45·24	·001350	8·29
300	60·09	·001479	10·
400	70·59	·001490	11·33
500	80·09	·001559	12·48

Experiment XIII.

Weight of wheels and axle, 2059 lbs.
Same wheels as Experiment XII.
By experiment, s o=22·447 inch.
s G=17·248 inch.

Experiment XIV.

Weight of wheels and axle, 2072 lbs.
Same wheels as Expt. XII.
By expt. s o = 26·70 in.
s G =17·248 in.

Length of plane in feet.	Time of descent in seconds.	Friction in parts of the weight.	Terminal velocity in feet per second.	Time of descent in seconds.	Friction in parts of the weight.	Terminal velocity in feet per seconds.
100	31·2	·001278	6·25	36·3	·001129	5·50
200	43·6	·001255	8·94	49·4	·001015	8·09
300	53·2	·001258	11·27	57·7	·001075	10·30
400	62·1	·001201	12·87	68·4	·000985	11·70
500	69·2	·001183	14·45	76·4	·001000	13·02

Experiment XV.

Weight of wheels and axle - 4480 lbs.
Same Wheels as Exp. XII.
By experiment - - s o = 26·10 inches.
s G=17·248 ditto.

Length of plane in feet.	Time of descent in seconds.	Friction in parts of the weight.	Terminal velocity in feet per second.
500	76·04	·001130	13·15 or 9 miles per hour.

Experiment XII. was made with two wheels, and an axletree, taken from underneath an experimental carriage; and the wheels, experiment XI., from one of the common coal waggons. In experiment XIII., the wheels were loaded by waggon axles, put across between the two wheels, and firmly fixed as near the axle, or centre of gravity, as possible; and, in experiment XIV., the same axles were put across, in the same manner; but placed as near the periphery as possible. In experiment XV., the spaces between the spokes of the wheel, were run full of lead, and made to weigh precisely two tons. The centre of oscillation, so, was found by suspending the wheels, in such a manner as to cause them to vibrate from a point in the periphery, as a centre.

Whence so $= \frac{t^2 l,}{n^2}$ where t, $=$ time in seconds, n, $=$ the number of vibrations in the time, t; and l, $=$ length of the pendulum vibrating seconds.

RECAPITULATION OF THE FOREGOING EXPERIMENTS.

TABLE VI.

Terminal velocity in feet per second.	Friction in parts of the weight.				
	Weight of wheel, 595 lbs.	Weight of wheel, 656 lbs.	Weight of wheel, 2095 lbs.	Weight of wheel, 2472 lbs.	Weight of wheel, 4480 lbs.
5·50 to 6·25	·001181	·001157	·001278	·001129	—
8·09 to 8·94	·001377	·001350	·001255	·001015	—
10·00 to 11·27	·001400	·001479	·001258	·001075	—
11·33 to 12·87	·001440	·001490	·001201	·000985	—
12·48 to 14·45	·001441	·001559	·001183	·001000	·001130

The result of these experiments shew, that the resistance of the wheels, rolling upon the rails, varies in light weights, from the 640th, to the 864th part of the weight; this is, however, with weights less than the pressure of almost any wheel carriage on a railroad, and, therefore, we cannot take this as the resistance generally. More heavily loaded, the resistance varies from the 800th, to the 1000th part of the weight. When, however, we consider that, in making these experiments, there was nothing to confine the wheels to move in a straight line, except that their periphery, was formed a little conical; and that the least difference in the diameter of either of them, would destroy their parallelism with the line of the road, and throw the flanches against the rails; or, if any of the joints of the rails were not quite smooth, this would produce a jolt, which would check the wheel thus acted upon, and throw the flanch against the rails. While, on the contrary, when a carriage is placed upon wheels, any side blow, acting, to throw the wheels out of the proper line of motion, is counteracted by the friction of the axle; and also, by the body of the carriage keeping the wheels in the proper position, and effectually preventing them from being diverted into an oblique line of motion. And, although, whilst conducting these experiments, all those defects were guarded against, and it was observed, that the wheels generally kept the line of direction very steadily; yet, perhaps, all these considerations may induce us to take the least resistance, deduced from these experiments, as that most likely to exist on a well formed railway. This will make the resistance of the rolling of the wheels equal to the 1000th part of the weight.

We find, from these experiments, likewise, that this is not increased by an increase of the weight; and that it is nearly the same, in velocities, varying from 5·50 to 14·45 feet per second; we, therefore, conclude, from these experiments, that *the resistance, by the rolling of the wheels, is an uniformly retarding force, both with respect to velocity and weight.*

Taking the resistance of the wheels, as equal to the 1000th part of the weight, and knowing the whole amount of friction, we obtain that of the attrition of the axles; applying this to the experiments previously detailed, we have the following result.

TABLE VII.

	Weight of carriage in lbs. including wheels and axles.	Weight of carriage resting on the axles.	Total resistance in lbs.	Resistance of wheels on rails, equal to the 1000th part of the weight in lbs.	Resistance of the axles by attrition, in lbs.	Resistance by attrition, in parts of the weight.	Ratio of the diameter of the wheels to that of the axles, the latter = 1.	Ratio of friction to insistent weight.
1	8540	7280	39·	8·54	30·46	$\frac{1}{239}$	12·36	19·
2	2604	1344	12·5	2·60	9·90	$\frac{1}{136}$	12·36	11·
3	2604	1344	13·5	2·60	10·90	$\frac{1}{123}$	12·36	10·
4	4816	3584	26·	4·81	21·19	$\frac{1}{169}$	12·36	13·6
5	7056	5824	34·	7·05	26·95	$\frac{1}{216}$	12·36	17·4
6	8512	7280	40·	8·51	31·49	$\frac{1}{231}$	12·36	19·
7	8456	7224	39·	8·45	30·55	$\frac{1}{236}$	12·36	19·
8	9408	8096	39·35	9·40	29·95	$\frac{1}{270}$	11·6	23·2
9	9408	8096	41·46	9·40	32·06	$\frac{1}{252}$	11·6	21·7
10	9408	8096	44·19	9·40	34·79	$\frac{1}{232}$	11·6	20·
11	3472	2160	12·73	3·47	9·26	$\frac{1}{233}$	11·6	20·
12	9100	7840	39·	9·10	29·90	$\frac{1}{262}$	12·36	21·2

We thus find, that, in the above experiments, the resistance, by the attrition of the axles, amounts, in the most favourable case, to the 23rd part of the insistent weight; or, taking the Nos. 1—6, and the following experiments, equal to the twentieth part of the weight; while, in some of the experiments, on the empty carriages, the friction appears much greater; from whence we would be inclined to conclude, that the resistance is diminished by an increase of pressure, and this amount is so much greater, than the general opinion of the amount of friction, as to render further inquiry necessary.

In the experimental carriage of Mr. Stephenson, and in the experiments of M. Pambour, the disagreement from theory is still more strikingly illustrated; in the former, the ratio of diameter of axle, to diameter of wheel, is as 1 : 26, and, in the latter, as 1 : 20. Taking the resistance of the wheels, equal to the 1000th part of the weight, the friction of attrition in Mr. Stephenson's carriage amounts to the eleventh part of the weight; and, in the single carriages of M. Pambour, equal to the tenth part of the insistent weight; which shews that, although the aggregate resistance is less, yet little benefit is derived from the diminished diameter of the axle.

There is no subject in science, perhaps, on which there is a greater diversity of opinion, than in the laws which govern friction; and the previous experiments, though, perhaps, sufficient in many cases for practical purposes, yet by no means tend to bring the inquiry into any more settled state. In Nos. 1 and 6, and the following experiments, the ratio only varies (except in one instance) from the nineteenth to the twenty-first part of the weight; and as, perhaps, in the other experiments, the resistance of the wheels,—the state of the axles,—the construction of the carriages,—or some other adventitious cause,—may have operated to increase the friction, so as to induce us to leave these experiments out of the question, and take the former as the more correct amount; still this amount, and especially that resulting from the other experiments, is so much greater than shewn by former experimentalists, as to render further enquiry necessary.

In some experiments, by Mr. Southern, in 1801, communicated to the Royal Society, and printed in the sixty-fifth volume of their transactions, the friction of the axles of a grind-stone, weighing 3700lbs., amounted to less than the fortieth part of its weight; now, there does not appear any reason why, in well-constructed carriages, the resistance on the axles should be greater than in other machinery; and, therefore, we are obliged to conclude, either that the resistance of the wheels must be greater than we have assigned; or that there were some defects in the construction, either of the carriage, or axles.

§ 5.—*Determination of Friction of Attrition.*

Under these circumstances, and considering the importance of obtaining the most correct information on the subject, I undertook a series of experiments, to determine the friction of attrition; I had an experimental carriage made, and fitted up with the utmost care; the axles and bearings of which were of the best material, and were kept in use a considerable time before the experiments were made, to render them as smooth as possible. The same wheels were used as in experiment XII., and the experiments were also made upon the same piece of railroad. Bearings of brass and cast-iron were both used, to ascertain which gave the least friction; and the carriage was loaded with different weights, to ascertain the relative resistance. The experiments were conducted with the utmost care, and repeated several times, to obtain correct results.

EXPERIMENTS made on an edge railroad, half lap-joints, surface, 2¼ inches broad; carriage, with semicircular brass bearings, three inches broad, wrought iron axles, 2·9 inches diameter; and case-hardened cast-iron wheels, 34·497 inches in diameter.

EXPERIMENT XVI.

	Weight resting on axles of carriage, (exclusive of weight of wheels and axles=1312 lbs.)									
	8960 lbs.		6720 lbs.		4480 lbs.		2240 lbs.		1120 lbs.	
Length of plane in feet.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.
100	29·16	·002234	29·10	·002097	30·	·001900	29·16	·001821	31·95	·002062
200	40·23	·002388	40·84	·002132	42·50	·002191	41·66	·001981	45·	·002140
300	50·41	·002433	50·26	·002279	52·08	·002211	50·83	·002058	55·	·002180
400	58·33	·002221	58·10	·002057	60·41	·001993	58·75	·001900	64·35	·002134
500	65·83	·002245	65·34	·002033	67·91	·001916	65·83	·001871	72·64	·002152
Average resistance,		·002304	....	·002120	....	·001926	....	·002042	....	·002134

EXPERIMENTS made on the same carriage, with cast-iron bearings, three inches broad, semicircular, as in the following experiment.

EXPERIMENT XVII.

	Weight resting on axles of carriage, (exclusive of weight of wheels and axles=1312 lbs.)									
	8960 lbs.		6720 lbs.		4480 lbs.		2240 lbs.		1120 lbs.	
Length of plane in feet.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.	Time of descent in seconds.	Friction in parts of weight.
100	29·	·002153	29·	·002046	29·10	·001869	29·74	·001793	31·88	·002035
200	40·95	·002281	40·65	·002062	41·35	·002083	42·16	·001864	44·50	·002002
300	50·19	·002368	50·	·002202	50·51	·002118	51·58	·001924	54·48	·002062
400	58·	·002134	57·90	·002007	58·40	·002006	60·25	·001864	63·75	·002007
500	65·41	·002153	65·12	·001989	65·41	·001813	67·66	·001821	72·	·002061
Average resistance,		·002218	....	·002061	....	·001978	....	·00185	....	·002033

TABLE VIII.—BRASS BEARINGS THREE INCHES BROAD.

—		Total weight of carriage on rails, 10272 lbs.; weight on axles 8960 lbs.	Total weight of carriage, or rolling pressure, 8032 lbs.; weight on axles, or rubbing pressure, 6720 lbs.	Total weight of carriage, or rolling pressure, 5792 lbs.; weight on axles, or rubbing pressure, 4480 lbs.	Total weight of carriage, or rolling pressure, 3552 lbs.; weight on axles, or rubbing pressure, 2240 lbs.	Total weight of carriage, or rolling pressure, 2432 lbs.; weight on axles, or rubbing pressure, 1120 lbs.
Total resistance	in parts of weight - -	·002304	·002120	·002042	·001926	·002134
	equal to the - -	434th	472d	489th	516th	468th
	in lbs. - - -	23·67	17·03	11·83	6·87	5·20
Rolling resistance in lbs. = $\frac{1}{1000}$th of weight		10·27	8·03	5·79	3·55	2·43
Friction on axles	in lbs. - - -	13·40	9·00	6·03	3·32	2·76
	in parts of weight -	·01779	·01600	·01611	·01771	·02936
	equal to the - -	56th	62d	62d	56th	34th

TABLE IX.—CAST-IRON BEARINGS.

—		Total weight of carriage, or rolling pressure, 10272 lbs.; weight on axles, or rubbing pressure, 8960 lbs.	Total weight of carriage, or rolling pressure, 8032 lbs.; weight on axles, or rubbing pressure, 6720 lbs.	Total weight of carriage, or rolling pressure, 5792 lbs.; weight on axles, or rubbing pressure, 4480 lbs.	Total weight of carriage, or rolling pressure, 3552 lbs.; weight on axles, or rubbing pressure, 2240 lbs.	Total weight of carriage, or rolling pressure, 2432 lbs.; weight on axles, or rubbing pressure, 1120 lbs.
Total resistance	in parts of weight - -	·002218	·002061	·001978	·001854	·002033
	equal to the - -	452d	485th	505th	539th	495th
	in lbs - - -	22·78	16·55	11·46	6·58	4·94
Rolling resistance in lbs. = ·001 of weight		10·27	8·03	5·79	3·55	2·43
Friction on axles	in lbs. - - -	12·51	8·52	5·67	3·03	2·51
	in parts of weight - -	·01661	·01508	·01506	·01609	·02666
	equal to the - -	60th	66th	66th	62d	38th

From these experiments, we find that in a well fitted up carriage, the whole resistance may be reduced to nearly the 500th part of the weight; and that, taking the resistance of the wheels upon the rails, as equal to the 1000th part of the weight, the friction of attrition at the axles amounts to no more than the sixtieth part of the weight, when the velocity of the surfaces in contact is equal to the progressive motion of the carriage. For in the first column of Table V. we have the total resistance equal to the 452d part of the weight, or with a weight of 10,272 lbs., equal to 22·78 lbs.; the rolling resistance of the wheels is supposed to be equal to the 1000th part of the weight, or 10·72 lbs., which leaves 12·5 lbs. for the friction of the axles equal to the 716th part of the insistent weight. But the diameter of the axle is to the diameter of the wheel as 2·9 to 34·497, and, therefore, $716 + \frac{2 \cdot 9}{34 \cdot 497} =$ 60th part of the insistent weight, when the velocity of the rubbing surface, and that of the progressive motion of the centre of gravity of the carriage is equal.

We have then, according to these experiments, the power required to drag such a carriage along a railroad $P = \frac{W}{f} + \frac{W'}{f'd}$, where, by the above experiments, $f = \cdot 001$, or the 1000th part of W, the whole weight of carriage and wheels; and $f' = \cdot 01666$, &c., the 60th part of W′, or the weight resting on the axles.

The resistance from the above experiments, being so much less than that previously found by practice, in carriages on railroads; and in the proportion of 60 to 40, less than that found by Southern; induced me to suppose there might have been some error, either in the experiments, or calculations; though in the prosecution of them the utmost care was taken; and the uniformity of result, in each of the experiments, almost proves, that no error could have been committed. The degree of polish given to the axles, though nothing more than what was effected by using the best materials, and causing the carriage to be run up and down the railroad, with the axles lucubrated with the best neat's foot oil; may account, in some degree, for the great reduction, compared with that of the former experiments, and, likewise, that good neat's foot oil was used, and applied copiously at the commencement of each experiment; whereas, in the experiments, of Table VII., the grease commonly used on the axles of coal waggons, was used.

To put the question, however, beyond all doubt, and, at the same time, to ascertain more particularly, all the phenomena of the friction of attrition, I commenced another series of experiments, for which purpose an axle was fitted up, which was loaded with different weights, and which was placed upon two chairs, or bearings; by which the rubbing friction alone could be ascertained, independent of that of rolling.

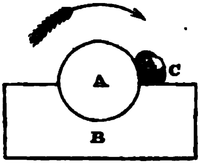
In conducting the previous experiments, on the descent of carriages, on inclined planes, where the gravitating force put the carriages from a state of rest into motion, I found very great difficulty in obtaining uniform results; as in starting the carriages, the trifling interval of half a second, considerably affected the result. I was therefore obliged to take the time, at different distances from the top, after the carriage was in motion, and calculating therefrom, the time occupied in starting the carriage, to compare with, and correct the observed time, before I could depend upon the accuracy of the experiment.

In pursuing the experiments on the single axle, I adopted the contrary mode. I first of all put the axle loaded with weights, into rapid motion, and ascertaining the time occupied, until it assumed a state of rest; I thus obtained more accurate results, than it was possible to do by pursuing the contrary method. To effect this, the axle was placed upon two bearings, at such a height from the ground, as would allow a weight to descend thirty feet; a wheel was fixed in the middle of the axle, two feet diameter, around which a cord was wound, to the end of which a weight was attached; and rings of lead were fastened upon the axle, to vary the weight. In each experiment, the cord was wound around the wheel, and the weight was thus elevated precisely thirty from the platform; by withdrawing a pin, the weight was then let free, and, falling thirty feet, unwound the cord, and put the axle and lead weights into rapid motion; the cord then detached itself, and left the axle to turn freely round, until the friction of the axles brought it to rest. By a proper apparatus, the time occupied, during each ten revolutious, of the axle, was measured, as also, the whole time, until it came to rest; by which means, not only the absolute amount of friction was obtained; but, also, the friction at different velocities; and, by varying the weights, from 1331 lbs. to 4140 lbs., the relative resistance with different weights, was also ascertained. The principal object, however, of instituting this set of experiments, was to ascertain if the friction varied with the surface of bearing; and, if there was any, and what size of bearing, subjected to a given pressure, produced the least resistance. With this view, bearings of three, four and a half, and six inches, respectively, were used; the diameter of the axle in each case being three inches; and, on each of which, the successive weights of 1331, 2465, 3622, and 4140 lbs., were placed. With these variations, the number of experiments made were more than 600, and they were repeated in every possible way, to leave no doubt, as to the accuracy of the result; the weight, in each experiment, falling precisely thirty feet.

It would be carrying the subject too far, to give detail of those experiments, which were so numerous; though, when we consider, that the friction of attrition forms so prominent, and, indeed, almost the sole resistance of carriages, any experiments, tending to elucidate the subject, must be of importance. Having, however, previously brought these experiments into the shape of a separate treatise, and finding them too voluminous to embody in this work, they will, probably, be presented to the notice of the reader, in some way or other; we shall, therefore, at present, only give the result of those, which seem to apply more particularly to the subject of our inquiries, as regards railroad carriages.

As before stated, the weight which put the axle in motion, was made to fall in every experiment, precisely thirty feet; when the weight of axle and lead, and the size of bearing were not varied, in every experiment, the number of revolutions, by the same moving power, ought to have been the same. But this, I found, was not the case; the difference, perhaps, was not of that magnitude, to render it of any importance, in practice, but still there was a variation in the result of each experiment, which could not be overlooked; and the degree of smoothness of the axle, and bearing, precluded the idea, that the variation proceeded from any asperities on the surface; and, if it did, the variation should have been uniform, and progressive, whereas, it was quite irregular; at last, I found the irregularity was owing to the quantity, and mode of applying the oil; which, as it appears of great consequence, in diminishing the friction, I shall endeavour to explain.

The axle rested upon the chairs, without any cap, or cover, as here shewn;



where A, represents an end view of the axle, and B, the chair. At the commencement of each experiment, the axle was oiled in the usual way, with fine neat's foot oil; but it was found, that unless the oil was continually feeding upon the axle, as it turned round, the result was never the same; unless the oil was supplied in such quantities, that when the axle turned round in the direction of the dart, the oil was heaped up against the axle, as shewn at C, and thus kept up a continual supply to the axle, the result was not uniform. When that was not the case, although the axle was well oiled, yet, unless the oil was kept constantly feeding upon the axle, as it turned round, a maximum effect did not take place.

The following Table, being one of the series of experiments, will shew the effect:—

TABLE X.

Weight of axle and lead, 2465 lbs., bearing 4½ inches.

Axle well oiled in the four first experiments.			Axle well oiled in the following experiment.		
Number of experiments.	Vibrations of pendulum.	Number of revolutions.	Number of experiments.	Vibrations of pendulum.	Number of revolutions.
274	505	238	301	551	265
275	549	258	Oil removed from top of chair.		
276	537	253			
277	540	252	302	454	206
Oil removed from top of chair.			303	357	160
			304	315	140
278	400	189	305	281	122
279	332	152	306	242	113
280	290	130	307	257	110
281	264	116	308	230	98
282	249	106	309	228	95
283	244	103	310	213	92
284	235	98	311	203	87
285	226	95	312	196	84
286	222	93	313	191	81
287	206	88	314	180	76
288	206	84	315	172	71
289	199	81	316	164	67
290	188	79	317	153	65
291	181	75	318	134	58
292	168	70	319	123	54
293	158	66	320	113	58
294	150	63	321	99	43
295	131	56	322	85	38
296	114	47	323	81	36
297	108	44	Axle well oiled in the two following experiments.		
298	94	39			
299	91	38	324	580	278
300	89	37	325	596	270

In conducting these experiments, the first four were made with the axle oiled, so as to keep it constantly feeding on, as shewn in the figure. The weight, being drawn up, was liberated, and falling thirty feet, the respective number of revolutions in the third column, were made before the axle came to a state of rest; the second column, being the number of oscillations of a pendulum, vibrating 300 times in 157 seconds. At the end of experiment 277, the oil, which was resting upon the bearing, heaped up, as shewn in the figure, was merely removed, as cautiously as possible, so as to allow that which surrounded the axle, to remain; the weight, then, was drawn up, as before, and falling precisely the same distance, the number of revolutions was, in that experiment, 189. No additional oil being applied, the weight was successively drawn up and liberated, as before, and the number of revolutions in each experiment, before the axle came to rest, are shewn in the Table; in the 300th experiment, the number of revolutions, by the same moving force, was only thirty-seven, during the whole of which period the axle was never touched, no oil was applied, or none removed. At the end of the 300th experiment, the axle was again copiously oiled, so as to feed on during the whole of the 301st experiment, as shewn in the diagram, when the number of revolutions were 265. The oil was then removed, as before, when the number regularly diminished, until the 323rd experiment, when it was again reduced to thirty-six; and when, in the next experiment, the oil was applied as before, the number was increased to 278; by the same weight, falling precisely the same distance, which, in the previous experiment, only produced thirty-six revolutions.

On examining the Table, it will be found that the number of revolutions in the first column, after the oil was removed from the chair, before a minimum effect took place, was 1949; and as, in each experiment, five turns were made in winding up the weight, the whole number of revolutions, by which a diminution of effect in the ratio of 252 : 37, was effected, were 2064; and in the second series, 2056 revolutions, reduced the effect from 265 to 36.

Applying this to wheel carriages, and supposing the diameter of the wheel to be twelve times that of the axle; the distance traversed in the above number of 2056 revolutions, would be about three miles and a half.

These experiments shew the manner in which oil or greasy substances act, in diminishing the friction of one surface rubbing against another; and will probably account for the irregular results, given by different experimentalists.

Oil, tallow, or other unguent substances, applied between the surfaces of metals sliding over each other, diminishes the friction, by separating the surfaces of the metals from each other, and interposing between those surfaces, substances, over the particles of which, the metals slide more readily, than over the surfaces of each other; in the same manner as friction rollers, interposed between two surfaces, diminish the friction, by causing the surfaces to roll, instead of to slide. From this view of the case, the surfaces of the metals should be effectually prevented from coming in contact; and, at the same time, to produce the greatest effect, the substance interposed, while it prevents contact, should be of such a nature, as that the surfaces of the metals will slide over it with the least resistance. Those two requisites, however, imply two very contradictory qualities, for that substance which most effectually prevents the contact of the surfaces, is that which is the least fluid; while the substance over which the metals slide with the least resistance, will be the most fluid. It follows, therefore, *that the unguent, which is the most fluid, and yet of sufficient viscidity, to prevent the surfaces from coming actually in contact with each other, will present the least resistance.* If we, then, use an unguent of a greater degree of tenacity than this, the friction is increased by the additional resistance, which the viscidity opposes to the surface of the metals sliding over it; and, on the other hand, if we use an unguent of a more fluid nature, then the friction is increased by the surfaces of the metal being imperfectly separated; by which they partially slide over each other, and partake of the degree of resistance which metals without unguents present.

A due consideration of these circumstances, will account for the great variety of results, given by different experimentalists; and shews the great care necessary in making experiments on friction, to obtain uniform results; for, in any two experiments, unless the materials, composing the two surfaces, are precisely similar, unless the degree of smoothness, area of surface, and insistent weight;—likewise the nature, degree of fluidity, and regularity of supply of oil, are precisely the same,—it is clear the result must be different. And when we consider the very great difficulty of accomplishing all these requisites, even when experimenting with the same carriage; it is not to be wondered at, that different experimentalists, not perhaps attending to all these minutiæ, should arrive at very various conclusions.

We are thus enabled to account for the seeming anomaly in the results of the experiments in Table VII., and those in Tables VIII., and IX.; the former were made with the common coal waggons, where, from their construction, an unguent of a viscid nature was obliged to be used, and which, no doubt, operated to increase the resistance; while those in Tables VIII. and IX. were made with neat's foot oil copiously applied.

Pursuing these considerations a little further, it will be seen, that, supposing we succeed in obtaining an unguent of precisely the proper degree of fluidity to keep the surfaces separate, with a certain area of bearing; if we increase the insistent weight without altering the area of bearing surface, the unguent will then be incapable of preventing contact; and hence, supposing the same unguent constantly used, we must increase the area of bearing surface, if we increase the insistent weight; or if the bearing surface remain the same, if we increase the insistent weight, we must use an unguent of a more viscid nature. This leads to the conclusion, that, in the use of any unguent, there must be a certain size of bearing, with a given insistent weight, to produce a maximum effect.

Taking the Tables VIII. and IX. as an example, we find a maximum effect, when the insistent weight was between 6720 lbs. and 4480 lbs.; probably the mean, equal to 5560 lbs.; the area of surface of bearing was 56·54 square inches; which would give about 98 lbs. pressure for every square inch of surface, when the resistance is a minimum.

In Table VII. we find the greatest insistent weight per square inch of bearing surface, is only 107 lbs., and with this bearing an unguent was used of a more viscid nature, than in the experiments of Tables VIII. and IX., and hence the diminution of effect.

§ 6.—*Friction with regard to Area of Bearing.*

The following Table, being the result of part of the experiments previously alluded to, having been made upon the friction of axles alone, the bearing surfaces, and insistent weights of which, being also more varied; will shew the comparative effect of different sized bearings, with the finest neat's foot oil.

Table XI.

Weight of lead and axle, in lbs.	Bearing 6 inches.		Bearing 4½ inches.		Bearing 3 inches.	
	Pressure per square inch of bearing, in lbs.	Effect.	Pressure per square inch of bearing, in lbs.	Effect.	Pressure per square inch of bearing, in lbs.	Effect.
4140	73·82	108·96	98·42	117·10	147·64	95·88
3622	64·58	99·18	86·12	134·46	128·87	122·79
2465	43·95	97·22	58·60	143·12	87·90	183·75
1331	23·78	86·62	31·64	117·04	47·47	146·01

From the above experiments, we find the maximum effect to take place, when the insistent weight is 98·42, and 86·12, and at 87·90 lbs. pressure, per square inch of surface, respectively. In the last set of experiments, the effect had not attained its maximum; as the pressure was only 47·47 lbs. per square inch. The experiments detailed in Tables VI. and VII. gave the pressure, 98 lbs. per square inch of surface; when the effect was a maximum, which agrees pretty well with the above experiments.

Supposing, therefore, we take a mean of these results, it appears, that to obtain a maximum effect, the pressure per square inch of surface should be about 90 lbs.; we find, from the above table, that this should be obtained by making the length of the chair, or bearing, nearly equal to the diameter of the axle, and not by increasing the length of bearing, for on inspecting the table, we find the effect when the pressure is 87·90 lbs. per square inch = 183·75; while, with a pressure of 86·12 lbs. per square inch, with a bearing 1½ times its diameter, the effect is only 134·46; and this is still more forcibly shewn with the weight of 4140 lbs., where the maximum effect is only 117·10, the pressure being 98·42 lbs. per square inch.

These experiments, though numerous, are not, perhaps, sufficiently varied, to determine the precise ratio of increase of resistance, when the pressure, per square inch, is increased or diminished; they appear to give an increase of resistance equal to sixty or seventy per cent. of the ratio of increase of the insistent weight, above the maximum standard; and of thirty per cent., of the diminution of insistent weight, below that standard. These proportions will, as before remarked, be varied, according to the unguent employed, the increase of resistance, when a *less* insistent weight is applied, being, as before stated, caused by the tenacity, or rigidity, of the unguent; if that is more or less viscid, the increase will be proportionably more or less; on the contrary, the increase of resistance, when a *greater* insistent weight is applied, is caused by the unguent not being capable of preventing the contact of the metals, and, consequently, a more or less viscid unguent will be more or less capable of effecting that separation; the standard of maximum effect will, therefore, vary, in terms of the pressure, per square inch, and likewise in the amount.

This is very satisfactorily illustrated, by some experiments, made by Mr. George Rennie, in 1825, on the friction of axles, with different unguents; and given in the transactions of the Royal Society, of which the following Table will shew the result.

TABLE XII.

Insistent weight in lbs.	Resistance in parts of the weight, and kind of unguent employed.				
	Tallow.	Oil.	Hogslard.	Soft Soap.	Anti-attrition.
56	—	$\frac{1}{37}$	$\frac{1}{34}$	$\frac{1}{26}$	—
112	$\frac{1}{36}$	$\frac{1}{32}$	$\frac{1}{36}$	$\frac{1}{32}$	$\frac{1}{14}$
224	$\frac{1}{38}$	$\frac{1}{32}$	$\frac{1}{29}$	$\frac{1}{37}$	$\frac{1}{24}$
336	$\frac{1}{40}$	$\frac{1}{20}$	$\frac{1}{14}$	$\frac{1}{35}$	$\frac{1}{32}$
448	$\frac{1}{40}$	$\frac{1}{18}$	$\frac{1}{10}$	$\frac{1}{35}$	$\frac{1}{35}$
560	$\frac{1}{40}$	$\frac{1}{19}$	$\frac{1}{11}$	$\frac{1}{37}$	$\frac{1}{38}$

The oil and hogslard shew, that the maximum effect took place with light insistent weights, gradually diminishing in effect, or shewing an increase of resistance, as the insistent weight was increased; while the contrary is the case, with the more viscid unguents of soft soap, and the anti-attrition mixture.

It would not, perhaps, have been necessary to have gone so much into length on this subject, had not all these experiments proved; that the practical result, as displayed in the modern built carriages, is, that the friction of attrition on their axles is greater than that of other machinery of a like nature. Either the axles and bearings are so proportioned, that with certain insistent weights, a maximum effect is not produced; or, that the unguent employed is of such a nature, as not to prevent the contact of the metals, or that it is more viscid than necessary.

When such large sums are expended, to make the gradients of the lines of railway moderate, it is equally important to diminish the resistance of the carriages, by diminishing the friction.

Coulumb found the friction, with hogslard, one-twenty-seventh of the weight; Tables VI. and VII. shew it the sixty-second, and sixty-sixth parts; Southern, the fortieth; Mr. Rennie, with tallow, the fortieth, and with oil the thirty-seventh; the experiments, with the common coal waggons, in Table V., the twentieth; the experiments on the Darlington railway, the twenty-first; while the experiments with Mr. Stephenson's carriage, on the Liverpool and Manchester railway, shews it equal to the eleventh part of the weight.

In the two latter cases, the ratio of the diameter of the axles, to that of the wheels, was as 12 : 26; therefore, the aggregate resistance is less in the latter, than the former; for $21 \times 12 = 252$, and $11 \times 26 = 286$th part of the weights.

The insistent weight in the former was about 100lbs. per square inch of bearing, and in the latter, more than 250 lbs. per square inch; experiment giving 90 lbs. per square inch, when the effect is a maximum.

It appears, therefore, that the weight of the carriage, and area of bearing surface on the axles of a carriage, should be such, as not to subject the latter to a greater pressure than 90 lbs. per square inch; and, having determined this, it then becomes a question, how the axle is to be proportioned, to obtain this pressure.

The experiments made on the single axle, shew the effect diminished, about fifty per cent. with the weights, 2465, and 1331, when the length of the bearing is doubled; *as, therefore, the resistance will be increased, in the direct ratio of the increase of the diameter of the axle, and only one half* in the terms of the *length; it appears that, in calculating the size of the axles, to obtain the necessary area of bearing surface, the length should be equal to twice its diameter, and that the area should be such as not to subject it to a greater insistent weight than* 90 *lbs. per square inch.*

Taking the result of the common coal waggon bearings as a standard, it would appear, that in practice, we may calculate on the friction upon the axles, as the twentieth part of the weight, or $f'=\cdot 05$, and making $f=\cdot 001$; we have the force, P, necessary to drag a carriage on a level railway $P=\frac{W}{f}+\frac{W'}{f'\frac{d}{D}}$.

It, however, becomes necessary, in order to complete our information, on this subject, to know if the friction does, or does not increase with the weight, and, likewise, what effect velocity has on the resistance.

The Experiment VII. was made for this purpose, by which it was found, that, when well oiled, the friction did not increase as the weight, except what arises from what has been before stated, relative to the effect on the unguent by the insistent weight being varied.

Experiment VIII. was made to ascertain the effect at different rates of speed; in this experiment no sensible difference was felt, but the rate of velocity was only varied from one mile and a half, to four miles and a half an hour; the experiment, immediately following, shews likewise, that velocity of motion does not affect the friction, except what arises from the wind.

All these experiments prove, not calculating upon the effect of the wind,

That in practice we may consider the friction of carriages moved along railways, as a uniform and constantly retarding force.

That there is a certain area of bearing surface, compared with the insistent weight, when the resistance is a minimum.

That when the area of bearing surface is apportioned to the insistent weight, the friction is in strict ratio to the weight.

We have now to consider the effect of the wind on the carriages, or train of carriages, and this is the more necessary as the rate of travelling has recently been so much increased. M. Pambour's experiments having been made on both single carriages, and, likewise, on considerable numbers linked together in trains; and being moreover made at a medium velocity of twelve miles an hour, (the velocity, at one period of the experiment being at double that rate,) are particularly adapted to determine this question practically.

Being made under these circumstances, they, of course, include the resistance of the air at that rate of velocity, taking Nos. 3, 4, 5, and 6, we find the average resistance 11·77 lbs. per ton, with single carriages; in Experiment II., with five carriages, the resistance per ton is 9·17 lbs., or 234·5 lbs. for the whole train; deducting therefrom 11·77 lbs., the resistance of the first carriage, leaves 174·25 lbs. for the resistance of the remaining four, and which gives for each of the carriages 8·50 lbs. per ton. As the air was quite calm during the experiments, the leading carriage would only be subjected to the action of the air; hence the resistance of the air to a single, or a leading carriage of a train, will be 11·77—8·50=3·67 lbs. per ton, at an average rate of velocity of twelve miles an hour.

Making the same allowance for the leading carriage in each train, M. Pambour gives the following Table of the friction of the intermediate carriages in each train; taken from the several resistances as determined by his experiments previously given.

TABLE XIII.

Number of experiment.	Description of trains.	Weight of trains, in tons.	Mean weight of each carriage, in tons.	Resistance of first carriage, in lbs. per ton.	Resistance of intermediate carriage, in lbs. per ton.
1	5 waggons	31·31	6·26	11·77	7·92
2	5 waggons	55·58	5·12	11·77	8·50
7	19 waggons	92·	4·84	11·77	7·91
10	14 waggons	61·65	4·40	11·77	7·99
11	11 carriages	48·72	4·43	11·77	8·33
12	25 carriages	110·	4·40	11·77	7·99
13	18 carriages	86·76	4·78	13·78	7·21
14	21 carriages	101·80	4·83	15·22	7·35
15	8 carriages	33·52	4·	15·84	9·04
Total means	126 carriages	591·	4·78	—	8·03

Taking therefore the resistance of the leading carriage at 11·77 lbs. per ton, that of the intermediate carriages, or a mean of these experiments, is 8·03 lbs. per ton. In general the locomotive engine precedes the train, in which case, if allowance is made for the resistance of the air in calculating the power of the engine, the friction of the whole of the carriages of the train may be calculated at eight pounds per ton.

As previously stated, the experiments on the Liverpool railway, were made with carriages having springs to support their weight; the experiments on the Darlington railway were made on carriages without springs, and as the latter appeared to have less friction, such a diminution of resistance might be attributed to the want of springs; an experiment was made on the Darlington railway by Mr. Dockray, to ascertain if such was the case. A carriage with springs was taken and tried upon the same plane, and the friction was found to be 8·35 lbs. per ton; the same waggon was tried with the springs wedged up, so as not to act, when the friction was found to be 8·58 lbs. per ton; giving a trifling result in favour of the use of springs.

§ 7.—*Tables of the Resistance of Carriages, on different Gradients on Railroads.*

Although the experiments with trains of carriages upon the Liverpool and Manchester railway give 8·03 lbs. per ton, as the friction of the intermediate carriages, and as the engine precedes the train of carriages, and, therefore, prevents the wind from acting upon them, that has been taken as the friction by M. Pambour; we think, however, in practice, this will be found to be too favourable a result, and that eight and a half, or nine pounds per ton will be more likely to be found to be the real amount of friction. We have, therefore, given two tables, shewing the amount of friction upon planes of different gradients, calculated at the 240th part of the weight, or about nine pounds per ton; and also the 280th part of the weight, or eight pounds per ton.

TABLE XIV.

Shewing the resistance of a carriage, on different inclinations of plane. Friction equal to the 240th part of the weight.

—	Inclination of the plane, equal to 1 in									
	0	100	200	300	400	500	600	700	800	900
0	·00416	·00416	·00916	·0075	·00666	·00616	·00583	·0056	·00541	·00527
10	·10416	·01325	·00892	·00738	·0066	·00612	·0058	·00557	·00539	·00526
20	·05416	·01249	·00870	·0073	·00654	·00608	·00577	·00555	·00538	·00525
30	·0375	·01185	·00851	·00719	·00649	·00605	·00574	·00553	·00536	·00523
40	·02916	·0112	·00833	·0071	·00643	·00601	·00572	·00551	·00535	·00522
50	·02416	·01082	·00816	·00702	·00638	00598	·0057	·00540	·00534	·00521
60	·02082	·01041	·00801	·00693	·00634	·00594	·00568	·00548	·00532	·00520
70	·0185	·01004	·00786	·00686	·0063	·00592	·00565	·00546	·00531	·00519
80	·01666	·00975	·00774	·00679	·00624	·00588	·00563	·00544	·0053	·00518
90	·01527	·00942	·00761	·00672	·0062	·00586	·00561	·00543	·00529	·00517

TABLE XV.

Shewing the resistance of a carriage, on different inclinations of plane. Friction equal to the 280th part of the weight, or 8 lbs. per ton.

—	Inclination of the plane, equal to 1 in									
	0	100	200	300	400	500	600	700	800	900
0	·00357	·00357	·00785	·0064	·00571	·00528	·00500	·0048	·00464	·00452
10	·08928	·01136	·00765	·00633	·0057	·00525	·0050	·00477	·00462	·00451
20	·04642	·01071	·00746	·0063	·00561	·00521	·00495	·00476	·00461	·00450
30	·0322	·01016	·00730	·00616	·00556	·00519	·00492	·00474	·00458	·00448
40	·02500	·0096	·00614	·0071	·00551	·00595	·00490	·00472	·00459	·00447
50	·02085	·00928	·00699	·00602	·00547	·00513	·0049	·00451	·00458	·00447
60	·01785	·00892	·00687	·00594	·00543	·00509	·00487	·00470	·00456	·00446
70	·0159	·00961	·00674	·00588	·0054	·00407	·00484	·00468	·00455	·00445
80	·00914	·00836	·00663	·00582	·00535	·00504	·00483	·00406	·0045	·00444
90	·01309	·00808	·00652	·00576	·0053	·00502	·00481	·00465	·00453	·00443

The following experiments were made, to ascertain the resistance of carriages moved along the plate rail, with the same dynamometer used in the experiments made upon the Killingworth railway.

TABLE XVI.

The rails were each four feet long, and 3⅝ inches broad, where the wheel runs upon them; and the height of the upright ledge three inches.

Numbers of experiments.	Description of carriages.	Resistance up the plane.	Resistance down the plane.	Mean resistance.
1	Two loaded carriages, each weighing 8512 lbs., cast-iron wheels 39¼ inches diameter, 1⅝ inches broad, the rim which runs upon the rails, brass bearings 1¾ inches broad, diameter of axle 2⅝ inches -	168	126	147
2	Six empty carriages, each weighing 2576 lbs., construction same as preceding - - -	187	147	167

From these experiments, we find the resistance of a loaded carriage, weighing 8512 lbs., to be 73·5 lbs., which is equal to the 116th part of the weight; and, comparing this with No. 2. Experiment IV., which had the same kind of bearing, we find the relative resistances of the plate to the edge-rail, as 73 : 63, which gives the most decided preference to the latter.

CHAPTER VIII.

FRICTION OF ROPES USED BY FIXED ENGINES ON RAILROADS.

§ 1. *Different Experiments on the Friction of Ropes.*

Ropes being generally used, as a medium of communication between the moving power and the resistance, in dragging carriages up acclivities, along level planes, or for lowering them from one level to another upon railroads; it is not only interesting, but, in the case of the self-acting planes, absolutely necessary, that a proper estimate of their friction should be obtained.

In fixed engines, where loads are dragged forward upon carriages by means of opes, unless we can calculate, *à priori*, the friction or resistance opposed by the use of such rope, we are at a loss to know how much engine-power is required to overcome the resistance, and to obtain the requisite velocity;—we may, by over-rating its effects, load the engine with unnecessary strength and power, or, by under-rating, erect an engine not adequate to perform the desired effect.

In self-acting planes, where gravity is the moving power, it scarcely need be stated, that the strictest regard should be observed in economising its effects; the power itself is acquired at no cost; and, on that account, its action should be extended to the utmost limit of its applicability.

The following experiments are selected, from a great many which we have been allowed to make upon the different railroads in the neighbourhood of Newcastle-upon-Tyne; and are such as appeared to us to be sufficient to shew the requisite resistance, and from which may be deduced the necessary data for calculating the effects upon other planes.

EXPERIMENT I.

Upon the Killingworth railroad: self-acting plane with a single sheeve, round which the rope winds, one end of which is attached to the descending, and the other to the ascending, carriages; length of the plane, 715 yards; descent, fifty-seven feet, six inches. Five loaded carriages, each weighing 8764 lbs., descended by their gravitating force, and drew up six empty carriages, each weighing 2800 lbs., on a mean of several times, in 200 seconds; wheels, thirty-four inches diameter; axles, two inches and three quarters diameter; size of rope, five inches circumference; weight, 3884 lbs. The descent of this plane is not regular, being greater at the top than at the bottom, the rails being laid, as shewn in *Fig.* 1. *Plate X.*, the line of road perfectly straight. Number of sheeves in action at once, seventy-three; weight, 3297 lbs.; diameter of sheeve where rope runs, eleven inches; and diameter of the axles, three quarters of an inch; ratio, 14·65 : 1; weight of wheel, W w, 4636 lbs.; diameter, ten feet; and in diameter of axles, six inches; ratio, 20 : 1.

We have then

$$\mathrm{F}' = \mathrm{G} - \frac{(\overline{\mathrm{W} + w\frac{\mathrm{SO}}{\mathrm{SG}}} + \overline{a' + a''\frac{\mathrm{SO}}{\mathrm{SG}}} + b + c + c') \times \mathrm{S}}{rt^2}$$

$$\text{And } \varphi = \mathrm{F}' - (\mathrm{F} + f + g)$$

The gravity of the loaded carriages will be

$$\mathrm{G} = \mathrm{W} + w\frac{\mathrm{H}}{\mathrm{L}} = \frac{\overline{8764 + 5} + 57{\cdot}5}{2145} = 1175 \text{ lbs.}$$

and the gravity of the empty carriages will be

$$g = a' + a'' \tfrac{\mathrm{H}}{\mathrm{L}} = \frac{\overline{2800 \times 6} \times 57{\cdot}5}{2145} = 450 \text{ lbs.}$$

Taking the friction of the carriages at $\mathrm{F} = 38$ lbs., and $f =$ 12 lbs., $\mathrm{W} = 7452$ lbs., $w = 1312$ lbs., $\frac{\mathrm{SO}}{\mathrm{SG}} = \frac{27{\cdot}07}{17{\cdot}25}$ and $w \frac{\mathrm{SO}}{\mathrm{SG}} =$ 2059. Therefore $\mathrm{W} + w \frac{\mathrm{SO}}{\mathrm{SG}} = 9511$ lbs., $a' = 1488$ lbs., and $a'' = 1312$, consequently $a' + a'' \frac{\mathrm{SO}}{\mathrm{SG}} = 3547$ lbs., $b = 3884$ lbs., $c = \frac{1}{2}\, \mathrm{W}\, \mathrm{W} = 2318$ lbs., and $c' = 1648$ lbs. Therefore $1175 -$

$$\frac{(\overline{9511 \times 5} + \overline{3547 \times 6} + 3884 + 2318 + 1648) \times 2145}{16\frac{1}{12} \times 200^2} =$$

920 lbs.

Whence by Theorem 13, $\varphi = \mathrm{F}' - (\mathrm{F} + f + g) = 920 - (190 + 72 \times 450) = 208$ lbs. The friction of the rope, sheeves, and wheel, at top of plane.

EXPERIMENT II.

Same plane, and similar carriages; six loaded carriages drew, up the plane, seven empty carriages, in 180 seconds.

Theorem $\mathrm{G} = \frac{\overline{8764 \times 6} \times 57{\cdot}5}{2145} = 1410$ lbs.

and $g = \frac{\overline{2800 \times 7} \times 57{\cdot}5}{2145} = 525$ lbs.

also $\mathrm{F}' = 1410 - \frac{(57066 + 24829 + 3884 + 2318 + 1648 \times 2145}{16\frac{1}{12} \times 180^2} =$

1041 lbs.

and $\varphi = 1041 - 525 + 228 + 84 = 204$ lbs., the friction of the rope.

The above plane, in practice, requires always six loaded carriages descending, to drag up six empty carriages. In fine weather, and when the rails are in good order, the brake, or convoy, is not required; but in windy weather, or when the rails are not in a good state, the six loaded carriages have some difficulty in overcoming the resistance of the six empty carriages and rope. With six carriages, therefore, this plane may be taken as an instance of the least inclination that can be used in practice, with ropes, sheeves, wheel, &c., of the weight stated, to secure a regular and constant conveyance, in all states of the weather. When at regular work, the usual time of descent is from three to four minutes.

Taking the above number of loaded carriages, as necessary to effect the constant passage, of the empty carriages up the plane,

We have the gravitating force, or moving power, $G = 1410$lbs.; and the friction, or resistance, of the whole train being $F' =$ 1041 lbs., leaving a surplus of gravitating force, equal to 369 lbs., to effect the motion of the whole matter upon the plane, with the requisite velocity, in all states of the weather.

EXPERIMENT III.

Self-acting plane, with wheel, similar to *Fig.* 1. *Plate IX.*, six feet in diameter. Length of plane 3906 feet, height 130 feet four inches. The descent of this plane is not regular, and has a considerable curve, also, in the line of road. Weight of inclined wheel 454 lbs., diameter six feet, diameter of axle three inches; number of sheeves in action at once 144, weight 4448 lbs.; circumference of rope five inches, weight 4807 lbs.; ratio of diameter of sheeves, to diameter of axle, 14 : 1.

Five loaded carriages, same as Experiments V. and VI., Chap. VII., each weighing 9408 lbs., in descending, drew up seven empty carriages, similar to Experiment IX. Chap. VII., each weighing 3472 lbs., in 300 seconds.

Theorem $\text{G} = \dfrac{\overline{9408 \times 5} \times 1564}{46872} = 1570$ lbs.

$$g = \frac{\overline{3472 \times 7} \times 1564}{46872} = 811 \text{ lbs.}$$

$\text{w} = 9408 - 1312 = 8096$ lbs. and $w \frac{\text{SO}}{\text{SG}} = 2059$. Therefore $\text{w} + w \frac{\text{SO}}{\text{SG}} = 10155$ lbs., $a' = 2160 + a'' \frac{\text{SO}}{\text{SG}} (2059) = 4219$ lbs., $b = 4807$ lbs., $c = 227$ lbs., and $c' = 2224$ lbs. Then

$$\text{F}' = 1570 - \frac{(\overline{10155 \times 5} + \overline{4219 \times 7} + 4807 \times 227 + 2224) \times 3906}{16\frac{1}{12} \times 300^2} = 1134$$

and $\varphi = 1334 - \overline{811 + 91 + 200} = 232$ lbs. friction of the rope, &c.

This plane, when at regular work, is always employed with seven loaded, and seven empty, carriages, which effect a constant action during all states of the weather, and have also a surplus of power, as the brake, or convoy, is always used upon particular parts of the plane.

With the above number in action we have $\text{G} = 2198$ lbs., and $\text{F}' = 1343$ lbs., which is more than necessary to effect the requisite velocity.

EXPERIMENT IV.

Self-acting plane-wheel, same as preceding; six feet in diameter, weight 454 lbs., ratio of diameter, to diameter of axle, 24 : 1, length of plane 3672 feet, height 129 feet six inches; descent not uniform, with a curve in the middle, forming part of a circular arc. Number of sheeves 263, weight 9759 lbs., ratio of diameter of sheeves, to diameter of axle, 14 : 1; rope 1200 yards, weight 4468 lbs., circumference five inches.

Five loaded carriages, similar to the last experiment, each weighing 9408 lbs., descended against seven empty carriages, each weighing 3472 lbs., in 360 seconds.

$$\text{Theorem } G = \frac{\overline{9408 \times 5} \times 1554}{44064} = 1659 \text{ lbs.}$$

$$g = \frac{\overline{3472 \times 7} \times 154}{44064} = 857 \text{ lbs.}$$

$$F' = 1659 - \frac{(\overline{10155 \times 5} + \overline{4219 \times 7} + 4468 + 227 + 4874) \times 3672}{16\frac{1}{12} \times 360^2} = 150 \text{ lbs.}$$

and $\varphi = 1501 - \overline{857 \times 200 + 91} = 353$ lbs., the resistance of the rope, &c.

The same number of carriages usually employed on this plane, as on the preceding, which leaves a considerable surplus of gravity, to effect their motion upon the plane.

EXPERIMENT V.

Self-acting plane, similar to the two last; length 2706 feet, height seventy-six feet five inches, descent nearly uniform, and line of direction quite straight; weight of wheel 454 lbs., ratio of wheel and axle 24 : 1, number of sheeves 139, weight 4173 lbs., ratio of diameter 16 : 1, rope 1000 yards, four inches and a half circumference, weight 2927 lbs., inclined wheel same as above.

Five loaded carriages descended the plane, and brought up seven empty carriages, same weight as preceding, in 280 seconds.

$$\text{Theorem } G = \frac{\overline{9408 \times 5} \times 917}{32472} = 1328 \text{ lbs.}$$

$$g = \frac{\overline{3472 \times 7} \times 917}{32472} = 686 \text{ lbs.}$$

$$F' = 1328 - \frac{(\overline{10155 \times 5} + \overline{4219 \times 7} + 2927 + 227 + 2086) \times 2706}{16\frac{1}{12} \times 280^2}$$

$= 114$ lb.; and $\varphi = 1145 - \overline{686 + 200 + 91} = 168$ lbs. the friction of the rope, &c.

The number of carriages, used in practice upon this plane, are seven descending, against seven ascending; but there is always more than sufficient preponderance.

EXPERIMENT VI.

Fixed-engine plane, where a steam-engine of sixty-horse power is erected, to drag the loaded carriages up; length 2646 feet, height 154 feet six inches, descent not regular, being less, near the top, than at the bottom; line curved laterally in the middle, forming an arc, the versed sine of which is about forty yards. Rope roll similar to A, *Fig 2. Plate IX.* on which the engine winds the rope, and which, during the experiment, was thrown out of gear, as shown in the drawing, the descending carriages unwinding the rope; weight of rope-roll with cog wheels 8960 lbs., ratio of diameter to diameter, of axle 10 : 1, number of sheeves 161, weight 10,278 lbs., ratio of diameter to diameter, of axle 14 : 1; length of rope 1000 yards, 7½ inches cercumference, weight 6967 lbs.

Three empty carriages, each weighing 3472 lbs., descended and dragged the rope out from the engine in 174 seconds.

In this kind of plane, the rope and sheeves are only in action upon the plane during one half of the time of descent, but that part of the rope which is not on the plane, being upon the rope-roll, the whole of its weight is subject to friction. The formula will be

$$\mathrm{F}' = \overline{\mathrm{G} + \tfrac{1}{2} b \sin. \mathrm{I}} - \frac{\left(\overline{\mathrm{W} + w \frac{\mathrm{SO}}{\mathrm{SG}}} + b + c + \tfrac{1}{2} c'\right) \times \mathrm{S}}{r t^2}$$

And $\varphi = \mathrm{F}' - f$

therefore $\mathrm{G} = \overline{3472 \times 3} \times \frac{1854}{31752} = 608$ lbs., and $\frac{1}{2} b \sin. \mathrm{I}$

$= 3483 \times \frac{1854}{31752} = 203$ lbs. And $\mathrm{F}' = \overline{608 + 203} -$

$$\frac{(4219 \times 3 + 6967 + 4480 + 2569) \times 2546}{16\frac{1}{12} \times 174^2} = 666 \text{ lbs.}$$

whence $666 - 39 = 627$ lbs., the friction of the rope, &c.

EXPERIMENT VII.

Fixed-engine plane, similar to last experiment; length 2325 feet, height 115 feet, descent nearly uniform, plane quite straight, weight of rope-roll 8960 lbs., ratio of diameter of roll to diameter of axle 10 : 1; number of sheeves 134, weight 4524 lbs., ratio of diameters 14 : 1; length of rope 875 yards, 7½ inches circumference, weight 6157 lbs.

Four empty carriages, each weighing 3472 lbs., descended the plane, and dragged the rope after them in 115 seconds.

Theorem $G = (3472 \times 4) \times \frac{1380}{27900} = 686$ lbs. $\frac{1}{2} b \sin. I = 153$ lbs.

$$\text{Then } F' = \overline{686 + 153 -} \frac{\overline{(4219 + 4} + 3078 + 4480 + 1131) \times 2325}{16\frac{1}{12} + 115^2} = 560 \text{ lbs.}$$

whence 560 — 52 = 508 lbs., the friction of the rope, &c.

EXPERIMENT VIII.

Fixed-engine plane, with rope-roll similar to A, in the drawing, *Fig.* 2. *Plate IX.*; length 2892 feet, height 57 feet 7 inches, weight of rope-roll 4500 lbs., ratio of diameter to diameter of axle 10 : 1, number of sheeves 138, weight 5288 lbs., ratio of diameter of sheeve, to diameter of axle 14·65 : 1; length of rope 1000 yards weight, 3696 lbs., circumference 5 inches.

Eight empty carriages, each weighing 2688 lbs., descended the plane, with the rope attached, in 330 seconds.

Theorem $G = (2688 \times 8 \times \frac{691}{34704} = 428$ lbs. $\frac{1}{2} b \sin. I = 37$ lbs.

$$\text{then } F' = \overline{428 + 37} - \frac{(3435 \times 8 + 3696 + 2250 + 1323) \times 2892}{16\frac{1}{12} \times 320^2}$$

= 408 lbs. whence 408 — 120 = 288 lbs., the resistance of the rope.

The above engine works regularly with eight carriages at a time, and that number of empty carriages is sometimes not found sufficient to draw the rope out from the engine when descending the plane; the engine being erected for the purpose of dragging the loaded carriages up the plane. In very windy weather, and when the rails are not in good order, they have been obliged to have recourse to a horse to assist the gravity of the carriages in dragging the rope out. This plane may, therefore, be taken in practice as having scarcely adequate descent, to secure a constant passage to that number of carriages down the plane, and to drag a heavy rope after them; with a lighter rope, and the rails in good order, the above number of carriages may be sufficient.

The excess of gravitating force, above the friction of the train,

$$\text{is } \frac{34748 \times 2892}{16\frac{1}{12} \times 330^2} = 57 \text{ lbs.}$$

to effect the descent of the train in the requisite time, which may be sufficient in favourable weather, and under favourable circumstances; but is certainly less than what ought to be allowed for all variations of weather, unless the road, sheeves, &c., are kept in the best possible order.

EXPERIMENT IX.

Fixed-engine plane, similar to the above: length, 3165 feet; height, forty-two feet; weight of rope-roll, 2018 lbs.; ratio of diameter to diameter of axle, 10:1; number of sheeves, 124; weight, 4216 lbs.; ratio, 14·65:1; length of rope, 1200 yards; weight, 3527 lbs.; circumference, four inches and a half.

Nine empty carriages, each weighing 3080 lbs., ran down the plane, and dragged the rope after them, in 360 seconds.

Theorem $G = (3080 \times 9) \times \frac{42}{3165} = 367$ lbs. $\frac{1}{2} b \sin. I = 23$ lbs.

$$\text{and } F' = \overline{367 \times 23} - \frac{\overline{(3827 \times 9} + 3527 + 1009 + 1054) \times 3165}{16\frac{1}{12} \times 360^2}$$

$= 330$ lbs., whence $330 - 126 = 204$ lbs., the friction of the rope.

When regularly at work, this engine drags twelve loaded carriages up this plane, and the rope is taken out again by the empty carriages descending the plane. In bad weather, that number is scarcely sufficient to accomplish it, and a horse is obliged to be sometimes used to assist the carriages in overcoming the resistance of the ropes. The plane has not an uniform descent, being least in the middle; the line of direction is also a little curved.

The preponderance of gravity is $\frac{27720 \times 3165}{16\frac{1}{12} \times 360^2} = 42$ lbs.

which, in fine weather, effects the descent in six minutes; but, from the circumstance of a horse being required to be sometimes used, it need scarcely be stated, that this preponderance is too little for general utility.

§ 2.—*Result of Experiments on the Friction of Ropes.*

RECAPITULATION of the preceding Experiments of the Friction of Ropes on Inclined Planes.

TABLE I.

Number of experiments.	Description of plane.	Length of plane, in yards.	Circumference of rope in inches.	Friction of rope in lbs.	Amount of pressure upon the sheeves, and rollers, in lbs.	Ratio of diminution of rubbing surface by the use of rollers.	Extent of rubbing surface exposed to pressure and friction.	Ratio of friction to rubbing surface and weight.
XIV.	Self-acting	715	5	208	12317	16:1	771	1:3·70
XV.	Ditto	715	5	204	12317	16:1	771	1:3·77
XVI.	Ditto	1302	5	232	10955	15:1	727	1:3·13
XVII.	Ditto	1224	5	353	16576	15·4:1	1076	1:3·05
XVIII.	Ditto	902	4½	168	8529	16·9:1	503	1:3·00
XIX.	Fixed-Engine	882	7¼	627	21666	12:1	1810	1:2·90
XX.	Ditto	775	7¼	508	17378	12:1	1584	1:3·11
XXI.	Ditto	964	5	288	9840	11:1	934	1:3·24
XXII.	Ditto	1055	4½	204	7652	12:1	642	1:3·14

From these experiments, we find that the proportion of the friction of ropes on inclined planes, when disposed upon sheeves or rollers, amounts to about one-third of the respective weights, or pressure of the whole apparatus, put in motion by such rope, supposing the velocity of the surface exposed to the action, or rubbing of that weight, be the same as that of the rope upon the plane;—when the rope is disposed upon sheeves, or rollers, the friction is of course diminished in the proportion which we diminish the velocity of the rubbing parts, compared with that of the rope. Thus, in Experiment XIV., the ratio of the friction to the weight, is as 1 : 3·70. By placing the weight upon rollers, the velocity of the periphery on which the rope runs, being to the velocity of the circumference of the axle, or part exposed to rubbing, as 16 : 1; we reduce the friction in that proportion, and make it equal to the 59·20th part of the weight, or 12317 : 208, as shown in columns five and six of the table. And, in like manner, the friction will always bear different proportions to the weight of the body, according to the diameter of the sheeves or rollers on which the rope or the weight is placed. When the diameter of the axle remains the same, column nine will then show the ratio which the friction bears to the weight, when it is not placed upon sheeves; and our reason for giving the ratio in this manner, was to express it in terms not variable with the size of the sheeves upon which it might be placed, but in constant terms which might be reduced to practice when the size of the sheeves was fixed upon. Column six shews the whole weight or pressure of the apparatus put in motion when the carriages are descending, and comprehends the weight of the rollers, the rope wheels, the rope, and its pressure upon the wheel which it winds round; observing, that in the fixed engines, only one half the weight of the sheeves is reckoned, as the amount of their action is only one half of the whole. The resistance of the rope, it will be perceived, is greater in some of the self-acting planes than the fixed-engine planes, which most probably arises from the rope of the former having to bend round wheels of smaller diameter than the fixed engine rolls when the carriages are traversing the plane; while, in the latter, the rolls are not only of larger diameter, but the rope is only uncoiled off the roller, as the carriages drag it out from the engine.

§ 3.—*Theoretical Conclusions on the Friction of Ropes.*

The maximum resistance in self-acting planes, is nearly the third, and the maximum as 1 : 3·77. In practice, it will, however, be sufficiently accurate, and perhaps more advisable, to take the third. In the fixed-engine plane, the same ratio should be taken; as the engine, in winding the rope upon the roll, will be subjected to the same amount of friction that occurs in the self-acting plane, from the bending of the rope. In calculating, however, upon a descent of plane, that will cause the carriages to drag the rope out from the engine, we may, under favourable circumstances, take the ratio at 3¼ : 1. Assuming, therefore, the ratio as one-third, by causing the rope to run upon rollers, the periphery of which, where the rope is supported, being twelve inches, and the diameter of the axle, on which the roller runs, one inch; then the friction will be diminished in that ratio, and become only the thirty-sixth part of the weight, and in the same proportion with any other size of roller. And, in general, we can calculate, "*à priori,*" the friction of the rope upon any plane, by taking the weight of the whole apparatus, inclined-wheel, sheeves, and rope; and the pressure of the latter upon the wheel, in winding round it, and also its extra pressure by any curves in the line of the road; then the friction will amount to one-third of the whole of that weight, if no rollers are employed. Knowing the diminution, by the size of sheeves fixed upon, the actual friction is found.

Thus let R = the weight of the wheel, or rope roll.
R' = that of the sheeves.
R'' = the weight of the rope.
P = the pressure upon the wheel, or rope roll.
and r = the ratio of difference between the diameter of the axle, and periphery of rope roll, or sheeves; diameter of axle = 1.

Then $\varphi = \frac{\text{R} + \text{R}' + \text{R}'' + \text{P}}{3\cdot 5\, r,\text{ or } 3\, r}$ for the self-acting plane,

and $\varphi = \frac{\text{R} + \frac{1}{2}\,\text{R}' + \text{R}''}{3\cdot 5\, r,\text{ or } 3\, r}$ for the fixed engine with a single rope.

Having thus ascertained the ratio of the friction to the weight, it will be evident that the friction of ropes of different lengths will be in proportion to those lengths, or to the weight.

The preceding proportion, expressing the resistance of the rope, we trust may be depended upon as a datum of calculation in general; but, in applying it to practice, it must undergo some limitation. It has been ascertained, under favourable circumstances, the planes were not prepared for the purpose; but taken as in actual use, and as they had remained for some years: but, during the experiments, the weather was favourable, and this has considerable effect upon the resistance; we must, therefore, found our calculations upon data, which will hold good under every possible variation of weather, and this can only be done by appealing to practice.

In the selection of the planes which we have here given, there is one which we consider just adequate, with the number of carriages usually employed, to effect a regular and constant passage during all states of the weather, except under very extraordinary circumstances indeed, such as the rails being covered with snow. We shall, therefore, make that the foundation of our data for estimating the effects on other planes.— To effect the descent of any carriage or train of carriages down a plane by the action of gravity, we must give a certain excess of preponderance above the friction of the respective parts, to accomplish that descent in a given time; and this time will be entirely governed, and be in precise proportion to the excess of gravitating force employed, compared with the weight of the carriages.

$$\text{being as } W : \frac{WS}{rt^2}$$

The self-acting plane, Experiment I., Chap. VIII., is one which, when six loaded carriages are employed in dragging six empty carriages up by the rope there described, we can safely state, from a frequent opportunity of witnessing its action, has just sufficient preponderancy to produce the required effect; and we do not think it would be proper in any case to allow less.

The whole weight there moved, including the inertia of the wheels, rope, sheeves, &c. will be 86198 lbs., and the excess of preponderance, above the friction and resistance of the whole train $G - \overline{g + F + f + \varphi}$ will be equal to 369 lbs. nearly.

Whence we have, if W denote the inertia of the whole mass in motion,

$$\frac{WS}{rt} = 369 \text{ lbs.}; \text{ or } G - F' = 369 \text{ lbs.}$$

$$\text{Then by Theorem (11) } t = \sqrt{\frac{(W + \frac{SO}{SG} + W') \times S}{G - F' r}} = 176''$$

By Experiment I., Chap. VIII., when the moving force, and resistance were in a state of dynamical equilibrium, the time of descent was 200 seconds. In practice, as above, we find that in order to effect the certain transit or passage, it is necessary the preponderance should be such as that, under the most favourable weather, the descent should be effected in 176 seconds; then the excess or preponderance of gravitating power to be given in practice above what is required to merely effect the descent in fine weather, or by taking the resistance as shewn in the table, must be in the ratio of 200 : 176, or, in even numbers, as 8 : 7.

CHAPTER IX.

THEORY AND APPLICATION OF THE VARIOUS KINDS OF MOTIVE POWER EMPLOYED ON RAILROADS.

THIS chapter will comprehend practical illustrations, as well as theoretical applications, of the different species of motive power previously enumerated; deduced from the foregoing disquisitions, and from experiments made on their performances in actual use upon railroads.

Retaining the classification adopted when describing the different kinds of motive power, we shall divide them into the following order:—

1. Horses.
2. Self-acting Planes.
3. Engine Planes.
4. Locomotive Engines.

§ 1.—*Horses.*

The power of a horse, or that part of his muscular exertion which, in travelling, he is capable of applying upon the load, has been variously stated by different authors. It is not the force he is capable of exerting at a dead pull, or for a short period, by which we are to judge of, or estimate his strength; it is what he can exert daily, and day after day for a long period, without injury to his physical powers, that we are to take as the criterion for practice.

A railroad is peculiarly adapted to show the power of a horse, as he is continually employed in overcoming the same resistance; and the inclination of the road, in general, has little effect upon the power required to overcome the gravity of his own weight.

Art. 1.—*Experiments on the Performances of Horses on Railroads.*

The following Tables will shew, on different railroads, where horses have been used for some years, the respective resistances; which the inclination of the road, and the friction of the carriages, presented to the action of the horse.

TABLE I.

Table of the line of road, on which one horse travels with six loaded carriages, each weighing 8540 lbs., similar to No. 1, Experiment I. Chapter VII. § 2; and returns with six empty carriages, each weighing 2604 lbs., same as No. 7, Experiment I. Chapter VII. § 2. Edge-rail, Killingworth Colliery Railroad; friction, loaded carriages 40 lbs., empty carriages 14lbs.

Respective distances in feet.	Descent of plane in inches.	Gravity of six loaded carriages down the plane in lbs.	Total resistance, being the difference between the friction and gravity, in lbs.	Gravity of the empty carriages up the plane, in lbs.	Total resistance, being the gravity and friction together, in lbs.
330	6·5	84	156	25	109
330	12·	155	85	47	131
330	16·5	213	27	65	149
330	18·5	239	1	72	156
330	14·	181	59	55	139
330	17·	219	21	67	151
330	18·	232	8	71	155
330	30·5	394	—	120	204
330	44·	569	—	173	257
330	25·5	329	—	100	184
330	2·	25	215	7	91
330	8·	103	137	31	115
330	11·	142	198	43	127
330	24·	310	—	94	178
330	23·5	304	—	92	176
330	—	—	240	—	84
330	14·	181	—	55	139
330	40·	517	—	157	241
330	33·5	433	—	132	216
198	9·	194	46	59	143

On examining the above Table, it will be seen, that the average resistance with the load is about 60 lbs.; and in returning with the empty carriages, 157 lbs.; the mean, 109 lbs.—The distance, 2156 yards.

The horses were very large and heavy; they generally traversed that distance eight times a day, being in all about nineteen miles. There were four horses regularly employed, but it was found necessary to keep a spare horse, to give the others alternately a day's rest; so that, in fact, five horses were kept to perform the constant work of four horses effectively.

TABLE II.

Table of the performance of horses, upon the Backworth Colliery Edge-railroad, where a horse takes six loaded carriages, each weighing 9010 lbs. down the plane; and returns with six empty carriages, up the plane, each weighing 3080 lbs.

Friction of each loaded carriage 42 lbs., and of each empty carriage 15 lbs.

Length of plane in feet.	Descent of plane in inches.	Gravity of six loaded carriages down the plane in lbs.	Total resistance in lbs., being the difference between the friction and gravity.	Gravity of six empty carriages down the plane in lbs.	Total resistance in lbs., being the gravity and friction together.
330	15·	204	48	70	160
330	14·5	197	55	67	157
330	7·	95	157	32	122
330	14·5	204	48	67	157
330	5·	68	184	23	113
330	5·5	75	177	25	115
330	18·	245	7	84	174
330	12·5	170	82	58	148
330	16·5	225	27	77	167
330	18·	245	7	84	174
330	31·	423	—	144	134
330	24·5	334	—	114	204
330	38·5	525	—	179	269
330	26·	354	—	121	211
330	20·	273	—	93	183
330	31·	423	—	144	234
330	48·	655	—	224	314
330	40·	546	—	186	276
411	41·5	454	—	193	283

The preceding Table will shew the performance of the horses, upon a portion of the Backworth Colliery railroad; these horses, like those employed on the Killingworth railroad, were extremely powerful, as may be presumed. The average resistance with the loaded carriages is 42 lbs., and with the empty carriages, 189 lbs., giving a mean of 115 lbs.; they traversed the distance backwards and forwards most frequently eight times a day, making nineteen miles. This Table may be taken as the maximum performance of horses, and will shew the resistance which a very powerful horse is capable of overcoming occasionally.

TABLE III.

Table of the performance of horses upon the Team Colliery edge railroad, where a horse travels with four loaded carriages down the plane in summer, and returns with the same number empty; and with three carriages in both directions in winter. Weight of loaded carriages 8540 lbs., friction 40 lbs., empty carriages 2604 lbs., friction 14 lbs.

Length of plane in feet.	Descent of plane in inches.	Ascent of plane in inches.	Resistance with four carriages				Resistance with three carriages.			
			Gravity of the loaded carriages in lbs.	Total resistance down the plane in lbs.	Gravity of the empty carriages in lbs.	Total resistance up the plane in lbs.	Gravity of the loaded carriages in lbs.	Total resistance down the plane in lbs.	Gravity of the empty carriages in lbs.	Total resistance up the plane in lbs.
430	81	—	536	—	163	219	402	—	123	165
500	32	—	182	—	55	111	137	—	42	84
500	58	—	330	—	100	156	248	—	75	117
500	48	—	273	—	83	139	205	—	63	105
500	42	—	239	—	72	128	180	—	54	96
500	50	—	284	—	86	142	213	—	65	107
500	37	—	210	—	64	120	158	—	48	90
500	—	—	—	160	—	56	—	120	—	42
500	—	6	34	194	10	46	26	146	8	6
500	—	32	182	322	55	1	137	257	42	—
500	—	9	51	211	15	41	39	159	12	30
500	3	—	17	143	5	61	13	107	4	46
500	7	—	39	121	12	68	30	90	9	51
500	3	—	17	143	17	73	13	107	13	55

Length of plane in feet.	Descent of plane in inches.	Ascent of plane in inches.	Resistance with four carriages.				Resistance with three carriages.			
			Gravity of the loaded carriages in lbs.	Total resistance down the plane in lbs.	Gravity of the empty carriages in lbs.	Total resistance up the plane in lbs.	Gravity of the loaded carriages in lbs.	Total resistance down the plane in lbs.	Gravity of the empty carriages in lbs.	Total resistance up the plane in lbs.
500	13	—	74	86	22	78	56	64	17	59
500	17	—	96	64	29	85	72	48	22	64
500	14	—	79	81	24	80	60	60	18	68
500	23	—	130	30	39	95	98	22	30	72
500	42	—	239	—	72	128	180	—	54	96
500	29	—	165	—	50	106	124	—	38	80
500	19	—	108	52	32	88	81	39	24	66
400	17	—	120	40	36	92	90	30	27	69
600	44	—	208	—	63	119	271	—	41	90
500	34	—	193	—	59	115	145	—	45	87
450	20	—	126	34	38	94	95	25	29	71

The horses employed upon the above railroad were not so strong and heavy as those upon the roads shewn in Tables I. and II. The average resistance with the loaded carriages is about 70 lbs., and with the empty nearly 100 lbs., making a mean of 85 lbs. The distance traversed is four times every day, which is nearly twenty miles. In winter, (for about five months in the year,) they are only able to travel with three carriages. Though less than the other horses, they were by no means small or light, but what may be termed moderately sized. The resistance upon one part of the road, with the load, amounts to 342 lbs.; but, as the distance is short, and the carriage has previously acquired considerable velocity, before it arrives at this part of the road, the momentum will aid the horse, in overcoming the resistance, for this short distance.

The average resistance overcome by the horses, in Table II., is 115 lbs., and in Table III., 85 lbs.; taking the former as the effect of the largest horses, and the latter as the effect of smaller, we shall have the mean effort of 100 lbs., as the performance of moderately-sized horses upon level roads, travelling twenty miles a day.

If the friction of carriages be reckoned at the 240th part of their weight, Table I., then the weight, which will present a resistance of 100 lbs. upon an edge railroad, will be 24,000 lbs.; as, however, the resistance of the carriages, in winter, would be greater than that shewn in the Table, we may, according to these experiments, take the power of these horses as equal to 112 lbs., the mean of Tables III. and IV., travelling at the rate of two, or two and a half miles an hour, or twenty miles a day; which, on a level railroad, would make the weight of goods conveyed equal to twelve tons.

Taking, then, twelve tons moved over the space of twenty miles a day, as the performance of a horse, the effect will be equal to 240 tons one mile; and, as this performance is effected at that pace, or velocity, which the horse inadvertently falls into himself, we may consider it his maximum effect. We have not, in the Tables, given the speed at which the horses travelled; that would vary much, according to the resistance presented in the different parts of the road; but the average velocity of Table I. did not amount to more than two miles an hour; and we are inclined to think, from attentively noticing the speed of the horses in the other, at various parts of the road, that the velocity with which they travelled would not be more.

The above was the conclusion stated in the second edition of this work, since that was written, it has been generally supposed, that this standard of the effort of a horse, was underrating his power; it must be observed, however, that the performance during one half of the journey, in each case, was, for the more powerful horses, 189 and 157 lbs. respectively; and, for the smaller horses, 100 lbs., making a general average of

148 lbs., which they exerted for ten miles a day; and, although, from the nature of their employment, for the return journey, they were only subjected to a comparatively small exertion, yet there can be no doubt that, without injury to their physical powers, they were capable of dragging a greater load than that to which they were subjected. Mr. Fary estimates a horse's power at 125 lbs. for twenty miles a day, at two miles an hour; and we have previously stated, that Mr. Watts assigns 150 lbs. as the power of a horse travelling at the rate of two miles and a half an hour. Having, since the publication of the former edition of this work, made numerous observations on the power of horses, we are inclined to place his performance a little beyond that formerly assigned, and to assign it at 125 lbs. moved at the rate of two miles and a half an hour, and for twenty miles a day, or 2,500 lbs. one mile; and, reckoning the friction of carriages at 8½ lbs. per ton, will give nearly 300 tons conveyed one mile, as the daily performance of a horse.

It is well known that the power, which a horse is capable of exerting upon the load, very much diminishes, when he is pushed to a rapid rate of speed; it is difficult, however, to obtain experiments on the power a horse is capable of exerting, at different rates of speed. The most extensive employment of horses is either in dragging heavy loads, at slow rates of speed, or light loads, or in coaches, at almost the extreme limit of that speed which he is capable of accomplishing, and which allows him to produce any useful result at all to the load. Instead, therefore, as in the former edition, of attempting to deduce his performance at all the intermediate rates of speed, we shall endeavour to ascertain the power a horse is capable of exerting upon the load, at that rate of speed which he is capable of accomplishing, when exerting a *maximum effort* upon the load;

and that rate of speed which may be considered a *maximum rate of speed*, and which, at the same time, allows him to produce a useful effort upon the load. We have already given the performance of a horse, in the former case, and we shall now give the best information in our power in the latter case.

Art. 2.—*Experiments on the Performances of Horses on Turnpike Roads.*

In Mr. Telford's reports on the state of the Holyhead and Liverpool roads, some experiments by Mr. M'Neil are given, upon the resistance of stage coaches on that road. The general results of these experiments, made with a stage coach weighing 18 cwt., and loaded with seven passengers, on the same piece of road, in different inclinations, and at different rates of speed, are as follow.

TABLE IV.

Rate of inclination.	Rates of travelling.	Force required.
1 in 20	6 miles an hour.	268 lbs.
1 in 26	6 ——	213 —
1 in 30	6 ——	165 —
1 in 40	6 ——	160 —
1 in 600	6 ——	111 —
1 in 20	8 miles an hour.	296 lbs.
1 in 26	8 ——	219 —
1 in 30	8 ——	196 —
1 in 40	8 ——	166 —
1 in 600	8 ——	120 —
1 in 20	10 miles an hour.	318 lbs.
1 in 26	10 ——	225 —
1 in 30	10 ——	200 —
1 in 40	10 ——	172 —
1 in 600	10 ——	128 —

Allowing, for the weight of coach and passengers, 28 cwt., the resistance of the whole, at a velocity of ten miles an hour, is 116 lbs., or 83 lbs. per ton. Taking, therefore, a stage coach, when loaded, on an average, to weigh two tons, the resistance will be 166 lbs., which, for four horses, is 42 lbs. exertion for each horse; and, supposing the general rate of travelling, with stage coaches, to be ten miles an hour, we have the performance of horses, in stage coaches, equal to 42 lbs., at the rate of ten miles an hour.

With respect to the distance per day which horses in stage coaches travel, we have a very important document, furnished by the coach proprietors on the Liverpool and Manchester turnpike roads; from which we shall be able to determine, what deduction is necessary, at the more rapid rate of travelling. It appears, from a petition presented to the House of Commons*, May 3, 1830, that there were, at that period, thirty-three coaches upon the different roads in that neighbourhood, running from Liverpool; viz., twenty-six to Manchester, four to Bolton, two to Wigan, and one to St. Helen's. As it appears from this document, that each of these coaches made a journey to these respective places, and back, in a day, the following would be the number of miles travelled:—

		Miles.				Coaches.		Miles.
Manchester	-	37	×	2	×	26	=	1924
Bolton	-	33½	×	2	×	4	=	268
Wigan -	-	22	×	2	×	2	=	88
St. Helen's	-	12	×	2	×	1	=	24
						Total	-	2304

Which is stated to have employed 709 horses; and, as

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* Note D., Appendix.

four horses are required at a time, the average distance travelled by each horse is, $\frac{2304}{709} \times 4 = 13$ miles per day. And, with this performance, the petitioners state, that the stock is to be renewed every three years. Although the speed, at which these horses travel, is very great, yet it will not exceed more than ten miles per hour; this will give, upon turnpike roads, in coaches, a performance of horses equal to 42 lbs., moved thirteen miles a day, at the rate of ten miles an hour, or, 546 lbs. one mile; and, reckoning the friction of railways equal to 8½ lbs. per ton, would be 64 tons moved one mile per day; and, consequently, the relative efforts, at 2½ and ten miles, as 300 : 64.

Art. 3.—*Experiments on the Performance of Horses dragging Boats on Canals.*

The most extraordinary performance of horses, at high rates of velocity, is that of dragging the swift boats on canals; a recent mode of applying boats for the conveyance of passengers. The following experiments were made by Mr. M'Neil, to ascertain the tractive force required to drag the passenger boats, upon the Glasgow and Paisley canal, in Scotland.

TABLE V.

Actual tractive power observed in working the Swift Boat, eight miles along the Glasgow and Paisley Canal, at the ordinary passenger speed, or nine miles per hour. Load, 11 passengers, and boat, 2 tons, 15 cwt., equal to 69 cwt., 3 qrs., 20 lbs.

Tractive power in lbs. observed at regular distances.											
170	210	205	225	230	360	350	225	235	240	200	110
400	205	220	215	235	350	240	240	235	310	235	110
400	210	200	210	245	300	300	230	225	260	200	100
280	215	200	225	270	240	305	260	215	235	120	90
260	215	195	195	260	290	270	250	215	245	120	100
265	210	190	220	230	320	235	275	215	240	150	
240	220	390	285	205	300	230	250	230	230	150	
230	245	425	270	215	270	235	230	240	215	130	
240	235	380	230	235	320	240	230	235	215	120	
230	265	230	220	235	250	235	210	270	240	100	
220	245	220	235	*300	340	225	215	260	210	110	

* At this part another passenger was taken in, which made the load about 71 cwt. This experiment gives an average resistance of 237 lbs.; the boat being dragged by two horses, is 118½ lbs. effort for each horse.

TABLE VI.

Actual tractive power observed in working the Zephyr Boat, eight miles along the Forth and Clyde Canal, at the ordinary passenger speed of nine miles per hour. Nine passengers, and boat, 3 tons, equal to 72 cwt., 25 lbs.

Tractive power in lbs. observed at regular distances.											
395	310	410	350	0	325	70	370	355	325	245	400
395	310	405	25 (	440	350	0	370	355	325	300	370
395	100	405	240	445	320	0	370	345	340	370	140
400	0	405	285	395	345	0	335	340	300	360	
415	0	375	320	385	340	0	330	315	310	310	
445	0	355	325	365	290	170	270	320	270	320	
555	80	355	350	380	200	330	160	315	310	345	
460	300	345	420	380	230	380	150	305	370	360	
190	355	320	425	385	250	385	0	300	355	390	
20	395	320	420	360	405	385	0	310	385	390	
20	420	330	260	350	395	390	0	295	360	390	
20	425	370	0	355	340	380	130	300	280	400	
300	425	375	0	330	190	385	310	325	265	400	

Experiment VI. gives an average resistance of 298 lbs., which is for each horse 149 lbs. The distance which the horses travel, in dragging swift boats, is generally about five miles, returning the same distance. On the Glasgow and Paisley canal, it is stated, by one of the canal proprietors, "that the entire number of horses kept in the year 1832, to work the improved boats 152 miles each day, was twenty-eight." This gives rather more than ten miles a day for each horse. The average resistance of the two boats, is 267 lbs., or, 133 lbs. for each horse, moved ten miles a day, at the rate of nine miles an hour; or, 1,330 lbs. moved one mile. Taking the friction at 8½ lbs. per ton, on a railway, would be equivalent to 156½ tons, moved one mile per day; which would give the relative performances of horses, at 2½ and ten miles an hour, or as 300 : 156½.

Art. 4.—*Result of the foregoing Experiments.*

The following Table shews the result of the foregoing experiments, on the power of horses, at the different velocities.

Experiments made on	Rate of Travelling, per Hour.	Force exerted, in lbs.	Distance performed per Day, in Miles.	Duration of Day's Work, in Hours.	Comparative Effect.
Railroads - -	2½	125	20	8·	2500
Turnpike Roads	10	42	13	$1{\cdot}\dot{3}$	546
Canals - -	9	133	10	1·11	1330

Art. 5.—*Theoretical Considerations of the Power of Horses.*

In the former edition of this work, we hazarded a theory of the power of a horse, at the different rates of velocity, which was expressed as follows:—

To obtain a sort of approximation to the energy of the power of horses, at different rates of speed, we formed a kind of rule, on which we founded our calculations. Taking the force, when continually exerted for ten hours, travelling at the rate of two miles an hour, or for twenty miles a day, as deduced from the preceding experiments, to be equal to 112 lbs., we made this a standard for his accumulated performance.

We found, when a horse, travelling with a load, was left at liberty to assume what pace he pleased, that heavy horses, such as used in Experiments I. and II., generally fall into a pace of two miles an hour; and lighter horses, such as in Experiment III., into two miles and a half an hour. We considered these as the paces where the muscular exertion of the horse suffered least, in performing a certain quantity of work, and at which his effort would be the greatest; as it was invariably found, on pushing a horse at a more rapid rate, he was more distressed in performing the same work. We then took 112 lbs., which, when the friction is equal to the 240th part of the weight, would be twelve tons, or 240 cwt. multiplied by two miles an hour = 480, as the general expression of his performance for twenty miles; and considered, that, in travelling twenty miles at any other rate, his effort would not be greater; at least, we considered that the extra muscular exertion required to transport his own weight, which is more than seven times that which is exerted upon the load, would be equal to that diminution of weight, which, multiplied into the speed, would make the sum of his effort remain the same, and equal to 480.

Taking this rule, and making v = the velocity in miles per hour, we have 224 lbs., as the effort of a horse at one mile an hour, and $\frac{224}{v}$ his effort at any other rate of speed; or, making 480 as the expression of his performance of the weight multiplied into the velocity, we have $\frac{480}{v}$, as the weight which he will drag upon a level railroad, at any other velocity.

Adopting the increased power assigned to the performance of a horse, viz., 125 lbs., at the rate of two miles and a half an hour, for twenty miles a day; and making this his maximum performance, which would be 125 × 20 = 2500 lbs. moved one mile, at the rate of two miles and a half an hour: let v = the velocity of two miles and a half an hour, then $\frac{2500\,v}{\text{V}} = \text{P}$, the performance of a horse at any other velocity, V. This theorem would give, for ten miles an hour, $\frac{2500 \times 2\frac{1}{2}}{10} =$ 625 lbs.; whereas the effort of horses, in stage coaches, is 546 lbs. Supposing the resistance of the coach, for each horse, to be 42 lbs., the theorem would give fifteen miles a day for his performance, which generally, may be considered not much beyond the average performance of horses in stage coaches.

The result of the power exerted by horses, in dragging the canal boats, is so much beyond the generally received opinion of a horse's power; that, unless we were assured of the fact, it would appear almost doubtful that horses could be found capable of continuing, for any length of time, so extraordinary a performance.

On further consideration, however, we shall find that, although such an effort, continued day after day, must have a very powerful effect on the wear and tear of his physical powers; yet, when judiciously applied, a horse is capable of such an exertion for a short period of time. The performance of horses in Experiment II., gives 247 lbs. as the effort of a horse for a considerable distance; if we pay no regard to the injury a horse would sustain, there is no doubt but that this effort might be kept up for the whole day; this would give his performance $247 \times 20 = 4940$ lbs., and, consequently, $\frac{4940 \times 2\frac{1}{2}}{9} = 1372$ lbs., at nine miles an hour, the performance on canals being 1330 lbs. This, however, can only be considered as the extreme performance of horses, and only kept up by the destruction of his physical powers; the short period, (viz., about half an hour,) which they are required to make such an effort, is the only mode of enabling them to perform the work.

Professor Leslie, in his Elements of Natural Philosophy, also gives a formula for calculating the force which a horse can exert upon the load at different rates of speed.

He states, "with regard to the power of draught, the formula $(12-v)^2$, when v denotes the velocity in miles an hour, will perhaps be found sufficiently near the truth. Thus, if a horse, beginning his pull with the force of 144 lbs., would draw 100 lbs. at a walk of two miles an hour, but only 64 lbs. when advancing at double that rate, and not more than 36 lbs., if he quickened that pace to six miles an hour; his greatest performance would hence be made with the velocity of four miles an hour."

According to the formula $(12-v)^2$ of Professor Leslie, the relative performance, at two and a half and ten miles per hour, is as 9 : 1. Mr. Tredgold, in his work on railroads, gives the effect as 4 : 1. Mr. Rastrick, in his report on the Liverpool railway, gives his opinion, also, as 4 : 1; while Mr. Walker, in his report on the same occasion, gives 6·4 : 1.

Our formula of $\frac{250}{v}$ gives the effect as 4 : 1. It will, however, be necessary to qualify this at the higher velocities; for, although so far as regards the power which the horse is capable of exerting upon the load, at the respective velocities, the ratio of 4 : 1 may be pretty correct; yet the injury to his physical powers is so great, by being thus driven so far beyond his natural pace, that he is by no means capable of performing so great a distance per day; and, therefore, some deduction from the performance assigned, is necessary, if we are to make the injury to his physical powers an element in the calculation. This will, however, come more properly under that part of the work which treats of the comparative cost of conveyance of goods at different rates of speed; and, therefore, we shall not take any further notice of it in this place.

We shall now give a Table of the quantity of work which a horse is capable of performing upon railways of different degrees of inclination. In many cases, however, we find that the great bulk, if not the whole of the goods, or minerals, have to be conveyed in one direction only. 125 lbs. is taken as the average effect; but the Tables of performances in the colliery railways shew, that, when loaded in one direction only, the horse is capable of exerting in that direction, or in one half of the distance travelled, a much greater force than in the other part of the distance, when the empty carriages only constitute the load. Upon the Backworth railway, the average force exerted, when loaded, was 189 lbs., the maximum for half a mile being 247 lbs. On the Killingworth railway, the average performance, loaded, is 157 lbs.; but, taking from this those parts where casual irregularities occurred, the average would be 168 lbs.; the maximum being 257 lbs. With these resistances, the horses travelled ten miles each day; the other ten miles being with the empty carriages.

Art. 6.—*Practical Conclusions of the Performance of Horses on Railroads.*

If we, therefore, assume 180 lbs. as the greatest performance he is capable of exerting, on an average, in one direction, and 70 lbs. in the other, making a mean of 125 lbs., and take the friction equal to 8·5 lbs. per ton, or the 263rd part of the weight, the following Table will shew the performance, at different rates of inclination of plane, which a horse is capable of conveying twenty miles a day, or ten miles in each direction; the proportionate weight of loaded to empty carriages, being 3 : 1.

Table VIII.

Inclination of plane.	Loaded carriages up, and empty carriages down the plane.	Loaded carriages down, and empty carriages up the plane.	Load equal in both directions.
	Tons.	*Tons.*	*Tons.*
Level	21·17	21·17	14·7
1 in 4480	20·	22·5	14·7
3360	19·46	23·23	14·7
2240	18·95	24·	14·7
1680	18·	25·71	14·7
1120	17·14	27·69	14·7
1000	16·76	28·75	14·7
900	16·37	29·95	14·7
800	15·93	31·58	14·7
700	15·38	33·83	14·7
600	14·71	35·01	14·7
500	13·86	34·06	13·86
448	13·33	33·82	13·33
400	12·76	32·9	12·76
350	12·08	31·71	12·08
300	11·27	30·81	11·27
250	10·31	30·93	10·31
200	9·14	27·42	9·14
150	7·68	23·04	7·68
100	5·82	17·46	5·82

The above Table is estimated upon the average performances, of 180 lbs., and 70 lbs., respectively; but we find, from Tables I. and II., that powerful horses are capable of exerting a force equal to 240, or even 250 lbs., for a short distance. If, therefore, casual undulations occur in a general line of railway, we may estimate the horse capable of overcoming, for a short period, a force equal to one third more than stated in columns 2 and 3, and one half more than column 4 of Table V.

In column 4, we take the performance as 14·7 tons upon a level road; in all the intermediate rates of inclination, from that, to 1 in 448. Suppose the average effort, in the two directions, to be 125 lbs., 14·7 tons will be the load taken, so long as the resistance up the plane does not exceed 180 lbs. When the inclination becomes greater, although the average resistance will still be 120 lbs., taking the passage up and down, yet the resistance will exceed 180 lbs. up the plane; which, being greater than our standard of the horse's powers, the performance will be diminished accordingly.

The Stockton and Darlington railway company have adopted a very useful expedient for increasing the work of a horse upon that railway, with the particulars of which we have been favoured by Mr. Storey, engineer to the company. Great part of the traffic, upon that railway, is in one direction; and portions of the railway, in the direction which the load is to be conveyed, have a considerable descent, equal to that which causes the carriages to run of themselves. A low platform carriage is provided, and taken with the train; and upon those parts of the road where the descent is so great as to overcome the friction, and the carriages descend by the force of gravity, the horse is made to mount the platform, and is carried down by the load. The effect of this, is, that the horse is enabled to perform a much greater distance, than if he travelled the whole way; and it is astonishing how soon the horse becomes accustomed to, and fond of, subverting the adage of the "cart before the horse," by making the cart carry the horse. Mr. Storey has favoured us with the following particulars of the increase of effect, by the adoption of this expedient.

"Previous to the carriages being used for the horses to ride on, a week's work, of six days, was

87 miles, with twelve tons of coals; and five tons and a half, empty carriages:
87 miles, with five tons and a half of empty carriages.
Total, 174 miles.

"A week's work, after using the horse carriage, was

120 miles, with twelve tons of coals; and five tons and a half, empty carriages:
120 miles, with five tons and a half of empty carriages.
Total, 240 miles."

And Mr. Storey observes: "This is nearly one third more work, and the horses improved in condition."

In order to obviate the great loss of power in horses, when travelling at great rates of speed, Mr. H. Brandreth, of Liverpool, at the Liverpool experiments, exhibited a machine, where the horse travelled at a rate of speed, equal to about one third less than the carriage itself.

To accomplish this, two horses were mounted upon a platform carriage, side by side, and, with their feet, turned a sort of endless chain, furnished with narrow boards like scales, which bent round two wheels, and, when stretched horizontally, presented a fit platform for the horses to travel upon, and turn round. This chain worked a wheel, the periphery of which travelled at about one third the rate of the carriage wheels. While the horses were thus going at the rate of four miles an hour, they would propel the carriage at the rate of twelve miles an hour. Independently of the injury to his physical powers, the horse, at twelve miles an hour, is not capable of exerting a force equal to one fourth of what he is capable of doing at four miles an hour; so that there was some reason to suppose, unless the friction, and disadvantageous mode of application, counterbalanced the economy of power, there would be an increase of effect. During the prosecution of the experiments, the construction of the machine was found defective; and we do not know if Mr. Brandreth has yet been able to bring it to practice.

Art. 7.—*Cost of conveying Goods on Railroads by Horses.*

The cost of conveying goods, at slow rates of speed, on railroads, will be pretty correctly ascertained, by a reference to the prices paid for leading coals along the Stockton and Darlington railway, while that company employed horses on that railway. The price paid for the haulage of the coals, including drivers, was one halfpenny per ton, per mile. This line is a descending one with the load, and, from calculations made in a subsequent part of this chapter, (Section 4, Art. 7,) it appears, that the resistance down the plane was $\frac{4}{9}$ of that on a level, and up the plane, $\frac{12\cdot 2}{9}$; and that the relative resistance between this line of railway, and a level road, is as 41·67 : 47·25; therefore, as 41·67 : ·5 :: *47·25* : ·*56d.* per ton per mile, the cost of conveying goods on a level railway, taking the cost of the Stockton and Darlington railway, as a standard. Supposing a horse to travel twenty miles a day, this would give, on a level railway, ·56 of a penny per ton, per mile, of useful load, and ·37 of a penny per ton per mile gross; and this, it will be observed, is the performance of a horse when the load is conveyed in one direction only, the empty waggons being the returning load, which, so far as expense goes, is a useless load.

If we take the cost of a horse, driver, &c. at 7*s.* per day, and suppose a horse's power equal to 125 lbs. for twenty miles a day, and that the resistance of a ton weight upon a railway is $8\frac{1}{2}$ lbs.; we have $14{\cdot}7 \times 20 = 294$ tons conveyed one mile for 7*s.*, or ·3 of a penny per ton per mile gross, or ·45 of a penny per ton per mile useful load, at the rate of two, or two miles and a half an hour, loaded in both directions, as a maximum performance; and, therefore, we see the practical effect fall nearly one fourth short of the estimated maximum performance. We shall, however, take the cost of haulage at ·56 of a penny per ton, useful load, and ·37 of a penny per ton, gross load.

The cost of finding waggons, or carriages, for the conveyance of coals and minerals, will be afterwards shewn (§ 4, Art. 8,) to amount to ·19, and the cost of loading and unloading coals, ·075 of a penny per ton per mile; the railway dues, ·208 of a penny per ton per mile; and the general expenses, ·100 of a penny per ton per mile; the entire expenses, therefore, exclusive of capital, would be 1·233*d.* per ton per mile.

Upon the Clarence, Hartlepool, and Stockton and Darlington railways, the entire charges for railway dues upon export coals, is one halfpenny per ton per mile. Landsale coals, on the two former railways, one penny per ton per mile; and, upon the latter, three-halfpence per ton per mile.

The expense of horse power upon railroads, at different rates of speed, will be in the proportion of the useful load which he can drag, at the several rates of speed; and, adopting the conclusions in Art. 5, we have the relative performances, at the several rates of two and a half, four, and ten miles an hour, as per following Table; and the cost likewise apportioned according to the useful effect produced at the different velocities.

TABLE IX.

Table of the Cost of conveying Goods and Passengers on Railroads, at different Rates of Speed, with Horses.

Rate of speed per mile per hour.	Resistance per ton in lbs.	Cost of haulage or motive power per ton per mile.	Cost of waggons per ton per mile.	Railway dues per ton per mile.			Total charges per ton per mile.		
				Export coals.	Landsale coals.	General merchandize.	Export coals.	Landsale coals.	General merchandize.
		d.	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
2½	8·5	0·56	0·19	0·5	1·0	2	1·65	2·15	2·69
4	8·5	0·9	0·227	—	—	2½	—	—	3·627
10	8·5	¼*d.* per passenger. 2·24 per ton	0·227	—	—	12	—	—	1*d.* to 1½*d.* per passenger, 1*s.* 3*d.* per ton.

The last column gives the cost of conveyance of railways, according to the average charges of some of the existing railways worked by horses. Upon the Edinburgh and Dalkeith railway, passengers are conveyed at the rate of one penny per mile, the horses travelling at the rate of nine miles an hour.

§ 2. *Self-acting Planes.*

The impelling force of this kind of motive power, is gravity; it is confined, as previously stated, to descending planes alone; and, when employed in practice, its object is, to effect, in a given time, the ascent of a train of carriages, by the descent of a similar train, more heavily loaded. The respective weights, and inertia of the descending and ascending train of carriages, being given, and the weights and inertia of the rolls, sheeves, and rope, we shall then have the following known quantities, derived from the preceding experiments; viz., the friction of the loaded and empty carriages, by Chap. VII., and the friction of the ropes denoted by φ in Chap. VIII.

Art. 1.—*Theoretical Conclusions of the Power of Self-acting Planes.*

Taking the friction and resistance of the several moving parts, as deduced from the experiments under their respective heads, and making T = the required time of descent of the carriages down the plane $= \frac{8}{7}\,t$, we have

$$\mathrm{T} = \tfrac{8}{7}\sqrt{\frac{(\mathrm{W} + w\,\frac{\mathrm{SO}}{\mathrm{SG}} \times \mathrm{W}') \times \mathrm{S}}{(\mathrm{G} - \mathrm{F}) \times r}} \quad (1.)$$

Whence the preponderance of gravity, necessary to effect the descent, in all states of the weather, in the time T, will be

$$\mathrm{G} - \mathrm{F}' = \frac{(\mathrm{W} + w\,\frac{\mathrm{SO}}{\mathrm{SG}} + \mathrm{W}') \times \mathrm{S}}{12{,}\,31\ \mathrm{T}^2} \quad (2.)$$

and, having the weight of the ascending, and descending, trains of carriages, the inclination of the plane will be

$$\frac{\mathrm{H}}{\mathrm{L}} = \frac{\dfrac{(\mathrm{W} + w\,\frac{\mathrm{SO}}{\mathrm{SG}} + \mathrm{W}) \times \mathrm{S}}{12{,}31\ \mathrm{T}^2} + \varphi}{\mathrm{W} - w} \quad (3.)$$

Or, adopting the notation used in calculating the result of the previous experiments, we have

$$\frac{\mathrm{H}}{\mathrm{L}} = \frac{\dfrac{(\mathrm{W} + w\,\frac{\mathrm{SO}}{\mathrm{SG}} + a' + a''\,\frac{\mathrm{SO}}{\mathrm{SG}} + b + c + c') \times \mathrm{S}}{12{,}\,31\ \mathrm{T}^2} + \varphi + \mathrm{F} + f}{(\mathrm{W} + w) - a' + a''}$$

Art. 2.—*Practical Application of the Power of self-acting Planes.*

It is impossible, in a case of such a compound nature, to give tables of the gradients, or inclinations, required in practice, for all the different lengths of planes; we shall, therefore, give one example, which will render any other a matter of easy calculation, and shall give one upon the Killingworth railway.

Example (1.) Suppose a descending plane, the length of which is equal to 1800 yards, down which it is intended to pass nine loaded carriages at a time, each weighing four tons, and which drag up nine empty carriages, each weighing 24 cwt.: required, the height of plane, or inclination, that will complete the descent, in 400 seconds?

Supposing $\mathrm{W} = 1312$, and $w \frac{\mathrm{SO}}{\mathrm{SG}} = 2059$, we have $\mathrm{W} + w \frac{\mathrm{SO}}{\mathrm{SG}} = 99{,}171$ lbs.; and, consequently, $a' + a'' \frac{\mathrm{SO}}{\mathrm{SG}} = 30{,}905$ lbs.

Let the rope be four inches and a half in circumference, then 1900 yards will be 5562 lbs. $= \varphi$. If the sheeves be placed ten yards apart, and weigh 30 lbs. each, then 180 sheeves will be 5400 lbs; whence $c' = 2700$ lbs.; $c = 227$ lbs. The value of

$$\varphi = \frac{\mathrm{R} + \mathrm{R}' + \mathrm{R}'' + \mathrm{P}}{3.5\, r} = \frac{454 + 5400 + 5562 + 1696}{3{\cdot}5 \times 16} = 234 \text{ lbs.}:$$

$\mathrm{F} =$ the 200th part of the weight $= 403$ lbs., and $f = 120$ lbs. Then $\frac{\mathrm{H}}{\mathrm{L}} =$

$$\frac{\dfrac{(99171 + 30905 + 5562 + 227 + 2700) \times 5400}{12{\cdot}31 \times 400^2} + 234 + 403 + 120}{80640 - 24192}$$

$= \frac{1}{50}$ nearly.

We may depend upon this result, in practice, where the apparatus is well fitted up, and kept in good order; but, when this is not the case, we should, perhaps, instead of $\frac{8}{7}t$, take $\frac{4}{3}t$, whence, according to the example above, we have $\frac{\text{H}}{\text{L}} = \frac{1}{45}$ nearly.

In practice, therefore, we must either elevate the plane, or increase the number of carriages, until we obtain the requisite preponderance; but, in every case, it will be necessary, in order to secure the constant action in winter and summer, that the excess amount to that given by the above formula.

Before dismissing the object of self-acting planes, it may be necessary to state, that considerable regard should be observed, in forming the line into a proper descent, or into that in which the velocity of the carriages, on all parts of it, shall be as equable as possible.

The action of gravity, causing bodies to descend with velocities uniformly accelerated, the motion of the carriages upon a plane, with a uniform descent, will be very variable, being accelerated as the square of the times employed in traversing the plane. The plane should not, therefore, be made with a regular and uniform descent, but such as will give a greater preponderance of gravity at the commencement, and then diminish, in such a ratio that the diminution of preponderance will abstract as much gravitating force, as will compensate for the increasing velocity of the carriages, so that the two will counteract each other, and thus produce a comparatively uniform velocity, in the carriages on the plane. The line of descent, to perform these conditions, is rather difficult to determine, but, perhaps, will approach near to the curve called a cycloid.

§ 3.—*Fixed Steam Engine.—Planes.*

To elicit the performance of steam engines, fixed, and dragging carriages up planes, inclined or parallel to the horizon, by means of ropes, we have selected the four following experiments, on engines that have been in use for some time, and which, we trust, will be sufficient to furnish data, by which we may calculate the performance of engines upon other planes.

Not to confine the data to one particular kind of engine, we have taken two low-pressure, or condensing, engines, and two high-pressure engines.

Art. 1.—*Experiments on the Power of Fixed Engines on Railroads.*

EXPERIMENT I.

Boulton and Watt's low-pressure condensing engine, with two thirty-inch cylinders, steam $4\frac{1}{4}$ lbs. per square inch above the ordinary pressure of the atmosphere; rope-roll similar to A, *Fig. 2, Plate IX.*; rope, seven inches and a quarter in circumference, same as employed in Experiment VI., Chap. VIII.; length of plane, 2646 feet; height or ascent, 154 feet, 6 inches, being the same as Experiment VI., Chap. VIII.

Time of drawing up seven loaded carriages, each weighing 9408 lbs., similar to those employed in Experiments II. and III., Chap. VII., 620 seconds, the engine making 374 single strokes, five feet each.

Then $(30^2 \times 2) \times \cdot 7854 = 1413\cdot 72$ area of cylinders, and $1413\cdot 72 \times 19\cdot 5$ the pressure of steam in the boiler $=$ 27,567 lbs. pressure upon the piston, which, in the experiment, was moved through $374 \times 5 = 1870$ feet; hence $27{,}567 \times 1870 = 51{,}550{,}290$ lbs. moved one foot, the power of the engine.

The resistance will then be, according to Formula 17,

$$\text{G} + \text{F} + \varphi + \overline{\tfrac{1}{2} b \sin. \text{I}} + \frac{(\text{W} + w\frac{\text{SO}}{\text{SG}} + b + c + \frac{1}{2} c') \times \text{S}.}{r\,t^2}$$

Then $\text{G} = 9408 \times 7 \times \frac{1854}{31752} = 3845$ lbs.

Also, by Experiments II. and III., Chap. VII., $\text{F} = 40 \times 7 = 280$ lbs.; and, by Experiment VI., Chap. VIII., $\varphi = 627$ lbs.; likewise, by ditto, $\frac{1}{2}\, b \sin. \text{I} = 203$ lbs.

Also $\frac{(\text{W} + w\frac{\text{SO}}{\text{SG}} \times b + c + \frac{1}{2} c') \times \text{S}}{r\,t^2} = 36$ lbs. the force required to overcome the vis inertiæ of the load upon the plane, or to cause it to describe that space in 620 seconds.

Then $3845 + 280 + 627 + 36 + 203 = 4991$ lbs., the resistance which, in the experiment, was moved through 2646 feet; whence $4991 \times 2646 = 13,206,186$ lbs., the resistance, moved one foot.

Therefore $\left\{\begin{array}{l}51,550,290\text{, power of engine.}\\ 13,206,186\text{, effect of resistance.}\end{array}\right\}$ Whence we have the effective power of the engine upon the load, compared with the pressure of the steam upon the piston, equal to 25·6 per cent.

Velocity of piston, 181 feet per minute.
Velocity of load, 256 feet per minute.

EXPERIMENT II.

Fixed engine, Boulton and Watt's double-power, similar construction to the preceding, and same power, viz., with two thirty-inch cylinders, steam four pounds and a half per square inch above the pressure of the atmosphere; rope seven inches and a quarter in circumference, same as Experiment VII., Chap. VIII.; plane the same also, length 2,325 feet, height or ascent 115 feet, carriages same as preceding experiment.

Time of drawing up seven loaded carriages 550 seconds, making 320 single strokes of the piston, five feet each.

This engine, by an additional rope, attached to the end of the above-named train of carriages, also dragged, at the same time, seven loaded carriages, of the same weight, up another plane, in extension of the other; length 770 yards, and height twenty-five feet six inches.

Then $(30^2 \times 2) \times \cdot 7854 = 1413 \cdot 72$, area of cylinders $\times\ 19 \cdot 5$, the pressure of the steam $= 27{,}567$ lbs. pressure on the piston, which, in the experiment, was moved through $320 \times 5 = 1600$ feet.

Therefore $27{,}567 \times 1600 = 44{,}107{,}200$ lbs. moved one foot, the impelling power of the engine.

$$\text{Then } G = \overline{9408 \times 7 \times} \ \frac{1380}{27900} = 3264 \text{ lbs.}$$

$$G = \overline{9408 \times 7 \times} \ \frac{25 \cdot 5}{2310} = 726 \text{ lbs.}$$

And, by Experiment II., Chap. VII., $F = 40 \times 14 = 560$ lbs.

Also, by Experiment VII., Chap. VIII., $\varphi = 508$ lbs.

And by another experiment, not here detailed, $\varphi = 127$ lbs.

Likewise $\frac{1}{2} b$ sin. I, by Experiment VII. Chap. VIII., $= 153$ lbs.

Also $\dfrac{(W + w\frac{\text{S'O}}{\text{S,G}} + b + c + \frac{1}{2}c') \times S}{r t^2} = 38$ lbs., the force required to overcome the inertia.

And, for the other plane, the inertia $= 38$ lbs. also.

Then $3264 + 726 + 560 + 568 + 127 + 153 + 76 = 5474$ lbs., the total resistance, which, in the experiment, was moved over 2325 feet; therefore $5474 \times 2325 = 12{,}727{,}050$ lbs. moved one foot, the resistance.

Whence $\begin{cases} \text{44,107,200, power of engine.} \\ \text{12,727,050, effect produced.} \end{cases}$

From which we have the effective power, equal to 28·8 per cent. of the pressure of steam upon the piston.

Velocity of piston 174 feet per minute.

Velocity of load 253 feet per minute.

EXPERIMENT III.

High-pressure engine; cylinder twenty-one inches in diameter, elasticity of steam in the boiler thirty pounds per square inch above the pressure of the atmosphere; length of plane 3165 feet, height forty-two feet, being the same as detailed in Experiment IX., Chap. VIII.; rope four inches and a half, also the same.

Time of drawing twelve loaded carriages, each weighing 9010 lbs., up the plane, 570 seconds; the engine making 444 single strokes, five feet each.

Then $21^2 \times {\cdot}7854 = 346{\cdot}36$, area of the cylinder, $\times$ 30 lbs. $= 10390{\cdot}8$ lbs., pressure of steam upon the piston, which, in the experiment, was moved through $444 \times 5 = 2220$ feet; therefore $10{,}390{\cdot}8 \times 2220 = 23{,}067{,}576$ lbs. moved one foot, the impelling power of the piston.

Then $\text{G} = \overline{9010 \times 12 \times} \frac{42}{3165} = 1434$ lbs., the gravity of the load; and $\text{F} = 42 \times 12 = 504$ lbs., friction of the carriages; also φ, by Experiment IX., Chap. VIII., = 213 lbs. resistance of the rope; likewise $\frac{1}{2}\, b \sin. \text{I}, =$ twenty-three pounds.

$$\frac{(\text{W} + w\,\frac{\text{SO}}{\text{SG}} + b + c + \frac{1}{2}\,c') \times \text{S}}{t^2} = 77 \text{ lbs., force re-}$$

quired, to cause the load to describe the length of the plane in the time t, = 570 seconds, supposing it free from friction.

Then 1434 + 504 + 181 + 213 + 23 + 77 = 2251 lbs., the resistance, which, in the experiment, was moved through 3165 feet, therefore 2251 × 3165 = 7,124,415lbs., the total resistance, moved one foot.

$$\text{Whence} \left\{ \begin{array}{l} 23{,}067{,}576, \text{ power of engine.} \\ 7{,}124{,}415, \text{ effect produced.} \end{array} \right.$$

Which makes the effective power of the engine equal to 30·9 per cent. of the pressure of the steam upon the piston.

Velocity of piston 234 feet per minute.

Velocity of carriages 333 feet per minute, or 3·78 miles per hour.

Experiment IV.

High-pressure steam-engine, cylinder sixteen inches, pressure of steam in the boiler fifty pounds per square inch; length of plane 2892 feet, height fifty-seven feet seven inches, being the same as Experiment X., Chap. VIII.; rope also the same, five inches in circumference.

Time of drawing eight loaded carriages up the plane, each weighing 8624 lbs., 390 seconds; the engine making 400 single strokes, five feet six inches each.

Then $16^2 \times {\cdot}7854 = 201$, area of piston, multiplied by fifty pounds; the elasticity of the steam is 10,050 lbs., the pressure of the steam upon the piston, which, in the experiment, was moved through $400 \times 5{\cdot}5 = 2200$ feet.

Therefore $10{,}050 \times 2200 = 22{,}110{,}000$ lbs. moved one foot, the power of the engine.

And $G = \overline{8624 \times 8 \times} \dfrac{691}{34{,}704} = 1373$ lbs.

Also $F = 40 \times 8 = 320$ lbs.; and, by Experiment XXV., $\varphi = 304$ lbs.

Likewise $\frac{1}{2}\, b \sin \text{I} = 37$ lbs.

Also $\dfrac{(\text{W} + w\,\frac{\text{S O}}{\text{S G}} + b + c + \frac{1}{2}\, c') \times \text{S.}}{r\, t^2} = 96$ lbs. the weight necessary to overcome the vis inertiæ.

Then 1373 + 320 + 304 + 37 + 96 = 2130 lbs., the total resistance, which, in the experiment, was moved through 2892 feet, therefore 2130 × 2892 = 6,159,960 lbs. moved one foot, the resistance.

$$\text{Whence} \begin{cases} \text{22,110,000, the power of the engine.} \\ \text{6,159,960 the effect produced.} \end{cases}$$

From which we find the effective power equal to twenty-seven per cent. of the pressure upon the piston.

Velocity of piston 338 feet per minute.

Velocity of load 445 feet per minute, or five miles an hour.

The same engine was tried, with nine loaded carriages, which were drawn up in 420 seconds.

The resistance, in this case, would be $\text{G} = 1544$ lbs.; $\text{F} = 360$ lbs.; $\varphi = 304$ lbs.; $\frac{1}{2}\, b$ sin. $\text{I} = 37$ lbs.; and the inertia = 94 lbs.; which, added together, is 2339 lbs. × 2892 = 6,764,388 lbs. moved one foot.

$$\text{Whence} \begin{cases} \text{22,110,000, the power,} \\ \text{6,764,388, the effect, and the effective} \end{cases}$$
power equal to 30 per cent.

Velocity of piston, 314 feet per minute.

Velocity of load, 413 feet per minute, or 4·7 miles an hour.

In this experiment, we find a greater effective power produced by applying a heavier load, but the time is diminished in nearly the same ratio.

The relative effective power is $\begin{Bmatrix} 27 \\ 30 \end{Bmatrix}$ per cent.

And the velocity - - $\begin{Bmatrix} 338 \\ 314 \end{Bmatrix}$ feet per minute.

Whence we find the relative performances, with respect to time and effect - - $\left\{\begin{matrix}9126\\9340\end{matrix}\right\}$

The preceding experiments, shewing the performance of these two kinds of engines, will form a rule for the practical application of similar engines to other planes. The effective power of the high-pressure engines is greater than that of the low-pressure, but, in these experiments, neither exceed 30 per cent.

We have taken, in these calculations, the common mode of determining the effective power of the engines; viz., by taking the pressure of steam in the boiler, and applying that pressure to the pistons. We are aware that the pressure of steam in the boiler does not shew that such elasticity is applied to the pistons, more especially in locomotive engines, where the quantity of water evaporated is the correct measure of the power applied. But as, in the case of fixed engines, the dimensions are fixed, as regards a certain area of cylinder, compared with the evaporating power of the boiler; when the same proportions are adhered to in every case, the preceding investigations shewing the useful effect in one case, will be applicable in every other case, where the same proportions are kept; and where we may presume, the power of evaporation is sufficient to supply the cylinder with steam. If the generally adopted proportions are varied, then the case will not apply correctly. Not having an opportunity of making the necessary experiments, to deduce the power, in accordance with the system of calculation adopted in the case of the locomotive engines, we did not think it advisable to withhold these calculations from the public, until others were substituted; and, as these will be found to be correct in all engines of similar proportions, and as the deviations from these, if any, will be very few, they will be found to be almost, if not entirely, sufficient for the purpose.

The velocity of the piston in these experiments was, however, very great; and this would have the effect of diminishing the performance, compared with the elasticity of steam in the boiler; otherwise we might have expected a greater amount of effective power. We shall afterwards, when treating on the locomotive engine, shew the effect of the velocity of the piston, upon the effective performance of high-pressure engines.

§ 4.—*Practical Application of the Power of Fixed Engines on Railroads.*

We shall now give two practical examples of the power, required to work inclined planes, with fixed engines, deduced from the preceding experiments.

In the case of an engine, fixed upon the summit of a hill, for the purpose of dragging the carriages up, and the inclination of which is sufficient to cause the descending carriages to drag the rope after them, the formula (17.) will apply, where

$$\mathrm{P}=\mathrm{G}+\mathrm{F}+\varphi+\tfrac{1}{2}\,b\,\sin.\,\mathrm{I}+\frac{(\mathrm{W}+w\frac{\mathrm{SO}}{\mathrm{SG}}+b+c+\frac{1}{2}c')\times\mathrm{S}.}{r\,t^2}$$

From the above experiments, we find, that P, being the effective power of the engine, should not exceed thirty per cent. of the whole power of the engine, reckoned by applying the pressure of the steam in the boiler, to the area of the cylinder. This will form a rule, in practice, for high-pressure engines, or engines working by the expansive power of the steam alone; but it may, perhaps, be more convenient, with condensing engines, to retain the common measure of horses' power, reckoned at 33,000 lbs., moved one foot in a minute.

Suppose an inclined plane, 1000 yards in length, height sixty feet, up which a train of eight loaded carriages, weighing 9408 lbs., is required to be dragged by an engine on the summit, in 300 seconds, with a rope five inches in circumference; required the power, P, of engine.

We have $\mathrm{G} = 9408 \times 8 \times \frac{60}{3000} = 1505$ lbs.

$$\mathrm{F} = \frac{9408 \times 8}{200} = 376 \text{ lbs.}$$

Then $\varphi = \frac{\mathrm{R} + \frac{1}{2}\mathrm{R}' + \mathrm{R}''}{3{\cdot}5\, r} = \frac{4500 + 1500 + 40{,}765}{3{\cdot}5 \times 16}$ $= 180$ lbs., supposing the weight of the rope roll, $\mathrm{R} = 4500$ lbs.; consequently $\frac{1}{2}\mathrm{R}' = 1500$ lbs., the weight of the rope, $\mathrm{R}'' = 4065$ lbs., and $r = 16 : 1$.

Then $\frac{1}{2} b \sin. \mathrm{I} = 40$ lbs., and $\frac{(\mathrm{W} + w\frac{\mathrm{S\,O}}{\mathrm{S\,G}} + b + c + \frac{1}{2}c') \times \mathrm{S}}{rt^2} =$

$$\frac{(10{,}155 \times 8 + 4065 + 2250 + 750) \times 3000}{16\tfrac{1}{12} \times 300^2} = 183 \text{ lbs.}$$

Whence $\mathrm{P} = 1505 + 376 + 180 + 40 + 183 = 2284$ lbs., which, to be moved 3000 feet in five minutes, is equal to 1,370,400 lbs., moved one foot in a minute; consequently $\frac{1{,}370{,}400}{33{,}000} = 41\frac{1}{2}$ horses' power. But as we found, in the case of the self-acting plane, it was necessary, to ensure the regularity of transit in all states of the weather, that the inclination should be $\frac{8}{7}\frac{\mathrm{H}}{\mathrm{L}}$ we have $41\frac{1}{2} \times \frac{8}{7} = 47\frac{1}{2}$ horses' power.

Suppose, that upon the above plane, the road is double, or similar to a self-acting plane, and that at the same time the engine is dragging the loaded carriages up the plane, a similar number of empty carriages are descending; the formula in this case will be

$$\text{P}=(\text{G}+\text{F}+\varphi+f+\frac{\text{W}+w\frac{\text{SO}}{\text{SG}}+a'+\overline{a''\frac{\text{SO}}{\text{SG}}}+b+c+\frac{1}{2}c')\times\text{S})}{rt^2}-g$$

Let the weight of the empty carriages be 3472 lbs. each; then $\text{G}=1505$ lbs.; $\text{F}=376$ lbs.; φ is, in this case, $=\frac{\text{R}+\text{R}'+\text{R}''+\text{P}}{3{\cdot}5\,r}=274$ lbs.; and $f=\frac{3472\times8}{200}=138$ lbs.

Likewise $g=\overline{3472\times8}\times\frac{60}{3000}=555$ lbs., and the inertia $=252$ lbs.

Whence $1505+376+274+138+252-555=1999$ lbs., which, moved 3000 feet in five minutes, or 600 feet in one minute, is $=1{,}199{,}400$ lbs., moved one foot.

Therefore $\frac{1{,}199{,}400}{33{,}000}=33\frac{1}{3}$ horses' power; or, making the proper allowance for bad weather, we have $33\frac{1}{3}\times\frac{8}{7}=$ 38 horses' power. In this last case, we find the assistance rendered to the engine by the descending train, equal to more than nine horses' power.

§ 4.—*Locomotive Engines.*

In the following investigations, respecting locomotive engines, we shall confine ourselves entirely to those, which effect their progressive motion, by means of the adhesion of their wheels upon the rails; experience having proved, that this mode is quite adequate to accomplish the progressive motion of these engines.

We have before explained the nature of the action of the engine-wheels upon the rails, and the principle by which the locomotion is effected; the great importance of knowing the precise amount of that adhesion, whereby we may be able to calculate, with certainty, upon what inclination of road, and with what number of carriages, the engines can effect their progressive motion, will be very evident; as by that the whole system of their action is regulated.

Art. 1.—*Adhesion of the Wheels upon the Rails.*

This may either be ascertained, by continued observation of the performance of engines, upon certain lines of road, or it may be made the subject of direct experiment. In adopting the latter mode, the great variation in the amount, arising from the surface of the rail, presenting more or less adhesion to the wheels, in different states of the weather, renders it difficult to subject the engines to experiments, at all the various changes; and almost compels us to have recourse to observation, or experiments made in the two extremes, in order to obtain a mean result. We shall, therefore, first of all, give the particulars of two experiments, one in the most favourable, and the other in the most unfavourable, state of the rails.

When the surfaces of the rails, and wheels, are either quite dry, or completely wet, the adhesion is the greatest, the surface being then most free from the presence of all extraneous matter; when the rails, on the contrary, are moistened with wet, and partly covered with mud, the adhesion is the least. The mud, interposing between the surfaces of the wheel and rail, diminishes the adhesion very considerably, in the same manner as oil, or grease, applied to the bearings of shafts, or other rubbing surfaces, reduces the friction. In all the intermediate states of the rail, the adhesion varies, and is greater or less, according as the state approaches, more or less, towards either of these changes.

It will be evident, that the total amount of adhesion, is that force which would be required to cause the engine wheels to slide upon the rail, if the wheels were prevented from turning round; or, will be that amount of force, compared with its weight, which the friction of similar rubbing surfaces bears to their weight. Knowing, then, the friction of iron sliding on iron, and the weight of the engine, we might calculate the amount of adhesion of an engine, compared with its weight; or, by fastening the engine wheels, and employing a force to drag the engine, loaded with different weights along the railroad, we could, by this mode, ascertain the amount of adhesion proportionate to the weight. Either of these, though very correct modes of ascertaining the total amount of adhesion, compared with the weight, would not, however, be an accurate standard for practical application. The force of the steam, at different periods of the stroke being very irregular upon each wheel, will occasion the result, in practice, to vary from that deduced by the foregoing methods; the following experiments were, therefore, under different circumstances, made, upon engines in actual use, to ascertain the amount of adhesion.

Experiments upon the Adhesion of the Wheels.

EXPERIMENT I.

Locomotive engine, with cast-iron wheels, three feet in diameter, weighing 6½ tons, and containing one ton of water, =7½ tons, dragged twelve loaded carriages, each weighing 9408 lbs., up a plane, ascending 134 inches in 1164 feet, with the convoy carriage, weighing 1½ tons; the wheels not slipping, rails quite dry; cast-iron edge-rail, 2½ inches broad at the top.

Then, weight of the engine, 16,800 lbs.
12 carriages, $\overline{9408 \times 12} = 112,896$
Convoy carriage - - 3,360

$133,056 \times \frac{134}{14,968} = 1277$ lbs. gravity.
Friction of 12 carriages, at 43 lbs. each, = 516
Friction of convoy carriage, - 17

1810 lbs., the total resistance overcome by the engine, (exclusive of the power required to propel itself forward,) and, consequently, the adhesion of the wheels upon the rails, when the surface of the rails was dry; and which is equal to the 9·28th part of the pressure on the rails, exclusive of the friction and resistance of the engine; which if we take equal to 568 lbs., the proportion will be equal to the seventh part of the weight.

EXPERIMENT II.

Same engine, with twenty-nine empty carriages, each weighing 3472 lbs., up an ascent of 1 in 324; rails slightly covered with mud, and in the worst state; wheels slipped a little, but the engine proceeded at the rate of about four miles an hour.

Then as before, $16,800 + 3360 + \overline{3472 \times 29} = 96,128 \times \frac{1}{324} = 296$ lbs., the gravity of the engine and carriages. Friction of carriages $29 \times 16 = 464 + 17 = 481$ lbs., which, added to the gravity, gives $481 + 296 = 787$ lbs., the adhesion in the worst weather, equal to the 21·3 parts of the weight; and, taking the resistance of the engine at 568 lbs., as before, the adhesion will be equal to the thirteenth part of the weight, nearly.

This latter should, of course, be taken as that resistance with which the engine should be loaded; and this would be sufficient to drag about seventy tons upon a level road. The engine wheels, however, as stated in the experiment, slipped a little, and though the progressive motion was, notwithstanding, kept up, yet such a slipping of the wheels would have a very injurious effect, not only upon the wheels, but also upon the rails. The load, therefore, should not be so great as to produce such an effect.

From several years' observation of the performance of those engines upon the Killingworth railroad, we are inclined to think the above result rather too high, without incurring the risk of slipping. There they travel sometimes with nine, and sometimes with twelve carriages, amounting to thirty-six and forty-eight tons, respectively. The greatest ascent upon any part of the railroad, with the load, is 1 in 330, and in returning with the empty carriages, 1 in 80. The general load is sixteen waggons, but the wheels, in very bad weather, slip sometimes with twelve carriages; but the engines, in the worst weather, are never prevented travelling with nine carriages.

Taking the latter as the datum, we have 8764 lbs. the weight of each carriage $\times 9 \times \frac{1}{330} = 61$ lbs., the gravity of the carriages, and $\overline{16{,}800 + 3360} \times \frac{1}{330} = 239$ lbs., the gravity of the engine and convoy. Then $9 \times 40 = 360$ lbs., the friction of the carriages, and 17 lbs. the friction of the convoy. Whence $61 + 239 + 360 + 17 = 677$ lbs., the resistance which the engine is capable of overcoming by the adhesion of the wheels, at all times, upon an edge railroad, without slipping.

The weight of the engine being about 16,800 lbs., whence the amount of adhesion will be equal to the twenty-fifth part of the weight; and as the friction, or adhesion, will always be in proportion to the pressure upon the rails, this expression will be constant, and will apply to engines of different weights.

The above result was from an engine similar in construction to Nos. 5 and 6, page 295, without springs, and with a chain to connect the two cylinders with each other. When the engines were improved, and the wheels connected, as shewn in the drawing, and springs adopted, it was found, that the amount of effective adhesion was increased. We had frequent opportunities of observing this; and some experiments, which were made, proved the fact, beyond any doubt. The following experiments, made with Messrs. Walker and Rastrick, while pursuing their inquiries, as to the moving power to be adopted upon the Liverpool and Manchester railway, will, perhaps, shew this very clearly; and which corroborated other experiments we had made for the same purpose. The experiments were made upon a piece of railway which had been prepared, to try the friction of carriages. Cast-iron edge-rail two inches and a quarter broad at top, with half-lap joints; the inclination of the road being as follows:

No. 1.	110 yards	1 in 132
No. 2.	110 —	1 in 97
No. 3.	110 —	1 in 113
No. 4.	110 —	1 in 120
No. 5.	110 —	1 in 114

Experiment III.

Engine weighing six tons, without springs, cast-iron wheels three feet in diameter, water and tender three tons.

No. I. dragged four carriages, each weighing four tons, up the spaces Nos. 1 and 2. The rails greasy, or water from melted snow and coal-dust being upon them. In this experiment there was, evidently, a slipping of the wheels.

No. II. The same engine, upon the same space, with three carriages of four tons each; wheels did not slip.

Experiment IV.

Engine weighing seven tons and a half, convoy carriage and water two tons and a half, wheels four feet two inches in diameter, with wrought-iron tires, "which had been at work twelve months, but did not appear worse;" engine upon springs.

No. I. Placed the engine below the bottom of the five spaces, or 574 yards, with seven carriages, each weighing four tons; the engine travelled up the 574 yards, the wheels making 133 revolutions.

No. II. Seven carriages, and engine as in last experiment.

No. 1. space	- -	27 revolutions.
No. 2. —	- -	27 —
Nos. 3 and 4.	- -	53 —
No. 5. —	- -	26 —
		133 revolutions.

No. V. With six carriages; number of revolutions same as before.

No. VI. Chalked the point of contact of wheel and rail, when the engine was at the top of the plane; it was then run down till it made sixty-eight revolutions, with six carriages attached. It made sixty-nine revolutions and a half of the plane, before it came to the same mark again; but as the slipping was considerable at starting, one revolution was supposed to be lost by that, and, therefore, the slipping, in ascending the plane, was half a revolution.

The result of these experiments is, that in No. I., Experiment III., the resistance was equal to the twentieth part of the weight of the engine, and with this the adhesion was not sufficient to prevent slipping. In No. II. the resistance was equal to the twenty-fourth part of the weight of the wheels upon the rails; and the adhesion was sufficient to overcome the resistance, without slipping.

In Experiment IV., No. I. the resistance amounted to the sixteenth part of the weight, and with this resistance the engine travelled 574 yards, with 133 revolutions of the wheels; this would make about six yards of slipping.

In No. VI. the rail was chalked, which was, perhaps, the most accurate way of ascertaining the extent of slipping; and, making allowance for the slipping at starting, the amount appeared to be about half a revolution of the wheel, or six feet and a half. The resistance opposed to the engine, in this experiment, amounted to the eighteenth part of the pressure on the rails.

From these experiments, we find that a greater power of adhesion existed in the latter engine, than in the one without springs, and with wheels of smaller diameter; in the proportion of, when no slipping took place, probably, as twenty to twenty-five.

It is scarcely necessary to say, that as all the modern engines, and those which may in future be constructed, will be with large wheels, and upon springs, we should take the result of the Experiment IV. as our rule for practice. This would give the adhesion equal to the twentieth part of the insistent weight. These experiments, being made when the rails were in their worst state, will, of course, exhibit the minimum effect.

These engines, as previously stated, are in construction similar to the drawing, Nos. 5 and 6, page 295, the cylinders being vertical, and each of them working a separate pair of wheels, which are connected by the side rods, shewn in the figure. The engines in use upon the Liverpool and Manchester railroad are different, both cylinders working the same pair of wheels, as shewn in *Pl. XII.*; and as there appears some difference of effect in the amount of adhesion, between engines so constructed, it will, perhaps, be necessary to explain the cause.

The action of the power of the cylinders upon each of the wheels of the engine, Nos. 5 and 6, page 295, is extremely irregular; when the piston, for instance, is at the top of one of the cylinders, say No. I., the power has no effect in turning the wheels round, and the circumvolution is effected by the other cylinder, No. II, through the connecting rod on each side of the wheels, pushing the pair of wheels, No. 1, round. When, however, the crank on the wheels, No. 1, has arrived at a certain period of its revolution, the action of the cylinder, No. I., gradually becomes greater, then equal to No. II., and then the predominant moving power, when the other pair of wheels, No. II., is dragged round by the action of the cylinder, No. I.; each pair of which is thus alternately pushed, and dragged forward, by the action of the pistons, and the connecting rods; and as the connecting rods cannot be keyed mathematically tight, such interchanges, in the intensity of the action of their forces, induce, at certain intervals, a slipping of the wheels. The weight of the pistons, and their connecting rods, also, are not balanced; and which, by producing an irregularity in the pressure on the rails, has the effect, also, of inducing a slipping on the descending, rather than on the returning, stroke; and it has hence been observed, that, when slipping does take place, it almost invariably commences with the wheels, on which the piston is descending, and is then communicated to the other, by the horizontal connecting rods.

It is, likewise, very difficult, to procure two sets of wheels strictly, or mathematically, of the same diameter, and, if they are not so, there must be a partial slipping. All these causes have a tendency to induce a commencement of slipping, especially upon the descending piston; and when once the least movement takes place, it is, of course, accelerated, until the piston arrives at that period of the stroke, when its power is diminished, and the other cylinder, through the connecting rod, becomes the predominant power; and hence we often find, in practice, when the two forces are nearly balanced, that a slipping takes place in the descending stroke, is recovered in the ascending, and again produced on the descent of the pistons.

In the description of engine shewn in *Plate XII.*, few, if any, of these defects exist; the power of both cylinders is communicated to the same pair of wheels. Any change of intensity of force, by the cylinders being placed so near each other, cannot be materially felt by either wheel; and the line of direction of the power of the pistons being horizontal, and parallel with the line of road, the pressure upon the rails is always the same; and, likewise, one pair of wheels only being worked by the cylinders, the evil, by the want of uniformity in the diameter of the four wheels, is remedied.

With all these advantages of construction, we find, as might be supposed, that these engines realize a greater amount of adhesion, compared with the insistent weight, than engines of the common construction, the whole of the wheels of which are applied to produce the power of locomotion. It, of course, results from this improved mode of construction, when only one pair of wheels is driven by the cylinders, that, supposing the whole weight of the engine equally divided upon the four wheels, or six wheels, we have only one half, or one third, of the weight of the engine applicable for the purposes of adhesion; but, perhaps, in every case it may be advisable, without producing any injurious effect upon the road, to throw a greater proportion of weight upon the two wheels worked by the cylinders. We are also convinced, that, in the change from three to four feet wheels, or from smaller to larger, an increase of adhesion was effected; for greater speed of travelling, still larger wheels are, and will be applied, whereby a still further increase may be expected. The injury to the rails will also be less, the pressure being the same, with large wheels, than with wheels of smaller diameter; not only from the bearing surface, in the former case, being greater, but also by being enabled to effect a better arrangement of the weight, by placing the centre of gravity so very low, when working two wheels only, and which cannot so conveniently be done, when the four wheels are all worked by the engines.

Perhaps we may, therefore, under these circumstances, place more than one half of the whole weight of the engine upon the two large wheels, worked by the cylinders; without effecting so much injury to the rails, as an engine of the old construction, with the weight equally divided upon the four wheels.

But, if the engine is to be employed to drag heavy loads, then, by side rods, all the four wheels may be coupled together; or, if the engine be placed upon six wheels, and it be required, all the six wheels may be coupled together, and the entire weight of the engine subjected to the action of adhesion. Some of the large engines on the Liverpool and Manchester railway, and several upon the Newcastle and Carlisle railway, are of the latter construction.

M^r Pambour, in his work on locomotive engines, in order to ascertain the adhesion of the Liverpool engines, instances an experiment made with the Fury engine, which dragged ten waggons, weighing 51·16 tons, and tender, weighing five tons, =56·16 tons, up the Whiston inclined plane, without slipping. The inclination of this plane being one in 89, this load will be equivalent to 244 tons on a level, or equal to a resistance of 1952 lbs. The weight of the engine was 8·20 tons, two wheels only being driven by the pistons, or subjected to adhesion, the weight upon which was 5·5 tons. According to this experiment, therefore, the engine was capable of dragging a weight, upon a level plane, equal to 44½ times the pressure upon the driving wheels, or that the force of adhesion was equal to $\frac{1}{6\cdot3}$ of the adhering weight.

This experiment was, however, made under the most favourable circumstances, when the rails were quite dry, and, therefore, must be considered as the maximum effect, similar to Experiment I., where the adhesion was equal to one seventh part of the weight. Mr. Pambour further adds, "In winter, when the rails are greasy and dirty, in consequence of damp weather, the adhesion diminishes considerably. However, except in very extraordinary circumstances, the engines are always able to draw a load of fifteen waggons, or seventy-five tons, tender included; that is to say, fourteen times their adhering weight. In other words, the resistance of seventy-five tons being 600 lbs., the force of adhesion is always, at least, one-twentieth of the adhering weight."

We have been favoured, by Mr. T. E. Harrison, with the result of the adhesion of the locomotive engines, upon the Stanhope and Tyne railway.

The greatest resistance upon that line of railway, where locomotive engines travel, is level, with the loaded waggons, and 1 in 211, ascent with the empty waggons.

The engines have six wheels, four feet six inches in diameter, four wheels coupled, and subjected to adhesion; the weight of the engines about eleven tons, eight tons being the weight upon the driving wheels; cylinders, fourteen inches; eighteen inches stroke of piston; weight of tender six tons; and the friction of the waggons about nine lbs. per ton.

In bad weather, these engines can always take twenty-eight waggons, either loaded, upon the level; or empty, up the gradient of 1 in 211. The ordinary number taken is thirty-two waggons, and, in fine weather, frequently forty waggons; the weight of the waggons averages thirty cwt. empty, and, when loaded, eighty-three cwt.

This will give the adhesion as follows:—

Loaded waggons, on a level.

28 loaded waggons, $= \frac{1}{16\cdot3}$

32 ditto - $= \frac{1}{14\cdot3}$

40 ditto - $= \frac{1}{11\cdot5}$

72 ditto - $= \frac{1}{6\cdot5}$ this being the greatest load ever taken.

Empty waggons, gradient 1 *in* 211.

28 empty waggons $= \frac{1}{16\cdot4}$

32 ditto - $= \frac{1}{15\cdot2}$

40 ditto - $= \frac{1}{12\cdot7}$

72 ditto - $= \frac{1}{7\cdot6}$ the greatest load ever taken.

On the Newcastle and Carlisle railway, there are about four miles with an average rate of inclination of one in 107; upon this, the locomotive engines constantly travel, with forty empty coal waggons, weighing, altogether, sixty-four tons, which, with the tender, makes seventy tons; exclusive of the weight of the engine, which is thirteen tons; the entire resistance, including the gravitation of the whole, will be equal to 1737 lbs. The weight of the engines employed for this work is thirteen tons, upon six wheels, four feet in diameter, which are all coupled, and driven by the pistons, and, consequently, subjected to the action of adhesion. This gives the adhesion, equal to the one thirteenth nearly of the insistent weight. With this the engines constantly travel, every day, at the rate of about ten miles per hour; on some days fifty waggons are taken, but we give forty waggons, as the practical every-day load.

Upon a review of all these experiments, and observations, we are inclined to adopt the conclusion come to in the former Edition of this work; and to consider the adhesion, exclusive of the power requisite to drive the engine itself, in the best or modern engines, as equal to the one fifteenth part of the insistent weight; and of the common engines, working with vertical cylinders, as equal to the twentieth part of the weight, pressing on the rails by the driving wheels.

Art. 2.—*Table of the Amount of Adhesion.*

We shall, therefore, give a table of the weight, which the adhesion of the wheels, of a locomotive engine, will enable it to drag, on planes of different inclinations; but in doing so, we shall give the load per ton of insistent weight of the driving wheels. As the weights of the driving wheels of the different engines vary so considerably, we could not give a table to meet each case; and, therefore, it will only be necessary, in order to know the weight which any engine can drag, upon the various planes given in the Table, to multiply that weight by the number of tons of insistent pressure, of the driving wheels, upon the rails.

Having ascertained the proportion which the power, that enables the engine to effect its progressive motion, bears to its weight, we can easily calculate the acclivities which, with certain weights, will present resistances, corresponding with this power. Thus, upon a level plane, the engine will overcome a resistance equal to the fifteenth and twentieth part of its weight, respectively; or, taking the friction of the carriages as equal to eight pounds and a half per ton, or equal to the 263d part of their weight, a load equal to $\frac{263}{15}$ or $\frac{263}{20}$ of its weight, or the weight acting upon the driving wheels. If the inclination of the plane be such that the weight be equal to the fifteenth or twentieth part of its length, then the whole adhesion of the engine will be required to drag itself forward, and none will be left for the load, supposing the whole weight of the engine disposed upon the driving wheels. If this is not so, then the engine will not be capable of propelling itself forward on such planes; and, therefore, in planes of all the intermediate degrees of inclination between a horizontal, and that which the engine cannot propel itself up, the load, which the engine can overcome, will be inversely as the sine of the angle of inclination, added to the friction of the carriages and tender.

Column 1. shews the inclination of the plane; column 2. the weight which a pressure of one ton, upon the driving wheels of an engine will drag up the several planes, taking the adhesion as equal to the tenth part of the weight; column 3. shews the same, the adhesion being taken as equal to the fifteenth part of the weight; and column 4. the same, with the adhesion equal to the twentieth part of the insistent weight on the driving wheels of the engine.

TABLE I.

Inclination of the Plane.	Load, in tons, which the adhesion of one ton will drag, $\frac{1}{10}$th of weight.	Load, in tons, which the adhesion of one ton will drag, $\frac{1}{15}$th of weight.	Load, in tons, which the adhesion of one ton will drag, $\frac{1}{20}$th of weight.
Level.	26·35	17·57	13·17
1 in 4480	24·89	16·59	12·44
— 3360	24·21	16·14	12·11
— 2240	23·58	15·72	11·79
— 1680	22·40	14·93	11·20
— 1120	21·33	14·22	10·66
— 1000	20·86	13·90	10·44
— 900	20·37	13·58	10·19
— 800	19·82	13·21	9·91
— 700	19·14	12·76	9·58
— 600	18·31	12·21	9·16
— 500	17·25	11·50	8·63
— 448	16·59	11·06	8·29
— 400	15·88	10·59	7·94
— 350	15·03	10·02	7·52
— 300	14·03	9·36	7·02
— 250	12·83	8·55	6·41
— 200	11·37	7·58	5·68
— 150	9·56	6·37	4·78
— 100	7·25	4·83	3·62

The above will give the limits, to which the nature of their action restricts the application of this kind of engine; and will shew upon what inclination of road they can be used. This will, of course, vary with the weight of the engine, and the load which it has to overcome. But, in every case, making K = the weight of the engine, or of the weight acting upon the driving wheels, if the total resistance, arising either from the gravity of a certain elevation of plane, or from the friction of the carriages, or from both combined, do not exceed $\frac{K}{15}$ or $\frac{K}{20}$, the adhesion of the wheels will be sufficient to enable the engine to effect a progressive motion, in all states of the weather, without slipping, and in fine weather equal to $\frac{K}{10}$. It is scarcely necessary to observe, with respect to the standard of $\frac{K}{20}$, that it has been obtained when the rails were in the worst state, or presented the least power of adhesion. This occurs, as previously stated, when the rails are partially wet, and, in that state, generally covered with a film of mud. When they become completely wet or dry, the power of adhesion is very considerably increased. It is, therefore, only on particular occasions that this occurs, and, generally, for very transient periods, such as the commencement of rain, and before the rails are quite wet; or, after rain, when the rails are semi-dry, on a thaw, after hoar frosts, or on a foggy, damp day, when the deposit of rain is not sufficient to completely wet the rails. On other occasions, the power of adhesion may be generally assigned to be $\frac{K}{15}$, and in fine weather $\frac{K}{10}$.

Those engines may, therefore, be often made to work with loads, beyond that which the power of adhesion, assigned by column 3. and 4. of this table will perform, and for several days together. Still, we think, it will always be advisable, on account of the injury done to the wheels and rails, by even partial slipping, to keep the load within, rather than beyond, the limit. We have very conclusive experience, in a case previously adduced, of the wear of the wheels of the Killingworth engines; the wear of the light engines, which slipped more frequently, being greater, in the proportion of 1·5 to 1, than the heavier engines, with larger wheels, which were less liable to slipping; and we find, also, that the wear of wheels upon the Stanhope and Tyne railway, where the engines take always a maximum load, and where the liability to slip is increased, is in the proportion of one third greater than upon the Newcastle and Carlisle railway, with the passenger and goods trains, where the load is not so great. The distance which one set of wheels travel, until the tire requires turning, being, on the former railway 15,000 miles, and on the latter upwards of 20,000 miles.

Art. 3.—*Friction of Engines unloaded.*

When the first edition of this work was published, locomotive engines had engaged little of public attention; they were exclusively used on private railways for the conveyance of coals, at slow rates of speed, and where economy of fuel was no object. The opportunities of subjecting them to experiment were, therefore, few, and not of that nature to develope all the capabilities, which subsequent experience has shewn them to have been susceptible of. So far, however, as we then had an opportunity of eliciting their powers, either by observation or experiment, we availed ourselves, and the result was then communicated to the public. This, however, went no further, than to shew that they were then capable of dragging forty tons, on a level railway, at the rate of six miles an hour.

Six years after this, and when the second edition of this work was published, those engines had but very recently been improved, and to a very important extent, by the adoption of tubular boilers. At that time, however, those improved engines having been a very short time in use, their powers had not been fully developed, few experiments had been made upon them, and, therefore, this edition, though giving all the information we could then obtain on the subject, fell far short of illustrating all the powers, capabilities, and properties of these engines. The short period, however, during which those engines had been in use, at that time, proved that they were then capable of conveying a gross load of thirty to forty tons, on a level railway, at the rate of fifteen miles an hour. Since that period improvements have been made in those engines, but not by any means, however, to the extent of what had previously been done. Their powers have not been much increased, but they have been made more perfect engines, and several defects, operating upon their economy, have been remedied. During all this time, though several detached observations and experiments had been made, no regular series of experiments, to fully develope the powers and properties of these engines, seems to have been undertaken to bring before the public that information which so important a subject demanded.

The Liverpool and Manchester railway being the first established, with the improved locomotives, no opportunity existed, consistent with our engagements elsewhere, to pursue those experiments, upon the improved engines, which we had previously done upon the engines within our reach. This has, however, been done by Mr. Pambour, a French engineer, through the liberality of the directors of that railroad, and as his experiments have been very judiciously conducted, and sufficiently extended to embrace the whole subject, we shall avail ourselves of that source of information, and which, combined with that obtained from other sources, will, we trust, enable us to place before the reader almost all the information necessary on the subject. We shall, first of all, give some experiments, made to ascertain the friction of the engines, or the resistance which the working parts of the engine oppose to the power applied to the pistons, when the engines are without a load.

a.—Killingworth Engines.

Upon the same plane or piece of railroad, described in Experiment II., Chap. VII., with a descent of eleven feet two inches in 388 yards, five loaded carriages, each weighing 9408 lbs., were allowed to descend freely, as explained in that experiment; which they performed in 120 seconds. We then had them drawn up the plane again, and attached the engine to them, shutting off the communication between the boiler and the cylinders, so that the steam could not act upon the pistons, either to accelerate or retard the motion of the engine, the top and bottom of the piston being alternately open to the atmosphere; the only obstruction to the motion of the engine down the plane was, then, the friction of the various moving parts. The carriages and engine were allowed to descend the plane freely, which occupied 150 seconds, making the obstruction of the engine to the gravitating force of the waggons equal to thirty seconds.

The weight of the engine and convoy carriage together was nine tons=20,160 lbs., to which add, for the rotatory motion of the wheels, 1800 lbs.,=21,960 lbs., the carriage weighing 9408 lbs., and for resistance of the rotation of wheels 747 lbs.; =10,155 × 5 =50,785 + 21,960 72,735 lbs., the mass in motion.

Then the retardation, caused by the friction of the whole, will be
theorem (8.) $\text{F} = \text{W} + w \sin. \text{I} — \frac{(\text{W} + w^{\text{S O}}_{\text{S G}}) \times \text{S}}{rt^2} = 410{\cdot}7$ lbs.,

the friction of engine and carriages. By Experiment II., we have the friction of the carriages, 39·35 × 5 = 196·75; whence 410·7—196·7=214 lbs., the friction of all the moving parts of the engine.

b.—*Liverpool Engines.*

Mr. Pambour made several experiments, on the resistance of engines unloaded, both with the dynamometer; and likewise by endeavouring to ascertain the minimum pressure, per square inch, on the piston, which would just move the engine. Both these modes were subject to great irregularities; the first, in the oscillation of the index of the dynamometer, from the inequalities of the road, and the difficulty of preserving a uniform force of traction; and the latter, from the extreme difficulty of keeping the pressure of steam, in the boiler, uniform. No dependance, therefore, can be placed upon those experiments, to fix a standard of resistance for these machines.

The experiments performed upon the Sutton inclined plane, on the Liverpool railway, by causing the engine to descend by its gravity, and ascertaining the distance it passed over on the level at the foot of the plane, in a similar manner to that by which the friction of the carriages was ascertained, being a much more accurate mode of determining the resistance, we shall give those experiments; as we consider them the most accurate mode to establish a standard, for the friction of the improved engines, when not loaded.

The engine, Jupiter, was placed upon the plane at the stake, No. 0, and left to descend by its gravity. Being first separated from the convoy carriage, it traversed a distance of 6189 feet, before stopping, the total descent being 36·78 feet. The weight of the engine was 7·90 tons. Consequently $\frac{36·78 \times 7·90}{6189} = 105$ lbs., the friction of the engine, without convoy, the velocity being from nine to ten miles an hour, two wheels being driven by the steam.

Atlas engine, being similarly subjected to experiment, traversed 5454 feet; difference of level, 32·07 feet; weight of engine, 11·42 tons; therefore, $\frac{32\cdot07\times11\cdot40}{5454}$ $=150$ lbs., the friction of the engine, without convoy. Mean velocity eight to nine miles an hour. In this engine, four of the wheels are driven by the steam.

The same machine, having been repaired, and the joints, in consequence, not being smooth, was placed upon the plane, and was found to traverse only 4665 feet, the descent being 35·40 feet; the friction was, therefore, found to be 194 lbs.

Vesta engine was, likewise, tried, after having been repaired, and found to traverse 3663 feet; descent, 35·07 feet; the weight of engine, 8·71 tons. Consequently, the friction was 187 lbs., without convoy; two wheels driven by steam.

Fury engine, weight 8·20 tons, traversed 5988 feet; descent, 36·68 feet; therefore, friction 113 lbs., without convoy.

Vulcan engine, weight 8·34 tons, traversed 5391 feet; descent, 36·52 feet; friction, 127 lbs., without convoy.

Leeds engine, weight 7.07 tons, traversed 5472 feet; descent, 36·32 feet; friction, without convoy, 105 lbs.

Same engine traversed 5061 feet; descent, 35·86 feet; friction, 112 lbs., without convoy.

c.—Table of the Friction of Engines, without a Load.

The following Table will shew the result of these Experiments:—

TABLE II.

Names of Engines.	Friction of Locomotive Engines, unloaded.					
	Diameter of Cylinder.	Length of Stroke.	Diameter of Wheels.	Weight of Engine.	Amount of Friction in lbs.	Friction, in lbs., per Ton.
	inches.	*inches.*	*feet.*	*tons.*		
Hetton Engine -	9	24	3·08	9·	214	23·8
Jupiter - -	11	16	5	7·90	105	13·3
Atlas - -	12	16	5	11·40	150	13·2
Fury - -	11	16	5	8·20	113	13·9
Vulcan - -	11	16	5	8·34	127	15·4
Leeds - -	11	16	5	7·07	108	15·2
Vesta - -	11½	16	5	8·71	187	20·0
Mean -	—	—	—	8·6	132	15·2

The result of these experiments is, that the friction of the engines is in the inverse ratio of the diameter of the wheels, when unloaded, and nearly in proportion to their weight. The average friction of the Liverpool engines is 15·2 lbs. per ton, with five feet wheels; and of the Hetton engine, with 3·08 feet wheels, 23·8 lbs. per ton; now, in inverse ratio, as 5 : 15·2 : 3·08 : 24·6.

Mr. Pambour concludes, from these experiments, that engines, with the four wheels coupled together, and worked by the steam, present more resistance than engines with only two wheels, worked by the steam; and instances the case of the Atlas, giving 152 lbs. friction, which is much more than the others; but he appears to have overlooked the circumstance, that the Atlas was a much more powerful, and, consequently, heavier engine, and that the friction, per ton, of that engine, is less than the average of the others.

We may, therefore, from these experiments, take, in practice, the friction of those engines, unloaded, at 15 lbs. per ton, with five feet wheels; and assume, that this amount of friction will vary, according to the weight of the engine, and the diameter of the wheels.

Art. 4.—*Friction of Engines loaded.*

Having, therefore, found the friction of the engines unloaded, we have now to ascertain their friction when they are employed in dragging loads after them, or that part of the power applied to the pistons which is requisite to propel the engine itself. In the consideration of this, the circumstances are materially different from that of the single attrition of all the parts of the machinery, the entire resistance to the motion being, in that case, simply its own weight. When those engines are employed in dragging loads after them, that part of the power required to produce a progressive motion in the load itself, as well as that of the engine, has to be transmitted from the impelling to the impelled part of the engine, or from the pistons to the wheels upon the rail, through all the intermediate machinery; and this pressure, acting upon all the various parts of the engine, forming the connection between these two points, will necessarily produce friction, and, consequently, add to the resistance; and this will be greater, when the engine is heavily, than when lightly loaded, being in proportion to the pressure thrown by the load upon all the intermediate machinery.

The total amount of friction will, however, depend upon the extent and number of the moving parts of the engine; and this will be always the same, in one revolution of these wheels, or in one complete stroke, whatever be the progressive motion of the engine in that revolution, except what arises from the rolling of the wheels upon the rail.

For, suppose the engine made to rest upon the axles, the wheels not touching the rails; if, then, we turn the wheels once round, we shall have caused the pistons to make a complete stroke, and all the parts of the engine to have performed one entire operation. Now, this will require the exertion of a certain force, and if we repeat this, as often as we make one revolution of the wheels, precisely the same degree of force will be required. If we now place the wheels upon the rails, and push the engine along, until the wheels make one revolution, it is clear, (if we set aside the resistance of the wheels upon the rails,) that the same amount of force will be expended to cause an entire revolution of all the parts of the engine, whatever may be the diameter of the wheels. If, therefore, having three feet wheels, we remove them, and substitute four feet ones, the amount of friction, arising from the moving parts of the engine, (except what arises from the wheels upon the rails,) will be the same during each revolution of the engine, while the progressive motion or space described will be as 12 : 9.

The quantity of friction, compared with the progressive motion of the engine, will, therefore, have been diminished in that ratio, by using wheels of three, and of four feet respectively. It is, however, necessary to notice, that the force required upon the pistons, to give motion to the machinery, and load, will always be as the diameter of the wheels directly, and will, therefore, be increased in the direct ratio of an increase of diameter of the wheels; and, therefore, the diameter of the wheels must be always proportioned to the velocity it is intended to travel.

With a view of ascertaining, practically, the effect of different sized wheels upon the same engine, and, likewise, the effect of different loads, and thereby to determine the friction of the engine, we commenced in 1824 a series of experiments on the Killingworth railroad, with the engines used thereon; and, by varying both the load and rate of speed, we were enabled to determine the relative performances, on all these points.

With the expectation of reducing the friction, we had previously affixed larger travelling wheels to the engine. By experimenting, therefore, upon the same engine, with different sized wheels, we were not only enabled to prove the relative performances of wheels of different diameters, but also to ascertain the actual amount of friction, inherent to the engine itself.

The following Tables will shew the result of these experiments.

a.—Killingworth Engines.

Account of some Experiments, made on the performance of Locomotive Engines, upon the Killingworth Railroad, in 1824.

Length of plane 2260 yards, with an ascent, in one direction, of six feet five inches; not uniform, varying from a dead level, or slightly undulating, to an ascent, in one place, of 1 in 330; edge-rail, 2½ inches broad on the surface; carriages, all the same construction, weighing 81¼ cwt. each; wheels, 34 inches in diameter; axles, 2¾ inches in diameter.

No. I.—Locomotive engine, of the construction represented in Nos. 5 and 6, page 295; length of boiler, eight feet; diameter, three feet nine inches; diameter of tube, in which the fuel is placed, twenty inches, with two cylinders, nine inches in diameter each; wheels of different diameter, as explained in the following Table; steam, 50 lbs. per square inch.

TABLE III.

Number of journeys.	Experiment I. 3-feet wheels; 9 carriages, weighing 73¼ cwt.				Experiment II. 4-feet wheels; 9 carriages, weighing 73¼ cwt.				Experiment III. 4-feet wheels; 12 carriages, weighing 975 cwt.			
	Up the plane.		Down the plane.		Up the plane.		Down the plane.		Up the plane.		Down the plane.	
	Time in minutes.	Strokes per minute.	Time in minutes.	Strokes per minute.	Time in minutes.	Strokes per minute.	Time in minutes.	Strokes per minute.	Time in minutes.	Strokes per minute.	Time in minutes.	Strokes per minute.
1	23	31	18	40	19	28	16	34	16	34	16	34
2	22	33	18	40	16	34	16	34	20	27	16	34
3	22	33	19	38	16	34	17	32	18	30	14	38
4	22	33	16	45	16	34	15	35	17	32	16	34
5	27	27	18	40	16	34	14	38	16	34	14	38
6	22	23	16	45	16	34	14	38	16	34	14	38
7	26	28	20	36	17	32	14	38	17	32	15	35
8	25	28	19	38	14	38	12	45	18	30	15	35
9	22	23	19	38	14	38	13	41	17	32	13	41
10	25	28	19	38	16	34	13	41				
11	19	38	20	36	17	32	16	34				
12	21	34	20	36	17	32	15	35				
13	21	34	18	40	16	34	14	38				
14	20	36	18	40	16	34	13	41				
15					16	34	11	49				
16					13	41	12	45				
17					15	35	14	38				
18					16	34	13	41				
19					16	34	13	41				
	317	32	258	39	302	34	265	39	155	32	133	36
	Distance traversed, 36 miles, in 9 hours 35 min.; coals consumed, 2534 lbs.; water, 890 gallons = 93 gallons per hour.				Distance traversed, 48·8 miles, in 9 hours 27 min.; coals consumed, 2534 lbs.; water, 854 gallons = 90·4 gallons per hour.				Distance traversed, 23 miles in 4 hours 48 min.; coals consumed, 1546 lbs.; water, 452 gallons = 94 gallons per hour.			

No. II.—Locomotive engine, similar construction as the preceding, except in the dimensions of the boiler and tube. Length of boiler, nine feet two inches; diameter, four feet; and diameter of tube, twenty-two inches; cylinders, each nine inches; wheels, as per following Table; steam, 50 lbs. per square inch.

TABLE IV.

Number of Journeys.	EXPERIMENT IV. 3-feet wheels, 9 carriages, weighing 731¼ cwt.				EXPERIMENT V. 4-feet wheels, 12 carriages, weighing 975 cwt.			
	Up the plane.		Down the plane.		Up the plane.		Down the plane.	
	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min. sec.	Strokes per min.	Time in min. sec.	Strokes per min.
1	17	42	16	45	11 40	34	9 4	44
2	20	36	18	40	9 20	43	8 5	49
3	21	34	18	40	8 22	47	7 40	51
4	21	34	18	40	8 16	48	7 42	51
5	23	32	18	40	8 10	49	7 55	50
6	23	32	18	40	—	—	—	—
7	21	34	18	40	—	—	—	—
8	21	34	18	40	—	—	—	—
9	23	32	19	38	—	—	—	—
10	22	33	19	38	—	—	—	—
	212	34	180	40	45 48	43	40 26	49
	Distance, each journey, 2260 yards. Total, 26 miles. Ascent, 6 feet 5 inches; time, 5 hours 32 min.; coals consumed, 1487 lbs.; water, 490 gallons.				Distance, each journey, 2002 yards. Total, 11·375 miles. Distance passed over in the above time, 1663 yards in each journey, or 9·45 miles; time, 1 hour 26 min. 14 sec.; coals consumed, 587 lbs.; water, 200 gallons.			

The preceding experiments were made upon a piece of railroad, with a nearly uniform inclination; the rails were not of the most modern construction, and would, therefore, in some places, present considerable obstruction to the wheels of the carriages. The experiments were performed with the strictest regard to accuracy; the coals were measured by a standard coal tub, strike measure; and, to be certain, with regard to the weight, several tubs were also weighed, and the difference of weight, which was scarcely worth noticing, averaged. The water was also carefully measured.

In the first four experiments, the time was marked, when the engine began to move from the end of the plane, so that the force required, and also the delay occasioned, by putting the carriages into motion, was included. No attempt was made to augment the speed of the engine, to the greatest that could be performed, our object being, to ascertain the relative performances, with different wheels, and different loads. We, therefore, endeavoured to keep up a speed, as equable as possible; and, in doing so, had frequently to regulate and check the velocity, to obtain the same number of strokes, per minute, in each experiment.

In the fifth experiment, the engine was allowed to traverse a given space, to put the train of carriages into their proper motion, before the time was noticed; the time was then marked, until the velocity was again checked, at the farther end of the stage; this will explain the difference between the two distances, mentioned in that experiment. The one was, the whole distance, from the commencement to the end of the stage; the other was, that part of the stage, which the engine passed over, when the regular velocity was acquired, and before the velocity was again diminished, at the end of the stage, to stop the train. The time given in the Table was that which transpired, while the engine was passing over that part of the stage, while the velocity was uniform, and may, therefore, be taken as a measure of speed.

Experiments I. and II. were made, to ascertain the effect, with wheels of different diameters. The engine was the same in each experiment; the only alteration made, was taking the three feet wheels from off the axles of the engine, and replacing them with wheels four feet in diameter. The experiments were made upon the same stage of the railroad, and every care was taken to make the experiment an accurate comparison of their relative effects.

On examining these experiments, it will be found, that when the consumption of coals, and weight propelled, remained the same,

No. I. engine, with	3-feet wheels,	traversed the respective distances of	36 miles.
	4-feet wheels,		48·8 miles.

Whence we find, that with the same quantity of fuel, the distance traversed by the engine, with different sized wheels, is in the ratio of the diameter of these wheels, when the load is the same, in both cases.

The consumption of fuel, when every circumstance remained the same, being as the space passed over; then, as 63,280 yards (the space passed over in Experiment I.) : 2534 lbs. (the coals consumed) : : 85,880 yards (the space passed over in Experiment II.) : 3439 lbs., the coals which would have been consumed in Experiment I., in traversing 85,880 yards. The relative consumption of coals will then be—

No. 1. engine, with -	3-feet wheels,	distance and load the same in each experiment,	3439 lbs.
	4-feet wheels,		2534 lbs.

From which we have the relative consumption of fuel by the same engine, with three and four feet wheels, as 3439 : 2534; which is nearly in the inverse ratio of their respective diameters.

It may appear paradoxical to some, that by increasing the wheels, the engine was enabled to pass over a greater distance, without any loss of effect, and might lead to a supposition, that by making the wheels extremely large, the engine might travel with very little power at all; but, when duly considered, it will prove very consonant with reason, and what, from the nature of the action of these machines, we might have been led to expect.

Before, however, explaining this, it will be necessary to ascertain the amount of the friction of the engines in the two cases. In Experiment III., the consumption of coals, for conveying 975 cwt. 23 miles, was 1546 lbs.; in Experiment I., the consumption was 2534 lbs. Now, if 1546 lbs. convey 975 cwt. 23 miles, 2534 lbs. would convey the same weight 37·7 miles, for, as 1546 : 2534 : : 23 : 37·7 miles.

The same engine, therefore, with the same fuel, propelled 975—731¾=243¼ cwt., or three carriages additional, by the substitution of four feet wheels. The friction of three carriages will be about 120 lbs., and, therefore, the diminution of friction would have been 120 lbs., had the distance travelled been the same; but, with the four feet wheels, the distance travelled was 37·7 miles, while, with the same fuel, the distance, by the three feet wheels, was only 36 miles; this will be an additional effect of 37·7 : 36. Hence, as the friction of 975 cwt. is 480 lbs., (or 40 lbs. each carriage,) we have $480 \times \frac{37\cdot7}{36} = 502$ lbs., the resistance overcome, exclusive of that of the engine, with four feet wheels. The weight taken by the three feet wheels was 731¾ cwt. = 360 lbs. resistance; whence, 520—360 = 142 lbs., the increase of effect, by the substitution of four feet wheels.

Now, as the increase of effect could only arise from a diminution of friction in the engine, this diminution was effected by an increase of one foot in the diameter of the wheels; they being, respectively, three and four feet in diameter. Hence, we may suppose, that, in the application of four feet wheels, one fourth of the resistance of the engine, in passing over the same space, was annihilated. Whence, 142 × 4 = 568 lbs., the total amount of friction of the engine, with three feet wheels, and as 4 : 3 : : 568 : 426 lbs., the friction of the engine, with four feet wheels, at the velocity of six miles an hour.

We see, therefore, the reason, why the same quantity of fuel produced different effects, with three and four feet wheels; in the former, the friction was 568 lbs.; increasing the wheels to four feet diminished that friction to 426 lbs., and this diminution of friction, equal to 142 lbs., amounts to more than the resistance of the difference of loads taken, or 244 cwt. In making this experiment, it will, however, be seen that no alteration took place in the axles, or in any other of the working parts of the engine, while the strain would vary considerably between three and four feet wheels. By farther enlarging the wheels, therefore, a corresponding increase of effect will not take place; as, if the wheels be farther enlarged, the diameter of the axles, and all the other working parts of the engine, subjected to an increased strain, should also be strengthened, so as to compensate for the additional strain; and that increase requiring to be in the direct ratio of the strain, the friction of the axles and those parts will remain the same, and, consequently, no diminution of resistance will be thus produced by the enlargement of the wheels. But, as the friction of the axles, and those parts requiring to be enlarged, by the use of wheels of greater diameter, forms only a small part of the whole friction; the previous experiments shew, that, when an increase of velocity is required, it ought to be effected by an increase in the diameter of the wheels.

b.—Liverpool Engines.

Having thus ascertained the friction of the engines with a single tube, and with vertical cylinders, we shall now give some experiments made by Mr. Pambour, on the Liverpool railway, to ascertain the friction of the engines used on that railroad, when loaded. The mode of conducting the experiments was, to load the engines, and cause them to ascend the Sutton inclined plane (an inclination of $\frac{1}{89}$), by which the resistance was so increased, as to nearly balance the power applied to the pistons of the engines. The difference between the power applied to produce the progression of the engine, and the resistance of the load, was taken to be the friction of the engine.

Thus, let d = diameter of cylinder.
K = 3,141, &c.
D = diameter of engine wheels.
l = length of stroke of piston.
m = weight of load in tons.
n = friction of load per ton.
p = pressure of steam in boiler per square inch.
g = gravity of engine and load.

By, therefore, placing an engine upon a level railroad, or upon any line of road of a uniform inclination, and keeping the pressure of steam on the piston of such an elastic force, p, as will produce a constant and uniform velocity to the engine and load; we have $\frac{p\,d^2 l}{D} - n\,m\,g = x$. x, in this case, representing the friction of the engine, or that amount of force, or difference of power between the impelling power on the pistons, and the resistance and inertia of the load, requisite to keep up the uniform rate of motion during the experiment.

The following experiments were made by causing the engines to travel up the inclined plane, and ascertaining the load they could drag with a given pressure of steam, the rate being so slow, that the same pressure acted upon the piston.

Vulcan engine, weighing 8·34 tons, with a first class train of nine common carriages, two empty carriages, and the mail, which, with tender, altogether weighed 39·07 tons; total weight of engine and train, 47·41 tons; pressure of steam, 57·5 lbs. per square inch; the mean velocity was 11·42 miles an hour, reduced at the summit to 7·5 miles an hour.

Then $\frac{p\,d^2 l}{D} =$ 1856 lbs. power applied.
$n\,m\,g =$ 1506 lbs. resistance.
350 lbs. friction of engine.

In this experiment, the velocity was not uniform, being 26·6 miles an hour before arriving at the plane, settled to twenty miles an hour for the first half of the ascent, took then an average of 11·42 miles an hour, the velocity at the last quarter of a mile of the plane being 7·5 miles an hour; the diminution of velocity during the experiment was, therefore, equal to 15·34 miles an hour. The total resistance opposed to the power of the machine was the friction and gravity of the load, minus that power which, acting on the mass moved, would, in the length of the plane, produce a velocity of 15·34 miles an hour.

We have previously determined this force to be $\frac{\text{W} + w \frac{\text{SO}}{\text{SG}} \times \text{S}}{r t^2}$; reckoning, therefore, the resistance for the rotation of the wheels $w \frac{\text{SO}}{\text{SG}}$ the same as heretofore, viz., 187 lbs. for each wheel, we have $\text{W} + w \frac{\text{SO}}{\text{SG}} =$ 115,922 lbs., and $t = \frac{2\,\text{S}}{v}$; hence $\frac{\text{W} + w \frac{\text{SO}}{\text{SG}} \times \text{S}}{r t^2} = 123$ lbs., the power acting on the train which would produce a velocity of 15·34 miles an hour in the length of the plane; therefore 350 + 123 = 473 lbs., the friction of the engine, or twenty-two per cent. of the power with a load of 1506 − 123 = 1383 lbs. at a mean velocity of 11·42 miles an hour.

Same engine on the Whiston plane, length 7761 feet, average rate of inclination $\frac{1}{96}$: with nine first class carriages, two loaded trucks, and the mail; altogether weighing, with tender, 41·32 tons. The average velocity maintained during the ascent was 18·75 miles an hour, reduced to twelve miles at the summit; pressure of steam in the boiler 57·5 lbs. per square inch.

We have, as in last experiment, the power applied = 1856 lbs., resistance of train = $\frac{1489}{367}$ lbs.; then the diminution of velocity, being equal to 6·75 miles an hour, will amount to 40 lbs.; consequently 367 + 40 = 407 lbs., the friction of engine, or twenty per cent. of its power with a load of 1489 − 40 = 1449 lbs., at a mean velocity of 18·75 miles an hour.

Atlas engine, on the Sutton plane, loaded with eight waggons, weighing, with convoy, 39·40 tons; pressure of steam, 55 lbs. per square inch; velocity, six miles an hour.

Power - - - 2111 lbs.
Resistance - - 1594 lbs.

517 lbs. the friction of engine, or twenty-five per cent. of its power with a load of 1594 lbs., at the velocity of six miles an hour.

In this experiment it is not stated whether any diminution of velocity took place, during the time of ascending the plane; we therefore presume the velocity was uniform.

Same engine was placed on the railway at the summit of the two planes, which is perfectly level; it drew after it forty waggons, weighing altogether, with convoy, 195·5 tons, at a uniform velocity of 9·23 miles an hour; pressure of steam 53·5 lbs. per square inch.

Power - - - 2054 lbs.
Resistance - - - 1564 lbs.

490 lbs. friction of engine, or twenty-four per cent. of its power, at a velocity of 9·23 miles an hour, with a load of 1564 lbs.

The same engine was tried upon the Sutton plane, with a train of eight loaded and four empty waggons, which, with convoy, weighed 40·15 tons; the pressure of steam in the boiler being forty-six pounds per square inch. The velocity of the engine, which, on arriving at the plane, was twenty miles an hour, was reduced, in the first ¼th mile to 7½ miles an hour, next ¼th to 4½ miles, third ¼th mile to 2¼, and then was stopped altogether, not being able to proceed further. The steam was then allowed to increase in elasticity until it was equal to fifty pounds per square inch, when the engine gradually acquired its motion, and accomplished the ascent, at a velocity of seven miles and a half per hour at the summit.

Mr. Pambour estimates the excess of power in the former case at 147 lbs., and in the latter at 339 lbs. Making allowance for the diminution of velocity, we find the excess of power, at the end of the
first quarter of mile = 544 lbs., or 26 per cent.
second quarter of mile = 376 lbs., or 19 per cent.
third quarter of mile = 275 lbs., or 14 per cent.
the mean resistance being 398 lbs., and the mean velocities, respectively 13¼, 6, and 3⅜ miles an hour. After the elasticity of the steam was increased, the excess of power is stated to be 339 lbs., the mean velocity being 6¾ miles an hour; in the latter case the circumstances are not stated, whereby to calculate the accuracy of this resistance.

Fury engine, on the Whiston plane, with ten waggons, weighing, with tender, 56·16 tons; pressure per square inch in boiler 65½ lbs.; mean velocity 6·31 miles, reduced to 3·33 miles on the summit of the plane.

Power - - -	2114 lbs.
Resistance - -	1951 lbs.
Excess of power - -	163 lbs.
Inertia of train - -	20 lbs.
	183 lbs.

183 lbs. friction of cylinder, or nine per cent. of its power, at a velocity of 6·31 miles an hour, with a load of 1931 lbs.

Same engine ascended the Sutton plane, with a train of ten waggons, weighing, with tender, 48·80 tons; pressure of steam, sixty-seven pounds per square inch; velocity, fifteen miles an hour. The engine drew its train with evident ease.

Power - - -	2162 lbs.
Resistance - -	1825 lbs.
	337 lbs.

337 lbs. friction of

the engine, or sixteen per cent. of its power at a velocity of fifteen miles an hour, with a load of 1825 lbs.

Same engine, on the Sutton plane, eight first class carriages, which, with convoy, weighed 32·99 tons; pressure of steam, 55 lbs. per square inch; mean velocity, 13·33 miles an hour, reduced to ten miles an hour at the summit of the plane.

Power - -	1775 lbs.
Resistance - -	1466 lbs.
Excess of power -	309 lbs.
Inertia of train -	12 lbs.

321 lbs. friction of engine, or 20 per cent. of its power, at a mean velocity of 13·33 miles an hour, with a load of 1466 lbs.

Leeds engine, on the Sutton plane, loaded with seven waggons, which, with tender, weighed 35·15 tons; pressure of steam, 48·5 lbs. per square inch. The velocity of fifteen miles an hour, for the first mile of the ascent, fell to ten miles for the following quarter, and to 6·6 miles for the last quarter of a mile, near the top; average velocity, ten miles.

Power - - -	1565 lbs.
Resistance - -	1344 lbs.
Excess of power -	221 lbs.
Inertia of train -	75 lbs.

296 lbs. friction of engine, or 19 per cent., at a mean velocity of ten miles an hour, loaded with 1326 lbs.

Vesta engine, on the Sutton plane, with seven loaded waggons, and convoy, weighing 34·43 tons; pressure of steam, 57·25 lbs. per square inch; velocity, at summit, 2·5 miles an hour; the machine started from a state of rest.

Power - - - 1891 lbs.
Resistance - - 1543 lbs.

348 lbs. friction of engine, or 18 per cent. of its power, at a mean velocity of 1·25 miles an hour, with a load of 1543 lbs.

Same engine, on same plane, with eight loaded waggons, and convoy, weighing 37·45 lbs.; pressure of steam, 58 lbs. per square inch; minimum velocity, 3·25 miles an hour.

Power - - - 1915 lbs.
Resistance - - 1462 lbs.

453 lbs. friction of engine, or 24 per cent. of its power, at a minimum velocity of 3·25 miles an hour, with a load of 1462 lbs.

Same engine, on same plane, with a load of 39·05 tons; pressure of steam, 56·5 lbs. per square inch; maintained seventeen strokes of the piston per minute, or three miles an hour.

Power - - - 1866 lbs.
Resistance - - 1514 lbs.

352 lbs. friction of engine, or 20 per cent. of its power, at a mean velocity of three miles an hour, with a load of 1514 lbs.

c.—Table of the Friction of Engines, loaded.

TABLE V.

Table of the Friction of the Liverpool Engines, loaded per Experiments of Mr. Pambour.

Names of Engines.	Diameter of cylinder.	Stroke of piston.	Diameter of the wheel.	Weight of the engine.	Friction without load.	Effective pressure in the experiment.	Velocity in miles an hour.		Load on a level.	Friction of engine loaded.
							Mean.	Min^{m}.		
	ins.	ins.	feet.	tons.	lbs.	lbs. per sqr. in.	Miles an hour.	Miles an hr.	tons.	lbs.
Vulcan -	11	16	5	8·34	127	57·5	11·42	7·5	188	473
Ditto -	11	16	5	8·34	127	57·5	18·75	12	186	407
Atlas -	12	16	5	11·40	150	65·0	6	—	199	517
Ditto -	12	16	5	11·40	150	53·5	9·23	—	196	490
Ditto -	12	16	5	11·40	150	51	11	2¼	202	398
Fury -	11	16	5	8·20	113	65·5	6·31	3·33	244	183
Ditto -	11	16	5	8·20	113	55	15	—	228	337
Ditto -	11	16	5	8·20	113	67	13·33	10	183	321
Leeds -	11	16	5	7·07	108	48·5	10	6·6	168	296
Vesta -	11⅛	16	5	8·71	187	57·25	1·25	—	193	348
Ditto -	11⅛	16	5	8·71	187	58	5	3·25	182	453
Ditto -	11⅛	16	5	8·71	187	56·5	3	—	189	352
Mean -	- -	- -	- -	9·05	143	56·85	9·19	—	196	381

The result of the foregoing experiments is, that, on the mean of the whole, a load of 196 tons gives a resistance of 381 lbs.; the mean friction of the same engines, unloaded, gave 143 lbs., which, deducted from 381 lbs., is 238 lbs., the increase of resistance, by a load of 196 tons, or, 1·22 lbs. per ton. The experiment with the Fury engine, being so much below the result of the others, we may probably take 1¼ lbs. per ton, for the additional friction, by the load of the train upon the working parts of the engine. Mr. Pambour's conclusion is one pound per ton, but this being rather below what his experiments gave; while, in his calculations, he has omitted noticing the effect of the diminution of velocity, during the experiments, which still further increases the resistance; we are, therefore, inclined to think 1¼ lbs. per ton, for every additional ton of load applied to the engine, will be a more correct result, in practice, than that assigned by Mr. Pambour.

Art. 5.—*Investigations of the Mode of raising Steam in Locomotive Engines.*

Having ascertained the resistance or friction of all the moving parts of the engine, both when not attached to a load, and when subjected to the dragging a load after it, together with the ratio of increase of resistance, in proportion to the amount of load attached to the engine; we come now to determine the quantity of work which these engines are capable of performing when constructed of certain dimensions. Although not perhaps absolutely necessary, yet it will tend much to elucidate the nature of the action of these engines, to give a short sketch of the progress of the successive improvements made subsequent to the memorable contest at Liverpool.

The impelling power of these engines, and indeed of all steam engines, being the pressure of the steam upon the piston of the cylinder; it follows, that the quantity of work they are capable of performing, or the power with which they act upon the load, depends entirely upon the intensity of pressure of the steam upon the piston, and the bulk of such steam which the engine is capable of producing at such pressure. We find, therefore, that it is the quantity or bulk of steam capable of being produced, and which acts upon the piston, and not the pressure of the steam in the boiler, which constitutes the power of the engine. For the elasticity of the steam in the boiler may be very different from that acting upon the pistons, unless the power of the engine to produce steam, be sufficient to raise such a quantity as will supply to the cylinders as much steam as they require, equal in elasticity to that in the boiler; and likewise that the area of the passages between the boiler and the cylinders, are such as not to obstruct or diminish the elasticity of the steam in its passage to the latter. Consequently the power of these engines, are more properly defined, by the quantity of steam they are capable of producing; than by the pressure of the steam in the boiler, and the diameter of the cylinder, or the dimensions of the working parts.

In ordinary steam engines, the power may be strictly defined by the area of the cylinder, and the pressure of the steam acting upon it, or in the boiler; because, whatever that pressure may be fixed to be, the capability of raising or providing that quantity of steam, is easily accomplished by the requisite number of boilers.

In locomotive engines it is, however, different, having to travel upon roads which are constructed only to support a certain weight, we are confined to the dimensions, or rather to the weight, of the several parts constituting the engine; and, therefore, the capability of raising steam is limited, and the power of the engine is strictly confined to its capabilities of raising a given number of cylinders, full of steam, per minute. In this case the diameter of the cylinder does not govern the power of the engine; for, having only a certain quantity of steam produced per minute, if we increase the size of the cylinder, we must either have a less number of strokes per minute, or steam of inferior elasticity; and if we diminish it, we then get a greater degree of elasticity of steam, or pressure, per square inch, or a greater number of strokes, or cylinders full, per minute. The power of such engines is not therefore, as in ordinary engines, determined by the diameter of the cylinder; but, strictly, to the quantity of steam which can be raised, or water evaporated into steam, in a given time.

a.—Of the old Engines.

The old engines, we have seen, were not capable of evaporating more than about fifteen cubic feet of water per hour; which, applied to the cylinders, was not capable of producing a more powerful engine, than was capable of dragging forty tons, at the rate of six miles an hour, such engines weighing about six tons and a half. The result of the experiments on the Liverpool railway in 1831, was, that the Rocket engine, weighing little more than three tons and a quarter, evaporated 18·24 cubic feet of water per hour; the following Table shewing the relative evaporating powers of the different engines at that period.

b.—Of the Liverpool experimental Engines.

TABLE VI.

Name of Engines.	Area of fire grate in feet.	Area of radient surface in feet.	Area of communicative surface in feet.	Cubic feet of water evaporated per hour.	lbs. of coke required to evaporate a cubic foot of water.	Weight of engines in tons.
Rocket -	6	20	117·8	18·24	11·7	3¼
Sans Pareil -	10	15·7	74·6	24	28·8	4¼
Novelty -	1·8	9·5	33	—	—	—
Old engines -	7	11·5	29·75	15·92	18·34	6½

In examining these experiments, we find a very important effect in the economy of fuel, produced by the Rocket over the old engines, in the proportion of 11·7 to 18·34, supposing the heating powers of coke and coal be equal; the cause of this is very obvious, and is entirely attributed to the use of the number of tubes of small diameter, presenting such an area of surface to the water in the boiler.

With a less area of fire-grate, than the old engines, the surface exposed to the radient heat of the fire, is as 20 : 11·5, and the surface exposed to the communicative power of the heated air and flame, as 117·8 : 29·75, nearly four times as great. Nor is this the only difference, in the old engines the area of the tube (of twenty-two inches in diameter) for the passage of the flame and heated air to the chimney, was 380·13 inches, and of this large body of flame and air passing through the tube, only an extent of surface of 69·11 inches was exposed to the water in the boiler. In the Rocket engine the area of heated air and flame in twenty-five tubes, three inches each in diameter, was 176·7 inches, while the surface exposed was 235·6 inches.

It is not necessary, perhaps, to pursue the comparison further. The economy of fuel which must result from the exposure of so much greater surface to the water, cannot fail to ensure a more perfect abstraction of the heat; and thus not only save the fuel, but increase the evaporating powers of the engine, and prevent great part of the previous destruction of the chimney, by the intense heat of the wasted caloric.

The same remarks apply to the Sans Pareil of Mr. Hackworth, as to the old engine, though in a less degree. In the Rocket, the surface exposed to the radient heat of the fire, compared with the area of the fire-grate, is as 3⅓ : 1, while in the Sans Pareil it is only 1½ : 1, the same proportion as in the old engines. In the Rocket, the surface exposed to the heated air and flame, compared with the area of the fire-grate, is as 19⅘ : 1; while, in the Sans Pareil, the proportion is only 7½ : to 1.

The bulk of air passing through the tube of the Sans Pareil, at its exit into the chimney, is 176·7 square inches, the exposed surface being 47·12, or 3,8 : 1 nearly; while, as before stated, the bulk of air passing through the tubes of the Rocket is 176·7 inches, or precisely that of the Sans Pareil, while the surface exposed is 235·6 inches, or 1⅓ : 1. These will sufficiently account for the great difference in the evaporating powers of the two engines, and also in the economy of fuel; the Rocket requiring only 11·7 lbs. to convert a cubic foot of water into steam, while the Sans Pareil required 28·8 lbs.

Some explanation is perhaps necessary, why the Sans Pareil should, in this respect, be more extravagant than the old engines, while the extent of surface, compared with the area of fire-grate, is much greater, and therefore should exhibit a more economical result; and this explanation is the more necessary, as, though not appearing at first sight, it involves a principle of the greatest importance in the economy of those engines, and which, if not acted upon, would render the use of the tubes, however otherwise valuable, considerably less effective.

It will readily occur to any one, paying a little attention to the matter, that the system of tubes may be carried so far as to reduce the temperature of the flame and heated air nearly equal to that of the water in the boiler; in which case, when it reaches the chimney, it will be incapable, from its reduced temperature, of producing a sufficient draught of air through the fire-grate. This would prevent all the advantages being taken of the refracting powers, which would, otherwise, result from the use of these tubes. It is stated, in another part of this work, that on the introduction of those engines, it was necessary to resort to the application of the waste steam, thrown upwards by a blast pipe into the chimney, to create a sufficient current of air through the fire; which was afterwards laid aside, or only partially used, when only slow rates of speed were required.

Mr. Hackworth had, it appears, in his engine, resorted to the use of this in a more forcible manner than before used, throwing it up as a jet; and which, when the engine moved at a rapid rate, and the steam thereby almost constantly issued from the pipe, had a most powerful effect.

This, though effecting the object for which it was intended, being carried too far, partly in consequence of the rapid speed at which the engine was made to travel, was productive of another evil; viz. the increased destruction of fuel, and which, though operating fatally so far as regarded that particular experiment, was capable of easy remedy.

The consequence was, that when the engine began to travel at the rate of twelve or fifteen miles an hour, the draught was so great that it actually threw the coke out of the chimney with considerable force; producing a destruction of fuel enormously great, so much so, that the consumption was at least 692 lbs. per hour.

The area of fire-grate of the Sans Pareil was ten feet, supposing that the area of the fire-grate of the Rocket had been the same, the consumption of the latter engine, with its power of exhaustion, would only have been 361 lbs.; shewing that the force of draught was so much greater in the Sans Pareil, as to consume nearly twice the quantity of fuel in the same time.

This will satisfactorily account for the apparent anomaly in the consumption of fuel with this engine compared with that of the old engines, having a single tube; otherwise, though not likely to have come up to the Rocket in point of economy of fuel, we should have expected an effect considerably greater than in the old engines. The combustion of the fuel being so very rapid, and the abstracting surface so small, the heated air would pass off at a very high temperature, thus accounting for the loss of effect.

The knowledge of this fact, or rather availing ourselves of this power, for the purpose of creating a draught in the chimney, leads to an inquiry of great interest. By an extension in the use of these tubes of small diameter, there is little doubt of our being able, (supposing we can force the necessary quantity of air through them) to reduce the temperature of the heated air, before its exit into the chimney, nearly equal to the water in the boiler. This would be abstracting all the useful heat, and, probably, effecting all the economy of which the fuel is susceptible.

Perhaps it would not be advisable to carry it quite so far as this, for when the temperatures became nearly equal, the abstraction of heat would be so slow as to require a greater length of tube, than it would be convenient to employ. We may therefore suppose, that in all cases, the temperature of heated air which passes into the chimney, will be greater than that of the water in the boiler. This heat, however, will not be sufficient, in engines of this kind, to cause a sufficient quantity of air to pass through the fire for the purpose of combustion; and it then becomes a question, whether we should allow a portion of the heat to escape for that purpose, or, by contracting the exit of the escape of the steam from the cylinders into the chimney, to effect the same object.

Whether the last method is the most economical or not, though there is every reason to suppose it is, perhaps it is the only one with these engines, that is suitable for their action upon railways, especially for quick travelling. The performance of those engines depending entirely upon the quantity of steam they can raise in a given time, when travelling at the rate of fifteen or twenty miles an hour, or upwards, the production of steam is required to be very rapid indeed; the mode of producing a proper draught through the fire by throwing the steam into the chimney, after it passes through the cylinders, is, perhaps, therefore the best; as the quicker the engines travel, and when, consequently, the necessity for steam is the greatest, the then rapid and almost continuous exit of the steam into the chimney, increasing in proportion to the increased speed of the engine, produces, at the same time, a correspondingly greater quantity of steam.

In the "Rocket" engine, this mode of increasing the draught of the chimney was but partially used; the steam was made to pass, into the chimney, by two pipes, one from each cylinder, and the size of the aperture was not sufficiently small to cause the steam to pass into the chimney with adequate force; still, in that engine, we find it only required 11·7 lbs. to evaporate a cubic foot of water, 36 per cent. less than with the old engines. We shall afterwards find, that this has been considerably more reduced, in the engines recently made.

The "Novelty" engine was on a different principle from those previously considered, the necessary supply of air to the fire being produced by a bellows. In this case, a chimney becomes unnecessary, and, from the way in which the "Novelty" was constructed, the air was forced through the fire in a very condensed or compressed state. The area of fire-grate being little more than one third of that of the "Rocket," and the surface exposed to the radient action of the fire less than one half, the temperature to which the fire was raised must, of course, be considerably greater, to evaporate an equal quantity of water in the same time. The abstraction of heat would be probably more perfect in the "Novelty," for the tube, through which the flame and heated air passed, in its exit to the atmosphere, was thirty-six feet in length, in one tube; whereas, in the "Rocket," there was the same length, though subdivided into six tubes. It is, however, extremely questionable, whether one tube, thirty-six feet long, or six tubes, each six feet long, of the same sectional area, are more preferable; the latter would, of course, give a much greater exposure of surface. The area of exit of the heated air, into the atmosphere, of the "Rocket," was twenty-five times that of the "Novelty;" from which we may imagine the degree of compression necessary to force the same quantity of air through the fire; though we do not mean to say, that, to raise an equal quantity of steam, an equal quantity of air, in that highly compressed state, is necessary.

It was much to be regretted, that the Experiment with the "Novelty" could not be continued sufficiently long, to ascertain the power of raising steam, by this method; the inquiry was of the utmost importance. Theoretically considered, we are of opinion, that this mode of generating steam is the more economical, in point of fuel, than in engines, the combustion of the fire of which, is kept up by the rarefaction in the chimney; but there are practical objections to set against this, of which the destruction of fire-bars, and the power required to work the bellows are not the least. We say theoretical, because, suppose two generators, the area of the grate-bars, extent of radiant and communicative surface, are in both the same, except the area of exit pipe into the chimney, which, with the generator, worked by the bellows, is one half of that by expansion of the chimney; if the same quantity of air pass through the grate-bars of each, in the same time, that with the bellows will necessarily be in a more compressed state, to force the same quantity of heated air through the narrow exit; and this compressed state of the heated air will, of course, cause more of the caloric to be abstracted, than in the other case; if we suppose the temperature of the heated air reduced to the same, in both cases, in its exit from the pipe. The only question is, whether the disadvantage, in practice, consequent upon the operation of such a principle, does not counterbalance any advantage gained in the economy of fuel, and this we must leave to experience to determine.

The question between the two modes, however, assumes a new character, since the application of the steam from the cylinder, to create a current of air in the chimney; as, in that case, we can, by the use of a great number of smaller tubes, reduce the temperature so low, until, if advisable to do so, it is equal to that of the water in the boiler. And it then becomes a subject of inquiry, which of the two modes occasions a greater loss of power, in obtaining the necessary current of air; the working of the bellows, in the one case, or the loss of power, by the obstructed passage of the steam into the chimney, in the other.

It is perhaps necessary, after the above remarks, to explain, so far as we are able, the cause of the failure of the Novelty engine, at the Liverpool experiments, and to shew that it arose from no defect in the principle of the engine. By the sketches of this engine, it will be seen, that the flame, and heated air, after leaving the fire, passed through the winding pipe of the horizontal generator; the generator was only twelve inches in diameter, and there were three folds of the flue-tube within it, in diameter from four inches at one end, to three inches at the other; very little space was, therefore, left between the flue-tube and the tops of the generator. The temperature of the flame within this tube, when the engine was running at a quick rate, was necessarily very great, especially where it left the upright generator; the evolution of the heat would, therefore, be so rapid, that the passage of the steam out, prevented the water from flowing along the horizontal generator; and the consequence was, that the flue-tube got dry, and either collapsed, with the heat and pressure, or gave way at the joint. This, it will be seen, however, arose from no defect of principle, and was easily remedied.

The saving of fuel was not, however, the great desideratum, or the most important circumstances arising from these experiments, the power of these engines was very much increased, and their applicability extended to an almost inconceivable extent; for we find the Rocket engine, although only one half the weight of the old engines, evaporating one half more water, and was, consequently, fifty per cent. greater power; and this was effected, not by the comparative increased destruction, but by a saving in the use of the fuel. The Rocket engine, as before stated, was much too light to render its powers of raising steam applicable to their utmost extent; but the discovery, at once, opened a wide field, for the further improvement of these engines, which, in a short time, enabled their promoters to produce engines of much greater power, and capable of keeping up a rate of speed, infinitely beyond that of the old engines.

c.—*The Liverpool improved Engines.*

We shall now give some account of the improvements arising from these experiments, previous to which, however, it may be necessary to add one remark, upon the result of those Experiments. It will be seen, on referring to the Tables of the performances, that although the "Rocket" engine, which was the most economical of fuel, requiring only 11·7 lbs. of coke, for the evaporation of a cubic foot of water, while the old engines required 18·34 lbs., that the expense of fuel, per ton, of goods conveyed, per mile, was considerably greater with the "Rocket," than with the old engines. This results from the employment of such light engines, where the goods conveyed bears so great a proportion to the weight or powers of the engine; subsequently, these engines have been made more powerful, and their effective performance and economy has been correspondingly increased.

After these Experiments were concluded, the "Novelty" underwent considerable alterations, a better communication was made to carry off the steam, from the horizontal generator, to the steam reservoir, to prevent a recurrence of an accident, similar to that which happened during the trials; and a separate cylinder was applied for working the bellows, with some other alterations; when these were completed, an experiment was made by Mr. Vignoles, upon the same piece of road on which the premium experiments were made.

The following is stated to have been the performance :—

EXPERIMENT I.

28·5 tons, conveyed 30·813 miles = 878·07 tons.
7·5 tons, — 3·224 — = 24·28 —
17·5 tons, — 33·205 — = 58·11 —

960·46 tons conveyed one mile. The consumption of fuel was,

for getting up the steam, which occupied 32 minutes, 62 lbs.
consumed during the time of experiment 526 lbs.

Total consumption - - 588 lbs., which, exclusive of the weight of the engine, is equal to .613 lbs., per ton per mile, nearly; and including the weight of the engine (4 tons), is 0·55 lbs. per ton, per mile; or, supposing the weight of goods to constitute two thirds of the gross weight of the carriages, the cost of conveyance of goods, per ton, per mile, would be 0·918 lbs. of coke per ton, per mile.

The time occupied in performing the whole distance was 6·26 hours. The average rate between the posts, while at full speed, is said to have been 8·05 miles per hour; the rate, in the above time, would, therefore, be about six miles per hour. The bellows was blown by a separate cylinder, and was said to have been at work during the whole time, or 6·26 hours; the quantity of steam expended was, therefore, that which required 6·26 hours to regenerate; and, on this account, perhaps, the average rate for the whole time should be taken, or one half of that occupied at each end, which would give the average rate about seven miles per hour.

Mr. Stephenson also improved the working of the "Rocket" engine, and, by applying the steam more powerfully in the chimney, to increase the draught, was enabled to raise a much greater quantity of steam than before. The following is the result of an experiment made with this engine, in dragging heavy loads:—

EXPERIMENT II.

			H.	M.	S.
37¼ tons,	conveyed	9 miles in	0	41	18
41¾ tons,	—	3 —	0	13	15
46¼ tons,	—	3 —	0	13	8
41		15 miles in	1	7	41

equal to 13⅓ miles per hour, nearly, with an average load of 40 tons.

No account was kept of the quantity of fuel consumed, but, as there was a lock-up valve, the steam could not be raised higher than 50 lbs. per square inch.

The following Experiments were likewise made by Mr. Stephenson, upon the same piece of road.

EXPERIMENT III.

Phœnix engine, having ninety tubes, each two inches in diameter; area of grate-bars, six square feet; extent of radiant, twenty square feet; and of surfaces exposed to the heated air and flame, 138·8 square feet.

34½ tons, conveyed over a space of 43½ miles, with a consumption of 1422 lbs. of coke. The average speed being from ten to twelve miles per hour. This is equal to 1500 tons, conveyed one mile. Consumption of fuel, including the engine and tender (seven tons), 0·78 lbs. per ton, per mile; exclusive of the engine, 0.94 lbs. per ton, per mile; and taking the goods, equal to two thirds of the gross weight, 1·42 lbs. per ton, per mile.

EXPERIMENT IV.

"Arrow" engine, of similar construction to the last, with ninety-two tubes, each two inches in diameter, passing through the boiler; area of fire-grate, six square feet; extent of radiant surface, twenty square feet; and extent of communicative surface, 144·81 square feet.

28 tons, conveyed over a space of 36¼ miles, and 32¼ tons, conveyed six miles, equal to 1208 tons, conveyed one mile; consumption of coke, 1008 lbs. The average speed being twelve miles an hour. The consumption of fuel in this Experiment will, therefore, be, including the weight of the engine and tender, 0·67 lbs. per ton, per mile; or, exclusive of the engine and tender, 0·83 lbs. per ton, per mile; and for *useful* weight, or goods, 1·25 lbs. per ton, per mile.

The following Table will shew the result of the foregoing Experiments, on the consumption of fuel, and performance of these engines.

TABLE VII.

No.	Engines.	Load in tons.	Average rate of speed in miles per hour.	Consumption of coke in lbs. per ton per mile.	Cubic feet of water evaporated per hour.
1	Rocket - -	37½	14	2·41	29·6
2	Sans Pareil - -	9½	15	2·47	24
3	Novelty - -	23	8	0·918	—
4	Phœnix - -	34½	12	1·42	34·4
5	Arrow - - -	35½	12	1·25	44

We see, from the above table, in a very striking point of view, the effect of employing engines of light weights, and small power, in the conveyance of goods, when travelling at great rates of speed. Although the "Rocket" engine consumed only 11·7 lbs. of coke in the evaporation of each cubic foot of water, while the old engines required 18·34 lbs.; or, in point of fact, although the steam in the "Rocket" engine was more economically generated, in the proportion of 11 : 18; yet, by that engine, when travelling at a quick rate of speed, only taking three times its weight of carriages, the expense of fuel per ton per mile is greater than in old engines. The great improvement is, however, in the evaporating powers, which is shewn, by the above table, to be increased from 15·92 cubic feet an hour by the old engines, to forty-four cubic feet per hour by the Arrow engine.

Following up these improvements, shortly after the experiments were made, two engines of large dimensions were put upon the Liverpool and Manchester railroads, and the following account of their performance was published at the time. The Sampson engine, weighing eight tons, with the front and hind wheels of the same diameter, proceeded from Liverpool to Manchester with a gross load of 153 tons 11 cwt., and being assisted up the inclined plane by the Goliah engine, reached to the latter place about eleven o'clock; the consumption of coke in this journey was only one third of a pound per ton per mile gross, or about one half of a pound per ton per mile of goods.

Since that period these engines have been still further improved, and improvements are at present going on, which will no doubt increase their power much beyond what they are at present; it will, therefore, be difficult to assign any specific amount of power, or fixed performance of this kind of engine, except in terms of the power of raising steam. We shall, therefore, first of all, ascertain the evaporating powers of the best of the engines at present in use, and, from the observed performances of these engines, endeavour to determine upon the power of other engines, according to their powers of raising steam.

Art. 6.—*Evaporating Powers of Locomotive Engines.*

Before giving the experiments made on the relative evaporating powers of the different engines, however, it will be necessary to offer one or two explanations of the manner in which the steam is produced in those engines.

The evaporation of steam is accomplished by *two* distinct modes, the direct action of the fire upon that part of the boiler which encloses it, and which is called the *radiant heat;* and the action of the heated air, passing from the fire through the tubes, which is called the *communicative heat.* All the water, therefore, which surrounds the fire-box, enveloping the fire, and the water against that end of the boiler, is exposed to the *radiant heat* of the fire; while the water which surrounds the tubes, is only exposed to the *communicative heat,* given out from the heated air in its passage from the fire to the chimney.

In the old engines the fire was placed within a tube, which either passed directly through the boiler from the fire to the chimney, or which passed from the fire to nearly the opposite end of the boiler, returned, and passed out to the chimney, at the same end of the boiler as that in which the fire was placed. The experiments previously detailed shew the evaporating powers of several of the old engines, the greatest of which does not appear to exceed sixteen cubic feet of water an hour, with engines having the fire within the boiler, and weighing about six tons.

Hackworth's engine, which was of this description, at the Liverpool contest, evaporated about twenty-four cubic feet per hour; but this, as previously explained, was accomplished at the expense of an increase in the consumption of fuel above that of the old engines in the proportion of 28·8 to 18·34 lbs. of coke for every cubic foot of water evaporated. We cannot, therefore, take the evaporating powers of engines with the fire within the boiler, and where the heated air passes through a single tube, at more than sixteen cubic feet of water per hour.

a.—Evaporating Power of the Killingworth improved Engine.

In the description of the different kinds of engines we have given an account of one, used on the Killingworth railway, with the fire placed within the boiler, and in which the heated air passes, through several small tubes, from the fire into the chimney. In an experiment made with this engine, of the following dimensions,—boiler, nine feet two inches long, four feet in diameter; elliptical tube, within which the fire is placed, two feet four inches broad by two feet in height, and four feet eight inches long; area of fire-grate, 12·9 square feet; number of tubes, forty-three, each four feet and a half long, and two inches in diameter; area of radiant surface, 22·56 square feet; area of communicative surface, 101·5 square feet; volume of heated air, passing through the tubes, 135 square inches; load, sixty tons, exclusive of tender;— the velocity upon a level railroad was nine miles an hour, the quantity of water evaporated per hour, 279 gallons, or 47·8 cubic feet, and the quantity of coal consumed equal to 14·7 lbs. for each cubic foot of water evaporated. Another experiment, with a load of forty tons, conveyed, at the rate of nine miles an hour, gave an evaporation of 247 gallons, or forty cubic feet, of water per hour; the consumption of fuel being 13·2 lbs. for each cubic foot of water evaporated.

In both these experiments the steam was blowing off, at the safety valve, during the experiment.

We see, by these experiments, that a considerable saving of fuel is effected over the old engines, as well as a great increase of evaporating powers; with this description of engine we may, therefore, take the evaporating power at forty cubic feet of water per hour.

The Rocket engine, brought out at the Liverpool experiments, had, at first, its evaporating powers only equal to 18·24 cubic feet of water per hour; yet, by a slight improvement in the blast pipe, by which the intensity of the fire was increased, its evaporating power was increased to nearly thirty cubic feet per hour. The Arrow engine shewed an evaporating power of 275 gallons, or forty-four cubic feet, of water per hour; and an experiment with the Planet engine gave a power of evaporation of 215 gallons, or thirty-four cubic feet, of water per hour.

The following Table will shew the relative evaporating powers of these engines, and the dimensions of the different parts of their heating surfaces.

TABLE VIII.

Table of the Powers of Evaporation of different Engines.

Names of engines.	Area of fire grate.	Area of radiant surface.	Area of communicative surface.	Area of volume of heated air through tubes.	Load in tons, convoy not included.	Velocity in miles an hour.	Cubic feet of water evaporated per hour.
	sqr. ft.	sqr. ft.	sqr. ft.	sqr. in.			
Rocket -	6	20	117·8	176·7	40	13	30
Arrow -	6	20	282·7	282	30	12	44
Planet -	7½	29	225	144·8	30	15	34
Old engines	7	11·5	29·75	432	48·75	6	16
Killingworth improved engine.	- -	- -	- -	- -	60	9	40

On examining this table, it will be seen, that a very great disparity exists in the proportions of the different heating surfaces in those engines; in the improved engines, the Rocket and Arrow, there is the same area of fire-grate, while the area of exit of heated air through the tubes is as 176 : 282. Supposing the propulsion of steam into the chimney to produce the same power of draught in both cases, the quantity of air that must pass through the fire will be much greater in the latter case than the former; hence the fire will be raised to a greater intensity of heat, and, consequently, a greater evaporation of water must follow.

In the Planet engine, the area of fire-grate is larger than in either the Rocket or Arrow, but the area of exit through the tubes for the heated air is less than in both the other engines; the evaporating power, as compared with the Arrow, is, therefore much diminished; but it is greater than the Rocket, occasioned by the much greater area of both radiant and communicative surface exposed to the water.

It appears, therefore, that no beneficial result follows from increasing the area of fire-grate, or even the area of radiant surface, unless the area of exit for the heated air is likewise increased; and it also appears to be necessary, at the same time, in order to economize the fuel, that the communicative surface should bear a proportionate ratio to the area of radiant surface, or of the volume of heated area passing through the tubes.

b.—Relative Powers of Evaporation of radiant and communicative Caloric.

Mr. Robert Stephenson has favoured us with a very interesting experiment, on the relative powers of evaporation of that part of the boiler subjected to radiant, and that part subjected to the communicative heat.

A box was used, similar in form to the fire-box of the "Rocket," except that it was open at the top; from this box a horizontal vessel or generator was attached, five feet and a half long, by sixteen inches wide, which was traversed by nine tubes, each three inches in diameter, through which the heated air passed, in a similar way to that of the "Rocket" boiler. The fire-box, exposed to the action of the fire, six square feet, and the tubes, 24½ square feet. The fire-box and generator being supplied with water, and the fire lighted, both vessels arrived at the boiling point in the same time, viz. thirty-two minutes. The evaporation may then be said to have commenced. In one hour and ten minutes from the time the fire was lighted, the fire-box had evaporated six gallons, and the tubular vessel eight gallons, of water. The time of evaporating the above quantities was, therefore, thirty-eight minutes; this would make the fire-box evaporate ten gallons, and the tubular vessel 12·75 gallons, per hour; hence, one foot of boiler, exposed to the immediate action of the radiant heat of the fire, in this experiment, evaporated $1\frac{2}{3}$ gallons per hour; and one foot, exposed to the heated air, in passing through the tubes, evaporated half a gallon per hour; this gives the comparative effects of the fire-box and tubes, or of radiant to communicative heat, as 3 : 1.

These results were obtained from a fire of considerable less intensity of heat, than that of the engines, as we find the quantity of water evaporated in the latter more than twice that of an equal area of surface in the experiment. We may suppose, therefore, that, with a more intense heat, the comparative evaporation of the fire-box with the tubes will be increased rather than diminished. Supposing it remains the same, we find, from the previous table, that the evaporating powers of the "Arrow" and "Planet" will be, in respect to the surfaces exposed, nearly equal; for $20 \times 1\frac{2}{3} + 282 \times \frac{1}{2} = 164$; and $29 \times 1\frac{2}{3} + 225 \times \frac{1}{2} = 160$. But though the evaporating surface is nearly the same in each, the comparative volume of air passing through the tubes, is as 144 to 282; therefore we find that an equal volume of heated air is exposed to double the surface of evaporation in the "Planet," as in the "Arrow" engine; or if we suppose the same quantity of heated air to pass up the chimney of both engines in the same time, then the density of the heated air in the tubes of the "Planet" engine will be equal to twice that of the "Arrow," and equal to the density in the chimney; which must have a considerable effect in the economy of fuel in the "Planet" engine.

c.—Evaporating Powers of the modern Engines.

We shall now give the result of the experiments, made by Mr. Pambour on the Liverpool railway, as regards the evaporating powers of some of the engines on that railway.

TABLE IX.

Experiments on the evaporating Power of the Engines on the Liverpool and Manchester Railway.

Number of the experiment.	Date.	Name of the engine.	Load of the engine, tender included	Water evaporated.		Total duration of the journey.	Delays on the road included in that time.	Average state of the spring balance.	Rising of the valve sufficient to give issue to all the steam generated in the boiler.	Average effective pressure, during the experiment, in lbs. per square inch.	Temperature of the water in the tender at starting.	Velocity of the engine in miles per hour.	Evaporation per hour in each experiment.	Heating surface.	
				In lbs.	In cubic feet.									Exposed to the action of radiating caloric.	Exposed to the action of communicative caloric.
	1834.		tons.			h. m.	min.						cubic ft.	sqr. ft.	sqr. ft.
1	July 22	Vulcan	39·07	4646	74·34	1 17	3	31–32·5	5	54·5	Just luke warm.	22·99	57·92	34·45	307·38
2	July 23	Atlas -	195·50	8260	132·16	3 17	15	50–50·7	4	53·7	Cold -	8·99	40·25	57·06	217·88
3	Aug. 4	Atlas -	127·64	5937	94·99	1 58	—	50–50·1	4	53	Cold -	15·00	48·30	—	—
4	July 31	Atlas -	40·15	5524	88·38	1 54	—	24–25·5	4	30	Cold -	15·53	46·52	—	—
5	July 24	Fury -	56·16	4878	78·05	1 30	—	31·2–32·6	5	57	Cold -	19·67	52·03	32·87	307·38
6	July 24	Fury -	48·80	5446	87·14	1 35	—	31·2–32·7	5	57	Cold -	18·63	55·03	—	—
7	July 26	Firefly	41·40	6143	98·29	1 40	5	14·5–14·5	3	44	Almost cold.	17·70	58·97	43·91	362·60
8	July 26	Firefly	41·40	6040	96·64	1 23	5	16·6–17·3	3	49	Luke warm.	21·33	69·86	—	—
9	Aug. 1	Vesta -	33·15	4130	66·08	1 5	—	20–21·3	3·5	51	Very hot	27·23	61·00	46·00	256·08
10	Aug. 15	Leeds -	88·34	5989	95·82	1 35	—	31–32·2	5	54	Just luke warm.	18·63	60·52	34·57	307·38
11	Aug. 15	Leeds -	37·51	5317	85·07	1 20½	3	26·5–28·5	5	49	Very hot	21·99	63·41	—	—
											Means -	18·86	55·82	43·12	288·35

The result of these experiments is, an average evaporating power of 55·82 cubic feet of water per hour, at an average rate of 18·88 miles per hour. Comparing this result with that of the Arrow engine, and taking the effect of the radiating and communicating heat as 3 : 1, we have $43{\cdot}12+\frac{288{\cdot}35}{3}=139$; the evaporating power of the average of the engines per Table IV.; and $20+\frac{282{\cdot}7}{3}=114$; then, as 114 : 139 :: 44 : 53·6 cubic feet per hour, the evaporating power, as compared with the experiment of the Arrow engine.

In the latter experiment, the velocity was only twelve miles an hour, whereas, in Table IX., the average velocity was 18·88 miles; it will, therefore, be necessary, to inquire what effect the difference of velocity can have in the evaporating powers of these engines.

d.—Evaporating Powers at different Rates of Speed.

The draught of air through the fire-grate, and combustion of the fuel is produced, not from the rarefaction of the air in the chimney, as in the common engines, but by the emission of steam into the chimney; and this will depend upon the rapidity of discharge, or the quantity thrown into the chimney in a given time. When the engine travels at double rate of speed, twice the number of cylinders full will be thrown into the chimney per hour; and, therefore, the rapidity of the combustion of the fuel, and, consequently, the evaporation of the steam, must be correspondingly increased. But there is a limit to this, we know, that when an engine travels at double the rate of speed, the load which it is capable of conveying is considerably less, and, consequently, the elasticity of the steam in the cylinders is reduced; its effect, therefore, in passing into the chimney, will be diminished, and, consequently, double the number of cylinders full of steam, when travelling at double the rate of speed, cannot increase the power of evaporation in that ratio.

On examining the table of Mr. Pambour, the greatest variation of the rate of travelling is in Experiments 2 and 3, with the Atlas engine; the difference of the speed between these two experiments, is as 9 to 15 miles an hour respectively, or an increase of about 40 per cent.; the increase of evaporation is about 20 per cent., or from 40, to 48 cubic feet per hour; therefore, in this case, although the number of cylinders full of steam thrown into the chimney has been increased $\frac{4}{10}$ths, the evaporation has only been increased $\frac{2}{10}$ths, therefore the evaporation has only been increased equal to one half of the extra number of cylinders full of steam thrown into the chimney. The load of the engine in the two experiments, was nearly as the ratio of the rate of travelling; for
Tons. lbs. lbs. lbs.
$195{\cdot}5 \times 8\frac{1}{2} + 527 = 2081$, the resistance of engine and carriages in Experiment 2, and $127{\cdot}64 \times 8\frac{1}{2} + 616 = 1637$lbs., the resistance in Experiment 3, which is nearly 15 to 9, the ratio of the velocity; therefore the density of the steam thrown into the chimney in the two experiments, would be nearly in that ratio. It follows from this experiment, therefore, that the evaporation is increased in the proportion of one half of the number of cylinders full of steam thrown into the chimney, the density being as the velocity.

This conclusion only results, however, from one set of experiments, and as the subject of determining the relative evaporation at different rates of speed, is of great importance, in the investigations of the power of these engines; we shall, in our calculations of the useful result produced in practice, suppose the power of evaporation constantly the same at all rates of speed, until we have an opportunity of more conclusively determining the relative evaporation at different rates of speed.

In adopting this mode of calculation at a medium velocity, we keep below the real powers of these engines; as when the engines travel at a greater rate of speed than the average rate adopted, the evaporating power will be greater than that given in the table. We are the more disposed to come to this conclusion, inasmuch as, in our calculations of the powers of these engines, we have not taken into account the increased resistance of the steam passing from the cylinders, arising from the contraction of the discharging pipe into the chimney, to produce the necessary draught of air through the fire at different rates of velocity. These two will, in some degree, balance each other, the resistance to the free discharge of the steam into the chimney will increase, as the velocity of discharge is increased; while, on the other hand, the degree of evaporation will, likewise, at the same time, be correspondingly increased.

We have made some experiments, to ascertain the resistance arising from the contraction of the blast-pipe at different rates of velocity, but these have not been sufficiently varied to produce results on which we could found calculations satisfactory to ourselves; until, therefore, experiments are made to determine both these effects accurately, at all the different rates of speed requisite to form a correct conclusion, we shall, as before stated, assume the evaporation of the steam by the locomotive engines to be constant, allowing the effect of the increase, at the higher rates of speed, to be counteracted by the increased obstruction of the steam, in its passage through the blast-pipe into the chimney.

The experiment of Mr. Robert Stephenson shews, that one square foot of surface, exposed to the heated air, produces an effect, only equal to one third of the same area of surface exposed to the radiant heat; the average area of surface exposed to radiant heat, in Table IX. is 43·12, and of communicative heat 288·35; the latter will, therefore, be equivalent to $\frac{288 \cdot 35}{3} = 96 \cdot 12$ square feet of radiant surface, which, added to 43·12, gives 139·24 square feet for an evaporation of 55·82 cubic feet of water per hour, or nearly equal to $\frac{4}{10}$ths of a cubic foot of water, for each square foot of surface.

M. Pambour calculates that, in applying this to practice, we should not take the effective evaporation, at more than $\frac{3}{10}$ths of a cubic foot of water, for each square foot of surface; to allow for the waste of steam through the safety valves, the loss by part of the water being thrown out into the cylinders mixed with the steam, and from other causes. By adopting this as a standard for the evaporating power of the engines, we are of opinion adequate allowance is made for the loss by all the causes above named; and, likewise, for the loss of power, by the transmission of the steam through the blast-pipe into the chimney.

Art. 7.—*Consumption of Fuel.*

We shall now endeavour to ascertain, the quantity of fuel, consumed by those engines; both as regards the absolute quantity, and also the comparative quantity with different loads.

a.—Consumption of the old Engines.

An inspection of the result of the experiments, given in Art. 3, § 4, Chap. IX., will shew this in the old engines; but as it will be found that the quantity varies much, it may be necessary to enter a little more into detail respecting the cause of such variation; and this explanation will also be the means of still further elucidating the principles of construction of these engines, for diminishing the quantity of fuel.

These experiments were made with two engines, which we have termed No. I. and No. II., the first affording the experiments of Table II., and the latter of Table III., Art. 3, § 4, Chap. IX. The construction of both engines was precisely the same, except in the size of the tube which passes through the boiler. No part of the boiler itself, as will be seen on examination of the drawing, Nos. 5 and 6, page 295, is exposed to the direct action of the ignited fuel. A tube is put through the boiler, within which, upon grate-bars, the fuel is placed; and in this manner the heat is communicated to the water in the boiler. The extent of surface of the water exposed to the direct action of the fire will then be equal to the semi-periphery of this tube. In the No. I. engine, this tube was 20 inches diameter; and in the No. II. engine, 22 inches diameter; and, except a corresponding difference in the size of the chimney, the two engines were in every other respect the same.

Comparing Experiments I. and IV., where the same load was taken, we find the quantity of fuel consumed by the former, in travelling 63,280 yards, to be 2,534 lbs.; and in the latter, for travelling on the same ground, 45,200 yards, equal to 1487 lbs. Then, as 63,280 : 45,200 :: 1487 : 2101 lbs. Therefore the relative consumption of fuel by the two engines, in producing the same effect, is as 2534 : 2101, which shews the saving of fuel by increasing the surface of the water exposed to the action of the fire, in the ratio of 32 : 40.

Knowing this, it need scarcely be added, that in every case, the consumption of fuel in these engines will, in some measure, depend upon the extent of surface exposed to the action of the fire and heated air.

This, no doubt, arises from the intensity of the heat necessary, in tubes where only a small area of fire-grate can be obtained, to keep up a constant supply of steam; and which, by producing a more rapid combustion of the fuel, throws it off imperfectly consumed. In wider tubes, the intensity is diminished, and the fuel not only undergoes a more perfect combustion, but, presenting a greater area of surface to the water in the boiler, more heat is abstracted, and the fuel thus produces a greater effect.

The extension of this principle has already led, and will no doubt still further lead, to a diminution in the consumption of the fuel in those engines; it would appear, therefore, scarcely proper, at present, to fix the basis of actual consumption, for the performance of a definite quantity of work, as deduced from these experiments. As, however, the ratio of saving can at any time be applied to any particular quantity fixed upon, we may, therefore, take the result of the consumption as deduced by the foregoing experiments, as useful where this description of engine is used, but shall, first of all, ascertain the relative quantity with different loads.

Comparing Experiments II. and III., which were performed by the same engine, and under precisely the same circumstances, except the load, which, in the former, was with nine carriages, weighing 731¼ cwt., and in the latter, with twelve carriages, weighing 975 cwt.;

the consumption was, with nine carriages, in travelling 85,880 yards, 2534 lbs.; and, with twelve carriages, 1546 lbs. in travelling 40,680 yards. Then, as 85,880 : 40,680 :: 1546 : 3263 lbs., which would have been consumed in conveying twelve carriages 85,880 yards; therefore the relative consumption of fuel, with nine and twelve carriages, is as 2534 : 3263.

We have previously ascertained the friction of the engine to be 426 lbs., and the friction of each of the carriages to be equal to 39·35 lbs. each.

Then $426 + \overline{39{\cdot}35 \times 9} = 780$ lbs., the resistance of the nine carriages and engine. And $426 + \overline{39{\cdot}35 \times 12} =$ 898 lbs., the same with twelve carriages, which makes the respective resistances as 780 : 898.

Now, as 2534 : 3263 :: 780 : 1000 lbs., so that the consumption of fuel is greater, in the ratio of 1000 : 898, than the direct increase of resistance by the friction of the additional load.

It was, however, before stated that the transmission of the increase of resistance, through all the working parts of the engine, would create an addititional degree of friction; and this will, perhaps, partly account for the consumption of fuel, increasing in a greater ratio than the simple resistance directly, though the different states of the rails, will frequently have a greater effect than this upon the consumption of fuel.

Comparing these with the experiments on No. II. engine, we have, making the distance the same in each experiment, viz.,

As 20,020 : 45,200 :: 587 : 1325 lbs. consumed by Experiment V., in traversing the same distance as Experiment IV. The two were performed with wheels of different diameters, therefore, as 3 : 4 :: 1487 : 115 lbs., the weight of fuel which would have been consumed by Experiment IV. if four-feet wheels had been used. The relative quantities, with nine and twelve carriages, will, therefore, be as 1115 : 1325 ; the relative resistance, as above stated, was as 780 : 898 ; therefore as 1115 : 1325 :: 780 : 926, the resistance which the quantity of fuel consumed in the experiment would have overcome ; the direct resistance is 898 ; so that the consumption of fuel, by experiment, is only greater in the ratio of 926 : 898 than the direct amount of friction of the engine and load.

This ratio being so very nearly equal, and as the variation of resistance, by the different states of the rails, will frequently amount to more than this ; we may, in practice, take the Experiment V. as the datum for the absolute quantity of fuel, and assume the relative consumption of different loads, dragged at the same rate of speed, as proportionate to the respective resistance presented by the friction of the load, added to the friction of the engine.

By taking this experiment as a datum, we proceed on sure grounds, as being nearly the maximum load ; for, if any diminution of friction takes place in the engine, when employed in dragging a lighter load, the consumption of fuel will be more than proportionably reduced ; and, though against the effect of the engine, will be on the safe side in practice.

The consumption of coals in Experiment V. was 587 lbs. for conveying 975 cwt. of goods, exclusive of the weight of the engine and convoy-carriage, 20,020 yards upon a horizontal plane.

Reducing this to the consumption per mile, we have, as 20,020 : 1760::587 : 51·55 lbs., the fuel consumed per mile in conveying 975 cwt., the resistance of 975 cwt., as before stated, is 472 lbs., and the friction of the engine, 426 lbs; therefore, the quantity of coals consumed in overcoming a resistance of $472+426=898$ lbs. for a mile, is 51·55 lbs.

Let P = the friction of the engine $=426$ lbs., R = the friction of any number of carriages, which may be taken as the 263d part of their weight.

Then, as 898 lbs., the friction of the carriages conveyed one mile, is to 51·55 lbs., the coals consumed in conveying those goods a mile, as per experiment; so is $P+R$ the resistance of any other number of carriages and engine, to $\frac{51{\cdot}55 \times \overline{R+P}}{898}$ the quantity of coals required to convey any given weight of goods, whose friction or resistance is equal to R, the distance of one mile upon a level edge railroad.

The formula $\frac{51{\cdot}55 \times \overline{R+P}}{898}$ will then represent the consumption of coals with any load R, by engines similar to those with a single tube; and if by a further diminution in the consumption of the fuel, the quantity per mile be reduced below 51·55, then the diminished quantity can be substituted in its stead, and the formula will still represent the quantity with different loads, travelling at the rate of six miles an hour.

On examining Experiments II. and III., we find one engine take 36 tons of goods, at the rate of five miles an hour; and 48 tons, at the rate of 4¾ miles per hour. This was effected by an engine, the area of the fireplace of which was 6⅓ square feet; the surface exposed to the radiant heat of the fire, being 10½ square feet, and to the flame and heated air, 21 square feet.

In Experiment V., the area of the fire-place of which was seven square feet, the surface exposed to the radiant heat, 11½ square feet; and to the communicative heat of the flame, on its passage to the chimney, 29¾ square feet; the evaporating surfaces being above one third more, we hence find the effect correspondingly increased. The performance of the latter engine was 48¾ tons, conveyed at the rate of 6·6 miles per hour, and, as the relative resistance, in the most favourable, and most unfavourable weather, has been shewn to be as 4 : 3; in the first edition of this work, the performance was called in practice forty tons, moved at the rate of six miles per hour.

Up to the period to which this relates (1825), we may state this as about the maximum performance of engines of that weight, working upon four wheels. Heavier engines had, in one or two instances, been used, where the evaporating surface was greater; and, in the case of the Wylam engine, a drawing of which was given in the first edition, the fire tube, instead of passing right through the boiler, was made to reach from one end nearly to the other, and then to return and pass out at the other end, at which the fire-place was. By this mode, a greater evaporating surface was obtained, but the area of the fire-place, from the return tube having to pass out at the same end of the boiler, was consequently diminished; and, therefore, though a partial economy in the consumption of fuel was effected, yet the initial performance of the engine was not increased.

We may, therefore, state, that, at this period, forty tons, conveyed at the rate of six miles an hour, was the maximum performance of those kind of engines; which is little more than the effective performance of seven horses, exclusive of the motive power required to propel the engine.

From the construction of the engine in the foregoing experiments, the consumption of fuel was proportionably great. Mr. Watt, who paid particular attention to the economy of fuel, states, that in the most judicious furnaces, it requires eight feet of surface to be exposed to the action of the fire and flame to boil off one cubic foot of water in an hour, and that a bushel of coals, *i. e.* 84 lbs., would evaporate ten cubic feet of water.

The following table will shew the consumption of fuel, in the experiment above alluded to, with the surface of the water exposed to the action of the heated air and flame.

TABLE I.

Experiment.	Cubic feet of water evaporated per hour.	Surface of tube in square feet.	lbs. of coal required to evaporate a cubic foot of water.	Consumption of fuel per ton per mile.
1	14·86	31·41	17·75	2·9
2	14·46	31·41	18·54	2·13
3	15·07	31·41	21·37	2·05
4	12·01	41·28	18·96	2·34
5	15·92	41·28	18·34	1·60
Mr. Watt -	15·00	120	8·4	—

The average of the first three experiments gives only 2·12, and the two last 2·95 square feet of surface for each cubic foot of water evaporated; while the area, according to Mr. Watt, should be eight square feet; and, accordingly, we find, that the general average gives nearly 19 lbs. of coal to convert a cubic foot of water into steam; whereas Mr. Watt found the quantity required, only 8·4 lbs.

We see, therefore, in a very striking manner, the cause of the great waste of fuel in locomotive engines of the above construction, arising from the want of proper area of water exposed to the fire and heated air; the greatest part of the heat, from the combustion of the fuel, passing up the chimney, without being abstracted by the water.

The above experiments give, respectively, the consumption of fuel, varying from 2·9 to 1·60 lbs. per ton per mile of the goods conveyed, exclusively of the weight of the engine.

The average of several years' consumption of the engines upon the Killingworth railway, gives 2·12 lbs. per ton per mile; and the consumption of the Darlington engines, as stated by Mr. Story, is 2·16 lbs. per ton per mile; and an experiment, detailed by Messrs. Stephenson and Locke*, with an engine upon the Bolton and Leigh railway, gave, in twelve hours, 158 waggons of marl and sand, each weighing four tons, exclusive of carriages, conveyed over a distance of $1\frac{4}{10}$ miles, equal to 488 tons, over one mile, with a consumption of 15 cwt. of coals by the engine, and 1 cwt. in heating water, which is 2·03 lbs. per ton per mile.

The three last adduced experiments give 2·10 lbs. per ton per mile, but as, in these cases, the engine had to drag the empty carriages back without any useful weight; we may, supposing the engine loaded equally in both directions, and upon a level railway, deduct one fourth, making the consumption 1·60 lbs. per ton per mile.

In the second edition of this work, we made the consumption 51·55 lbs. for conveying 48·75 tons, including carriages; or 31·8 tons of goods one mile, equal to 1·62 lbs. per ton per mile. We have before seen, that the relative consumption of fuel, with different loads, is as the respective distances of the friction of engine and load; the friction of 48·75 tons was 472 lbs., and the engine, 426 lbs.

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* On the comparative merits of locomotive and fixed engines, p. 18.

Let P = the friction of the engine = 426 lbs., R = the friction of the load.

Then $\frac{51{\cdot}55 \times R + P}{898}$ = the quantity of coals required to convey any given weight of goods, whose friction or resistance is equal to R, along a level railroad, the distance of one mile, when loaded in both directions; or $\frac{66{\cdot}78 \times R + P,}{898}$ when the goods are conveyed in one direction only, and the engine has to return with the empty carriages, the average rate of speed being six miles per hour. But, as considerable waste generally occurs in practice, perhaps, in most cases, it may be advisable to calculate upon the last-named quantity. This, therefore, may be taken as the consumption of fuel with locomotive engines of the best construction, with a single tube. An experiment with an engine of a double tube, gives the consumption 1·60 lbs. per ton per mile.

We have before stated, that, in 1825, the power of these engines was rateable at about forty tons, conveyed six miles an hour; at this period they were not, therefore, adapted for quick rates of speed. Their power being in strict proportion to the area of evaporating surface, it follows that, to obtain a greater power of engine, we must either increase the area of evaporating surface, or produce the same effect by the increase in the intensity of the fire. In the old form of engines, the single or double tube formed almost insuperable obstacles to their improvement; for, if we increased the size of the tube, it increased the weight of the engine; and an increase in the intensity of the fire, could only be effected by a waste of fuel, already disproportionably great, by a want of a proper area of heating surface. Accordingly, we find, that so long as the formation of the steam was effected by boilers with a single or double tube, the improvement of those engines, and their adaptation to quick rates of travelling, made little progress. Upon the Darlington railway, an engine with a much greater evaporating surface of boiler was applied; but the weight was proportionably increased, so as to render the employment of six wheels necessary.

b.—Consumption of Fuel of the improved Engines.

We now come to the consumption of fuel by the improved engines. In the account of the contest for the premium, for the best locomotive engine at Liverpool, we gave the result of the trials of the different engines. These trials were accurate experiments, as to the consumption of coke, with the different loads attached to the engines. In the old engines, which were exclusively employed on private railways, the description of fuel used is coal. On public railways it is made imperative by the legislature, that "the engines should emit no smoke;" and, in some acts, that coke should be exclusively used. In the following inquiries, as to the consumption of fuel, we shall confine ourselves to experiments with coke.

The result of the experiments at the Liverpool contest has been given in §§ 8, 9, 10, Chap. VI., which shews the quantity of coke required to convert a cubic foot of water into steam, in the different engines. We there see, that, with the Rocket engine, 11·7 lbs. of coke converted a cubic foot of water into steam, while, by the old engines, it required 18·34 lbs. The area of the fire-grate of the two engines was nearly the same, being six square feet in the Rocket, and seven square feet in the old engines. Supposing the intensity of the fire to be the same in both cases, the relative quantity of fuel consumed per hour should be in the proportion of 6 : 7;

but we find that the relative quantity of water evaporated per hour, is 18·24 : 15·92; so that, besides effecting a saving in the consumption of fuel, a greater evaporating power is also attained. The cause of this is apparent; the capacity of the fire-place is much increased, by the adoption of a vessel separate from the boiler, in which the fire is placed; and, therefore, although the area of fire-grate is in the proportion of 6 : 7, the capacity of the fire-place, or the surface exposed to the direct radiation of the heat of the fire, is as 20 : 11·7. This, therefore, by exposing a greater surface of the water to the direct action of the fire, increases the evaporating powers of the engine, and, at the same time, effects a greater abstraction of the heat. But this is not the sole, or indeed the most important part of the improvement of these engines. In the old engines, the heated air either proceeded direct from the fire-place to the chimney, through a single tube of large dimensions, or by the same tube returned twice the length of the boiler; whereas, in the improved engines, the heated air passes through a large number of tubes of small diameter. In the old engines, the tube was 22 inches diameter, and, consequently, the area 380·13 inches. This large body of heated air had only to pass about six feet along this tube, and the surface exposed to the water of the boiler was only 69·11 square inches; a very great portion, therefore, of the heated air never comes in contact with the outer surface of the tube, and, consequently, passes into the chimney without communicating any part of its heat to the water, and this was seen by the great destruction of the lower end of the chimney, which was constantly red hot. In the Rocket engine, the tubes were three inches diameter, and twenty-five in number; consequently, the area of heated air was 176·7 inches, and the surface exposed to the water, 235·6 square inches. This, therefore, satisfactorily accounts for the great difference, not only in the economy of fuel, but also in the increased evaporating powers of the improved engines.

By thus placing the fuel in a separate vessel from the boiler, and by passing the heated air through tubes of small diameter, we obtain a very great evaporating power, without increasing the weight of the engine very materially. The Rocket engine, though its evaporating powers were increased in the proportion of 18 : 15, weighed only 4¼ tons, while the old engines weighed about six tons. Soon after these improvements were made, we find larger engines constructed, with increased evaporating powers, with larger areas of fire-grate, and with tubes of still smaller dimensions, and more numerous. In one of the engines on the Liverpool railroad, the area of fire grate is 75 square feet; the area of the surface exposed to the radiant heat of the fire being 40·2 square feet; the number of tubes being 140, and the surface exposed to the action of the heated air equal to 416·9 square feet; the bulk of heated air passing through the tubes being only 290·2 inches.

When these relative dimensions of the old and improved engines are considered, it will at once be seen, that a very great increase of their evaporating powers must be effected, and a very great diminution in the quantity of fuel, required to evaporate the same quantity of water.

c.—Table of the Consumption of Fuel of the modern Engines.

We have already shewn the consumption of fuel in some of the improved engines, from experiments made soon after their first introduction; but the most extensive set of experiments has been made by M. Pambour, and given in his work on the locomotive engine, we shall, therefore, give the result of these experiments.

Names of engines.	Number and description of carriages.	Weight of load in tons.	Time in traversing 29½ miles.	Stops during the journey.	Velocity in miles per hour.	Pressure of steam in boiler.	Quantity of coke consumed during the journey.	Coke consumed per ton per mile.	Observations.		
									Assisted or not assisted up plane.	Temperature of water in convoy at commencement.	State of the weather.
			hr. min.	*min.*		*lbs.*	*lbs.*	*lbs.*			
Atlas, Liv. to Man. -	40 loaded waggons	193·	3 2	15	9·7	53·7	1596	·28	Assisted -	Cold -	Calm.
Ditto - -	25 ditto - -	123·13	1 48	12	16·4	53·	1102	·30	Assisted -	Lukewarm	
Ditto -	25 ditto -	122·64	1 58	- -	15·	53·	1224	·34	Assisted -	Cold -	Calm.
									Connecting rods of machine too tight keyed.		
Ditto - -	25 ditto - -	118·90	1 31	19	19·4	61·5	1118	·32	Assisted -	Cold -	Calm.
Ditto - -	25 ditto -	117·61	1 41	5	17·5	53·	1136	·33	Assisted -	Lukewarm	
									Piston not tight.		
Ditto - -	25 ditto - -	113·90	1 50	5	16·	53·	1104	·33	Assisted -	Rather warm	
Ditto - -	20 ditto -	94·66	1 25	23	20·4	53·5	1081	·39	Assisted -	Lukewarm	Calm.
Ditto - -	15 ditto - -	65·40	1 27	3	20·2	54·	1012	·52	Assisted -	Very warm	Fine and calm.
									Axle of one waggon much heated.		
Man. to Liv. -	8 loaded and 4 emp.	35·15	1 54	- -	15·5	30·	881	·73	Not assisted	—	—
Ditto -	3 do., 8 do., and 2 do.	25·30	1 26	3	20·6	54·5	720	·82	Not assisted	Very warm	Fine and calm.
Vesta, Liv. to Man. -	20 loaded waggons	92·75	1 42	5	17·3	53·	916	·33	Assisted -	Warm -	Calm.
Man. to Liv. -	5 do. and 5 empty	28·15	1 5½	- -	27·	51·	774	·80	Not assisted	Very warm	Fine weather, wind moderate, and favor of moⁿ.
									Machine recently repaired.		
Vulcan, Liv. to Man.	20 loaded waggons	97·70	1 37	3	18·2	54·5	1071	·37	Assisted -	Lukewarm	Calm.
Man. to Liv.	9 first class carriages	34·07	1 17	3	23·3	54·5	664	·56	Not assisted	Cold -	Fine weather, wind aga^t moⁿ.
Leeds, Liv. to Man. -	20 loaded waggons	83·34	1 35	- -	18·6	54·	897	·36	Assisted -	Rather warm	Fine weather, and calm.
Man. to Liv. -	8 ditto - -	32·01	1 17½	3	22·9	49·	690	·62	Not assisted	Very warm	ditto.
Fury, Liv. to Man. -	10 loaded waggons	51·16	1 30	- -	19·6	60·	806	·46	Not assisted	Cold -	ditto.
Man. to Liv. -	10 ditto - -	43·80	1 35	- -	18·6	59·	746	·49	Not assisted	Cold -	Fine, wind strong occasionally.
Jupiter, Liv. to Man.	8 first class carriages	33·09	1 12	3	23·2	53·	742	·76	Assisted -	Almost cold	Calm and fine.
Man. to Liv.	7 ditto - -	30·09	1 12	4	23·2	53·	836	·94	Assisted -	- - -	Fine, moderate wind, contrary.
Firefly, Liv. to Man.	8 ditto - -	36·40	1 35	5	18·6	44·	879	·82	Assisted -	Almost cold	Fine weather.
									Machine not in good order.		
Man to Liv. -	8 ditto - -	36·40	1 18	5	22·8	49·	870	·81	Assisted -	ditto -	Rainy, strong wind contrary.

In these experiments, the fire-grate was filled with coke to the level of the bottom of the fire-door; a quantity of coke was then weighed, and placed in the tender; at the conclusion of each experiment, the fire-grate was filled to the same height, and the quantity of coke remaining on the tender again accurately weighed.

The coke was of the best description, being made in close ovens, and was from the Worsley colliery. The coke left from the distillation of gas, having been previously found to be prejudicial to the tubes, and having been likewise found to require 12 per cent. more, was not used. The calculation of the consumption per mile was thus effected; the distance traversed by the engines, from station to station, was 29 miles; of this distance, there was three miles of plane, viz. 1½ miles ascending, and 1½ descending; there was, therefore, 26¼ miles of level, the resistance of the ascending plane is equal to four times that of the level; therefore, 26¼ + (4 × 1½) = 32¼ miles, the distance upon a level, equivalent to that of the level part of the line, and the ascending plane, when the engines were not assisted up the plane by another, or by two engines. When the engine and load were assisted up by two engines, one third of the effort would be overcome by the engine under experiment; therefore, 26¼ + 2 = 28 miles, the distance upon a level plane, equivalent to the effect of the engine under experiment.

In these calculations, the gravity of the engine and convoy, in ascending the plane, has not been taken into consideration. Suppose them to weigh 13 to 14 tons, the inclination being $\frac{1}{94}$th, will be equal to the resistance of 40 tons on a level for 1½ miles; when, therefore, the weight of the train was 30 tons, (which was the case generally, when the engine was not assisted up the plane), this additional resistance will be equal to that weight conveyed two miles, and, therefore, $32\frac{1}{2}+2=34\frac{1}{2}$ miles, the distance taken by M. Pambour in calculating the ninth column, when the engine was not assisted. If the trains were 60 to 80 tons, (which was the case when the engine was assisted,) the additional resistance would be only equal to one half, or to one mile, with a train of that load; therefore, $28\frac{1}{2}+1=29\frac{1}{2}$ miles, the distance taken for the engine, when assisted up the plane.

On examining the table, it will be found, that the average consumption, for 73 tons, is about 948 lbs. of coke, or about 0·4 of a lb. per ton per mile. M. Pambour shews, however, that, taking the cost of fuel from the half-yearly reports of the Liverpool railway, the consumption, for the year ending June 30th 1834, was equal to 0·90 lbs. per gross ton per mile, on a level, with an average load of 32 tons.

The consumption on the Darlington railway, with tubular boilers, is about 0·86 lbs. per gross ton per mile, on a level; but, on this railway, the weight of the trains, conveyed at a time, is greater than those upon the Liverpool railway, which produces a more economical result.

The following Table will shew the consumption of fuel, and performance of the engines, on the Stanhope and Tyne railway, for the years 1835 and 1836, furnished us by T. E. Harrison, Esq., engineer.

and, therefore, at that time little progress had been made in their improvement.

We cannot subscribe to the conclusion of Messrs. Walker and Rastrick, that the same engine, capable only of moving a load of sixty tons, including itself, at the rate of five miles an hour, will propel thirty tons at the rate of ten miles an hour. This is supposing, what is not the case, that the friction of the engine is not greater per ton than the carriages. We have shewn, in Experiment VIII., that the friction of the moving parts of the old engines, when divested of the action of the steam, is equal to 214 lbs., and this was with an engine, the weight of which, including the tender, was nine tons; this is, therefore, the least friction we can calculate upon, being the resistance of the engine without a load. We have previously stated, in respect of the consumption of fuel, that the whole resistance, or that which results when the engine is loaded, should be taken into account. Supposing, however, the resistance of the moving parts only be considered, without reference to the additional resistance, by the pressure of the steam and load, we have the friction of the engine = 200 lbs. If we, now, take the friction of the load at 10 lbs. per ton, or 500 lbs., the whole resistance will be = 700 lbs., or 700 × 5 = 3500, the effect at five miles an hour.

Then 3500 ÷ 10 = 350, the resistance which the same power is capable of moving at the rate of ten miles an hour; whence 350 − 200 = 150 lbs., the useful effect which the engine is capable of producing, or fifteen tons gross, equal to ten tons of goods.

Our estimate of forty tons, at six miles an hour, would, according to the above calculation, give sixteen tons gross, conveyed at the rate of ten miles an hour.

Supposing, however, Messrs. Walker and Rastrick's standard, to have been at ten miles an hour, and that the proposed engine would take nineteen tons and a half gross, or thirteen tons of goods, at that rate of speed; this would give only six tons and a half gross, or four tons of goods, at the rate of fifteen miles an hour, or at the average rate of travelling upon the Liverpool and Manchester railway at present.

We see, therefore, that in 1825, and for four years afterwards, there did exist some grounds for arriving at the conclusions, which, subsequently to the Liverpool experiments, led to some very satirical remarks, in some of the journals, on the performance assigned in the first edition. As a practical work, it would, especially in that year of excitement, have been very reprehensible to have assigned performances, in anticipations of improvements, which might, or might not, have taken place.

On a reference to that edition, it will be seen, that sufficient stress was laid upon the improvements, of which it was said those engines were susceptible; but it would have been departing from the character of the work, to have assigned performances in anticipation of improvements, that might lead to the adoption of those engines, and which, when adopted, might have been found inadequate to perform the work assigned to them.

We feel the above remarks necessary, in explanation of an error which we have been accused of disseminating, but which, we trust, will have been productive of less injurious consequences than if we had erred in the opposite way.

Apologising for this digression, we shall now endeavour to fix some standard for the present performance of these engines. In doing so, we, however, feel a difficulty of no ordinary kind. These engines have just, or scarcely yet, perhaps, emerged from a course of improvements, as rapid as they have been astonishing. Little more than eight years ago, we find them incapable of effecting any great rate of speed, four, and, at most, six miles an hour, being their ordinary rates of travelling upon the railways on which they had been introduced; and now we find their regular day's work, with goods, averaging more than twelve miles, and in their daily work with passengers, averaging more than twenty miles an hour, with the utmost ease.

With improvements such as these in progress,—for every engine yet made seems superior to that preceding it,—we need scarcely say, that it is extremely difficult to decide upon any fixed standard, without erring on either one side or the other. Perhaps, even before the work issues from the press, their capabilities may be very considerably increased. We are, however, notwithstanding the error into which we are accused of having previously fallen, inclined to fix our data, rather upon their present powers, than upon any speculative capabilities, which, we do not doubt, they may hereafter be made to attain.

We shall, in doing so, be obliged to confine ourselves to the engines on the principle of Messrs. Stephenson and Co.; for, although Messrs. Braithwaite and Erickson, and others, may produce engines, capable of competing with those, in performance, at some time or other, yet, we have, at present, no data, on which we can assign any tangible performance to these engines. We understand, that in an engine, made by Braithwaite and Erickson, for the Liverpool railway, those gentlemen abandoned the principle of forcing the air through the fire, by means of the bellows, and adopted that of exhaustion, by means of a fan-wheel, applied, in a chamber, at the chimney end of the generator. We have, however, no opportunity of giving correct data of the performance of these engines; and we, therefore, abstain from any opinion whatever as to their merits. An experiment made at Mr. Laird's works, at Liverpool, upon a low-pressure boiler, by an exhausting apparatus, of Messrs. Braithwaite and Erickson's principle, having shewn a surprising result, as to economy of fuel, may induce some to adopt this principle. The length of flues, in this Experiment, (see Note E, Appendix,) was, however, forty-five feet; a length, we should imagine, rather difficult to obtain in a locomotive engine, and to which, we suspect, the economy of fuel in this experiment was attributable.

Both the engines of Messrs. Stephenson and Erickson may, therefore, be said to be on the same principle, viz., that of exhaustion, by mechanical means; the former, by the application of the steam into the chimney, after its passage through the cylinders, and the other by a fan. It remains yet to be ascertained, which, in the first place, produces the most complete exhaustion, and then, which of the two requires the greatest power to effect it; the power required to work the fan, on the one hand, or the loss of power, occasioned by the contraction of the exit pipe, to produce a jet of steam into the chimney, on the other. The principle of exhausting, or producing a current of air for combustion, by mechanical means, allows the whole of the useful heat to be abstracted; none being required to produce a draught in the chimney, as in engines, the process of the combustion of the fuel of which is kept up by the rarefaction of the air in the chimney; and, therefore, we should expect a considerable effect produced, in the economy of fuel of those engines, the draught of the fire of which is produced by mechanical means.

These were, generally, the observations made in the second edition of the work, published in 1831. At that time, the improvements, resulting from the Liverpool experiments, were just being carried into practice, and every succeeding engine made was more powerful, and in a higher state of perfection, than that which preceded it. Since that time these improvements have been extended, so as to produce engines much more efficient, more compact, and with evaporating powers more than five times greater, than engines of the same weight were capable of effecting formerly; and their power of dragging loads, compared with their weight, has been comparatively increased.

a.—Explanation of the Principles which govern the Power of Locomotive Engines.

We have already explained, that the power of a locomotive engine, is not to be estimated by the pressure of the steam in the boiler, and the diameter, and length of stroke, of the piston. In passing between the boiler and the cylinder, the elastic force of the steam is diminished, before it reaches the cylinder, by the smallness of the apertures of the steam pipes, through which it has to pass. This difference is, likewise, more frequently produced, by the evaporating power of the engine, not being capable of keeping up a supply of steam to the cylinders, of the elasticity equal to that in the boiler; and, therefore, the pressure upon the piston is less than that against the steam valve of the boiler;

and this diminution of the elasticity of the steam, in the cylinders, as compared with that in the boiler, will, in many cases, be in the ratio of the increase of velocity of the engine. Thus, suppose an engine, capable of evaporating a certain quantity of water, per hour, or converting it into a certain bulk, or quantity of steam, of the elasticity indicated by the valve on the boiler; if this production of steam is sufficient to supply as many cylinders full of steam, of the density of that in the boiler, as shall be equal to the number of strokes, per minute, of the piston, required to produce the given velocity; then, the elasticity of the steam, in the cylinder, will be the same as that in the boiler, except that which is required to force the steam, through the steam passages, with the requisite velocity; and, consequently, the pressure on the piston will be nearly the same as that in the boiler. But, if the velocity of the engine is such, that the number of cylinders full of steam required is greater than the evaporation of the boiler can supply, at the elasticity marked by the steam valve, then the elasticity in the cylinders is correspondingly diminished. Thus, suppose an engine, capable of evaporating 50 cubic feet of water into steam per hour, and that the pressure, on the steam valve, is 50 lbs. per square inch; this will supply a given number of cylinders full of steam of that elasticity. Suppose the resistance, to the motion of the piston, be equal to this pressure of the steam, or equal to the elasticity of 50 lbs. per square inch, of the surface of the piston; then the engine will travel at that rate, which the evaporating power of the engine will supply it with the requisite number of cylinders full of steam. But, suppose the resistance upon the piston increased, by a change in the gradients of the railway, then the velocity of the engine will be diminished, until the evaporating power raises the elasticity of the steam in the boiler, so as to counterbalance the increased resistance of the piston, and the engine will, consequently, move more slowly. On the contrary, if the resistance be diminished, by a change of the gradients of the railway, then steam of a less density will be required, and, consequently, a greater number of cylinders full will be furnished by the boiler, and the velocity of the engine will be increased.

We see, therefore, that the only correct expression of power of these engines, is the evaporating power of the boiler, and that the velocity, with which the engine will move, will depend entirely upon the quantity of water it can convert into steam, in a given time; or the number of cylinders full of steam, of a given elasticity, which the boiler can produce in a given time. Having found, therefore, by experiment, the quantity of water which an engine, of given dimensions, can evaporate per hour; we then find the power, which that engine is capable of exerting upon the piston, and the velocity, or number of strokes, per minute, which that evaporation will produce, with a given load. The volume of steam, which a cubic foot of water will produce, depends upon the elasticity; this has been ascertained by various experimentalists, and the following Table will shew the result.

Table of the Volume of the Steam generated under different Pressures.

TABLE I.

Total pressure expressed.		Corresponding temperature by Fahrenheit's thermometer.	Volume of the steam compared to the volume of the water that produced it.
In lbs. per square inch.	In atmospheres.		
lbs.		degrees.	
15	1·021	212·6	1·670
20	1·361	227·9	1·282
25	1·701	240·3	1·044
30	2·041	250·8	883
35	2·381	260·0	767
40	2·721	268·1	678
45	3·061	275·4	609
50	3·401	282·0	553
55	3·742	288·1	506
60	4·082	293·8	468
65	4·422	299·1	435
70	4·762	304·0	407
75	5·102	308·7	382
80	5·442	313·1	360
85	5·782	317·3	341
90	6·122	321·3	324
95	6·463	325·1	308
100	6·803	328·8	294

In these remarks, we have supposed the production of steam in the boiler to be a constant quantity, or the same quantity per hour, whatever be the velocity of the engine. We have seen, when treating on the evaporating powers of these engines, that the rate of production is increased per hour, when the velocity is increased. We shall, however, for the present, to avoid complication in the calculations of their powers, assume that the evaporation is the same per hour, at all velocities.

b.—Theory of the Power of Locomotive Engines.

Then let P=the total pressure of the steam in the boiler, per square inch.
S=the effective evaporating power of the engine, expressed in the number of cubic feet of steam the boiler is capable of evaporating, in an hour, at the pressure P.
And m=the ratio of the volume of the steam, at the degree of pressure P, to the volume of water.

Then $m \times S$=the total volume of steam generated in an hour, at the pressure P of the boiler; and as the volume of the steam will be in the inverse ratio of the pressure of the boiler, and the cylinders; let R=the pressure in the cylinders. Then $m \times S \times \frac{P}{R}$=the space occupied by the steam in the cylinders, and if $\frac{1}{2}\, x\, d^2$= the area of the two cylinders $\frac{m\, S\, P}{\frac{1}{2}\, x\, d^2\, R}$ =the velocity of the piston per hour, d being the diameter of the cylinder, and x=the ratio of the diameter to the circumference.

To determine, therefore, the velocity of the engine, let l=the length of stroke of the piston, and D=the diameter of the wheels of the engine worked by the pistons.

Then $\mathrm{V}=\frac{m\,\mathrm{S\,P\,D}}{\mathrm{R}\,d^2\,l}$ = the velocity, in feet, per hour, and by dividing this by 5280, we have the velocity in miles per hour.

Thus, suppose an engine capable of evaporating 41·87 cubic feet of water per hour $=\mathrm{S}$, which we may suppose to be converted into steam of the *effective* pressure of 50lbs. per square inch, or a total pressure, P, of 65lbs. per square inch; the *effective* pressure being the pressure above that of the atmosphere. Now, in referring to the Table in page 555, we find that steam of a total pressure of 65lbs. per square inch, occupies 435 times the space of the water which produces it $=m$; then, $m\times\mathrm{S}=0{\cdot}70\times435=304$ cubic feet of steam produced per minute, at the total pressure, P, of 65lbs. per square inch. And suppose the pressure R in the cylinders =46lbs. per square inch; then $304\times\frac{65}{46}=430$ cubic feet, the volume of steam, the engine is capable of producing to the cylinders per minute. In this, we have calculated the bulk of steam to be inversely as the pressure; but we find by the Table it is not quite so; we may however, in practice, assume that it is, as the variation will not affect the result materially.

If we suppose $d=0{\cdot}917$ feet, $l=1{\cdot}33$ feet, and $\mathrm{D}=5$ feet. Then $\frac{m\,\mathrm{S\,P\,D}}{\mathrm{R}\,d^2\,l}=\frac{435\times41{\cdot}87\times65\times5}{46\times0{\cdot}917^2\ \times163}=11{,}506$ feet per hour, the velocity which an engine, capable of evaporating 41·87 cubic feet of steam per hour, is capable of accomplishing, with a load upon the piston equal to 46lbs. per square inch of surface, which, divided by 5280, gives 21·79 miles an hour.

Having ascertained the pressure per square inch of surface of the piston, which an engine, with a given evaporating power, is capable of exerting upon the piston, we have now to find the value of R, or resistance to the motion of the piston, at the different velocities of the engine, in miles per hour. This is composed of

1st. The friction or resistance, of all the working parts of the engine itself.

2d. The friction of the load.

3d. The pressure of the atmosphere, upon the surface of the pistons.

4th. The resistance to the free emission of the steam, from the cylinders into the chimney, through the blast-pipe.

1st. The first of these resistances, viz. the friction of the engine itself, varies according to the pressure on its several working parts, by the action of the load; and, therefore, it is a variable resistance, depending upon the load to which the engine is subjected. Let F = the friction of the several parts of the engine without a load, and S = the additional friction imparted to it per unit, or for every additional ton weight of load, and M = the number of tons composing the total load.

Then $F+SM$ will be the friction of the engine, with the load, M. We have already, § 4, page 487, determined the value of $F = 15$ lbs. per ton of the weight of the engine, and § 4, page 504, found $S = 1{\cdot}25$ lbs. per ton, for every additional ton of load.

2d. The second of these resistances, is composed of the friction of the axles, and the resistance of the wheels of the carriages upon the rails; we have, also, ascertained these to be equal to 8·5 lbs. per ton. Making, therefore, M = the number of tons weight of the carriages and tender, and $n = 8{\cdot}5$ lbs., we have $n\,M$ = the resistance of the carriages and tender.

3d. The pressure of the atmosphere on the pistons, will be 14·7 lbs. per square inch of surface, which make $= p$.

4th. The resistance to the free discharge of the steam, arises from the contraction of the blast-pipe, for the purpose of causing a sufficient quantity of air to pass through the fire-grate. This resistance is variable, to a certain extent depending upon the area of the pipe, and the velocity with which it is required to pass into the chimney; when the engine is moving at a rapid rate, the velocity being required to be greater than when moving at a slow rate. We have not yet made experiments sufficient to satisfy ourselves, what the actual obstruction, to the free emission of the steam, from the cylinders is, at different rates of velocity; by applying a mercurial barometer to the inside of the cylinder, and also into the chimney, we are disposed to place the resistance at about 3 lbs. per square inch of surface of the piston.

We have before seen, in Art. 6, § 4, page 527, that the evaporation of steam is correspondingly increased, by the rapid emission of the steam into the chimney, at high rates of velocity; if, therefore, we take the evaporating power, of these engines, at a determinate rate of speed, or at twenty miles an hour, and make an allowance of three lbs. per square inch of surface of the piston, at that rate of speed, allowing the increased powers of evaporation as a set-off against the increased resistance, from the blast-pipe, at high rates of velocity, we shall not err much, in the absence of conclusive experiments.

We must, therefore, make $p = 14{\cdot}7 + 3 = 17{\cdot}7$ lbs. per square inch; or, 2880 lbs. per square foot of the piston, for the resistance of the atmosphere, and the obstruction to the free emission of the steam from the cylinders.

We have, then, $\mathrm{R}=(\mathrm{F}+\delta\,\mathrm{M}+n\,\mathrm{M})\,\frac{\mathrm{D}}{d^2 l}+p.$

By expressing the quantities, $\text{D}\ l$ and d, in feet, and p, in lbs., per square foot.

Then $\text{V} = \frac{m\text{PSD}}{[\text{F} + (\delta + n)\text{M}]\text{D} + pd^2 l}$, the velocity of the engine, in feet, per hour; and which, divided by 5280 feet, will give the velocity, in miles, per hour.

We thus find the velocity, which an engine, capable of evaporating the quantity of steam R S, can travel with the load, M.

By, therefore, transposing this formula, we find $\text{M} = \frac{m\text{PSD} - pd^2 l\text{V}}{(\delta + n)\text{VD}} - \frac{\text{F}}{\delta + n}$, the load, including tender, which the same engine can draw at the velocity V.

Thus, suppose $\text{P} = 9360$ lbs., the pressure, per square foot, in the boiler.

$m = 435$, the volume, which steam, at the above elasticity, occupies above that of water.

$\text{S} = 54$ cubic feet, the evaporating power of the engine.

$\text{D} = 4{\cdot}5$ feet, the diameter of the driving wheels of the engine.

$d = 1$, diameter of the cylinder, in feet.

$l = 1{\cdot}5$, length of the stroke of piston, in feet.

$p = 2880$ lbs., the pressure, per square foot, on the piston, equal to the pressure of the atmosphere, $= 2448$ added to 432 lbs., the resistance to the steam, in passing through the blast-pipe.

$\text{F} = 180$ lbs., the friction of the several parts of the engine, unloaded, the weight being twelve tons.

$\delta = 1{\cdot}25$ lbs., the increase of friction, which every ton weight of the load imparts to the engine.

$r = 8{\cdot}5$ lbs., the friction of the carriages, and tender, per ton.

$\text{M} = 106$ tons, the supposed weight of the load, tender included.

c.—*Power of Engines, with respect to Velocity, with different Loads.*

The velocity, v, which an engine of the above dimensions, and powers, will travel, with a load of 100 tons, exclusive of the tender, will be

$$\mathrm{v} = \frac{m\,\mathrm{P\,S\,D}}{[\mathrm{F} + \overline{(\delta + n\,\mathrm{M}}]\,\mathrm{D} + p d^2 l} = 101{,}160 \text{ feet per hour;}$$

$$\text{or,} = \frac{435 \times 9360 \times 54 \times 4{\cdot}5}{[180 + (8{\cdot}5 + 1{\cdot}25 \times 106] \times 4{\cdot}5) + 2880 \times 1^2 \times 1{\cdot}5}$$

$=101{,}160$ feet per hour; which, divided by 5280, gives nearly nineteen miles an hour; the rate at which an engine of the above dimensions will travel, with a load of 106 tons, tender included; or, 100 tons, exclusive of the tender.

This expression of v, must, however, be taken, within certain limits; R, may be so reduced, as to give, by theory, a velocity, beyond that which prudence would dictate; as, for instance, if no load at all was attached to the engine, except the tender, which may be taken at six tons; we find, by the formula, that the velocity would be upwards of 47·5 miles an hour. At this rate of velocity, the resistance of the air would increase, so as to make the resistance to the motion more than that assigned to the engine, and tender, and the obstruction to the steam, passing through the blast-pipe, would also increase, in proportion to the velocity; on the other hand, we would have an increase to the production of steam, still no useful effect would be produced, by such an engine, at so rapid a rate of travelling.

If the maximum velocity be thirty miles an hour, the load, including the tender, would be about thirty-one tons; we see, therefore, that if a greater velocity than thirty miles an hour is required, we must, to produce a useful practical result, have engines of greater evaporating powers.

We now give the rates of speed at which locomotive engines, of different evaporating powers, will travel, with various loads upon a level railroad.

TABLE II.

Load in tons, tender included.	Rate of speed in miles per hour, with the different evaporating powers of			
	42 cubic feet per hour.	48 cubic feet per hour.	54 cubic feet per hour.	60 cubic feet per hour.
25	30·90	31·45	31·71	32·15
50	25·15	26·13	26·81	27·36
75	22·54	23·63	24·45	25·02
100	18·18	19·37	20·38	21·29
125	15·98	17·17	18·15	19·13
150	14·29	15·42	16·41	17·37
175	12·28	13·98	14·97	15·90
200	11·20	12·81	13·75	14·67
225	10·77	11·81	12·73	13·62

The dimensions of the engines, from which the performances, shewn in the above Table, are calculated, are as follow :—

TABLE III.

	Evaporating power in cubic feet of water per hour.			
	No. 1.	No. 2.	No. 3.	No. 4.
Diameter of cylinder -	12 ins.	13 ins.	14 ins.	14 ins.
Length of stroke - -	16 ins.	16 ins.	16 ins.	18 ins.
Weight of engine - -	10 tons.	11 tons.	12 tons.	13 tons.
Diameter of driving wheels -	5 feet.	5 feet.	5 feet.	5 feet.
Area of heating surface -	140 sqr.ft.	160 sqr.ft.	180 sqr.ft.	200 sqr.ft.

d.—Power of Engines, with respect to Loads, at different Velocities.

Having the velocity, at which it is intended a locomotive engine should travel, we can determine the load, M, which the engine will drag; let the velocity, V, be equal to 19·16 miles an hour, or 101,160 feet per hour.

$$\text{Then } M = \frac{m\ P\ S\ D - p d^2 l V}{(\delta + n)\ V\ D} - \frac{F}{\delta + n};$$

$$\text{or, } \frac{435 \times 9360 \times 54 \times 4{\cdot}5 - 2880 \times 1^2 \times 1{\cdot}5 \times 101{,}160}{1{\cdot}25 + 8{\cdot}5 \times 101{,}160 \times 4{\cdot}5}$$

$124{\cdot}4 - \frac{180}{1{\cdot}25 + 8{\cdot}5} = 106$ tons, the load, including tender, which an engine of the preceding dimensions, and power, will drag, at the rate of 19·16 miles an hour.

We now give the load, which locomotive engines, of different evaporating powers, will travel with, at different rates of speed upon a level railroad.

TABLE IV.

Rate of speed in miles per hour.	Load in tons, including tender, which an engine will drag, with the evaporating powers of			
	42 cubic feet per hour.	48 cubic feet per hour.	54 cubic feet per hour.	60 cubic feet per hour.
10	249·01	284·14	318·12	352·00
12½	184·20	208·21	232·27	257·10
15	138·29	157·60	175·39	193·84
17½	106·64	121·42	134·69	148·64
20	82·91	94·32	104·15	114·75
22½	64·46	73·23	80·40	88·38
25	49·70	56·36	61·40	67·29
27½	37·62	42·55	45·86	50·04
30	27·55	31·06	32·91	35·66

e.—Comparative useful effect of Engines, travelling at different rates of Speed.

An inspection of Table IV. will shew the practical effect, as regards the quantity of goods, conveyed at the different rates of speed; this will not, however, give the comparative effect, for a given time, or for a day's work. An engine, travelling at a greater rate of speed, will, of course, in the same time, travel a greater distance; and this, therefore, will, to a certain extent, compensate for the diminished load; but, notwithstanding this, there is a very considerable diminution of useful effect, in travelling at great rates of speed.

By taking the relative distances, which such engine travels in a given time, and multiplying that into the load conveyed; we shall find the comparative useful effect, at different rates of speed, from the load, mentioned in the Table, we must, however, from this, deduct the weight of the tender.

The following Table will, therefore, exhibit the comparative useful effect of engines, travelling at different rates of speed.

Table of the useful effect of locomotive engines, at different rates of speed, with different loads.

Table V.

Comparative performances of engines with different loads at various rates of speed.		
Rate of speed in miles per hour.	Load in gross tons exclusive of tender.	Comparative useful effect.
10	312·12	3121
12·5	226·27	2818
15	169·39	2540
17·5	128·69	2252
20	98·15	1963
22·5	74·40	1674
25	56·40	1385
27·5	39·86	1076
30	26·91	807

We see, in these tables, the very great disparity in point of useful effect, and, consequently, economy, between engines travelling at a moderate, and at a high rate of speed; the difference between twenty and thirty miles an hour being more than sixty per cent. To accomplish, therefore, any practical economical effect, except for passengers, with a rate of speed equal to thirty miles an hour, it is clear we must have much more powerful engines, and capable of producing a more rapid evaporation of steam. This again increases the quantity of useless weight taken, as compared with the useful load; still, if the object be to travel with passengers, at a high rate of velocity, by having more powerful engines it is perfectly practicable.

We must, in this case, however, either increase the diameter of the wheels propelling the engine, or cause them to make a greater number of revolutions than one, for each double stroke of the piston. For a velocity of twenty miles an hour, a wheel of five feet is generally used; suppose the length of the stroke of the cylinder sixteen inches, this will cause the piston to travel at the rate of about 270 feet per minute, which is quite as great a velocity as should be attempted. It follows, therefore, that we must either shorten the length of the stroke, which is attended with a great waste of steam, at each change of motion, or increase the diameter of the propelling wheels of the engine, to accomplish a higher rate of speed. If the latter is done, the increase should be in the ratio of the velocity; and, therefore, if the rate of travelling is to be thirty miles an hour, the diameter of the wheels should be seven feet and a half; and forty miles, ten feet; fifty miles, twelve feet and a half; and sixty miles, fifteen feet; or, which would amount to the same effect, smaller wheels increased in velocity by cog-wheels.

Mr. Harrison, of the Stanhope and Tyne railway, has a patent to effect the velocity by the latter method, which is to be tried on the Great Western railway; and Mr. Brunel is likewise increasing the size of his propelling wheels to ten feet in diameter.

We now give a table of the performances of several of the engines on the Liverpool and Manchester railway, as observed by M. Pambour, in his inquiries on the subject of the powers of locomotive engines, which can be compared with the preceding theoretical tables.

TABLE VI.

Performances of engines on the Liverpool and Manchester railway, from the experiments of M. Pambour.

From Liverpool to Manchester.	Gradients of the line of railway from Liverpool to Manchester.																Effective pressure of steam in boiler.	State of the regulator.	From Manchester to Liverpool.
	0.53 miles level.		5·23 miles descent $\frac{1}{1094}$.		1·47 miles ascent $\frac{1}{96}$.		1·39 miles descent $\frac{1}{89}$.		6·60 miles descent $\frac{1}{849}$.		5·62 miles ascent $\frac{1}{1300}$.		4·26 miles ascent $\frac{1}{4237}$.		Level.				
	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.	Load in tons.	Miles per hour.			
Atlas engine	124	17·14	90	21·17	—	—	—	—	80	23·72	154	18·75	133	17·89	—	—	61·5	$\frac{3}{4}$	
Ditto -	105	15·00	75	21·43	—	—	—	—	67	25·07	129	22·64	112	19·63	—	—	53	$\frac{2}{4}$	
Ditto -	71	20·00	50	24·54	—	—	—	—	44	26·13	89	21·51	76	20·81	—	—	53	$\frac{1}{4}$	
	—	—	—	—	—	—	114	15	36	27·93	22	31·43	26	26·47	—	—	+	+	Atlas engine.
Atlas engine	196	9·23	142	14 12	—	—	—	—	127	16·21	240	8 00	209	5·87	—	—	54·5	1	
	—	—	—	—	—	—	199	6·00	—	—	—	—	—	—	—	—	+	+	Atlas engine.
Atlas engine	67	20·00	59	21·82	—	—	—	—	53	23·26	96	19·75	84	14·16	—	—	25·5	1	
	—	—	53	15·79	—	—	202	7·50	57	16·08	29	23·00	37	19·53	40	16·38	+	+	Atlas engine.
Atlas engine	128	15·00	92	17·14	—	—	—	—	82	20·52	158	15·38	137	15·24	—	—	53	1	
	—	—	—	—	—	—	219	3·75	—	—	—	—	—	—	—	—	+	+	Atlas engine.
Fury engine	56	17·14	40	18·00	244	6·31	—	—	35	23·28	70	21·82	60	21·17	—	—	55	$\frac{3}{4}$	
	—	—	63	18·46	—	—	228	15·00	68	18·62	36	22·00	45	21·43	49	17·50	+	+	Fury engine.
	—	—	50	24·82	—	—	183	13·33	53	24·61	28	26·94	35	25·71	38	25·00	+	+	Ditto.
	—	—	176	13·33	—	—	—	—	—	—	—	—	—	—	138	10·91	+	+	Ditto.
Firefly engine	41	24·00	—	—	—	—	—	—	25	25·45	52	21·29	45	21·33	—	—	35	1	
	—	—	54	24·82	—	—	—	—	58	23·44	31	24·44	38	23·68	41	25·71	+	+	Fireflyengine.
Vesta engine	49	24·00	34	29·09	—	—	—	—	30	27·00	61	23·56	52	25·71	—	—	50	1	
	—	—	44	28·80	—	—	165	14·11	47	28·93	24	34·74	30	30·00	33	29·00	+	+	Vesta engine.
	—	—	121	18 75	—	—	—	—	129	12·10	71	24·00	87	18·46	94	15·00	+	+	Ditto.
	—	—	—	—	—	—	183	3·25	—	—	—	—	—	—	—	—	+	+	Ditto.
	—	—	—	—	—	—	189	3·00	—	—	—	—	—	—	—	—	+	+	Ditto.
Leeds engine	88	18·26	64	20·72	—	—	—	—	57	24·00	109	20·34	95	18·82	—	—	54	$\frac{3}{4}$	
	—	—	—	—	—	—	—	—	55	25·31	30	30·00	37	24·54	35	22·50	+	+	Leeds engine.
Leeds engine	38	21·81	27	29·09	—	—	—	—	23	28·96	48	21·43	41	18·75	—	—	46·	$\frac{3}{4}$	
	—	—	—	—	—	—	188	11·42	—	—	—	—	—	—	—	—	+	+	Vulcan engine.

f.—Theory of the Power of Engines on Inclined Planes.

Having thus ascertained the load, which a locomotive engine can drag at different rates of velocity upon a horizontal railway; we now come to the effect of inclined planes, occurring on the line of road, to which all lines of railway are subjected. Considerable discussions have arisen upon this part of the subject, not only for the purpose of determining the absolute weight, which an engine is capable of dragging upon given inclined planes; but for the purpose of comparing the relative merits of different or competing lines of road with each other, where the planes or gradients were not the same in the intermediate parts of the road, but where the level of the two termini were the same. Professor Barlow, and Dr. Lardner, have been most prominent in this inquiry, and both these gentlemen have given theories on the subject. Without going into all the theoretical considerations of the question, which would extend our inquiries further than our limits will allow, we shall endeavour to consider the subject in its application to practice.

We have already seen, that the production of the steam does not vary materially from, but that it may be considered as, a constant quantity; and that the pressure in the cylinder, is always less than that in the boiler, and further, that this difference becomes greater as the velocity of the engine, is increased. Suppose then, that a locomotive engine travelling along a horizontal plane, arrives at the foot of an ascending plane; in addition to the friction and resistance of the load, the engine has then to overcome the gravity of the plane upon the whole train, engine and tender included; the resistance R, is therefore increased, and the velocity, V, will be diminished, until the pressure in the cylinder becomes nearly the same as that in the boiler, when the motion will become uniform, and will be equal to that which the evaporating power of the engine will supply steam at that elasticity, which is competent to overcome the aggregate resistances.

In all ascending planes, therefore, we must add to the resistance, R, the effect of the gravity upon the load; and the gravitation of the load, has likewise the same effect upon the friction of the engine as that of the load, M; making, therefore, G equal the gravitation of the whole train, we have $F+\delta\,\overline{M+G}=$the friction of the engine, and $n\,\overline{M+G}=$the resistance and friction of the train.

The resistance, R, upon ascending planes, will then be $=\left[F+(\delta\,M+G)+n\,M+G\right]\frac{D}{dl}+p$, and, therefore, by applying this to the preceding theorems, we can readily ascertain the load which an engine can drag up any plane of a given inclination; or the rate of speed at which an engine will travel up such plane with a given load.

We come now to the effect upon descending planes, in this case, the gravitation of the load upon the plane diminishes the resistance, and, therefore, must be taken from it, and, consequently, R, will be $=\left[F+(\delta\,\overline{M-G})+n\,\overline{M-G}\right]\frac{D}{d^2l}+p$, from which, by adopting the theorems in the preceding section, we can determine the load which an engine will drag down any plane with a given inclination; or the velocity, which such engine will travel upon such plane with a given load.

This expression must, however, be taken subject to certain limitations. We may suppose, that, in the case of an engine traversing a horizontal plane, the resistance, R, may be so diminished, that the velocity may become greater than it is prudent to keep up; in such a case, by closing the damper in the chimney, the production of the steam is diminished, until the velocity becomes uniform, and the limit of speed will then be that which it is deemed advisable in practice to attain. This operation becomes more apparent, in the case of a train descending a plane. Upon a horizontal plane, the production of steam being as the time, and not as the velocity, when the speed increases, the elasticity of the steam in the cylinders is reduced; and, therefore, the moving power is diminished, and, consequently, the motion at last becomes uniform, unless the resistance is so much diminished, that, before reaching that extent, the velocity becomes dangerous; when, by management, the rapidity of production of steam is also checked, until an uniform velocity is attained.

In the case of an engine and train descending a plane, the case is different. We may suppose the inclination to be such, that the gravitation diminishes the resistance of the engine and carriages, to so great an extent, that no steam is required, and gravity being a constant force, the motion then becomes an accelerated one; or the gravitation may be such, as to diminish the resistance to such an extent, as that, added to the force of steam acting on the pistons, the velocity becomes accelerated, and is allowed to increase until it reaches the limit of safety. Artificial means, or the brake, is then obliged to be resorted to, to check the further acceleration, and reduce the speed to a uniform and safe velocity. We shall take a case where the inclination is such, that the gravity will not urge the load down the plane, with sufficient velocity, but that a certain quantity of steam is obliged to be used, to urge the engine up to the requisite speed; the precise quantity, however, being less than that of the evaporating powers of the boiler, the quantity of steam produced will, in this case, be regulated by the action of the damper; or, in cases where the rapidity of evaporation cannot be sufficiently checked, the steam is prevented from acting upon the piston, and is made to escape by the safety valve of the boiler.

We may assume, therefore, that, whether the load is diminished on a horizontal plane, for the purpose of acquiring speed, or that it is diminished on a descending plane by the action of gravity; there is still a certain rate of velocity, which it is not prudent to exceed, and which when acquired, the acceleration must be checked, and the rate of speed made to be uniform.

If we are desirous of obtaining a maximum effect, both with respect to speed, and the load, upon any line of railway which undulates; we must, therefore, calculate what load the engine will drag at the required average rate of speed, making the requisite allowances for the diminution in the ascending, and the increased rate of speed in descending, planes. On a line of railway, therefore, which, although undulating in the intermediate parts, is level at the two extremities, we may, first of all, set out with an average rate of speed upon the level parts of the road, which say is twenty-four miles an hour, and we may assume, upon descending planes, that the maximum velocity shall not be greater than thirty miles an hour; keeping within these limits, we can then determine the relative velocities, which can be accomplished by a locomotive engine upon the various gradients on the line, and by this we can calculate the comparative merits of different lines of railway.

Thus, suppose, upon the horizontal parts of the line, or, upon the general average gradients of the line between the two termini, we make V = twenty-four miles an hour, then the load will be

$$\mathrm{M} = \frac{m\,\mathrm{P\,S\,D} = p\,d^2\,l\,\mathrm{V}}{(\delta + w)\,\mathrm{V\,D}} - \frac{\mathrm{F}}{\delta + w}\,;$$

setting out with this load, M, we have, upon all the ascending planes, the velocity, V, equal to

$$\mathrm{V} = \frac{m\,\mathrm{P\,S\,D}}{[\mathrm{F} + (\delta + w)\,\mathrm{M} + \mathrm{G}]\,\mathrm{D} + p\,d^2\,l,}$$

and the velocity V, upon any descending plane equal to

$$\mathrm{V} = \frac{m\,\mathrm{P\,S\,D}}{[\mathrm{F} + (\delta + w)\mathrm{M} - \mathrm{G}]\,\mathrm{D} + p\,d^2\,l.}$$

In the latter case, we must not make V, exceed thirty miles an hour, or whatever rate may be fixed upon as the maximum rate of speed.

By, therefore, taking, according to the preceding formula, the several rates of speed, upon the different ascending gradients on the line, and multiplying that by the respective distances travelled at that rate; and the same with the descending gradients, taking, in the latter, the velocity never greater than that assigned as the maximum rate of speed, we have a general result, which will shew the comparative merits of different lines of railway, so far as regards the mechanical effect: we shall see, however, that, with our present stock of information, we cannot determine, all the quantities required by the preceding formula. If the comparative cost of working the different lines of railway, have to be determined, it must be done in a different manner. Having ascertained, that on one line of road, the general average rate of speed is less than that upon another, we must then calculate what increased power of engine is necessary, to convey the same quantity of goods at a similar rate of speed; and next ascertain the increased cost of working such engine, compared with the cost of working the engines of less power, upon the other lines of road, but which smaller engines are enabled to drag the same load, at the required velocity.

This will be a more difficult problem, as all the cost of working those engines must enter into the calculation. If, however, the question simply is, whether one line is preferable to another, or not; without inquiring the degree or precise amount of superiority, as regards the cost of working, the preceding formula will determine the question.

We have stated, that an average rate of speed of twenty-four miles per hour, should be taken upon the level parts of the line; any other rate may be assumed, and it must be taken upon the level parts of the line, when the termini are upon the same level; when this is not the case, we must then take the load which an engine can travel with, at the proposed rate of speed, at the average rate of inclination between the two termini, and, in this latter case, we must estimate the result in both directions; and, to make the comparison complete, the quantity of traffic in both directions should be taken, to establish a general average.

Adopting the same dimensions of engine, as in the preceding investigations, (page 561,) viz., with an evaporating power, equal to fifty-four cubic feet of water per hour, and with a load of 100 tons, exclusive of the tender, weighing six tons; the following Table will shew the rate of speed, at which such engine will drag that load up planes of the different gradients given, and likewise the rate of speed, which such engine will travel down these planes. Taking one mile of plane, both ascending and descending, the third and fourth columns of the Table, will shew the time which the engine is in traversing that mile of road; the fifth column shewing the mean time, in both directions.

TABLE VII.

Gradients, or inclinations of plane.	Velocity in miles per hour, in ascending planes.	Velocity in miles per hour, in descending planes.	Time in min. in traversing one mile of ascending planes.	Time in min. in traversing one mile of descending planes.	Mean time in min. in traversing one mile in both directions.
Level.	19·16	19·16	3·1315	3·1315	3·1315
1 in 4480	18·65	19·69	3·2172	3·0472	3·1322
1 in 2240	18·17	20·25	3·3021	2·9630	3·1325
1 in 1120	17·28	21·49	3·4722	2·7920	3·1322
1 in 1000	17·07	21·80	3·5149	2·7522	3·1335
1 in 900	16·87	22·15	3·5565	2·7088	3·1326
1 in 800	16·63	22·58	3·6079	2·6572	3·1325
1 in 700	16·32	23·19	3·6764	2·5872	3·1318
1 in 600	15·93	24·02	3·7664	2·4979	3·1321
1 in 500	15·41	25·30	3·8935	2·3715	3·1325
1 in 400	14·69	27·51	4·0844	2·1810	3·1327
1 in 300	13·64	32·19	4·3988	1·8682	3·1335

These calculations are, however, founded, on the supposition that the evaporating power of the engine, is the same at all the different rates of speed; that the engine is capable of evaporating fifty-four cubic feet of water per hour, whether the engine is moving at the rate of 13·64, or at 32·19 miles an hour; and by this mode of calculation, the mean effect is nearly the same, whether the railway undulates, or is of an uniform level, between the two termini. This, however, though exhibiting the mechanical effect, requires some modification in practice; and shews the necessity, in attempting to determine the comparative merits of competing lines of railway, of attending to all the minutiæ of the motive power to be used upon them. We find, in § 4, Art. 5, that the evaporating powers of locomotive engines, are not the same at all rates of speed; and that, therefore, it is not in the nature of these machines to make up the loss of time, in ascending the planes, by the increased rate of speed, in descending. We find that, although there is an increase, per hour, of evaporation, by an increased rate of speed, yet, such increase of evaporation is not in the ratio of the increase of speed; but, according to the experiment, given in that section, only about equal to half the increased rate of speed; and, therefore, the piston, not being supplied with steam, of the density required by the theorem, from which the Table is calculated, the velocity will be reduced, and a diminution of effect will take place.

Until, therefore, we have ascertained, from numerous and conclusive experiments, the precise evaporating powers of these engines, at all the different rates of speed, and under all the circumstances, bearing upon the question; we cannot determine the relative merits of different lines of railway, where the two termini are the same, but where the gradients, in the intermediate space, differ from each other. We have commenced a series of experiments, to determine the evaporating powers of these engines, under all the different rates of speed, to solve this question; but which could not be finished in time for the publication of this work. And, when we consider the immense sums expended in effecting uniform gradients, on all the principal lines of railway, the importance of ascertaining, from correct and unquestionable experiments, the actual loss sustained, by a departure from uniform lines, must be admitted; and, therefore, it is of the utmost consequence, that such experiments should be sufficiently numerous, and strictly accurate, so as to determine the question satisfactorily.

With such information only, therefore, as we at present possess, it would be a waste of time to go further into the question; except to shew that undulating lines of railway, are, to a certain extent, inferior to uniform lines, for the use of locomotive engines. Taking the rate of evaporation as previously determined, we find that, for every mile per hour increase of speed, the evaporating power of the engine is increased only 1⅓ cubic feet per hour; an evaporation of fifty-four cubic feet produces a rate of 19·16 miles per hour, requiring 2·8 cubic feet of water, converted into steam, for each mile per hour rate of motion. If this ratio of evaporation is correct, it follows, that, for every mile per hour increase of speed above 19·16 miles, as shewn in Table VII, there will only be produced steam sufficient to supply the pistons with a rate of speed equal to half a mile per hour; and, consequently, we must make a reduction from the increase of velocity, of the descending trains. On the other hand, the evaporation will be diminished, by the reduced rate of speed, on the ascending gradients, but to what extent we cannot determine. Until, therefore, the precise rate of evaporation is known, we cannot test competing lines of railway by the effect of the moving power upon them; except that, as the steepest gradients will require a more rapid rate of speed, in descending, to make up for the loss of time in ascending; and as the diminution of effect will be in some ratio as the increased rate of speed, any line of road, with gradients of greater inclination, will be inferior to a line with gradients of a lesser rate of inclination.

We have not in these remarks, noticed the effect of the accelerating force of gravity on the descending planes, which, though not acting with great effect at the rapid rates of speed at which the trains move, must not be overlooked. Professor Barlow, in an appendix to the second edition of his work on the strength of timber, &c., has entered at considerable length into the question of the effect of different gradients on locomotive engines, which is well worth the attention of those interested in the subject. The conclusion he comes to, with respect to the comparative merits of different gradients, we think, requires revision. He takes the diminution of effect upon the ascending gradients, which may be considered as equivalent to those of Column 2 or 4, Table VII., and then takes the effect of the descending gradients, the same as upon a level; or makes what in Columns 3 and 5 varies with the gradients the same as for a level plane; or as 19·16 and 3·1315 respectively, for all the different gradients, and gives the mean of these as the effect upon different planes. Now, whatever may be the precise amount of assistance given to the motive power, by the gravitation of descending planes; it is quite clear they are more favourable than horizontal planes; and, therefore, the deductions by Professor Barlow, on this question, cannot be strictly correct in practice.

3.—*Table of the Power of Engines on Inclined Planes.*

We now give tables of the relative load in tons, which engines of the dimensions given in Table III., are capable of dragging, exclusive of the tender, weighing six tons; at the various rates of speed, from ten to thirty miles an hour, on different inclinations of road.

TABLE VIII.

Gross load in tons, which a locomotive engine, capable of evaporating 42 cubic feet of water per hour, will drag, exclusive of the tender, at the under-mentioned rates of speed, on different inclinations of planes.

Inclination of plane.	10 miles an hour.	12½ miles an hour.	15 miles an hour.	17½ miles an hour.	20 miles an hour.	22½ miles an hour.	25 miles an hour.	27½ miles an hour.	30 miles an hour.
Level -	tons. 243·01	tons. 178·20	tons. 132·29	tons. 100·69	tons. 76·91	tons. 58·46	tons. 43·70	tons. 31·62	tons. 21·55
1 in 4480 -	228·62	167·41	124·05	94·21	71·75	54·32	40·38	28·97	19·46
1 in 2240 -	215·75	157·75	116·68	88·40	67·13	50·62	37·41	26·61	17·59
1 in 1120 -	193·67	141·21	104·04	78·46	59·21	44·27	32·33	22·55	14·39
1 in 1000 -	188·98	137·69	101·36	76·35	57·53	42·93	31·25	21·69	13·72
1 in 900 -	185·24	134·88	99·21	74·66	56·18	41·85	30·38	20·99	13·17
1 in 800 -	178·83	130·08	95·54	71·77	53·88	40·01	28·90	19·82	12·24
1 in 700 -	172·17	125·08	91·73	68·77	51·49	38·09	27·37	18·59	11·28
1 in 600 -	164·01	118·97	87·06	65·10	48·57	35·75	25·49	17·09	10·09
1 in 500 -	153·61	111·17	81·12	60·41	44·84	32·76	23·09	15·11	8·59
1 in400 -	140·14	101·07	73·39	54·34	40·01	28·88	19·99	12·70	6·63
1 in 300 -	121·94	87·42	62·97	46·14	33·48	23·65	15·79	9·36	3·99
1 in 200 -	95·76	67·79	47·98	34·34	24·08	16·12	9·76	4·55	·20
1 in 100 -	55·25	37·42	24·79	16·09	9·55	4·48	·42	—	—

TABLE IX.

Gross load in tons, which a locomotive engine, capable of evaporating 48 cubic feet of water per hour, will drag, exclusive of the tender, at the under-mentioned rates of speed, upon different inclinations of planes.

Inclination of plane.	10 miles an hour.	12½ miles an hour.	15 miles an hour.	17½ miles an hour.	20 miles an hour.	22½ miles an hour.	25 miles an hour.	27½ miles an hour.	30 miles an hour.
	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
Level -	278·14	202·21	151·60	115·42	88·32	67·23	50·36	36·55	25·06
1 in 4480 -	261·74	190.03	142·23	108·06	82·47	62·55	46·62	33·57	22 72
1 in 2240 -	247·07	179·13	133·85	101·48	77·23	58·36	43·27	30·91	20·63
1 in 1120 -	221·92	160·45	119·48	90·19	68'25	51·18	37·53	26·35	17·04
1 in 1000 -	216·58	156·49	116·43	87·80	66·35	49·66	36·31	25·38	16·28
1 in 900 -	212·31	153·31	113·99	85·88	64·83	48·44	35·33	24·60	15·67
1 in 800 -	204·85	147·89	109·82	82·60	62·22	46·36	33·67	23·28	14·63
1 in 700 -	197·42	142·26	105·48	79·20	59·51	44·19	31·93	21·90	13·56
1 in 600 -	188·13	135·35	100·17	75·03	56·19	41·54	29·81	20·21	12·23
1 in 500 -	176·27	126·55	93·41	69·71	51·96	38·15	27·11	18·06	10·54
1 in 400 -	160·92	115·14	84·64	62·82	46·49	33·77	23·60	15·28	8·35
1 in 300 -	140·18	99 74	72·79	58·52	39·09	27·86	18·87	11·52	5·40
1 in 200 -	110·34	77·58	55·74	40·13	28·44	19·34	12·06	6·10	1·14
1 in 100 -	64·19	43·30	29·38	19·42	11·97	6·13	1·53	—	—

TABLE X.

Gross load in tons, which a locomotive engine, capable of evaporating 54 cubic feet of water per hour, will drag, exclusive of the tender, at the under-mentioned rates of speed, on different inclinations of planes.

Inclination of plane.	10 miles an hour.	12½ miles an hour.	15 miles an hour.	17½ miles an hour.	20 miles an hour.	22½ miles an hour.	25 miles an hour.	27½ miles an hour.	30 miles an hour.
	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
Level -	312·12	26·27	169·39	128·69	98·15	74·40	55·40	39·86	26·91
1 in 4480 -	293·78	212·69	158·98	120·54	91·69	69·26	51·32	36·64	24·41
1 in 2240 -	277·37	200·56	149·66	113·25	8592	64·67	47·67	33·78	22·18
1 in 1120 -	249·24	179·74	133·69	100·75	76·02	56·8	41·42	28·84	18·35
1 in 1000 -	243·27	175·32	130·3	98·09	73·92	55·13	40·09	27·79	17·54
1 in 900 -	238·49	171·78	127·59	95·97	72·24	53·79	39·03	26·95	16·89
1 in 800 -	230·32	165·74	122·95	92·34	69·37	51·5	37·21	25·52	15·78
1 in 700 -	221·83	159·46	118·13	88·57	66·38	49·13	35·32	24·03	14·63
1 in 600 -	211·44	151·77	112·23	88·13	62·72	46·22	33·01	22·21	13·21
1 in 500 -	198·18	141·96	104·71	78·06	58·06	42·51	30·06	19·89	11·41
1 in 400 -	181·	129·25	94·96	70·43	52·02	37·7	26·25	16·88	9·09
1 in 300 -	15 7·81	112·09	81·8	60·12	43·86	31·21	21·09	12·81	5·92
1 in 200 -	124·44	87·40	62·85	45·29	32·12	21·87	13·67	6·96	1·38
1 in 100 -	72·80	49·19	83·54	22·35	13·95	7·41	2·19	—	—

TABLE XI.

Gross load in tons, which an engine, capable of evaporating 60 cubic feet of water per hour, will drag, exclusive of the tender, at the under-mentioned rates of speed, on different inclinations of planes.

Inclination of plane.	10 miles an hour.	12½ miles an hour.	15 miles an hour.	17½ miles an hour.	20 miles an hour.	22½ miles an hour.	25 miles an hour.	27½ miles an hour.	30 miles an hour.
	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
Level -	346·	251·10	187·84	142·64	108·75	82·38	61·29	44·04	29·66
1 in 4480 -	325·72	236·09	176·35	133·66	101·65	76·75	56·83	40·54	26·95
1 in 2240 -	307·58	222·67	166·06	125·62	95·30	71·71	52·84	37·40	24·54
1 in 1120 -	276·47	199·65	148·44	111·85	84·41	63·07	45·99	32·03	20·39
1 in 1000 -	269·87	194·76	144·70	108·93	82·11	61·24	44·54	30·89	19·51
1 in 900 -	264·59	190·85	141·70	106·58	80·25	59·77	43·38	29·98	18·80
1 in 800 -	255·56	184·17	136·59	102·5	77·09	57·25	41·40	28·42	17·60
1 in 700 -	246·17	177·22	131·27	98·43	73·81	54·65	39·33	26·79	16·35
1 in 600 -	234·68	168·72	124·75	93·34	69·78	51·46	36·80	24·81	14·82
1 in 500 -	220·02	157·87	116·45	86·85	64·65	47·38	33·58	22·28	12·86
1 in 400 -	201·04	143·82	105·69	78·44	58·01	42·11	29·40	19·	10·33
1 in 300 -	175·39	124·85	91·16	67·09	49·03	34·99	23·76	14·57	6·91
1 in 200 -	138·48	97·54	70·24	50·74	36·12	24·74	15·64	8·20	1·99
1 in 100 -	84·07	55·30	37·89	25·46	16·14	8·88	3·09	—	—

Art. 9.—*Cost of Locomotive Engines on Railways.*

We shall now endeavour to ascertain the cost of working railways by locomotive engines, and shall take, in the first place, the cost of the Liverpool and Manchester, which has been longest in use of any of the public railways in this country. We are, however, aware, in doing this, it will shew a result unfavourable to the system; for this railway was established before the locomotive engines, as applicable to public railways, came into operation; and, therefore, all the improvements and expense, of raising the locomotive engine, from a very inefficient to its present state of perfection, have been borne by that railway. In consequence thereof, many of the first engines and carriages became quite useless, or not adapted to the improved system, long before they were worn out; the expense, therefore, of establishing a system of motive power, added to the cost of working under such disadvantageous circumstances, would, of necessity, enhance the expenses much beyond what must be expected upon more modern lines of road, having all the benefit of this experience, and commencing with engines of the most improved description.

The rails upon the Liverpool railway were also laid down much too light, and not at all adapted to the weight of the improved engines. Independently, therefore, of having to incur the expense, of keeping up a line of road, quite incapable of sustaining the weight of the modern engines and carriages; the company have had almost the entire line of railway to replace with heavier rails, blocks, chairs, &c. With these explanations, we now give the cost of working that line, taken from the half yearly accounts of that company.

We have divided the charges into the following classifications, for the purpose of ascertaining the cost of each department of the work.

a.—*Expense of working the Liverpool and Manchester Railway.*

1. Locomotive power, or haulage.
2. Maintenance of railway.
3. Coaching department, or conveyance of passengers.
4. Carrying department, or conveyance of goods.
5. Stationary engine expenses.
6. General expenses.
7. Interest of capital.

The following tables will, therefore, shew the expenses of each of the several departments of cost, from the 31st December 1831 to the 30th June 1834.

TABLE I.

Expense of haulage, or locomotive power, on the Liverpool and Manchester railway, from the half yearly accounts, from 31st December 1831 to the 30th June 1834.

	Half year ending 30th June 1832.			Half year ending 31st Dec. 1832.			Half year ending 30th June 1833.			Half year ending 30th Dec. 1833.			Half year ending 30th June 1834.			Total.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Coke and carting - - -	2,957	8	0	3,848	10	8	2,795	4	5	3,197	4	4	2,882	11	4	15,680	18	9
Wages to coke fillers, and watering engines - - - -	-	-		-	-		338	16	10	348	8	5	386	19	5	1,074	4	8
Gas, oil, tallow, hemp, &c. - -	507	3	1	661	1	9	760	15	2	865	14	9	881	18	4	3,676	13	1
Copper and brass tubes, iron, timber, &c., for repairs - - -	5,947	6	5	3,723	9	7	3,290	8	8	3,755	3	7	4,140	19	6	20,857	7	9
Men's wages, repairing - -	-	-		3,352	16	2	4,115	0	8	4,401	4	10	5,432	8	8	17,301	10	4
Enginemen's and firemen's wages -	1,170	18	0	1,060	11	6	892	4	4	784	8	5	836	14	3	4,744	17	2
Out-door repairs to engines -	-	-		-	-		943	6	8	613	3	9	-	-		1,556	10	5
New engines - - -	-	-		-	-		1,580	0	0	-	-		1,080	6	4	2,660	6	4
Total - - -	10,582	16	2	12,646	9	8	14,715	16	9	13,965	8	1	15,641	17	10	67,552	8	6

TABLE II.

Maintenance of railway expenses, on the Liverpool and Manchester railway, from 30th December 1831, to 30th June 1834.

Maintenance of railway.	Half year ending 30th June 1832.			Half year ending 30th Dec. 1832.			Half year ending 30th June 1833.			Half year ending 30th Dec. 1833.			Half year ending 30th June 1834.			Total.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Wages to plate-layers, joiners, &c. - -	3,929	8	0	3,675	16	5	3,648	18	5	2,937	19	2	4,221	2	5	18,413	4	5
Stone, blocks, sleepers, keys, chairs, &c. -	2,668	12	3	2,355	17	1	2,052	5	11	2,411	2	4	1,482	18	7	10,970	16	2
Ballasting and draining	733	0	3	846	10	9	1,013	4	11	925	16	11	493	2	0	4,011	14	10
New rails - -	-	-		-	-		-	-		150	16	3	3,153	14	5	3,304	10	8
Repairs to walls and fences - -	-	-		-	-		296	4	0	665	3	4	644	0	11	1,605	8	3
Total -	7,331	0	6	6,878	4	3	7,010	13	3	7,090	18	0	9,994	18	4	38,305	14	4

TABLE III.

Expense of the coaching or carrying department, on the Liverpool and Manchester railway, from 31st December 1831 to 30th June 1834.

	Particulars of cost.	Half year ending 30th June 1832.	Half year ending 31st Dec. 1832.	Half year ending 30th June 1833.	Half year ending 31st Dec. 1833.	Half year ending 30th June 1834.	Total.
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Expenses of attendants, &c.	Guards and porters wages - -	1,104 4 6	1,173 19 6	1,150 4 0	1,168 4 6	1,167 11 10	5,764 4 4
	Parcel carts, horse keep, and drivers wages - - -	254 10 5	375 14 4	401 18 6	361 1 7	359 13 0	1,752 17 10
	Gas, oil, tallow, cordage, &c. -	238 14 6	282 11 7	324 4 0	196 4 11	358 15 6	1,340 10 6
	Stationery and petty expenses -	441 1 7	414 19 7	236 15 6	277 4 5	165 2 5	1,535 3 6
	Taxes on offices, stations, &c. -	- -	- -	112 18 4	116 0 8	65 8 11	294 7 11
	Guards clothes - - -	- -	- -	- -	64 15 0	- -	64 15 0
	Compensation for losses of goods, &c. - - - -	101 10 9	209 15 11	38 1 2	142 4 8	26 3 10	517 16 4
	Coach office establishment, rent, and taxes - - -	680 3 1	631 19 0	680 6 7	142 4 8	678 3 0	2,812 16 4
							14,082 11 9
Upholding coaches.	Materials for repairing carriages	1,777 9 4	464 1 9	383 15 11	689 12 6	1,007 9 7	2,544 19 9
	Men's wages, repairing ditto		613 18 1	578 10 6	1,041 1 3	1,221 15 5	5,232 14 7
							7,777 14 4
	Duty on passengers - - -	1,082 0 7	985 19 1	2,466 15 4	3,224 11 11	3,008 1 11	10,767 8 10
		5,669 14 9	5,102 18 10	6,373 9 10	7,423 6 1	8,058 5 5	32,627 14 11

TABLE IV.

Expense of carrying goods, on the Liverpool and Manchester railway, from 31st December 1831, to 30th June 1834.

	Particulars of cost.	Half year ending 30th June 1832.			Half year ending 31st Dec. 1832.			Half year ending 30th June 1833.			Half year ending 31st Dec. 1833.			Half year ending 30th June 1834.			Total.		
		£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Conducting traffic.	Agents and clerks salaries -	1,749	5	10	1,822	13	2	1,703	17	6	1,728	16	9	1,740	14	2	8,745	7	5
	Porters and brakemen's wages, horse keepers - -	4,328	6	5	3,925	7	4	4,687	9	7	5,006	6	10	5,397	8	5	23,344	18	7
	Gas, oil, tallow, cordage, &c. -	461	12	6	296	11	7	648	4	11	529	17	0	708	17	4	2,645	3	4
	Stationery and petty expenses -	503	10	8	540	13	5	336	9	0	429	5	1	290	3	2	2,100	1	4
	Taxes and insurance on offices, &c. - - - - -	-	-		-	-		798	1	8	456	17	7	469	6	2	1,724	5	5
	Sacks, for grain - - -	-	-		-	-		-	-		110	3	10	-	-		110	3	10
	Compensation for losses on goods	288	10	3	150	19	11	1,033	18	3	223	10	11	645	6	0	2,342	5	4
																	41,012	5	3
Waggons expenses.	Repairs to gigging, trucks, &c. -	163	14	11	398	3	11	405	13	1	366	9	11	716	2	8	2,050	4	6
	Smiths and joiners' wages -	586	6	7	583	0	5	598	3	1	718	19	7	773	3	8	3,259	13	4
	Iron, timber, castings, &c. -	265	0	9	350	12	10	320	1	4	700	9	1	728	12	4	2,364	16	4
	Cordage, paint, &c. - -	155	10	10	31	0	0	82	7	3	28	5	2	109	19	2	407	2	5
	Canvass for sheets - -	-	-		-	-		-	-		163	6	5	240	0	0	403	6	5
																	8,485	3	0
	Total - -	8,501	18	9	8,099	2	7	10,614	5	8	10,462	8	2	11,819	13	1	49,497	8	3

TABLE V.

Maintenance of stationary engine expenses on the Liverpool and Manchester railway, from 31st December 1831 to 30th June 1834.

Stationary engine expenses.	Half year ending 30th June 1832.			Half year ending 31st Dec. 1832.			Half year ending 30th June 1833.			Half year ending 31st Dec. 1833.			Half year ending 30th June 1834.			Total.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Coal for engine -	265	7	0	209	15	3	155	8	1	302	6	5	327	12	1	1,260	8	10
Engine and brakemen's wages -	290	9	9	316	5	7	363	8	10	319	12	2	385	7	0	1,675	3	4
Repairs, gas, oil, tallow, &c. -	165	8	9	326	14	7	340	15	11	419	15	5	273	11	1	1,526	5	9
New ropes -	-		-	-	-	-	-	-	-	266	3	6	-	-	-	266	3	6
Total -	721	5	6	852	15	5	859	12	10	1307	17	6	986	10	2	4,728	1	5

TABLE VI.

General expenses on the Liverpool and Manchester railway, from 31st December 1831 to 30th June 1834.

—	Half year ending 30th June 1832.			Half year ending 31st Dec. 1832.			Half year ending 30th June 1833.			Half year ending 31st Dec. 1833.			Half year ending 30th June 1834.			Total.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Advertising accounts	-	-		-	-		50	8	7	6	10	0	16	15	0	73	13	7
Bad debt account -	394	5	7	81	6	0	176	18	6	374	10	1	75	12	3	1,102	12	5
Coal disbursements -	26	8	10	27	2	10	120	16	1	82	0	9	45	1	0	301	9	6
Charge for direction -	308	14	0	295	1	0	252	0	0	312	18	0	289	16	0	1,458	9	0
Engineering department - - -	520	9	0	450	0	0	441	17	4	319	3	9	352	10	0	2,084	0	1
Office establishment -	811	8	1	727	7	0	744	16	11	722	6	2	877	2	4	3,883	0	6
Police - - -	1,356	9	11	902	16	5	950	4	7	1,022	7	6	1,016	18	1	5,284	16	6
Petty disbursements -	75	1	0	66	2	0	70	0	0	61	19	6	60	0	0	333	2	6
Rent - -	1,840	1	10	1,246	5	0	601	15	8	603	10	8	363	11	11	4,655	5	1
Taxes and rates -	1,109	14	9	3,483	18	2	1,891	0	7	3,409	11	0	1,778	16	10	11,673	1	4
Law disbursements -	-	-		118	3	8	-	-		300	3	9	100	0	0	518	7	5
																31,331	17	11
Cartage to Liverpool	-	-		-	-		18	4	6	80	17	10	80	17	6	179	19	10
Manchester	1,420	4	9	2,744	18	7	2,460	16	1	3,173	18	0	2,988	6	2	12,788	3	7
Interest - - -	5,966	14	11	4,555	15	7	5,367	11	9	5,140	6	4	5,546	4	0	26,576	12	7
Total -	13,829	12	8	14,698	16	3	13,146	10	7	15,610	3	4	13,591	11	1	70,876	13	11

We also give the cost of working the said railway, from 30th June 1834 to 30th June 1837, classified under the same heads, but not giving the particulars so fully as in the preceding period, the directors having determined, in 1835, not to publish the expenses with such minuteness.

TABLE VII.

Total expenses of working the Liverpool and Manchester railway, from the 31st December 1831 to and with 30th June 1837. Taken from the accounts of the company.

	—	From 31st Dec. 1831 to 30th June 1834, as per former accounts.			Half year ending 31st Dec. 1834.			Half year ending 30th June 1835.			Half year ending 31st Dec. 1835.			Half year ending 30th June 1836.			Half year ending 31st Dec. 1836.			Half year ending 30th June 1837.			Total.		
		£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
General expenses	Advertising accounts -	73	13	7	—			—			—			—			—			—			73	13	7
	Bad debt account -	1102	12	5	292	2	6	246	18	4	332	15	10	233	13	9	244	15	6	221	18	0	2674	16	4
	Coal disbursements -	301	9	6	220	1	8	188	0	7	223	16	8	202	11	8	414	8	6	313	1	2	1863	9	9
	Charge for direction -	1458	9	0	301	7	0	311	17	0	269	17	0	309	15	0	347	11	0	366	9	0	3365	5	0
	Engineering department	2084	0	1	352	10	0	352	10	0	352	10	0	427	10	0	296	5	0	125	0	0	3990	5	1
	Office establishment -	3883	0	6	887	1	1	901	10	6	917	15	1	945	9	10	941	7	11	1002	2	8	9478	7	7
	Police - - -	5248	16	6	1033	4	4	1155	7	11	1154	8	3	157	10	4	1237	1	11	1158	17	8	12145	6	11
	Petty disbursements -	333	2	6	40	0	0	55	5	0	39	18	4	52	0	1	30	0	0	50	5	2	600	11	1
	Rent - - -	4655	5	1	233	15	0	254	5	3	180	6	7	148	8	2	239	12	5	494	19	7	6206	14	1
	Taxes and Rates -	11673	1	4	2729	17	6	2157	9	4	3356	4	11	2666	0	5	3098	6	8	2509	18	3	28190	18	5
	Law disbursements -	518	7	5	100	0	0	250	0	0	200	0	0	—			200	0	0	150	0	0	1418	7	5
	Cartage to Liverpool -	179	19	10	59	16	8	73	15	10	101	6	5	211	6	7	168	8	2	321	9	1	1116	2	7
	Cartage to Manchester -	12788	3	7	3247	2	3	3322	14	6	4266	18	7	3775	1	8	3986	9	8	3613	2	0	34999	12	3
	Interest - - -	26576	12	7	6725	14	5	6878	1	6	9056	10	8	6681	7	7	9675	9	4	6253	8	3	71847	4	4
	Locomotive power -	67552	8	6	18364	12	7	16462	0	0	15681	17	9	20425	8	4	21526	17	4	22154	19	6	182168	4	0
Coaching expenses	Coach disbursements -	29297	2	3	8128	16	2	8372	1	8	10012	15	5	10202	0	6	12627	14	8	10296	11	6	88937	2	2
	Compensation - -	517	16	4	43	1	11	85	3	4	59	17	4	27	12	2	56	8	9	59	9	6	799	9	4
	Coach office expenses -	2812	16	4	676	5	0	693	9	6	688	18	6	670	18	8	741	2	11	840	7	10	7123	18	9
Carrying goods	Carrying disbursements -	38669	19	11	8562	0	0	9257	10	8	9490	13	11	10463	10	6	10601	1	3	9646	12	1	96691	8	4
	Compensation - -	2342	5	4	222	19	8	—			3409	16	0	349	7	1	136	14	1	201	0	3	6662	2	5
	Waggon expenses -	8485	3	0	2680	2	4	2857	6	7	2767	10	10	3166	0	0	5043	8	11	2861	7	2	27860	18	10
Railway	Maintenance of way -	36700	2	1	7963	8	10	6116	15	10	7536	10	4	5749	4	2	4714	8	11	4113	4	3	72893	14	5
	Repairs to walls and fences	1605	12	3	712	9	9	699	8	10	724	4	11	907	2	1	1204	2	10	876	7	3	6729	7	11
	Stationary engine expenses	4728	1	5	67	9	11	488	10	10	712	2	7	812	4	10	1076	13	7	965	6	6	9350	9	8
	Total - -	263,588	1	4	64,143	18	7	61,190	3	0	71,536	15	11	69,584	3	5	76,608	9	4	68,595	16	8	677,187	8	3

The following Table will shew the gross Receipts of the Liverpool and Manchester Railway, from 31st December 1831 to 30th June 1837.

TABLE VIII.

Gross receipts on the Liverpool and Manchester railway, for five years and a half, ending 30th June 1837.

Half years ending	Receipts for passengers.			Receipts for merchandize.			Receipts for coal.			Total receipts.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
30th June 1832	40,044	14	7	32,477	14	0	2,184	7	6	74.706	16	1
31st December 1832	43,120	6	11	34,977	12	7	2,804	3	4	80,902	2	10
30th June 1833	44,130	17	2	39,301	17	3	2,638	15	9	86,071	10	2
31st December 1833	54,685	6	11	39,957	16	8	2,591	6	6	97,234	10	1
30th June 1834	50,770	16	11	41,087	19	5	2,925	15	11	94,784	12	3
	232,752	3	4	187,802	19	11	12,144	9	0	433,699	11	5
31st December 1834	60,292	7	4	41,197	18	6	3,408	16	4	104,899	2	2
30th June 1835	52,437	3	4	43,631	1	4	3,406	11	4	99,474	16	0
31st December 1835	67,897	19	2	46,375	15	8	3,682	8	8	117,956	3	6
30th June 1836	57,914	2	5	47,441	1	1	4,000	8	4	109,355	11	10
31st December 1836	75,986	13	9	45,742	6	4	3,550	10	4	125,280	0	5
30th June 1837	59,956	4	6	42,698	13	4	3,296	18	2	105,951	16	0
Total	607,236	13	0	454,890	6	2	34,490	2	2	1,096,617	1	4

And the following Table will shew the performances of the engines, and the different quantities of traffic and passengers, conveyed upon that road, for two years and a half, ending 30th June 1834.

TABLE IX.

Half years ending	Merchandize.		Coals.		Passengers.	Locomotive engines.	
	Liverpool and Manchester.	To and from different parts of the road. 1.	Liverpool and Bolton Junction. 2.	From different parts of the road by the engines. 3.	Number of passengers booked at company's offices.	Number of trips, of 30 miles each, by engines with passengers.	Number of trips, of 30 miles each, by engines with merchandize.
	tons.	tons.	tons.	tons.			
30th June 1832	54,174	3,707	14,720	22,045	174,122	2,636	2,482
31st Dec. —	61,995	6,011	18,836	39,940	182,823	3,363	1,890
30th June 1833	68,284	8,712	19,461	41,375	171,421	3,262	2,244
31st Dec. —	69,806	9,733	18,708	40,134	215,071	3,253	2,587
30th June 1834	69,522	15,201	19,633	46,039	200,676	3,317	2,499
Total -	323,781	44,364	91,358	189,533	944,113	15,831	11,702

1. These are the goods carried to the branches of Wigan and Warrington, which may be taken at fifteen miles.
2. These goods may be considered to be conveyed fifteen miles along the railway.
3. The coals travel, on an average, one half the length of the line, or fifteen miles.

The distance generally travelled by each locomotive engine, is about 20,000 miles per annum, although some have travelled upwards of 30,000 miles; the average may be taken at 20,000 to 24,000 miles per annum.

We shall now consider the charges, under their different heads.

1.—*Locomotive Power, or Haulage of Goods and Passengers.*

The entire cost of locomotive power, from 31st December 1831 to and with 30th June 1834, including new engines, is -	£67,552	8	6
Deduct new engines, added to the stock during that time - - -	2,660	6	4
	£64,892	2	2

	Tons.
During this period there was conveyed, between Liverpool and Manchester, thirty miles - - - - -	323,781 of goods.
To and from different parts of the line, averaging 15 miles, 44,364 tons, for 30 miles - - - - -	22,182 ditto.
	345,963 of goods

conveyed 30 miles, or from one end of the line to the other.

In another part of this work, we have seen that the undulations and planes, upon the Liverpool railroad, produce an increase of resistance to the motive power, equal to 4½ miles on a level, which must be added to the thirty miles, to bring out the performances upon a level road; we have then 345,963 × 34½ = 11,935,713 tons of goods conveyed one mile.

The number of trips, of 30 miles each, with goods during that period was 11,257, and with passengers 15,831, = 27,533. Taking the entire cost of the engines, and dividing it, in the proportion of the number of trips, we have as 11,257 : 27,533 :: 64,892 : 27,580*l.*, the cost of conveying the goods; which, for 11,935,713 tons, is equal to 0·55*d.* per ton per mile.

We see that the engines made 11,257 trips, for the conveyance of 345,963 tons of goods; the quantity conveyed at each trip would, therefore, average 30·73 tons.

We cannot apply this to other railroads, however, unless we take in the gross load conveyed; as the proportions between the goods and the gross load, and also the quantity conveyed at a time, may vary on different lines of road. The weight of the empty carriages is about 1·5 tons, and the load which they generally carry is 3·5 tons; we have, therefore,

the weight of goods - - - = 345,963 tons.
Weight of the waggons 345,963 × $\frac{1\cdot5}{3\cdot5}$ = 148,270
And as the traffic in this case is not equal in both directions, the engines have to bring back from Manchester about half the waggons empty, which is a dead weight, equal to one fourth of the weight of the whole waggons - - = 37,067

531,300 tons gross,

conveyed a distance equal to 34½ miles on a level, = 18,329,850 tons conveyed one mile; or, 0·36*d.* per ton per mile gross load; the gross load taken each trip being 47·2 tons.

The average rate of travelling with passengers is, exclusive of stops, 24 miles an hour, and with goods 15 miles; we have, therefore, 15,831 trips at 24 miles, and 11,257 trips at 15 miles an hour, the average being 20 miles an hour; and as in the cost of the engines we have taken the average for both passengers and goods, it follows, that the above cost per ton per mile, will be at an average velocity of 20 miles an hour.

We come now to the cost of conveying passengers, taking the expense of the engines in the same manner as for the goods, we have the entire cost, in the above time, 37,312*l.* There has been conveyed, in that time, 944,113 passengers, a distance equal on a level road of 34½ miles, or equal to 32,571,898 passengers one mile, which, for 37,312*l.* is 0·27*d.* per passenger per mile. Reducing this into the cost per ton per mile, we find that there were 15,831 trips, which, for 944,113 passengers, is 60 passengers each trip. The number of carriages generally taken in each train is, 6 first class carriages, each weighing 3·05 tons, and the mail weighing 2·71 tons = 21 tons; and for the second class trains, 5 carriages, each weighing 2·23 tons, and one glass coach, weighing 3·05 tons. The system kept up is 13 trains of first class, for 13 trains of the second class; we thus find the average weight of the carriages for each trip of the engine, will be 17·2 tons; reckoning 15 passengers per ton, and 28lbs. of luggage to each passenger,

we have 944,113 passengers, at 15 per ton, -	62,941 tons.
15,831 trains of carriages, at 17·2 tons each, -	272,293
Luggage for 944,113 passengers, at 28 lbs. each, - - - - - -	11,801
	347,035 tons,

conveyed a distance equal to 34½ miles; or 11,971,709 tons conveyed one mile, at an expense of engine power of 37,312*l.*, is nearly 0·75*d.* per ton per mile, and the load for each trip will be nearly 22 tons; we see, therefore, the increased expense of travelling at great rates of speed with light loads.

In the aggregate cost we have the entire expense of locomotive power 64,892*l.* 2*s.* 2*d.*; the quantity of goods and passengers conveyed for this outlay is 18,329,850 tons, and of passengers 11,971,709 tons, gross load one mile, which is equal to ·51 of a penny per ton per mile, gross load.

Reckoning the proportion of useful to gross load as 3·5 : 5, the cost per ton per mile of useful load is equal to ·73 of a penny; the average load for each trip being 32·4 tons gross, or about 24 tons of goods.

The following table will shew the expense of locomotive power, or haulage, of the different descriptions of traffic, according to the above mode of calculation.

	Merchandise.		Passengers.		Aggregate cost per ton per mile.	
	Per ton per mile of goods.	Per ton per mile gross load.	Per passenger per mile.	Per ton per mile gross.	Useful load in goods.	Gross load.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
Locomotive power, or haulage -	0·55	0·36	0·27	0·73	0·73	0·51

We understand that the London and Birmingham Railway Company, have contracted for their motive power, at 0·5*d.* per ton per mile of goods, and 0·25*d.* per mile for passengers.

2.—*Maintenance of Railway.*

Table II. will shew the expense of the maintenance of the railway for 2¼ years. As previously stated, the rails upon the Liverpool and Manchester railway were originally laid down 35lbs. per yard, which was found to be quite inadequate to carry the heavy engines, required to keep up the rate of travelling, adopted on that line of railway. This not only increased the expense of keeping the road in repair, but it was found necessary to replace the rails, by others of a greater weight and strength. As our object in this inquiry, is more to ascertain the cost of maintaining railways properly constructed; than to shew the cost of the Liverpool, we ought to deduct the charges for new rails, and the expense of laying the rails down.

Total cost of maintenance of railway		£36,701 1 9
Deduct:		
New rails -	£3,304 10 8	
Labour, &c. in laying new rails - -	540 0 0	
		3,844 10 8
		£32,756 11 4 for 2¼ years,
		or 13,103*l.* per annum.

The entire length of the Liverpool and Manchester railway is 30 miles 1,240 yards, besides the tunnel for passengers; but, as the passengers and goods are conveyed along different branches or tunnels, we may take the entire distance as equal to 31 miles; which, for 13,103*l.*, is equal to 422*l.* 13*s.* 6*d.* per mile per annum of double line.

The quantity of traffic conveyed along the line, during the 2¼ years ending 30th June 1834, is as follows, per Table II.

	Tons.	
Goods between Liverpool and Manchester, 323,781 tons, for 31 miles, equal - -	10,037,211	one mile.
Goods to and from different parts of the road, 44,364 tons, for 15 miles, equal -	665,460	ditto.
Goods from Liverpool to Bolton Junction, 91,358 tons, for 15 miles, equal - -	1,370,370	ditto.
Coal from different parts of the road, 189,533 tons, for 15 miles, equal -	2,842,995	ditto.
Weight of waggons $\frac{6}{14}$ parts of the weight of goods, 6,392,587 tons - - Waggons brought back empty, one fourth of the whole, 1,598,146 tons - -	7,990,733	ditto.
Total gross load of goods and waggons, conveyed one mile - - -	22,906,769	
Passengers as before, 944,113, at 15 passengers per ton - - - - -	62,941	
15,831 trains of carriages, at 17·2 tons each	272,293	
Luggage of passengers, at 28 lbs. each -	11,801	
	347,035	tons gross

load, conveyed 31 miles, or 10,758,085 tons conveyed one mile.

Apportioning the entire expense, according to the gross load conveyed along the railway, the following table will therefore shew the cost of maintaining the railway.

Head of charge.	Cost per mile per annum.	Merchandise per ton per mile.		Passengers.		Aggregate cost per ton per mile.	
		Goods.	Gross load.	Per mile.	Per ton per mile gross.	Goods.	Gross load.
	£ s. d.	d.	d.	d.	d.	d.	d.
Maintenance of Railway -	422 13 6	·307	·233	·085	·233	·307	·233

This charge will be considerably reduced, on all railways laid with strong rails, and where the blocks are well laid, and the road sufficiently consolidated. A great portion also of the above cost consists in ballasting, for raising the road where it yielded, and where it required raising to its proper level.

3.—*Coaching Department, or Expense of conveying Passengers.*

This may be divided into three heads of charge; the cost of keeping the carriages in repair, the expenses of conducting the traffic, and the duty on passengers; and we may likewise subdivide these into the cost, as relates to the expense of the coaching department alone, and the cost, when merged into the general traffic of the railway.

The total cost of keeping the carriages in repair, for 2½ years, ending 30th June 1834, is, as per Table III. 7,777*l.* 14*s.* 4*d.*; the expenses of conducting the traffic, 14,082*l.* 11*s.* 9*d.*; and the amount of duty on passengers, 10,767*l.* 8*s.* 10*d.*

The total number of passengers conveyed one mile, in the same time, is 32,571,898; the gross weight of passengers' luggage and carriages is 11,971,709 tons, conveyed one mile; by which the cost per passenger, and likewise per ton per mile, is calculated for that department alone. Combined with the general expense of working the railway, we have the aggregate amount of tonnage, equal to 18,329,850 tons of goods and carriages, and 11,971,709 tons of passengers and carriages, making a gross amount of 30,301,559 tons conveyed one mile; and if we take the relative weight of goods and carriages as 3·5 : 1·5, or, useful to gross load, as 3·5 : 5, we have the aggregate amount of useful load equal to 21,211,090 tons conveyed one mile; from which the following table is calculated.

Table of the Cost of the Coaching Department, on the Liverpool and Manchester Railway.

Head of charge.		Passengers.		Aggregate cost per ton per mile.	
		Per mile.	Per ton per mile gross.	Goods or useful load.	Gross load.
		d.	d	d.	d.
Coaching department -	Keeping coaches in repair.	·054	·146	·082	·058
	Expense of attendants, &c.	·104	·282	·158	·111
	Duty on passengers -	·071	·216	·108	·076
	Total cost - -	·229	·644	·348	·245

The first head of charge will appear greater, than what is likely to occur in future, if the carriages are constructed according to the most improved form; the second head of expense is also enhanced, by the number of trains set off from each end daily, to accommodate the public.

4.—*Carrying Department, or Cost of conveying Goods.*

We shall also divide this into two heads of charge; the cost of upholding waggons, and the cost of conducting the traffic; and the following table will shew the expense of each, and also the aggregate cost of carrying goods, calculated in the same manner as in the coaching department. We see by Table IV. that the entire cost of upholding waggons for 2¼ years, ending 30th June 1834, is 8,485*l.* 3*s.* 0*d.*, and the expense of conducting the traffic is 41,012*l.* 5*s.* 4*d.*; the gross amount of tons conveyed is 18,329,850 tons, conveyed one mile; and taking the proportion of useful to gross load at 3·5 : 5, the amount of useful load will be 12,830,895 tons conveyed one mile; the aggregate amount of traffic being the same as for the previous head of charge.

Head of charge.		Merchandise per ton per mile.		Aggregate cost per ton per mile.	
		Useful load or goods.	Gross load.	Useful load or goods.	Gross load.
		d.	*d.*	*d.*	*d.*
Carrying goods	Upholding waggons	0·227	0·159	0·094	0·067
	Conducting traffic -	1·08	0·76	0·463	0·324
Total cost - -		1·307	0·919	0·557	0·391

5. & 6.—*Stationary Engine, and General Expenses.*

In the first head of charge, although the passengers do not pass down the large tunnel, we have divided the expense over the whole traffic of the railway, to obtain the aggregate cost per ton per mile; and, in the second head of charge, we have also apportioned it according to the relative weight of goods conveyed along the railway. The total cost of working the stationary engine, is 4,728*l.* 1*s.* 5*d.*, and the general expenses 31,331*l.* 7*s.* 11*d.*;

taking the quantity of goods and passengers as in the preceding calculations, viz., 30,301,559 tons, conveyed one mile. The calculation for the separate charges, of goods and passengers, is taken by dividing the general expenses into the number of tons, of goods and passengers respectively; or, as 18,329,850 to 11,971,709 tons, making each of the charges the same cost per ton per mile, as the aggregate cost.

The following Table will shew the Result of the Cost of these Heads of Charge.

Heads of charge.	Merchandise per ton per mile.		Passengers.		Aggregate cost per ton per mile.	
	Useful load or of goods.	Gross load.	Per mile.	Per ton per mile gross.	Useful load or of goods.	Gross load.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
Stationary engine	- -	- -	- -	- -	0·053	0·037
General expenses -	0·354	0·248	0·091	0·248	0·354	0·248

In the general expenses, we have deducted the charge for interest, which cannot be considered a charge for working the railway, being, more properly, a part of, or substitution for, capital; and likewise the charge for cartage, at each end of the railway, which is not part of the cost of conveyance.

The following summary will, therefore, shew the expense of working a railway 30 miles in length, but with gradients such as increase the resistance, so as to make the cost of haulage equivalent to that of a level railway 34½ miles in length; taking the cost of working the Liverpool and Manchester railway, from 31st December 1831 to 30th June 1834, as a standard for the expenses.

TABLE X.

Heads of charge.	Merchandise per ton per mile.		Passengers.		Aggregate cost per ton per mile.	
	Useful load or of goods.	Gross load.	Per passenger per mile.	Per ton per mile gross.	Useful load or of goods.	Gross load.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
Locomotive power - -	0·55	0·36	0·27	0·73	0·73	0·51
Maintenance of railway -	0·307	0·233	0·085	0·233	0·307	0·233
Coaching { Upholding carriages	- -	- -	0·054	0·146	0·082	0·058
Coaching { Conducting coaching	- -	- -	0·104	0·282	0·158	0·111
Coaching { Duty on passengers -	- -	- -	0·071	0·216	—	—
Carrying goods - { Upholding waggons -	0·227	0·159	- -	- -	0·094	0·067
Carrying goods - { Conducting traffic -	1·08	0·76	- -	- -	0·463	0·324
General expenses - -	0·354	0·248	0·091	0·248	0·354	0·248
Total cost - -	2·518	1·760	0·675	1·855	2·188	1·551

The preceding inquiries relate to the cost of conveying goods, and passengers, upon public lines of railway; in the conveyance of general merchandise, the cost is very much enhanced, by the establishment required, for loading and unloading, receiving, and storing the goods, together with the expense of attendance at the different stations. We see, therefore, that the cost, per ton, for carriages, and for conveyance, is much greater, than for the passengers; in the application of public lines of railway, for the conveyance of coals, minerals, or other heavy articles, the loading and unloading of which are not great, or which is not done by the railway company, we find the cost very much diminished. We shall now, therefore, give the cost of transit of coals, by locomotive engines, upon some of the lines of railway, in the neighbourhood of Newcastle-upon-Tyne.

b.—Expense of working the Stockton and Darlington Railway.

We shall be able to give the cost of conveyance, upon this line of railway, pretty accurately. The company, in the first establishment of the railway, provided their own locomotive engines; in 1833, they entered into an agreement, with a company, to take their entire stock of engines, and convey the coals, at a certain price per ton, per mile. The contractors took not only all the stock of engines, but likewise all the shops, tools, machinery, &c., necessary for keeping them in repair; they were to haul all the coals upon the line, keep the engines in good working repair, finding all workmen and materials, and find all fuel, oil, tallow, grease for waggons, &c., and likewise pay *5l.* per cent. interest on the stock, which was to be valued to the contractors, and revalued at the end of the term; the railway company engaging to take all the stock again, and to pay, or receive, the difference, in value.

The contract price paid to the contractors, was four tenths of a penny per ton, per mile; the value of the stock being about 11,000*l.*, which, at *5l.* per cent. per annum, would be *550l.* per annum.

We have given, in the Appendix, (Note F.) the gradients of the railway, by which it will be seen, that it is a descending line, some parts of which are so much that the gravitating force is greater than the resistance of the load, while, in other parts, it is level, or nearly so. Taking the average load conveyed, in each trip, at 63 tons, and the weight of the waggons and tender, 36 tons, = 99 tons, at 9 lbs. per ton friction, is 891 lbs. for 95 tons, or $\frac{1}{236}$; on all those parts of the line, therefore, above $\frac{1}{236}$, the train would require no propelling force.

The distance, which the train would run of itself, is about 8·99 miles, and the distance which it would require to be propelled, 11·79 miles; the latter being of an average inclination of $\frac{1}{1112}$, the gravitation of which would be about 2 lbs. per ton, making the resistance 7 lbs. per ton, for 11·79 miles, and nothing, for 8·99 miles; the average being about 4 lbs. per ton, the mean resistance, with the load. With the empty load, the gravity of the plane increases the resistance, the whole distance; and the gravity acts upon the engine, and tender, as well as the load. The average inclination is $\frac{1}{286}$, acting upon the entire train, engine, and tender, weighing altogether, 32 + 4 + 12 = 48 tons, will be equal to 348 lbs., or, 10·9 lbs. per ton, upon the empty carriages; which, added to 9 lbs., the friction will be 19·9 lbs. per ton, the mean resistance with the empty carriages.

Reducing these to a level, and taking the friction at 9 lbs. per ton, we find the resistance of the loaded waggons, in descending one mile, equal to the resistance of the same load, conveyed four ninths of a mile on a level; and the resistance of the empty carriages, equal to that of the same weight, dragged 2·99 miles on a level.

The weight of the load is 2·65 tons, and the waggons, 1·30 tons; we then have the resistance, with the load, $\overline{2{\cdot}65 + 1{\cdot}30} \times 4 = 15{\cdot}80$; and, with the returning waggons, $\overline{1{\cdot}30 \times 19{\cdot}9} = 25{\cdot}87$. Then, $15{\cdot}80 + 25{\cdot}87 = 41{\cdot}67$, the resistance, in both directions. On a level road, the resistance would be $\overline{2{\cdot}65 + 1{\cdot}30 \times} 9 + \overline{1{\cdot}30 \times 9} = 47{\cdot}25$. Therefore, the resistance upon the Stockton and Darlington railway, for traffic, entirely in one direction, the empty waggons being the only load in returning, is as 41·67 : 47·25 on a level road, with the same description of traffic.

In one year, from the 30th June 1833, to 30th June 1834, the quantity of coals led was equal to 6,764,951 tons, conveyed one mile; the number of trips, of 20 miles each, being 5318½, and the average load, in each trip, 63·6 tons. The sum paid for interest of capital would, therefore, amount to ·02 of a penny per ton per mile; which, deducted from ·4, gives ·38 of a penny per ton per mile, as the cost of haulage on the Stockton and Darlington railway, in 1834.

Since that period, the cost of working the engines has been reduced, and, at present, the cost is stated, by the engineer of the railway, about ·3 of a penny per ton per mile; we may, however, safely take the cost of leading coals on that railway at ·35, the present charge for haulage being about ·4 of a penny per ton per mile. Reducing this to a level, we have, as 41·67 : 47·25 :: 35 : ·39 of a penny per ton per mile, or nearly equal to four tenths of a penny.

c.—Expense of working the Clarence Railway.

Clarence Railway.—Upon the Clarence railway, the charge for haulage, by locomotive engines, is three eighths, or, ·375 of a penny per ton per mile. This road descends, towards the shipping places, at an average rate of 7½ feet per mile; consequently, the diminution of resistance will be about equal to the 700th part of the whole, which will make the above rate of ·375 equivalent to ·376 of a penny per ton per mile, as the cost of haulage on a level road.

d.—Expense of the Killingworth Locomotive Engines.

Killingworth Railway.—An accurate account has been kept, of the cost of working this railway, for some years past, and the following result, for the year ending 1st November 1837, may be taken as the average yearly cost of these engines. One of the engines, on that year, led 283,644 tons of coals one mile, the entire cost, including repairs, coals, interest of capital, and upholding tubes, wheels, &c., was 264*l.* 2*s.*; this is equal to ·22 of a penny per ton per mile, the average load taken at a time being 42½ tons. The general inclination of the road, is about ten feet per mile, with the load, but it undulates, with a rise of 1 in 330, in that direction, which restricts the quantity taken at a time; taking, however, the resistance upon the whole line, the cost, upon a level, will not be materially increased, but may be taken at ·25 of a penny per ton per mile. This engine has a boiler fitted up, with tubes, as shewn in *Fig.* 14, *Plate VI.*

Another engine, less powerful, upon the same line of railway, and which did not convey more than 194,000 tons; cost nearly the same annual sum, including coals, and the expense was ·31 of a penny per ton per mile.

e.—Cost of Conveyance generally, with different descriptions of traffic on Railways.

We may, therefore, take the cost of haulage, by locomotive engines, upon a level railway, where the goods are conveyed in one direction only, at 0·38 of a penny per ton per mile; and, in favourable circumstances, at 0·25 per ton per mile. But, in this latter case, we must observe, that it is where the engines take a maximum load in every trip; and where they travel only at such a rate, as will produce the most economical result.

We thus see the great sacrifice of economy, by adopting a rapid rate of travelling, upon public lines of railway, where a mixed traffic of goods and passengers, is conveyed along the same line of road; and where, from necessity, the rate at which goods are conveyed, must, to a considerable extent, be the same as that for the conveyance of passengers. We find the cost on the Liverpool and Manchester railway ·55 per ton, per mile, the average load at each trip being 30¾ tons; while, upon the Stockton and Darlington railway, the cost is ·38 of a penny per ton, per mile, the average load being 63½ tons. Upon the Killingworth railway, the cost is ·25 per ton, per mile, the average load being 42½ tons; but it must be considered, that the Killingworth engines are not nearly the power of the Liverpool engines; the evaporating power of the former being, from 50 to 60 cubic feet, of water per hour, and the latter from 30 to 40 cubic feet, per hour.

The *cost of maintenance of the railway*, on railways exclusively adapted for the conveyance of heavy goods, may be taken at 0·2 of a penny per ton, per mile; the total expense, upon the Stockton and Darlington railway, for the year ending 30th June 1835, being 0·208 of a penny per mile, per ton of goods.

The *expense of waggons*, upon railways, used for the conveyance of coals, is not so great as the charge under the head of *carrying goods*, on public railways; the expense of loading and unloading the goods being so much greater than with coals. Upon the Stanhope and Tyne, and Brandling Junction railways, the company contract for finding waggons, and the sum paid is at the rate of 4*l.* per annum, for each waggon, with cast-iron wheels, carrying 53 cwt. of coals, the company being liable to all breakage. They charge the parties sending coals down their line, ½*d.* per chaldron of 53 cwt., per mile, for the use of waggons; which is equal to ·19*d.* per ton, per mile.

The coal proprietor loads the waggons, which costs about 1·13 pence per ton; and a separate charge of 1·13 pence per ton, is made for emptying the coals into the vessels. We cannot reduce this into the cost, per ton, per mile, without assuming a certain length of railway. If the railway is 30 miles, or equal to the Liverpool and Manchester, the cost of loading and unloading would be ·075*d.* per ton, per mile; or, ·265*d.* per ton, per mile, for the entire expense of loading, conveying, and unloading.

Upon the Newcastle and Carlisle railway, the minerals being partly conveyed at the same rate, and with the same trains as the passengers, malleable iron wheels of Mr. Losh's patent are used, which are contracted for at 5*l.* each per annum; the charge, made by the company, to the coal proprietors, being ·25*d.* per ton, per mile; which would make the entire cost ·325*d*. per ton, per mile, upon a public railway, for the conveyance of coals, including the cost of loading and unloading, the coals, the carriage of goods being in one direction only. (Note L., Appendix.)

General Expenses.—This sum will vary greatly, according to the quantity of coals led along the line annually; as the items, constituting this charge, will generally be nearly the same for a large, as for a small quantity. The cost, upon the Stockton and Darlington railway, in 1835, amounted to ·069*d*. per ton, per mile; but, upon this railway, the total quantity led amounts to upwards of 252,000 tons, annually; while, upon the Liverpool and Manchester railway, the quantity of goods does not average more than 170,000 tons annually, led from one end of the line to the other. We shall, therefore, suppose one tenth of a penny per ton, per mile, as the amount of the general expenses.

Upon the Stockton and Darlington, as well as upon the Clarence, and Hartlepool, railways, the entire dues, for maintenance of railway, general expenses, and interest of capital upon coals exported, is ½*d*. per ton, per mile; we have seen the cost of maintenance of the way to be ·2: this leaves only ·3 of a penny per ton, per mile, for general expenses and interest of capital.

The following table will, therefore, shew the cost of working a level line of railway, adapted for the conveyance of heavy goods, or for a mixed traffic, when the latter is such, that a maximum effect can be produced in the conveyance of heavy goods, without interruption to the general traffic of the line; and where the goods are generally carried in one direction only, the carriages having to be brought back empty in the other direction.

Heads of charge.	Cost per ton per mile.	
	Useful load.	Gross load.
	d.	*d.*
Locomotive power, or haulage - -	0·380	0·191
Maintenance of railway - -	0·208	0·104
Upholding waggons, including loading and unloading coals.	0·265	0·133
General expenses - - -	0·100	0·051
Total cost - -	0·953	0·479

We have added the cost, per ton, for the gross load, including waggons; on railways, where the traffic is not entirely in one direction, the cost, per ton, of useful load can be calculated. The weight of the waggons is 1·30 tons, the coals 2·65 tons; we have, therefore, 1·30+2·65 = 3·95 tons, the load in one direction, and 1·30 tons in the other; or, for every 2·65 tons of goods, or coals, 2·60 tons of waggons, or 5·25 tons gross; therefore, the proportion of useful to gross load is as 2·65 : 5·25, or nearly one half.

We may, therefore, according to the above table, take the entire cost of working such a railway, all the goods being conveyed in one direction, at 1*d.* per ton, per mile, of goods, and ½*d.* per ton per mile gross load.

We now come to the entire cost of conveying coals, including interest of capital. Upon the *Stanhope and*

Tyne railway, which is almost entirely a railway for the conveyance of coals, the charges, per chaldron, per mile, is 3*d.* for haulage and railway dues, or 1·13*d.* per ton; ½*d.* per chaldron, per mile, for finding waggons, or ·19; and 6*d.* per chaldron for shipping coals, each chaldron being 53 cwt.

But as, in the comparison with other modes of conveyance of heavy goods, these articles are always loaded and unloaded at the expense of the carriers, we shall not include that part of the charges; the entire cost, therefore, of conveying coals upon that line is 1·32*d.* per ton, per mile.

We have been favoured with the particulars of the cost of repairs, of the locomotive engines upon the Stanhope and Tyne railway, for the years 1835 and 1836.

Table XI.

Particulars of cost.	Year ending 31st Dec. 1835.			Year ending 31st Dec. 1836.		
	Materials.	Labour.	Total.	Materials.	Labour.	Total.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Boiler, fire-box, &c. -	84 18 9	118 0 4	202 19 1	304 7 3	151 0 3	455 8 6
Pumps, water-gauges, &c. -	45 10 6	40 17 3	86 7 9	60 14 3	70 18 2	131 12 5
Wheels - - -	128 7 4	26 8 7	154 15 11	251 14 2	41 16 0	293 10 2
Lifting and stripping engines, &c.	3 8 10	120 3 5	123 12 3	1 0 3	149 16 0	150 16 3
Machinery of engines -	31 3 2	108 17 9	140 0 11	76 4 9	131 10 8	207 15 5
Frames, springs, &c. -	26 0 7	43 11 3	69 11 10	21 12 3	49 15 9	71 7 11
General charges - -	4 17 1	14 6 4	19 3 5	6 11 9	17 17 3	24 9 0
	324 6 3	472 4 11	796 11 2	722 4 7	612 15 1	1,334 19 8
Tender, tanks, &c. -	60 1 6	45 16 1	105 17 7	55 1 5	62 17 1	117 18 6
Total - -	384 7 9	518 1 0	902 8 9	777 6 0	675 12 2	1,452 18 2
Quantity of work performed - - -	Gross load - 5,037,939 tons 1 mile. Goods - - 2,388,109 tons 1 mile.			Gross load - 5,284,627 tons 1 mile. Goods - - 2,437,200 tons 1 mile.		

We find, therefore, that the repairs of these engines, on the average of the two years of 1835 and 1836, amount to about ·111*d.* per ton, per mile, gross load, or ·237*d.* per ton, per mile, of goods.

In the Appendix, (Notes I. K.,) we give the particulars of the above expenses, arranged under the different heads of cost; from these, it will be seen, that a very great proportion indeed of these expenses consists of labour; or, in taking to pieces, and in obtaining access to the parts requiring repair, and that little more than one half the cost consists of materials; arising almost entirely from the construction of the engines, in placing all the machinery underneath the boiler, and by putting it into as small a space as possible. Mr. Harrison has attempted to diminish the expense of repairs, by placing the boiler and the machinery upon different carriages, with a steam-tight universal joint, of a very ingenious construction, to communicate between the boiler and cylinders, for which he has obtained a patent. *Plate XII.*

The following Table will shew the wear of wheels of the locomotive engines upon that railroad.

TABLE XII.

Names of engines.	Wheels manufactured by Robert Stephenson & Co.		Malleable iron tires.—Losh's patent wheels.
	Number of miles.	Number of miles.	Number of miles.
Robert Stephenson	12·756	15·280	15·600 will wear 4 months.
James Watt -	10·868	11·262	15·970 will wear 3 months.
Thomas Harrison -	10·928 (1)	15·358	—
Jacob Perkins -	13·822 (2)	21·418	—
Nathaniel Ogle -	16·082	12·104	5·228 wheels good.
John Buddle -	10·476	11·894	9·426 not worn out.
Thomas Newcomen	15·456	2·180 new	—

(1) Manufactured by R. & W. Hawthorn.

(2) Manufactured by Tayleur & Co.

From the preceding table, it will appear, that the wear of wheels, will be about 15,000 miles without turning; these wheels being four feet and a half in diameter.

Upon the *Clarence railway*, the charges are, haulage ·375*d.* per ton, per mile, railway dues ·5*d.* per ton, per mile; and as the company do not find waggons, if we take the cost the same as the Stanhope and Tyne railway, or ·19*d.* per ton, per mile, the entire charges for conveying coals along that line would therefore be 1·065*d.* per ton, per mile.

These charges are upon the export coals, or coals shipped; upon coals delivered at the landsale depôts, the charges for railway dues are 1*d.* per ton per mile, making the entire charge for those coals 1·565*d.* per ton, per mile.

The *Stockton and Darlington railway* company charge upon export coals, for haulage, ½*d.* per ton, per mile, from which a per-centage is deducted, reducing it to ·4*d.* per ton, per mile; railway dues ½*d.* per ton, per mile; and if we take the cost of waggons at ·19*d.*, the entire cost for export coals will be 1·09*d.* per ton, per mile, or a little more than is charged by the Clarence railway company. The charge for railway dues upon depôt or landsale coals is 1½*d.* per ton, per mile, making the entire cost 2·09*d.* per ton, per mile.

f.—Table of the Cost of conveying heavy Goods on Railways.

We have, therefore, the cost or charges made for conveying coals, upon the railways, in the north of England, as per following table.

TABLE XIII.

Names of railway.	Charges for haulage per ton per mile.	Cost of waggons per ton per mile.	Railway dues per ton per mile.		Total charges per ton per mile.	
			Export coals.	Landsale coals.	Export coals.	Land-sale coals.
		d.	d.	d.	d.	d.
Stanhope and Tyne	Charged in dues.	0·19	1·32	1·33	1·32	1·32
Clarence - -	0·375	0·19	0·5	1·0	1·065	1·565
Stockton and Darlington - -	0·400	0·19	0·5	1·5	1·090	2·09

g.—Table of the Cost of conveying Goods and Passengers on Railways.

Having, therefore, determined the expense of conveyance by locomotive power on railways, both on public railways, for the conveyance of general merchandize, minerals, and passengers; and, likewise, of minerals alone, on public railways, we now give the result in a tabular form, taking the cost on the London and Birmingham railway for the expense of haulage.

TABLE XIV.

Table of the cost of conveyance of goods and passengers by locomotive engines, on railroads.

Rate of speed in miles per hour.	Resistance per ton in lbs.	Cost of haulage per ton per mile.	Cost of carriages per ton per mile.	Cost of conveyance per ton per mile.	Charges for conveyance per ton per mile.	Remarks.
		d.	d.	d.		
8	8·5	0·375	0·19	1·065	1·065*d.*	Export coals.
					1·566*d.*	Landsale coals.
12	8·5	0·5	0·227	2·138	3·5*d.*	General merchandise.
20	8·5	0·25 per passenger.	0·206	0·675 per passenger.	1*d.* to 1½*d.* per passenger.	—
		1·73 per ton		2·855 per ton	12·37 per ton	—

In this table a very great difference of cost will be observed, between the conveyance of coals, and general merchandize; the latter amounting to 2·138*d.* per ton, per mile, while the average of the former is 1·315*d.* per ton, per mile. This arises from several causes. On public railways, for general merchandize and passengers, when the latter is conveyed at a high rate of speed, it is almost, if not entirely unavoidable, to prevent the trains with goods partaking, to a certain extent, of a rate of speed beyond that of the most economical; the trains are likewise obliged to be set off, at certain stated periods, whether they are fully loaded or not. We see that the trains, with general merchandize, upon the Liverpool and Manchester railway, from which the above cost is deduced, average only 47·2 tons gross load; upon the Stockton and Darlington railway the average load is 63·6 tons; the former travelling at the rate of twelve to fifteen miles an hour, and the latter eight to ten miles an hour. On a reference to § 4, Art. 7, Chap. IX., it will be seen, that the relative economy of these engines travelling at different rates of speed, and with loads proportioned to the rate of speed, is in the ratio of the resistance of the gross load taken, including the engine; the relative resistances of these loads will be as 66 : 83. The cost of conveyance on the Stockton and Darlington railway is ·4*d.* per ton, per mile; therefore, as ·4 : 66 : : 83 : ·5, which is nearly the cost of the Liverpool engines.

The above calculation will account for the increase of expense of the motive power; but this only amounts to ·125*d.* per ton, per mile, whereas the difference is ·873*d.*, leaving ·748*d.* per ton per mile not accounted for. We observe, that the expense of carriages is greater for general merchandize than for coals and minerals; but the great difference exists in the expense of conducting the traffic of general merchandize upon public railways, in receiving and storing, loading and unloading goods, and in the expense of the necessary attendants; none of whom are required for coals and minerals, which are generally loaded and unloaded by the proprietors. The expense of conducting the traffic, including the above enumerated charges, amounts to 1*d*. per ton, per mile, upon the goods, actually subject to the above charges; or ·460*d*. per ton, per mile, upon the aggregate traffic on the Liverpool and Manchester railway. This expense, together with several other items, which will be seen on examining the particulars under the respective heads of charge, incidental to a public railway, with a mixed traffic; will account, satisfactorily, for the difference between the cost of conveying merchandize on such railways, and coals or minerals on railways more particularly applicable to the conveyance of such articles.

It is, however, a question of some importance, how far public railways, with a mixed traffic, and on which passengers are to be conveyed at high rates of speed, are applicable to the economical conveyance of heavy goods or minerals. We have before remarked, that the example of the cost of the Liverpool and Manchester railway, must be taken as being beyond what may reasonably be expected to be the cost of future railways. Taking, however, the cost of that railway, we find the expense of motive power ·*55d*., of maintenance of the railway ·307*d*., and the cost of upholding waggons ·227*d*., altogether 1·084*d*. per ton, per mile. These are the direct expenses, any traffic on which dues above these sums can be charged, will operate to diminish the general or constant expenses of the establishment, and will, therefore, be profit, with the exception of a portion of expense of attendants, &c.; if we take the general charges the same as upon the Stockton and Darlington railway, or at ·100*d.* per ton, per mile, we have the whole expense equal to 1·184*d.* per ton, per mile.

We see, therefore, that the entire cost of conveying minerals or coals along a public railway, with a mixed traffic, will be 1·184*d.* per ton, per mile; without reckoning any charge for interest of capital, or profits, and taking the expense of the Liverpool railway as a standard; and if we take the contract price for haulage, upon the London and Birmingham railway, this will be reduced to 1·134*d.* per ton per mile. We have already explained, that the expense of the motive power is increased by the diminished load taken at each trip, that the cost of maintenance of the Liverpool railway is greater than may be expected in future; we may, therefore, state, generally, that the direct expenses, exclusive of loading and unloading, and of conveying coals or minerals along public railways, will amount to about 1*d.* per ton, per mile; and that any charge beyond that, will assist in reducing the general expense of the necessary establishment of the railway, for conducting the other traffic.

CHAPTER X.

COMPARISON OF THE DIFFERENT DESCRIPTIONS OF MOTIVE POWER ON RAILROADS.

§ 1.—*Horses and Locomotive Engines.*

WE shall now endeavour to shew the relative performances of horses, and locomotive engines, on railroads; and, in doing so, we shall place them in contrast with each other, at three different rates of speed, viz., 1st, That when with regard to horses, their performance with the load may be considered a maximum, or at 2½ miles an hour; 2d, That when travelling, with light carts, at the rate of four miles an hour; and, 3d, That when travelling at the greatest rate of speed, which they are capable of doing, when yielding any available power to the load.

With regard to locomotive engines, the rate of speed in each of these divisions will greatly exceed that of horses; but still the comparison will, in some degree, hold good, as, with those engines, we have their performance with heavy loads, at from six to eight miles an hour; with merchandize, at from twelve to fifteen miles an hour; and, with passengers, at upwards of twenty miles; or, in each of the three cases, a little beyond double the rate of speed of horses.

In the former edition of this Work, we confined ourselves to a comparison of the relative performances of horses and locomotive engines, only with respect to the quantity of work which each was capable of performing; this comparison, however, did not comprehend the whole question, and was, in some respects, objectionable, In the first place, scarcely two locomotive engines are of precisely the same power, and, therefore, in fixing upon a standard whereby to compare with the power of a horse, it will depend entirely upon the power of engine we fix upon, to compare with horses, what number of horses' work such an engine is capable of performing; and although the comparison might be useful, as shewing the relative capabilities as to the mechanical effort, of the two descriptions of motive power, it would not be productive of any useful purpose, in practice.

The sole object of the employment of both these modes of transport is, to convey goods, or passengers, and the rate of speed and cost at which they can be conveyed, is the great desideratum; for, although an engine may be capable of performing the work of several horses, yet the cost may be more than in proportion to the increased performance; and, consequently, unless we know the cost of each of the two systems, the information will be defective. We shall, therefore, in this edition, give the cost of conveying goods by horses, and locomotive engines, deduced from the preceding investigations. Referring to Table IX. Chap. IX. § 1, Art. 7, we have the cost of conveying goods and passengers, by horses, on railroads; and to Table XIV. § 4, Art. 8, in the same chapter, we have the cost of the same work, by locomotive engines, from which the following table has been constructed.

Art. 1.—*On the comparative Cost of Horses and Locomotive Engines.*

Table of the relative cost of conveying goods, and passengers; by horses, and locomotive engines, on railroads, at different rates of speed.

TABLE I.

Horses.			Locomotive engine.		
Rate of speed in miles per hour.	Cost of haulage per ton per mile.	Charges of conveying goods and passengers.	Rate of speed in miles per hour.	Cost of haulage per ton per mile.	Charges of conveying goods and passengers.
	d.	*d.*		*d.*	*d.*
2½	0·56	1·65 per ton per mile.	8	0·375	1·065 per ton per mile.
4	0·9	3·627 per ton per mile.	12	0·5	3·5 per ton per mile.
10	½*d.* per passenger.	1*d.* to 1½*d.* per passenger.	20	0·25 per passenger.	1*d.* to 1½*d.* per passenger.
	2·24 per ton per mile.	1*s.* 3*d.* per ton per mile.		0·73 per ton per mile.	12·37 per ton per mile.

The above table will shew, in a very conclusive manner, the superiority of locomotive engines, over horses, in the conveyance of goods and passengers on railroads; and likewise exhibits the great increase in the rate of performance, at the higher rates of speed. In point of cost of the motive power, we see that goods can be conveyed, at five times the rate of speed, by locomotive engines, and at a less rate than with horses; and that passengers can be conveyed, at double the rate of speed, capable of being attained by horses, at very little more than at the same price per ton, which horses are capable of conveying goods, at their minimum rate of travelling.

Upon any railroad, therefore, where goods are conveyed at the rate of from ten to twelve miles an hour, passengers could be conveyed, in the same train with the goods, at a rate of speed quite as great as horses are capable of effecting, if employed exclusively in the conveyance of passengers; the power of competition, with horses, in such a case, is, therefore, quite out of the question. The cost, per ton, of conveying goods, and, of course, passengers also, by locomotive engines, at twelve miles per hour, is 0·5 per ton, per mile; while, at the rate of ten miles an hour, by horses, the cost is 2½*d.* per ton, per mile, or nearly four times as great; and, consequently, the profit derived from the conveyance of passengers, by locomotive engines, is nearly four times that by their conveyance with horses. All light goods, and passengers required to be conveyed, at a quick rate, will be best, and most economically performed, by engines; but, with respect to heavy goods, there is a limit.

The cost of conveyance, at the rate of eight miles an hour, is performed by engines with a maximum load; at the rate of twelve miles an hour, the quantity conveyed is not the greatest which the engine could convey, at that rate of speed; still it is very considerable, and those engines, being very powerful, take a very heavy load at a time. It may not be always convenient or practicable to obtain a maximum load, for the convenience of the traffic, it may be necessary that the trains should make a certain number of trips each day, whether there be a complete load or not, in the same manner as a stage coach, is obliged to start, if it has not obtained a full complement of passengers; and, in this case, or, in others, where the traffic is not considerable, the quantity of goods to be conveyed between one place and another, may either be so inconsiderable, as not to afford full employment for one engine; or, the nature of the traffic may be such, as may require so many trips each day, and thus reduce the quantity to be taken at once, below that of a profitable quantity with engines; and, therefore, in some cases, horses may be more economical than locomotive engines. Thus we see, that, at the rate of 2½ miles an hour, goods are conveyed for 0·56*d.* per ton, per mile, by horses, and that, at 12 miles an hour with engines, the cost is 0·5*d.*, being nearly the same; and, therefore, in very short lines of railway, where time for the delivery of the goods is of little consequence, and where the quantity to be conveyed is not great, horses may be beneficially employed.

And if, in such a case, the railway for the use of horses, be constructed at a less cost than for the use of engines, the balance may be in favour of horses.

But upon long lines of railway, where expedition in the delivery of goods is of consequence, and where the passengers to be conveyed are considerable; and where the traffic is of such an extent, as to warrant the construction of a railway for locomotive engines, that description of motive power will be found to be the most economical.

§ 2.—*Fixed and Locomotive Engines.*

The inquiry, instituted by the directors of the Liverpool and Manchester railway, as to the motive power most advisable to be adopted on that road, has often been noticed. The engineers appointed for that purpose, having visited, in the spring of the year 1829, all the different railways, where any information on the subject was likely to be obtained, and having published their report; some very valuable information of the relative economy of the different modes of transit on railways, at that time, and more particularly on the two the subject of our present attention, is presented to us. And as these reports, together with some observations upon them, furnish information, which we deem valuable, on this subject; we feel it a duty we owe to the public, in our capacity of pretending to present to its notice a practical work on railways, to give the substance of these reports, for which we are indebted to the liberality of the directors of the Liverpool railway.

In doing so, it is necessary to observe, that the estimates of Messrs. Walker and Rastrick were made *previous* to the improvements in the locomotive engines, induced by the Liverpool experiments; while the estimates of Messrs. Stephenson and Locke, contrasted with them, were made *subsequent* to those improvements. The former of these estimates, therefore, more properly exhibits the comparative value of the two modes, at the period antecedent to those improvements, than that of the present time; and, on that account, it is scarcely fair, perhaps, to contrast them with estimates founded upon data, the result of subsequent improvements, which have so materially altered the position of the two modes, with regard to their respective values; and, therefore, shewing that the estimates of Messrs. Stephenson and Locke, being made after those improvements, would be the most proper. There being, however, some difference of opinion between the two estimates, not resulting from the improvements alluded to; and the details of the estimates of Messrs. Walker and Rastrick, furnishing some very useful information on the subject, we trust no *apology* is necessary, in laying before our readers a brief statement of the two calculations, except in what is due to Messrs. Walker and Rastrick, for presenting their estimates under such disadvantageous circumstances. Trusting, however, that with regard to those gentlemen, the previous brief explanation will be sufficient to counteract any impressions, arising from a contrast of their conclusions, with those derived from materials partly furnished by ulterior improvements.

Art. 1.—*Messrs. Walker and Rastrick's Estimates.*

The report of Messrs. Walker and Rastrick* arose from a request, of the directors of the Liverpool and Manchester railway, that those gentlemen should undertake "a journey to Darlington, and the neighbourhood of Newcastle; to inspect the different railways in those districts, and to ascertain, by a thorough investigation into the power of the engines, the cost of working them, and their actual performances, the comparative merits of the two descriptions of moving power;" or, as Mr. Walker very briefly expresses it, "What, under all circumstances, is the best description of moving power, to be employed upon the Liverpool and Manchester railway?"

As a basis for the calculation of the reporters, the following extent of traffic was assumed by the directors as likely to occur.

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* Report to the Directors of the Liverpool and Manchester railway, on the comparative merits of locomotive and fixed engines. By James Walker and J. U. Rastrick, civil engineers.

FROM LIVERPOOL, OR TOWARDS MANCHESTER.

Daily.		Gross weight, about Tons.
1000	tons of goods and merchandize, exclusive of waggons, from Liverpool to Manchester -	1500
500	tons cattle, sheep, pigs, &c.; that is, the cattle will occupy the room of 500 tons of goods, and the difference in actual weight will not be great - - - - - -	750
	This large quantity may not occur more than two or three days in the week; still it must be provided for, as the conveyance of cattle cannot be delayed.	
400	tons of coals, a distance of 12 to 15 miles, say from Kenyon to Manchester - -	600
800	empty coal waggons, a distance of 8 to 20 miles, say from Liverpool to Whiston, Rainhill, and Newton - - -	800
800	passengers from Liverpool to Manchester, occupying about 35 carriages - -	100
	Gross weight towards Manchester, Tons	3750

FROM MANCHESTER, OR TOWARDS LIVERPOOL.

Daily.		Gross weight, about Tons.
500	tons of goods, lime, stone, &c., exclusive of waggons - - - -	750
300	empty waggons, or stages, which will have brought cotton or other goods, at 15 cwt. each, say - - - - -	250
200	empty coal waggons, a distance of 12 to 15 miles, say from Manchester to Kenyon .	200
1600	tons of coals a distance of 8 to 20 miles, say from Newton, or Whiston, to Liverpool - - - - -	2400
250	empty cattle carriages - - -	250
800	passengers from Manchester to Liverpool, occupying about 35 carriages - -	100
	Gross weight towards Liverpool, Tons	3950

The section of the railway, from Liverpool to Manchester, being as follows:—

	Distance.		Inclination.
	Miles.	Yds.	
Tunnel (engine plane) - -	1	240	Rise 1 in 48.
Level - - - -	½	120	Level.
To foot of Whiston, or Rainhill inclined plane.	5⅛	—	Fall 1 in 1092.
Rainhill plane - - -	1½	—	Rise 1 in 96.
Rainhill level - - -	1⅞	—	Level.
Sutton plane - - - -	1½	—	Fall 1 in 96.
Parr Moss, &c. - - -	2½	—	— 1 in 2640.
- - - - -	6½	—	— 1 in 880.
Chat Moss, &c. - - -	5½	—	Rise 1 in 1200.
To Manchester - - -	4½	—	Level.

The following is the estimate of Messrs. Walker and Rastrick, on a transit, equal to 2000 tons of goods, or 3000 tons gross daily.

LOCOMOTIVE ENGINES.

The power of each engine was assumed to be that of 10 horses, weighing 8 tons, and, with its water and fuel, 10½ tons, and capable of taking 19½ tons gross, or 13 tons of goods, and 6½ tons of waggons, at the rate of 10 miles an hour (*a* note M).

Cost of one engine - - -	£550
Spare engine for every five - -	110
Tender, tank, ditto - - -	50
One fifth for spare engine - -	10

Total cost, £720, and supposing the

				£	s.	d.
average durability equal to 20 years, or 12½ years' purchase, the annual charge for capital will be, after deducting 60*l.* for old materials, receivable at the end of 20 years, equal to 36*s.* in present money - - - - - - - -				55	16	0
Annual repairs (*b* note M) - - - - -				107	8	0
Coal for fuel, 382 tons, at 5*s.* 10*d.* (*c* note M) -				111	8	4
Wages, grease, hemp, &c. (*d* note M) - - - -				92	12	0
Total cost of one engine, working 312 days -				£367	4	4
Each engine being calculated to take 13 tons of goods, it is supposed, that, exclusive of stoppages, it may travel 3 journeys daily, equal to 90 miles, = 1170 tons 1 mile; the daily traffic being taken at 4000 tons, conveyed 30 miles, or 120,000 tons, 1 mile, will require 102 engines constantly at work, which, at 367*l.* 4*s.* 4*d.* each, is				37,456	2	0
Messrs. Walker and Rastrick considered the power of locomotive engines quite inapplicable upon the two inclined planes (*e* note M), and therefore calculated upon those planes being worked by stationary engines with ropes, the expense of which (*f* note M) is equal to - - - -				5,013	6	0
Crossing upon level of way, 120*l.*, of which the interest is - - - - - - - -				6	0	0
Annual expense of water stations (*g* note M) -				922	10	0
Duplicates of engines	£400	0	0			
Duplicates of ropes, 18 tons 17 cwt. 16 lbs., at 51*l.* -	960	14	3			
Signals - -	100	0	0			
	£1,460	14	3 at 5 per cent.	73	2	0
Interest of capital, and annual expenditure of locomotive engines - - - -				£43,471	0	0

which, for 4000 tons, moved 30 miles per day, is equal to 0·2787 of a penny per ton per mile.

AMOUNT OF CAPITAL FOR LOCOMOTIVE ENGINES.

123 engines and tenders, at 600*l.* - - - -	£73,800	0	0
Fixed engines for Rainhill and Sutton inclined planes, (*f* note M) - - - - - -	9,190	0	0
Duplicates for same, and machinery (as above) -	400	0	0
Ropes for Rainhill, deducting old, (*f* note M) -	792	0	0
Duplicate ropes, (as above) - - - - -	961	14	3
Cost of iron crossings - - - - - -	120	0	0
Signals for Rainhill and Sutton planes - -	100	0	0
Ten water stations, at 560*l.* (*g* note M) - -	5,600	0	0
Requisite capitals for locomotive engines	£90,963	14	3

STATIONARY ENGINES.

Messrs. Walker and Rastrick, in order to carry this system into effect, proposed to divide "the space between the Liverpool tunnel, and the foot of Rainhill plane, about six miles, into four stages, each 1½ mile long. The ascending and descending planes, each to form one stage; the two miles' level upon Rainhill, two stages; and the nineteen miles, from the foot of the plane, to Manchester, into twelve stages, of 1½ mile each; and one stage, of one mile, nearest to Manchester." The speed, when in motion, to be twelve miles an hour, which, including stoppages, will be reduced to an average rate of nine miles an hour.

The engine power will then be as follows:—

	Horses' power.
1— 30 horse power engine, at the top of the Liverpool tunnel, to drag the carriages towards itself - -	30
2— 60 ditto, to the foot of the Rainhill plane, (*a* note N) -	120
1— 40 ditto, at the foot of the plane - - - -	40
2—120 ditto, to work Rainhill and Sutton planes, (*b* note N)	240
2— 40 ditto, one between the two planes, and one at the bottom of the Sutton plane - - - -	80
12— 60 ditto, between the foot of the Sutton plane and Manchester - - - - - - -	720
1— 24 ditto at Manchester - - - - - -	24
Total horses' power -	1254

ESTIMATE OF THE EXPENSE OF STATIONARY ENGINES.

	£	s.	d.
At the top of the tunnel at Liverpool, 30 horse engine, cost of - - - - - - -	2,000	0	0
To work the two planes of Rainhill and Sutton, two 60-horse engines (*b* note N) - - -	10,000	0	0
At the foot and middle of the flat on the top of the two planes, three stations, with two 20-horse engines at each, (*c* note N) - - - - -	8,130	0	0
15 stations, with two 30-horse engines, each cost 3500*l* (*d* note N) - - - - - -	52,500	0	0
Two 12-horse engines, at the Manchester end, (*e* note N) - - - - - -	1,725	0	0
Pullies for two lines of road, each 29¾ miles long, 8 yards distant, = 13,090 at 15*s.* each, including fitting up - - - - -	9,817	10	0
Extra foundation of engine, and engine houses, on Chat Moss - - - - - -	3,000	0	0
	£87,172	10	0

	£	s.	d.
Interest of capital 5*l.* per cent., and depreciation 1½ per cent. = 6½ per cent. on 87,172*l.* 10*s.* is - -	5,666	4	3
Repairs, coals, and working expenses (*f* note N) -	11,257	15	8
Ropes, at $\frac{8}{100}$ of a penny per ton per mile, upon 4000 tons, conveyed 27 miles per day, for 312 days, (*g* note N) - - - - - -	11,232	0	0
Ropes upon Rainhill and Sutton planes (detailed in *e* note M) - - - -	3,315	12	0
Rope for tail-rope on Rainhill and Sutton planes, at $\frac{2}{100}$ of a penny per ton per mile, upon 4000 tons conveyed 3 miles per day, for 312 days (*g* note N) -	312	0	0
Spare rope, interest upon value (*h* note N) - -	219	15	0
Sundry expences (*i* note N) - - -	1,291	4	6
Interest of capital and annual expenditure of stationary engines - - - -	£33,294	11	5

which, for 4000 tons, conveyed 30 miles per day, for 312 days, is equal to 0·2134 of a penny per ton per mile.

AMOUNT OF CAPITAL FOR STATIONARY ENGINES.

	£	s.	d.
Cost of engines - - - - -	87,172	10	0
Duplicates of same (*i* note N) - - -	1,354	0	0
Ropes 4395*l.* (*h* note N) and 792*l.* (*e* note M) -	5,187	0	0
Cast-iron crossings - - - - -	300	0	0
Store-ropes 5336*l.* 16*s.* 8*d.* (*h* note N), and 961*l.* 14*s.* 3*d.* (per locomotive engine estimate) - -	6,298	11	0
Signals - - - - - - -	550	0	0
Requisite capital for stationary engines -	£ 100,862	1	0

COMPARISON OF THE TWO SYSTEMS.

	Capital.			Annual expense.			Expense of taking a ton of goods one mile.
	£	s.	d.	£	s.	d.	
Locomotive engines.	90,403	14	3	43,464	9	0	0·2786 of a penny.
Stationary engines.	100,862	1	0	33,317	7	3	0·2135
Difference -	10,458	6	9	10,147	1	9	0·0651
Locomotive system.	Less.			More.			More.

Art. 2.—*Messrs. Stephenson and Locke's Estimate.*

The publication of the report, containing these calculations and conclusions, brought forth an examination of their correctness, from Mr. R. Stephenson, son of Mr. Stephenson, engineer to the railway, and Mr. Locke, one of the sub-engineers.* Disclaiming

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* Observations on the comparative merits of locomotive and fixed engines, by Robert Stephenson and Joseph Locke, civil engineers.

any intention of entering into, or exciting any controversy, as to which of the two estimates exhibit the most correct value of the two modes of conveyance; we think the details of each of sufficient utility in a work of this kind, to justify their insertion, and it is on that account *alone* we are induced to present them to the reader. It will be readily seen, on a slight inspection of the two estimates, that the fundamental difference arises from the increase of power, effected in the construction of the locomotive engines *since* the estimates of Messrs. Walker and Rastrick were formed; and which those gentlemen, as reporting upon the *then* practical work of those engines, were not bound to contemplate. In this view of the case, it would have been sufficient, to have given Messrs. Stephenson and Locke's estimate, as forming the latest, and that deduced from the improved state of those engines; but there are other differences in the estimates, besides those arising from the causes above named, which, we trust, will excuse us in offering the whole in the briefest possible state; recommending to those more deeply interested in the inquiry, a perusal of the respective pamphlets, which contain much valuable information on the subject.

LOCOMOTIVE ENGINES.

The power of each engine is taken as equal to 20 tons of goods, or 30 tons gross, conveyed 90 miles, or three trips between the two places daily = 1800 tons conveyed 1 mile, at the rate of 12 miles an hour. Engine weighing under 5 tons (*a* Note O).

Cost of one engine and tender - -	£600
One fifth for spare engines and tender -	120
Total cost - -	£720

	£	s.	d.
Interest of capital, including depreciation of 720*l.*, at 7½ per cent. - - - - - -	54	0	0
Add annual repairs, as ascertained by actual observation on the Springwell and Darlington railways (*b* note O) - - - - - -	50	0	0
Engine man, wages 21*s.* per week, assistant 26*l.* per annum - - - - - - -	80	12	0
Coals for fuel, 439 tons per annum, at 5*s.* 10*d.* (*c* note O) - - - - -	128	0	0
Grease, oil, hemp, &c. - - - - -	12	0	0
Total cost of one engine, working 312 days -	£324	12	0
Each engine being calculated to take 20 tons of goods 90 miles, or 1800 tons 1 mile; and the daily traffic being estimated at 4000 tons conveyed 30 miles, or 120,000 tons 1 mile, will require 67 engines to perform the work at 324*l.* 12*s.* 10*d.* per annum, is -	21,750	19	10
Messrs. Stephenson and Locke estimate that locomotive engines are capable of conveying goods up the inclined planes, which they proposed to do by assistant engines, which will perform $\frac{12}{20}$ths of the work on a level, = 12 tons, and supposing each engine to make 20 journeys, or 60 miles a day, will be 246 tons. Hence $\frac{4000 \times 12}{20 \times 240} = 10$ assistant engines, at 324*l.* 12*s.* 10*d.* (*d* note O) - - - -	3,246	0	0
Annual cost of five water stations, at 104*l.* each (*e* note O) - - - - - -	520	0	0
	£ 25,517	8	2

Interest of capital, and annual expenditure of locomotive engines, which, for 4000 tons, conveyed 30 miles per day, is equal to 0·164 of a penny per ton per mile.

AMOUNT OF CAPITAL FOR LOCOMOTIVE ENGINES.

	£	s.	d.
93 engines and tenders, at 600*l.* - -	£55,800	0	0
4 water stations, at 500*l.* (*e* note O) - -	2,000	0	0
Crossings at the Rainhill and Sutton inclined planes, for the assistant engines to pass from one line of road to the other - - - - -	200	0	0
Total capital for locomotive engines -	£ 58,000	0	0

STATIONARY ENGINES.

Dividing the distance into the same number of stages as Messrs. Walker and Rastrick, the following is the power calculated by Messrs. Stephenson and Locke.

	Horse power.
1—40-horse power engine at the tunnel (*d* note P)	40
3—80 ditto, on the 1½ stages, to the foot of the Rainhill plane (*a* note P)	240
2—50 ditto, at the foot of the two planes (*d* note P)	100
1—48 ditto, on the level between the planes (*b* note P)	48
2—80 ditto, to work the two planes (*c* note P)	160
12—80 ditto, between the foot of the Sutton plane and Manchester (*a* note P)	960
1—24 ditto at Manchester	24
Total horses power	1572

ESTIMATE OF THE EXPENSE OF STATIONARY ENGINES.

	£	s.	d.
1 engine of 40-horse power at the tunnel	£1,800	0	0
17 stations, including the two planes, with two 40-horse power each (*e* note P) at 4200*l.*	71,400	0	0
2 stations at the bottom of the two planes, with two 25-horse power each (*f* note P) at 2880*l.*	5,760	0	0
1 station on top of planes, with two 24-horse engines, same as above	2,880	0	0
1 24-horse power engine at Manchester (*g* note P)	1,890	0	0
Sheaves for ropes, 13,090 at 12*s.* each	7,854	0	0
4 sets of crossings, and turn-outs at each station, 88 at 50*l.*	4,400	0	0
	£95,984	0	0
Interest and depreciation of capital, 95,984*l.* at 6½ per cent.	6,238	19	2
Coals for engines, repairs, and working expenses (*h* note P)	18,917	5	0
Ropes (*i* note P)	16,136	7	10
Duplicate ropes, interest of value upon (*k* note P)	739	4	5
Interest of capital and annual expenditure of stationary engines	£42,031	16	5

which, for 4000 tons, conveyed 30 miles per day, for 312 days, is equal to 0·2694 of a penny per ton per mile.

AMOUNT OF CAPITAL FOR STATIONARY ENGINES.

	£	s.	d.
Estimated capital as before - - -	95,984	0	0
Ropes, &c. in use (*i* note P) - - - -	10,727	18	0
Duplicate ropes and machinery (*k* note P) - -	14,784	9	0
Capital requisite for stationary engines -	£ 121,496	7	0

COMPARISON OF THE TWO SYSTEMS.

	Capital.	Annual expense.	Expense of taking a ton of goods one mile.
	£ s. d.	£ s. d.	
Locomotive engines.	58,000 0 0	25,517 8 2	0·164 of a penny.
Stationary engines.	121,496 7 0	42,031 16 5	0·269
	63,496 7 0	16,514 8 3	0·105
Locomotive system.	Less.	Less.	Less.

We trust we have given a brief, and, at the same time, sufficiently explanatory account of the estimates of the two systems; and shall, therefore, leave it to the reader to draw his own conclusions. We are the more inclined to do this, from having, in 1822, advocated the superiority of the locomotive over the stationary system; and, therefore, any observations of ours, might be deemed as coming from one predisposed to judge in favour of the former system.

With regard to the *policy* of employing one or other of these modes upon public lines of railway, we must, however, in candour,—and we think so much due to our readers,—state, that we entirely concur with Messrs. Stephenson and Locke in opinion, " That in considering the long chain of connected power of the stationary engines, given out by so many machines, with the continual crossings of the trains from one line to the other, and subject to the government of no fewer than 150 men, whose *individual* attention is *all* requisite to preserve the communication between two of the most important towns in the kingdom. We cannot but express our decided conviction, that a system which necessarily involves, by a single accident, the stoppages of the whole, is totally unfitted for a public railway.

Mr. Walker virtually expresses the same opinion, when he says, " The probability of accident, upon any *particular part* of the system, is, I think, less with the stationary, than with the locomotive, but, in the former, the effects of an accident extend to the *whole line*, whereas, in the latter, they are confined to the *particular engine and its train*, unless they happen to obstruct the way, and prevent others from passing. The one system is like a number of short unconnected chains; *the other resembles a chain, extending from Liverpool to Manchester, the failure of one link of which would derange the whole.*

These comparisons refer, more particularly, to public railways, and to lines of road nearly level; on private railways, for the conveyance of goods or minerals alone, and where the inclination is too great for the application of locomotive engines, these estimates will be extremely useful, in calculating the expenses attendant upon each particular system. We have previously given the formula for calculating the power required to work planes, either by fixed engines, or self-acting by the power of gravity; and, in the Appendix, we give (note Q) a Table of the wear of ropes upon several planes, which will still further assist the reader in making the necessary calculations.

Art. 3.—*Modern Lines of Railway, with Fixed and Locomotive Engines, compared.*

Although locomotive engines have been much improved, and altered, since the above comparison was made, we have deemed it advisable to present these estimates to the public, as shewing the cost of fixed engines, compared with locomotive engines, of a certain construction, and such as produces a more economical result, than by the improved modern engines; they are, therefore, the description of engine, which ought more properly to be placed in contrast with fixed engines, than the locomotive engines, constructed more with a view to rapidity of transit, than economy.

For although the modern engines, are infinitely better adapted for the conveyance of passengers and goods, at a quick rate of speed, yet they are much more expensive than the old engines. This is shewn, in comparing the cost of haulage, by the Killingworth engines, and the engines upon the Liverpool and Manchester railway; the former being accomplished at the cost of less than ¼*d.* per ton, per mile, while the other is above ½*d.* per ton, per mile; this is partly, but not entirely, attributable to the latter not being furnished with a complete load at each trip. We, therefore, think, these estimates may be useful, as shewing the cost of working locomotive engines, adapted solely to situations exclusively used for the conveyance of coals, or heavy goods, and not for passengers; and as such, are properly placed in contrast with fixed engines.

And, we would add, that the result of the estimates of the locomotive power, taking the average of the two, are fully borne out by the practical result on the Killingworth railway; and, if we take the average of the fixed engines, in like manner, we will find that, in point of economy, there is little difference between the two modes.

When, however, we consider that a system of fixed engines, precludes the conveyance of passengers, it is, therefore, almost unnecessary to say that it is quite inapplicable to public railways; and, consequently, the comparison can only exist upon private railways, where passengers cannot be conveyed.

We may, likewise, place these systems, in contrast with each other, in the charges made for conveying coals, where both of them are in use. In Chap. IX., § 4, Art. 8, we have given the cost of conveying coals, by locomotive engines, upon the Stanhope and Tyne, and other railways in the North of England. We have been favoured with the cost of conveying coals along the Durham and Sunderland railway, which is entirely worked by fixed engines. In (note R, Appendix), we have given a section of this railway. The charges for conveying coals, not including finding waggons, or filling the coals into the waggons, but including every other expense of transit, is *3d.* per chaldron, per mile, for conveyance, and *3d.* per chaldron for emptying the coals into the vessels at the shipping places. Each chaldron consists of 53 cwt.; therefore, the cost of conveyance, or haulage, is 1·1*3d.* per ton, per mile, which is precisely the same as the charges for locomotive power upon the Stanhope and Tyne railway; the charges upon the Clarence railway, with locomotive engines, being ·875*d.* per ton per mile.

We see, therefore, that where economy of transit is the only object, and especially upon lines of railway exclusively employed for the conveyance of minerals; there is no very great difference between locomotive power, and fixed engines; except that the employment of the latter, as the motive power, precludes the conveyance of passengers, as a source of revenue.

CHAPTER XI.

TURNPIKE ROADS.

The resistance of carriages upon turnpike or common roads has, of late years, been very much diminished, by covering the surface with materials broken into smaller pieces than formerly, thereby forming a much smoother surface; and experience has shewn that such a surface is much more easily kept in repair, than the rough uneven roads previously in existence. The public are indebted to Mr. M^{c}Adam, for the introduction of this system, of breaking the stones smaller than they had previously been done; but the late Mr. Telford, who was engineer to government, in forming and improving the Holyhead line of road, has contributed more largely than any other person to our stock of information on road making, and the principles requisite for their construction, and which may be all summed up in one simple rule, viz. "that a good foundation is the first requisite."

It is not, however, our intention to enter into either the principles or practice of road making; the reader, who is desirous of doing so, will obtain all the requisite information by consulting Sir H. Parnell's work on this particular subject, and the reports of Mr. Telford on the Holyhead line of road. Our object being, to present to the reader such facts, as will shew the resistance of the carriages, and cost of conveyance upon turnpike roads; and to compare their capabilities, with other modes of internal communication.

§ 1.—*Experiments on the Resistance of Turnpike Roads.*

We shall, therefore, at once, proceed to give the result of some experiments made to ascertain the resistance upon turnpike roads, extracted from the reports of the Holyhead Road Commissioners.

The following table, shewing the number of pounds requisite to drag a waggon of the weight of 21 cwt. 8 lbs. at the rate of two miles and a half an hour, has been extracted from the Seventh Report of the Holyhead Road Commissioners.

TABLE I.

1.	2.	3.	4.	5.	6.	7.
Parts on which the experiments were tried.	No. of observations.	Rate of inclination.	Actual draught in lbs., or proportional number of horses required on each station.	Correction of the rate of inclination.	Draught reduced, or the proportional number of horses that would be required if the road were horizontal.	OBSERVATIONS. All the experiments were made in the middle of the month of March 1830, during dry weather.
No. 1. *Piccadilly Pavement.*						
From Stratton Street to Devonshire House	15	Rise 1 in 114	60½	20½	40	Excellent, smooth, well laid pavements.
From Devonshire House to Dover Street -	14	Rise 1 – 156	48¼	15¼	83	Ditto - ditto.
From Dover Street to St. James's Street -	13	Fall 1 – 429	42¼	5¾	48	Pavement uneven, and worked into holes; the top of the stones a good deal rounded, and the joints opened.
From St. James's Street to Bond Street -	8	Rise 1 – 245	54	9	45	
From Bond Street to Burlington Arcade -	11	Fall 1 – 286	40	8½	48½	
From Burlington Arcade to Albany Court	20	Horizontal.	41¾	- -	41¾	
No. 2. *Archway Road.*						
Between toll-bar and new house on the right	32	Rise 1 in 23	173	102½	70½	This road lately repaired by putting on a cemented foundation, and covering the fifteen middle feet with broken Guernsey granite six inches in thickness.

(continued)

1.	2.	3.	4.	5.	6.	7.
Parts on which the experiments were tried.	No. of observations.	Rate of inclination.	Actual draught in lbs., or proportional number of horses required on each station.	Correction of the rate of inclination.	Draught reduced, or the proportional number of horses that would be required if the road were horizontal.	**OBSERVATIONS.** All the experiments were made in the middle of the month of March 1830, during dry weather.
No. 2. *Archway Road*—continued.						
Between new house and depôt No. 1. -	13	Rise 1 in 23	163	102½	60½	
Between depôt No. 1. and archway -	64	Rise 1 – 22	171	108	63	
Between archway and lamp No. 11. -	81	Rise 1 – 49	115	48	67	
Between 11th and 12th lamp posts - -	18	Rise 1 – 229	78	10¼	67¾	
Between 12th and 13th lamp posts - -	12	Horizontal -	47	- -	47	
Between 13th and 15th lamp posts - -	26	Fall 1 in 382	46	6¼	52¼	
Between 19th and 21st lamp posts - -	35	Rise 1 – 27	151	87	64	
Between 21st and 22d lamp posts - -	22	Rise 1 – 27	152	87	65	The surface not perfectly consolidated, and shaded with trees.
Between 22d lamp post and M'Pherson's -	16	Rise 1 – 3437	59	½	58½	On this portion Hartshill was used instead of granite.
Between Wellington Inn and Whetstone Road	20	Horizontal -	44	- -	44	
No. 3.						
Hockliffe and Stratford Trust.						
Near Fountain Inn, Shenley - -	49	Horizontal -	97	- -	97	12 inches of limestone; low fences.

Near Talbot Inn, north of Shenley -	36	Rise 1 in 20¼	232	115	117	Do. good foundation, firm and dry, not worked in.
Flat, north side of Shenley - -	34	Fall 1 – 119	93	19¾	112¾	12 inches limestone, plantation south side.
Ditto, near Speckland Hollow - -	77	Horizontal -	120	- -	120	11 inches pebble and limestone, plantation south side.
Crown Hill - - - -	38	Rise 1 in 45	128	52¾	75¼	Embankment; paved foundation, covered with 10 inches of broken limestone.
Ditto, near summit - - -	26	Rise 1 – 27	136	87	49	
Between Crown Hill and the toll-bar -	56	Rise 1 – 66	115	35¾	79¼	12 inches limestone; no sub-pavement.
Flat between Two Mile Ash and Stoney Stratford.	68	Rise 1 – 3487	60	1	59	18 inches limestone, low fences, no trees.
Near same place, tried back - - -	58	Fall 1 – 3437	57	1	58	Ditto - ditto.
No. 4.						
Stratford and Dunchurch Trust.						
Flat between 65th milestone and brick house	23	Rise 1 – 20	270	118	152	6 inches limestone, low fences each side, trees and high bank on west.
Between brick house and road to Northampton.	7	Rise 1 – 21	292	112	180	5½ inches limestone, high hedges and bank on south-west.
Over small embankment above brick house	22	Rise 1 – 22¾	343	103	240	6 inches limestone, high hedges, new stone, on a week.
Between sand pits and road to Stowe -	23	Rise 1 – 39	128	60½	67½	6 inches limestone, open, and low fences.
Between road to Stowe and the Angel Inn	37	Rise 1 – 71½	95	33	62	5 inches limestone, open, wide space between, low fences.
Between hollow and 66th milestone -	70	Rise 1 – 31	130	76	54	3½ inches of Hartshill, and 2 inches of limestone, on pitching.
Between 66th milestone and summit of hill	80	Rise 1 – 26	145	91	54	3 inches ditto, ditto, over embankment.
Rising next hill - - - -	60	Rise 1 – 50	90	47	43	5 inches ditto, ditto, through cutting.

The preceding table, it is stated, "was not intended for any thing further than to get practical results, the description of which could be easily understood by road surveyors and their assistants, and even by men in the habit of driving coaches; it could not be expected that experiments made with a large unwieldy waggon, mounted with common axletrees, besmeared with tar, could furnish result on which to found a refined mathematical calculation."

From the above table, we find, that the average resistance of a waggon, weighing 21 cwt. 8 lbs., upon a level road, is 77 lbs., or equal to 73 lbs. per ton.

We give, likewise, the following extract from Mr. Telford's report on the state of the Holyhead and Liverpool roads.

"Being authorized by the commissioners to have the machine invented by my assistant, Mr. M'Neil, (for measuring the force of traction, or the labour of horses in drawing carriages,) completed, and also to have the several districts of the Holyhead road in England tried by it; Mr. M'Neil has done so, and prepared a statement, shewing the results of the trials between London and Shrewsbury, a distance of 153½ miles.

"The general results of these experiments, on different sorts of roads, are as follow; the resistance being for one ton weight.

"1. On well made pavement, the draught is 33 lbs.

"2. On a broken stone surface, on old flint road, 65 lbs.

"3. On a gravel road, 147 lbs.

"4. On a broken stone road, upon a rough pavement foundation, 46 lbs.

"5. On a broken stone surface, upon a bottoming of concrete, formed of Parker's cement and gravel, 46 lbs."

The following experiments, given in Sir H. Parnell's work on roads, were made by Mr. M'Neil, to determine the resistance of carriages due to the axle, and the wheels upon common roads.

"1st. Half a ton of stone was put in a waggon (weighing 10 cwt.), as nearly as possible in the centre between each axletree; the waggon was then drawn over a timber platform, perfectly horizontal, by weights suspended from a line; to effect this it required 50¾ lbs.

"2d. A ton of stone was placed in the waggon, half a ton over each axletree; and the power required to drag the waggon, over the same surface, was 70 lbs.

"3d. A ton and a half of stone was placed in the waggon, and distributed equally over each axletree; the weight or power required to drag the waggon was then found to be 90 lbs."

The resistances arising from the friction of the axletrees, in the above experiments, were then calculated for each wheel, and the total resistance, arising from the axles thus determined, was subtracted from the draught or power found by experiment, as requisite to draw the waggon; the difference gave the resistance of the surface, caused by the penetration of the wheels into the timber surface.

The results of these experiments, are given in the following table.

TABLE II.

Weight of waggon and load in lbs.	Power required to drag the waggon.	Resistance of the axles.	Resistance of the surface.
lbs.	lbs.	lbs.	lbs.
2240	31·0	13·0 10·6 } 23·6	7·4
2800	52·0	16·2 13·3 } 29·5	22·5
3360	70·0	19·5 15·9 } 35·4	34·6
3920	91·0	2·7 8·6 } 41·3	49·7

By a considerable number of experiments, with the same waggon, on roads of different kinds, the draught was found to agree very nearly with the results calculated from the empirical formula, $P=\frac{W+w}{93}+\frac{w}{40}+v$; in which W=the weight of the waggon, w, the load; c, a constant number, which will depend on the surface, over which the waggon is drawn; and v, the velocity in feet per second. By putting V=3·7, which was the velocity used in the foregoing experiments, the constant number for a timber surface was determined, and found to be equal to 2.

For other surfaces, the value of c may be taken as follows:

On a paved road - - - - -	2
On a well made broken stone road, in a dry and clean state - - - -	5
On a well made broken stone road, covered with dust - - - - - -	8
On a well made broken stone road, wet and muddy - - - - -	10
On a gravel or flint road, in a dry clean state	13
On a gravel or flint road, in a wet muddy state - - - - - - -	32

On an inclined plane, the above formula becomes $P=\frac{W+w}{93}+\frac{w}{40}+v+\frac{h}{v}\cdot\frac{W+w}{1}$ for a common stage waggon; and $P=\frac{W+w}{100}+\frac{w}{40}+c\,\frac{h}{l}\cdot\frac{W+w}{1}$ for a stage coach.

We find, therefore, that the resistance of carriages, upon common or turnpike roads, cannot be estimated at less than 72 lbs. per ton.

§ 2.—*Cost of conveying Goods and Passengers, on Turnpike Roads.*

We may divide the transit upon turnpike roads, into three descriptions; viz. first, heavy waggons, for the conveyance of bulky or heavy articles; second, light vans or carts, for the conveyance of light goods; and, third, coaches for the conveyance of passengers.

Heavy stage waggons are of various weights, according to the number of horses employed, and the rate of travelling is about 2 to 2½ miles an hour. The cost of conveyance by this mode of transport is 7*d.* to 9*d.* per ton per mile; the average being 8*d.* per ton per mile, at the rate of 2½ miles an hour; the cost of haulage, or finding horses, being about 3*d.* per ton per mile.

The light vans, or carriers' carts, travel at the rate of 3 to 4 miles an hour, and the charges for conveying light goods will average about 1*s.* per ton per mile, at the rate of four miles an hour. The cost of haulage, or finding horses and drivers, being about 4¼*d.* per ton per mile.

The general rate of coach travelling is eight to nine miles an hour, according to the evidence of Mr. M'Neil, before a committee of the house of commons. It appears, that the weight of a four-horse stage coach varies from 15 cwt. 3 qrs. to 18 cwt., and that these coaches frequently carry upwards of two tons of passengers and luggage; we may, however, assume, that ten passengers, which, including luggage, weigh 30 cwt., are the more general average of the weight carried by these coaches. We find, by the document of the coach proprietors, (*Note* D. Appendix), that the entire cost of working 2304 miles for 312 days, including duty and coach-men, is 64,602*l.* 13*s.* 4*d.*; or 2·2*d.* per passenger, per mile, or reckoning 30 cwt. on the average of each trip, about 15*d.* per ton, per mile. The cost of haulage alone, exclusive of drivers, is nearly 10*d.* per ton, per mile; and the charges are from 3*d.* to 4*d.* per passenger, per mile; we shall, therefore, assume the cost to be 3*d.* per passenger, per mile, conveyed at the rate of nine miles an hour, which will be equal to about 3*s.* per ton, per mile.

The following table will, therefore, shew the cost of conveying goods, and passengers on turnpike roads.

TABLE III.

Description of carriage.	Rate of travelling in miles per hour.	Resistance per ton on a level.	Cost of haulage per ton per mile.	Cost of conveyance.
		lbs.	*d.*	
Stage waggon -	2½	73	3	8*d.* per ton per mile.
Van or light cart -	4	73	4½	12*d.* per ton per mile.
Stage coach -	9	83	10	3*d.* per passenger per mile.

CHAPTER XII.

ON CANALS.

The immense capital embarked in canals, renders it a subject of very great importance, to determine their relative utility with railroads, in the transit of goods from one place to another. We shall, therefore, in the first place, endeavour to ascertain the power required to convey goods on canals, at different rates of velocity; and then, from such information as we have obtained, determine the actual cost of conveying goods and passengers, upon this description of internal communication. After which we shall compare these with the resistance, to the motive power on railways, and with the cost of conveyance, by that mode of transport.

Not having an opportunity, from our own personal observation, of ascertaining, with sufficient accuracy, the weights which a horse can drag in a boat upon a canal; we shall be obliged to have recourse to the reports of those engineers, whose practice in that line has enabled them to obtain the necessary data.

§ 1.—*Experiments on the Resistance of heavy Boats.*

Mr. R. Stevenson, of Edinburgh, in his report on the Edinburgh railway, in 1818, states, "upon the canals in England, a boat of thirty tons burden is, generally, tracked by one horse, and navigated by two men and a boy; on a level railway it may be concluded, that a good horse, managed by a man or lad, will work with eight tons. At this rate, the work performed on a railway by one man and a horse, is more than in proportion of one third of the work done upon the canal, by three persons and a horse;" and Mr. Stevenson, in his calculations, afterwards, assumes the power of a horse upon a good railway equal to ten tons.

Mr. Sylvester, in his report on the Liverpool and Manchester railway, gives twenty tons as the performance of a horse upon a canal, travelling at the rate of two miles an hour.

The variation between these two statements, may have arisen from the observations being made on canals of different widths. Mr. Stevenson, in another report, states, that the striking difference between the draught of horses, on coming out of a narrow canal into a more capacious one, induced the reporter to give the subject particular attention; and by means of experiments made with the dynamometer, so far as he had an opportunity of carrying the experiments into effect, the difference appeared to be at least one fifth in favour of the great canal.

We have been favoured by Mr. Bevan with some experiments and observations on the force of traction, with different loads and velocities, on canals.

In these experiments, the resistance was ascertained by a spring dynamometer, attached to the towing-rope. The length of the boat was 69·5 feet, breadth 6·92 feet. The correct transverse section of the canal was not obtained, but was from 90 to 100 feet; the immersed part of the boat being about nineteen feet, or one fifth of the channel.

The force of traction, required to move this boat, loaded with 23·77 tons, at a mean velocity of 2·45 miles an hour, was, on an average, of fifty-four observations, 79·5 lbs., which is equal to three pounds and a half per ton of useful load. With this load, Mr. Bevan remarks, one horse generally travelled twenty-six miles and a half a day; which would give the effect of a horse, 2106 lbs. moved one mile per day.

The same gentleman has also favoured us with the following experiments, made on the Grand Junction canal at Paddington:—

Transverse section of canal - -	142 feet.
Loaded boat - - - -	17·2 feet.

A weight of 72 lbs., acting over a pulley, drew the empty boat at the rate of 3·45 miles an hour.

A weight of 77 lbs., acting in a similar way produced a medium velocity of 2·5 miles an hour, when the boat was loaded with twenty-one tons of cast iron. And all circumstances the same as in the last experiment, it required a weight of 308 lbs. to produce a mean velocity of 3·83 miles an hour.

Mr. Bevan adds, "the length of the towing-line may be considered ninety-eight feet, and the mean distance of the boat from the towing path twenty feet." From this experiment, considering that the canal in that part was of greater area than it is upon an average, it may be inferred, that to maintain a velocity of four miles an hour, with a loaded boat, it would require the aid of four horses, provided the safety of the banks would allow; but, as the canal is now formed, it would not be capable of withstanding the waste produced by such a velocity.

Mr. Chapman, (Canal Navigation, page 73,) states, that he observed a boat, eight feet width of floor, ten feet width of water line, fifty feet extreme length, loaded with fourteen tons, and drawing 2·25 feet water, dragged against a stream, the velocity of which was five miles and a half an hour, with twenty-eight trackers, and three men in the boat, pulling it on, and yet it did not advance more than a quarter of a mile an hour.

Mr. Smeaton's estimate was twenty-two tons burthen, from two to two miles and a half an hour, with on horse.

Mr. James Walker, of London, made some exp riments in the London Docks, on the relative resi ances, at different velocities, the result of which h communicated to the Royal Society, (May 31st 1827 which being very conclusive, and conducted with gre care, we give an abstract of them. (Note S. Appendi

The result of these experiments was, that the resi ance increased in a greater proportion, than the duplica ratio of the velocities. The respective resistances bei as follow :

TABLE I.

Velocity in miles an hour.	Observed resistance, in lbs.	Resistance calculated in duplicate ratio of the velocity.
2·529	9·41	Standard.
4·529	42·59	38·11
3·871	28·07	22·07

Mr. Palmer gives, in the first volume of the Transactions of the Civil Engineers, an account of experiments made on the resistance of canal boats in different canals, and dragged at different velocities, which having been conducted on a large scale, are valuable. The following Table shews the result of these experiments.

To face page 654.

st- e, ng e.	Load of useful effect.	Whole effect.	Fraction of the force to the load.	Fraction including the barge.	Number of the horses, men, &c.	Observations.
	tons.	tons.				
3	1·20	49½	$\frac{1}{73}$	—	3	Vessels with masts and rigging.
2	·40	92	$\frac{1}{370}$	$\frac{1}{381}$	2	Surface exposed to wind much greater than that of ordinary canal barges.
0	empty	52	—	$\frac{1}{382}$	2	Canal irregular in depth. Wind at the time sensibly affected the experiments.
0	empty	52	—	$\frac{1}{382}$	2	Nos. 3. and 4. disturbed the water considerably.
8	10	14½	$\frac{1}{183}$	$\frac{1}{193}$	Men.	The only errors observable in the experiments on the Ellesmere canal were attributable entirely to the wind, the effect of which is seen in the results.
0	10	14½	$\frac{1}{182}$	$\frac{1}{191}$	Ditto.	
7	10½	15	$\frac{1}{305}$	$\frac{1}{430}$	Ditto.	
0	10½	15	$\frac{1}{470}$	$\frac{1}{372}$	Ditto.	
0	21	30	$\frac{1}{940}$	$\frac{1}{1344}$	Ditto.	
6	10¾	19¾	$\frac{1}{305}$	$\frac{1}{370}$	Ditto.	With the wind.
1	10¾	19¾	$\frac{1}{264}$	$\frac{1}{435}$	Ditto.	Against the wind.
8	20¾	29¾	$\frac{1}{470}$	$\frac{1}{380}$	Ditto.	
5	20¾	29¾	$\frac{1}{266}$	$\frac{1}{381}$	Ditto.	
4	21	39	$\frac{1}{237}$	$\frac{1}{382}$	Ditto.	
2	21	39	$\frac{1}{272}$	$\frac{1}{307}$	Ditto.	
6	42	60	$\frac{1}{480}$	$\frac{1}{383}$	Ditto.	
0	—	31	—	$\frac{1}{363}$	Horses.	The experiment made by Mr. Bevan.
0	empty	6½	—	$\frac{1}{182}$	Men.	Corrected for the effect of the wind, estimated at 8 lbs. The weight in both cases was 72 lbs., and the experiment was repeated with the barge turned about, merely for this comparison.
4	Do.	6½	—	$\frac{1}{323}$	Ditto.	
8	21½	27	—	$\frac{1}{203}$	Men & horses.	There was no wind when the last two experiments were made.
7	21½	27	—	$\frac{1}{314}$	Men.	

No. 1. experiment was made with the packet boat used to convey passengers between Liverpool and Manchester, and which is usually towed at the rate of $5\frac{1}{4}$ miles an hour. Nos. 5, 6, 7, and 8, were made on the Ellesmere canal, with a boat built for the purpose, and which was of the same length as those commonly used, but exactly half their width. Nos. 9, 10, 11, 12, and 13, were made with one of the ordinary canal barges. Nos. 14, 15, and 16, were made with two boats joined together, end to end, and the curves to the head of one, and the stern of the other, so planked over as to form one boat, of double the ordinary length.

No. 17, having been made by Mr. Bevan, Mr. Palmer states, he has no other information relating to it, than the facts as given in the table.

Nos. 18, 19, 20, and 21, were tried under circumstances as favourably as are usually met with; the effect of the wind was, however, very apparent.

These experiments were submitted to Professor Barlow, who, after remarking upon the difference of opinion, previously existing on the subject, reports as follows:—" It will appear, however, from the following investigations, that, in the case of loaded canal boats, the resistance varies in a still higher ratio, viz^t, as the cube of the velocity, very nearly, if not exactly. In order to make this comparison, it is only necessary to proceed as below, by saying,

$$\text{V}^m : v^m :: \text{F} : f$$

using, for V, v, F, f, the actual velocity, and moving powers employed.

" From this proportion, is very easily obtained the theorem $m = \frac{\text{Log. F} - \text{Log. } f}{\text{Log. V} - \text{Log. } v}$; and employing in this, the velocities and forces given in the first four experiments, there are obtained the following results, comparing the experiment,

1 to 3 - - - $m=3·2$
1 to 4 - - - $m=2·7$
2 to 3 - - $m=3·0$
2 to 4 - - $m=2·6$

Mean value of $m=2·9$, or 3 nearly.

"By comparing experiments 7 and 8, which are made under like circumstances, and on the same boat, we find $m=3·2$; and, in the same way, experiments 17 and 18, give nearly the same result, viz. $m=3·0$, the general mean being $m=3·0$.

"It is clear, therefore, that, whatever may be the deduction from theory, the actual resistance of canal boats varies very nearly as the cubes of the velocities; and by adopting this law, the velocities due to any force and load may be computed, from the velocity and resistance in any other case being given."

"As it will be seen, by the experiments on the different railways, that, at a mean, 1 lb. will drag along 180 lbs, and that a power of 1 to 200 is the greatest that the most perfect railway can ever be expected to attain, I have computed what velocity is attainable on a canal, answering to those two cases, namely, when the moving force is $\frac{1}{180}$th part of the whole load moved. These results are given in the following table, omitting those made on empty boats and sea-going barges."

TABLE III.

Navigation, description of the barges, &c.	Authority.	Whole load, including barge.	Moving force.	Number of lbs. drawn by 1 lb.	Rate, in miles per hour.	Computed rate when 1 lb. draws 180 lbs.	Computed rate when 1 lb. draws 200 lbs.	Remarks.
		Tons.	lbs.					
Ellesmere boats: half the usual breadth, length 69 feet, breadth 3 feet 6 inches	Palmer	14½	168	193	4·60	4·70	4·54	
		14½	170	191	4·69	4·78	4·62	
		15	77	436	3·63	4·97	4·70	
		15	50	672	2·96	4·59	4·43	
Common boat	Ditto	30	50	1344	1·90	3·71	3·58	
Common boat, half load	Ditto	19¾	79	500	2·94	4·29	4·12	The moving weights were 66 lbs. and 91 lbs; they were corrected for the effect of the wind.
		19¾	78	567	2·80	4·10	3·96	
Common boat, full load	Ditto	29¾	98	680	2·73	4·25	4·09	
		29¾	175	381	3·27	4·19	4·05	
Two common boats, end to end	Ditto	39	164	532	2·80	4·01	3·87	
		89	172	507	2·58	3·64	3·51	
Do., full load	Ditto	60	196	689	2·50	3·91	3·75	
Common boat	Bevan	31	80	863	2·45	4·13	4·08	
Common boat, full load	Barlow, Donkin, &c.	27	308	203	3·87	4·02	3·88	
		27	77	814	2·44	4·04	3·90	
					Mean	4·22	4·06	

"It is clear therefore, that on a canal, where the moving power is $\frac{1}{300}$th of the whole load, including the barge, it may be taken forward at the rate of 4¼ miles per hour. It is easy also, from what has now been stated, to compute the power on a canal, at different velocities; for example."

TABLE IV.

Rate of velocity, in miles per hour.	Number of lbs. which 1 lb. will drag on a canal.	Resistance, in lbs. per ton.
4	200	11·20
3¾	243	9·22
3½	299	7·50
3¼	373	6·00
3	474	4·73
2¾	615	3·64
2½	819	2·73
2¼	1124	2·00
2	1600	1·40

These experiments were made upon boats moving at slow rates of velocity, recently, extraordinary efforts have been made to apply canal boats to convey passengers at a high rate of velocity, and the most surprising results have been put forth by the friends of canal navigation, on the diminution of resistance after these boats attained a certain rate of speed; until lately, however, no experiments were made to satisfy the public upon this point, and the results being quite at variance with the generally received opinions of the law of resistance of fluids, to bodies moving in them, it became necessary that experiments should be made, to set the question at rest. Robert Grahame, Esq., one of the proprietors of the Forth and Clyde canal, and one of the most strenuous and active promoters of the use of swift boats on canals, and to whose active exertions the public are indebted to the application of the system, at rates of velocity previously deemed impracticable, has been mainly instrumental to the developement of the hitherto unknown laws of resistance to the motion of bodies moving, at high rates of velocities, on canals.

§ 2.—*Experiments on the Resistance of swift Boats on Canals.*

The public being so extremely sceptical on the conclusions put forth by the canal proprietors, the committee of management of the Forth and Clyde canal, at length determined to institute a set of experiments on the boats in actual use; and upon such a scale as to be entirely free from objections, and which should be so conducted as to determine accurately the amount of resistance, at all the different rates of velocity, capable of being attained in practice by the most improved boats.

Mr. M'Neil was employed to conduct these experiments, and it is only doing him justice to say, that they appear to have been conducted in a very masterly manner, and to be quite conclusive, as to their accuracy. The particulars of these experiments are given in the first volume of the transactions of the civil engineers, to which work we would refer the reader, desirous of obtaining more complete information on the subject.

As the question is of infinite importance to the economy of internal communication, we have taken from these experiments an abstract of the results, arranged so as to shew the resistance at three several rates of speed; viz., as nearly as could be obtained, at four, eight, and the maximum rate, or at about ten, miles an hour respectively; and have given the resistances at those rates of speed, with the different boats upon which the experiments were made, the boats being loaded with different weights in each experiment.

TABLE V.

FORTH and CLYDE CANAL; average width, 60 feet; extreme depth, 9 feet.

RAPID BOAT.—Weight, 7692 lbs.; 64 feet 6 inches long; 6 feet 9 inches wide.								
Number of experiments in M'Neil's tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
1, 2, 6	1.065	8,757	3·45	30·3	$\frac{1}{35}$	$\frac{1}{289}$	12½	9
8	—	—	5·98	91·2	$\frac{1}{11·7}$	$\frac{1}{96}$	—	—
89	—	—	9·	258·	$\frac{1}{4}$	$\frac{1}{34}$	—	—
87, 88	3,305	10,997	3·90	45·3	$\frac{1}{73}$	$\frac{1}{242·7}$	12⅛	12⅛
85, 86	—	—	8·39	273·2	$\frac{1}{12}$	$\frac{1}{40·3}$	—	—
84	—	—	10·98	386·9	$\frac{1}{8·5}$	$\frac{1}{28·4}$	—	—
83	5,545	13,237	3·54	43·9	$\frac{1}{126·3}$	$\frac{1}{301·5}$	14	14
80	—	—	7·76	281·8	$\frac{1}{19·7}$	$\frac{1}{47}$	—	—
82	—	—	11·39	465·2	$\frac{1}{11·9}$	$\frac{1}{28·4}$	—	—
79	7,785	15,477	3·92	56·7	$\frac{1}{137·3}$	$\frac{1}{272·9}$	15⅞	15⅞
70, 71, 72, 73, 74, 77	—	—	8·33	339·4	$\frac{1}{22·9}$	$\frac{1}{45·6}$	—	—
78	—	—	10·59	451·8	$\frac{1}{17·2}$	$\frac{1}{34·2}$	—	—
55	10,585	18,277	4·39	63·8	$\frac{1}{166}$	$\frac{1}{286·4}$	19½	15½
22, 30	—	—	7·91	333·	$\frac{1}{31·8}$	$\frac{1}{54·9}$	—	—
49, 57	—	—	9·92	444·3	$\frac{1}{23·8}$	$\frac{1}{41}$	—	—

TABLE VI.

VELOCITY BOAT.—Weight 8465 lbs.; 67 feet long; 8 feet wide.

Number of experiments in M'Neil's Tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
158	1,065	9,530	8·88	267·8	$\frac{1}{4}$	$\frac{1}{35\cdot6}$	11	8
157, 159	—	—	11·55	397·9	$\frac{1}{2\cdot7}$	$\frac{1}{24}$	—	—
162	3,305	11,717	3·96	41·2	$\frac{1}{80\cdot2}$	$\frac{1}{284\cdot4}$	11	11
160	—	—	8·92	337·2	$\frac{1}{9\cdot8}$	$\frac{1}{34\cdot7}$	—	—
161	—	—	11·25	440·0	$\frac{1}{7\cdot5}$	$\frac{1}{26\cdot6}$	—	—
165	5,545	14,010	4·32	56·9	$\frac{1}{97\cdot4}$	$\frac{1}{246\cdot2}$	12¼	12¼
164	—	—	8·41	372·2	$\frac{1}{14\cdot9}$	$\frac{1}{37\cdot6}$	—	—
163	—	—	10·53	442·8	$\frac{1}{12\cdot5}$	$\frac{1}{31\cdot7}$	—	—
168	7,785	16,250	4·15	53·9	$\frac{1}{144\cdot4}$	$\frac{1}{301\cdot4}$	13½	13½
167, 170	—	—	8·25	409·4	$\frac{1}{19}$	$\frac{1}{39\cdot6}$	—	—
166, 169, 171, 172	—	—	9·93	456·3	$\frac{1}{17}$	$\frac{1}{35\cdot6}$	—	—
174	10,585	19,050	4·04	51·6	$\frac{1}{205}$	$\frac{1}{369}$	15½	15½
173, 175, 176, 177, 178, 179	—	—	8·46	487·5	$\frac{1}{21\cdot7}$	$\frac{1}{39}$	—	—

TABLE VII.

EAGLE BOAT.—Weight 8303 lbs.; 89 feet 6 inches long; 7 feet 4 inches wide.

Number of experiments in M'Neil's Tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
182	1,065	9,368	4·12	59·2	$\frac{1}{18}$	$\frac{1}{158\cdot2}$	18	18
181, 183	—	—	9·47	306·3	$\frac{1}{3\cdot5}$	$\frac{1}{30\cdot6}$	—	—
180	—	—	11·5	383·2	$\frac{1}{2\cdot8}$	$\frac{1}{24\cdot4}$	—	—
186	3,305	11,608	4·27	61·2	$\frac{1}{54}$	$\frac{1}{189\cdot7}$	16⅛	16⅛
185	—	—	9·38	318·6	$\frac{1}{10\cdot4}$	$\frac{1}{36\cdot4}$	—	—
184, 187, 188	—	—	11·01	398·1	$\frac{1}{8\cdot3}$	$\frac{1}{29\cdot1}$	—	—
191	5,545	13,848	5·64	112·3	$\frac{1}{49\cdot4}$	$\frac{1}{123\cdot3}$	14⅛	14⅛
190	—	—	8·82	348·9	$\frac{1}{15\cdot9}$	$\frac{1}{39\cdot7}$	—	—
189, 192, 193	—	—	10·48	403·2	$\frac{1}{13\cdot7}$	$\frac{1}{34\cdot3}$	—	—
196	7,785	16,088	5·77	123·8	$\frac{1}{62\cdot9}$	$\frac{1}{130}$	13⅝	13⅝
195	—	—	8·62	366·2	$\frac{1}{21\cdot3}$	$\frac{1}{43\cdot9}$	—	—
194, 197, 198	—	—	10·11	412·4	$\frac{1}{18\cdot9}$	$\frac{1}{39}$	—	—
201	10,585	18,888	6·16	154·9	$\frac{1}{68\cdot3}$	$\frac{1}{122}$	15¼	15¼
199, 200 } 202, 203 }	—	—	9·03	427·5	$\frac{1}{24\cdot7}$	$\frac{1}{44\cdot2}$	—	—

TABLE VIII.

ZEPHYR BOAT.—Weight 4765 lbs.; 65 feet 4 inches long; 5 feet 2 inches wide.

Number of experiments in M'Neil's Tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
90	1,065	5,830	4·42	38·7	$\frac{1}{27·5}$	$\frac{1}{150·6}$	7	5
91	—	—	8·53	166·2	$\frac{1}{6·4}$	$\frac{1}{35}$	—	—
92	—	—	9·33	186·9	$\frac{1}{5·7}$	$\frac{1}{31}$	—	—
96, 97	3,305	7,980	3·97	39·4	$\frac{1}{84}$	$\frac{1}{203}$	8½	7½
95	—	—	9·33	225·4	$\frac{1}{14·6}$	$\frac{1}{35·4}$	—	—
94	—	—	12·33	362·8	$\frac{1}{9}$	$\frac{1}{22}$	—	—
105	5,545	10,22	4·36	48·1	$\frac{1}{115}$	$\frac{1}{212·4}$	10	9
103, 104	—	—	9·35	266·6	$\frac{1}{21}$	$\frac{1}{38·4}$	—	—
102	—	—	11·69	400·9	$\frac{1}{13·8}$	$\frac{1}{25·5}$	—	—
106	7,785	12,460	4·04	50·4	$\frac{1}{154·5}$	$\frac{1}{247}$	12	11
109, 110	—	—	8·53	288·1	$\frac{1}{27}$	$\frac{1}{43}$	—	—
108	—	—	11·69	427·5	$\frac{1}{18·2}$	$\frac{1}{29}$	—	—
113	10,585	15,26	4·29	59·9	$\frac{1}{176·7}$	$\frac{1}{254·7}$	13¾	12¾
112	—	—	8·11	331·1	$\frac{1}{32}$	$\frac{1}{46}$	—	—
111	—	—	10·71	422·3	$\frac{1}{25}$	$\frac{1}{36}$	—	—

TABLE IX.

LARK BOAT.—Weight 7088 lbs.; 66 feet 9 inches long; 7 feet 3 inches wide.

Number of experiments in M'Neil's Tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
128	1,065	8,153	4·39	55·9	$\frac{1}{19}$	$\frac{1}{145\cdot8}$	10⅜	10⅜
127	—	—	9·28	257·8	$\frac{1}{4}$	$\frac{1}{31\cdot6}$	—	—
126	—	—	11·38	348·9	$\frac{1}{3}$	$\frac{1}{23\cdot4}$	—	—
138	3,305	10,393	3·93	36·1	$\frac{1}{91\cdot6}$	$\frac{1}{288}$	11⅝	11⅝
137	—	—	9·54	294·2	$\frac{1}{11\cdot2}$	$\frac{1}{35\cdot3}$	—	—
136	—	—	11·616	303·3	$\frac{1}{11}$	$\frac{1}{34\cdot3}$	—	—
142	5,545	12,633	4·02	45·	$\frac{1}{123}$	$\frac{1}{280\cdot7}$	13⅛	13⅛
141	—	—	8·86	334·1	$\frac{1}{16\cdot6}$	$\frac{1}{37\cdot8}$	—	—
140	—	—	10·92	407·5	$\frac{1}{13\cdot6}$	$\frac{1}{31}$	—	—
144	7,785	14,873	3·86	45·3	$\frac{1}{171\cdot9}$	$\frac{1}{328\cdot3}$	14⅝	14⅝
145	—	—	8·57	365·5	$\frac{1}{21\cdot3}$	$\frac{1}{40\cdot7}$	—	—
143	—	—	10·53	418·1	$\frac{1}{18\cdot6}$	$\frac{1}{35\cdot6}$	—	—
154, 147	10,585	17,673	3·7	48·1	$\frac{1}{220}$	$\frac{1}{367\cdot4}$	16⅛	16⅛
146, 149, 151, 153, 148	—	—	7·93	364·	$\frac{1}{29}$	$\frac{1}{48\cdot5}$	—	—
150, 152, 155, 156	—	—	9·82	445·7	$\frac{1}{23\cdot75}$	$\frac{1}{39\cdot7}$	—	—

TABLE X.

HAWK BOAT.—Weight 4566 lbs.; 89 feet 6 inches long; 7 feet 4 inches wide.

Number of experiments in M'Neil's tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
							From marks	
210	1,065	9,601	6·43	136·7	$\frac{1}{7\cdot7}$	$\frac{1}{70\cdot2}$	16⅝	18⅜†
209	—	—	9·84	318·6	$\frac{1}{3\cdot3}$	$\frac{1}{30}$	—	—
208	—	—	11·71	402·7	$\frac{1}{2\cdot6}$	$\frac{1}{23\cdot8}$	—	—
241	2,409	10,945	9·63	342·45	$\frac{1}{7}$	$\frac{1}{32}$	11¾	11¾*
240	—	—	10·94	392·7	$\frac{1}{6}$	$\frac{1}{27\cdot9}$	—	—
239	3,865	12,401	9·23	358·	$\frac{1}{10\cdot8}$	$\frac{1}{34\cdot6}$	15¾	15¾†
238	—	—	10·79	403·85	$\frac{1}{9\cdot5}$	$\frac{1}{30\cdot7}$	—	—
232	5,545	14,081	4·42	64·8	$\frac{1}{85\cdot6}$	$\frac{1}{217\cdot3}$	15	15†
231, 233, 234, 235	—	—	9·18	380·2	$\frac{1}{14\cdot6}$	$\frac{1}{37}$	—	—
230	—	—	10·59	404·2	$\frac{1}{13\cdot7}$	$\frac{1}{34\cdot8}$	—	—
224	7,785	16,321	4·72	76·4	$\frac{1}{101\cdot9}$	$\frac{1}{213\cdot6}$	14	14†
223	—	—	8·74	387·7	$\frac{1}{20}$	$\frac{1}{42}$	—	—
222	—	—	10·41	413·	$\frac{1}{18}$	$\frac{1}{39}$	—	—
215	10,585	19,121	4·52	65·4	$\frac{1}{46\cdot8}$	$\frac{1}{161\cdot8}$	12¾	12¾†
214, 216, 217	—	—	8·35	421·6	$\frac{1}{25}$	$\frac{1}{45\cdot3}$	—	—
213	—	—	10·78	468·4	$\frac{1}{22\cdot6}$	$\frac{1}{40\cdot8}$	—	—

† In these experiments marks were made 18½ inches above the water, when the boat was light.

* This experiment gives the actual draught of water.

TABLE XI.

MONKLAND CANAL.—Average width, 40 feet; 5 feet deep.

RAPID BOAT.—Weight 7692 lbs.; 64 feet 6 inches long; 6 feet wide.

Number of experiments in M'Neil's Tables.	Load, in boat, in lbs.	Load, including boat, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Fraction of force to the load.	Fraction, including the boat.	Draught of water, in inches.	
							Stem.	Stern.
285	1,207	8,899	4·41	64	$\frac{1}{18\cdot8}$	$\frac{1}{139}$	11	8¾
283	—	—	8·65	343·1	$\frac{1}{3\cdot5}$	$\frac{1}{25\cdot9}$	—	—
282	—	—	11·15	356·5	$\frac{1}{3\cdot3}$	$\frac{1}{24\cdot9}$	—	—
273, 279	3,305	10,997	4·48	69·7	$\frac{1}{47\cdot4}$	$\frac{1}{157\cdot7}$	14¼	9¼
269, 276, 280, 271	—	—	8·07	376·8	$\frac{1}{8\cdot7}$	$\frac{1}{29}$	—	—
261, 262, 268, 274, 277	—	—	10·84	381·5	$\frac{1}{8\cdot6}$	$\frac{1}{28\cdot8}$	—	—
255	4,985	12,677	8·45	358·2	$\frac{1}{13\cdot9}$	$\frac{1}{35\cdot3}$	12¾	12¾
254	—	—	10·29	405·6	$\frac{1}{12\cdot2}$	$\frac{1}{31\cdot2}$	—	—
253	6,329	14,021	8·65	394·3	$\frac{1}{16}$	$\frac{1}{35\cdot5}$	13¾	13¾
252	—	—	10·18	423·7	$\frac{1}{14\cdot9}$	$\frac{1}{33}$	—	—
251	7,225	14,917	8·19	403·6	$\frac{1}{17\cdot9}$	$\frac{1}{37}$	14¼	14¼
250	—	—	9·68	425·1	$\frac{1}{17}$	$\frac{1}{35}$	—	—
242	10,585	18,277	7·03	315·6	$\frac{1}{33\cdot5}$	$\frac{1}{57\cdot9}$	16	16
243, 244	—	—	7·88	476·6	$\frac{1}{22\cdot2}$	$\frac{1}{38\cdot3}$	—	—

There is a difference in the weight and shape of these boats, as will be seen on examining their dimensions, which may effect the relative result of each form of boat; but for the purpose of giving a general expression, for the resistance at different velocities, we have classed the entire resistances under the three rates of velocities given in the preceding tables, and have taken the average weight of the boats.

The following Tables will therefore shew the average resistances of canal boats, dragged at the different rates of velocities, corresponding as nearly as possible, with the rate of speed adopted for horse power on railroads.

TABLE XII.

Names of the boats.	Load 1065 lbs. Do. and boat 7873 lbs.		Load 3305 lbs. Do. and boat 10,113 lbs.		Load 5545 lbs. Do. and boat 12,353 lbs.		Load 7785 lbs. Do. and boat 14,593 lbs.		Load 10,585 lbs. Do. and boat 17,393 lbs.	
	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.
Rapid - - -	3·45	30·3	3·90	45·3	3·54	43·9	3·92	56·7	4·39	63·8
Zephyr - - -	4·42	38·7	3·97	39·4	4·36	48·1	4·04	50·4	4·29	59·9
Lark - - - -	4·39	55·9	3·93	36·1	4·02	45	3·86	45·3	3·70	48·1
Velocity - - -	—	—	3·96	41·2	4·32	56·9	4·15	53·9	4·04	51·6
Eagle - - -	4·12	59·2	4·27	61·2	—	—	—	—	—	—
Hawk - - -	—	—	—	—	4·42	64·8	4·72	76·4	4·52	65·4
Average - -	4·09	46	4·01	44·6	4·13	51·7	4·14	56·5	4·18	57·5
Tractive force, for useful load -	96·7 lbs. per ton.		30·2 lbs. per ton.		20·9 lbs. per ton.		16·3 lbs. per ton.		12·1 lbs. per ton.	
— Ditto —, for gross load -	13·1 lbs. per ton.		9·8 lbs. per ton.		9·3 lbs. per ton.		8·6 lbs. per ton.		7·4 lbs. per ton.	

TABLE XIII.

Names of the boats.	Load 1065 lbs. Do. and boat 7873 lbs.		Load 3305 lbs. Do. and boat 10,113 lbs.		Load 5545 lbs. Do. and boat 12,353 lbs.		Load 7785 lbs. Do. and boat 14,593 lbs.		Load 10,585 lbs. Do. and boat 17,393 lbs.	
	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.
Rapid - - -	—	—	8·39	273·2	7·76	281·8	8·33	339·4	7·91	333·0
Zephyr - - -	8·53	166·2	9·33	225·4	9·35	266·6	8·53	288·1	8·11	331·1
Lark - - - -	9·28	257·8	9·54	294·2	8·86	234·1	8·57	365·5	7·93	364·0
Velocity - - -	8·88	267·8	8·92	337·2	8·41	372·2	8·25	409·4	8·46	487·5
Eagle - - -	9·47	306·3	9·28	318·6	8·82	348·9	8·62	366·2	—	—
Hawk - - -	9·84	318·6	—	—	9·18	380·2	8·74	387·7	8·35	421·6
Average - -	9·20	263·3	9·09	289·7	8·73	330·6	8·50	359·4	8·15	387·4
Tractive force, for useful load - -	553·8 lbs. per ton.		196·3 lbs. per ton.		133·5 lbs. per ton.		103·4 lbs. per ton.		81·9 lbs. per ton.	
— Ditto —, for gross load - -	74·9 lbs. per ton.		64·1 lbs. per ton.		59·9 lbs. per ton.		55·1 lbs. per ton.		49·8 lbs. per ton.	

TABLE XIV.

Names of the boats.	Load 1065 lbs. Do. and boat 7873 lbs.		Load 3305 lbs. Do. and boat 10,113 lbs.		Load 5545 lbs. Do. and boat 12,353 lbs.		Load 7785 lbs. Do. and boat 14,593 lbs.		Load 10,585 lbs. Do. and boat 17,393 lbs.	
	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.	Rate, in miles per hour.	Tractive force, in lbs.
Rapid - - -	9·00	258·0	10·93	386·9	11·39	465·2	10·59	451·8	9·92	444·3
Zephyr - - -	9·33	186·9	12·33	362·8	11·69	400·9	11·69	427·5	10·71	422·3
Lark - - -	11·38	348·9	11·61	393·3	10·92	407·5	10·53	418·1	9·82	445·7
Velocity - - -	11·55	397·9	11·25	440·7	10·53	442·8	9·93	456·3	—	—
Eagle - - -	11·50	383·2	11·01	398·1	10·48	403·2	10·11	412·4	9·03	427·5
Hawk - - -	11·71	402·7	—	—	10·59	404·2	10·41	413·0	10·78	468·4
Average - -	10·74	329·6	11·42	396·3	10·93	420·6	10·54	429·8	10·05	441·6
Tractive force, for useful load -	693·2 lbs. per ton.		268·6 lbs. per ton.		169·9 lbs. per ton.		123·6 lbs. per ton.		93·4 lbs. per ton.	
— Ditto —, for gross load - -	93·8 lbs. per ton.		87·7 lbs. per ton.		76·2 lbs. per ton.		65·9 lbs. per ton.		56·8 lbs. per ton.	

TABLE XV.

SUMMARY of the foregoing Experiments.

Average rate of velocity, in miles per hour.	Gross load 3·53 tons.		Gross load 4·53 tons.		Gross load 5·53 tons.		Gross load 6·53 tons.		Gross load 7·76 tons.		Average load 5·57 tons.	
	Tractive force, in lbs.	Tractive force, in lbs. per ton.	Tractive force, in lbs.	Tractive force, in lbs. per ton.	Tractive force, in lbs.	Tractive force, in lbs. per ton.	Tractive force, in lbs.	Tractive force, in lbs. per ton.	Tractive force, in lbs.	Tractive force, in lbs. per ton.	Tractive force, in lbs.	Tractive force, in lbs. per ton.
4·11	46	13·1	44·6	9·8	51·7	9·3	56·5	8·6	57·5	7·4	51·26	9·20
8·78	263·3	74·9	289·7	64·1	330·6	59·9	359·4	55·1	387·4	49·8	326·08	58·53
10·75	329·6	93·8	396·3	87·7	420·6	76·2	429·8	65·9	441·6	56·8	403·58	72·45

From these experiments, we find the following result of the resistances of boats moved at different rates of velocities on canals; taking the maximum, and minimum load, with which the boats were loaded during the experiments.

TABLE XVI.

Velocities, in miles per hour.	Common boats.	Improved boats.		
	Resistance, in lbs. per ton.	Maximum load. Resistance, in lbs. per ton.	Minimum load. Resistance, in lbs. per ton.	Average load. Resistance, in lbs per ton.
2½	2·73	—	—	—
4	7·07	7·4	13·1	9·20
8¾	—	49·8	74·9	58·53
10¾	—	56·8	93·8	72·45

The above table shews the resistance per ton, including the weight of the boat; we must, therefore, in order to ascertain the comparative cost of traction between canals and other species of transport, determine the useful load generally taken with boats travelling at the different rates of speed above enumerated.

The heavy canal boats, which are dragged at the rate of two miles and a half an hour, and which carry twenty or twenty-one tons of goods, weigh six tons and a half; and boats carrying twenty-four tons of goods, may be taken at nine tons weight; these will give the useful load, about seventy-five per cent. of the gross load.

The lightest canal boats which have been, for any length of time, in use, are the fly boats, employed by Messrs. Pickford, and other carriers. Previous to being launched, these boats weigh from seven to seven tons and a half, and they carry from ten to fifteen tons of goods; the useful load being, therefore, about sixty-five per cent. of the gross load.

The swift boats, used for the conveyance of passengers, weigh, as per table of experiments, about three tons; but, more recently, these boats have been made lighter, and we shall take them at two tons weight. They carry from eighty to ninety passengers each, weighing, with luggage, from five to six tons; the useful load may, therefore, be stated at about seventy-five per cent. of the gross load.

§ 3.—*Cost of conveying Goods and Passengers on Canals.*

We come now to the cost of conveying goods by canals, at the different rates of speed above enumerated, and it would have been desirable, in order to place the different systems of transport fully before the reader, to have classed the expenses of canal conveyance under the same heads as those used in estimating the cost of turnpike and railroad; viz. the cost of haulage; the cost of boats; the maintenance of the canal; and the general expenses. The great canal supporter, Mr. Grahame, in his publications on the subject, has carefully abstained from entering into all the particulars of these expenses of canal conveyance, though, from his connections with that property, he must be fully acquainted with all the minutiæ of such expenses. Not being possessed of that information, to such an extent as we could wish, we prefer leaving the subject incomplete, in this respect, rather than hazard estimates, which might not be either satisfactory to ourselves, or conclusive to the public. We shall, therefore, as far as regards canals, generally, confine ourselves to such of these items as we can satisfactorily establish, and shall give the charges on some of the canals sufficiently minute, we trust, to place them in contrast with other modes of conveyance.

We find the resistance of heavy boats on canals 2·73 lbs. per ton gross, at two miles and a half an hour; we have taken the power of a horse at 125 lbs., and, therefore; a horse would drag a boat, weighing forty-five tons, twenty miles a day; or 900 tons, one mile per day, would represent his performance. Mr. Bevan states, that, on the Grand Junction canal, the horses usually travel twenty-six miles a day, and drag a boat, containing about twenty-four tons, at the rate of 2·45 miles an hour; the empty boat weighing nine tons, the gross load being thirty-three tons, this gives the performance = 858 tons, one mile per day. Taking, therefore, seventy-five per cent. as the useful load in the former case, and twenty-four tons in the latter; we have the useful load equal to 675, and 624 tons respectively; the average being 650 tons, conveyed one mile in a day, as the useful performance of a horse, dragging heavy boats on a canal, at the rate of two miles and a half an hour. In calculating the cost of conveyance on railways we estimated the expense of a horse and driver at seven shillings per day, and the performance 280 tons, conveyed one mile, or ·3 of a penny per ton, per mile; adopting the same estimate for the canal, we have 858 tons conveyed one mile, for seven shillings, or nearly one tenth of a penny per ton, per mile; or, making the same allowance as in the case of railways, we have the cost of haulage on canals as equal to ·123 of a penny per ton, per mile.

Mr. Grahame states, that the contract price paid by the carrying companies, for the trackage of a heavy goods boat along the Forth and Clyde, and the Union canals between Edinburgh and Glasgow, a distance of fifty-six miles, is twenty-one shillings.

These boats carry from thirty to forty tons, and the contract time is eighteen hours, the speed being a little diminished in the Union canal. The former canal is sixty feet wide, and nine feet deep; and the latter forty feet wide, and five feet deep. The price paid is different on the two canals; that on the Forth and Clyde, twenty-four miles, is seven shillings; and on the Union, thirty-two miles, fourteen shillings. Supposing the boat to carry thirty tons, we have the cost of haulage, on the Forth and Clyde canal, equal to ·12 of the penny per ton, per mile; and on the Union canal ·18 of a penny per ton per mile, useful load. This, however, is supposing the boat fully loaded, in both directions.

The entire cost of conveyance by canals varies on almost all the different canals in the country, dependent, of course, upon the first cost of formation; and the quantity of traffic upon each of them. The general cost may be taken at about two-pence per ton, per mile, for goods; coals, and other heavy minerals, being conveyed at a less rate, or about 1½*d.* per ton, per mile. On the Merthyr Tidvil and Cardiff canal, iron is conveyed for 1½*d.*, coal, 1⅛*d.*, and iron ore, 1⅜*d.* per ton, per mile. The cost of haulage and boat here is, generally, about nine-pence to eleven-pence per mile, with a boat carrying twenty tons of goods, and returning empty, which is about ½*d.* per ton, per mile. If this is generally correct, and we take ·18 of a penny for haulage, we have for boat hire, steersman, &c., ·32 of a penny per ton, per mile; and, for the general expenses, about a penny per ton, per mile. Mr. Grahame cites one case, of the canal companies charging two shillings and threepence canal dues, for thirty-one miles and a half, upon the Union canal to Edinburgh; which, we may presume, is a minimum charge, being for coals, and being in competition with coals brought along a public railway to the same place. This would give, for canal dues, ·86*d.*, haulage, ·18*d.*, and boat-hire, &c., ·32*d.*, altogether 1·36*d.* per ton, per mile; which is equal to the charge for conveying iron ore on the Merthyr Tidvil canal.

We may, therefore, take the minimum cost of conveying heavy goods, on canals, at 1·36*d.* per ton, per mile; and minerals, generally, at 1·5*d.* per ton, per mile; which will be, for the gross load, assuming the useful load to be seventy-five per cent., about 1·02*d.* per ton per mile.

With the fly boats, the resistance at four miles an hour, we have seen, is 7·07 lbs. per ton. A horse travelling at this rate of speed, will only exert a power equal to 78 lbs.; consequently, his performance, on a canal, will be 220 tons gross conveyed one mile; or, taking sixty-five per cent. as the useful load, the performance will be 143 tons, conveyed one mile in a day, as the useful performance of a horse, dragging fly boats on canals at the rate of four miles an hour. The cost of haulage of this kind of boat is, likewise given, by the canal proprietors on the Forth and Clyde, and Union canals, between Edinburgh and Glasgow; viz., fifteen shillings for twenty-five miles on former canal, and sixteen shillings for thirty-two miles on the latter, for finding horses and drivers; the distance of fifty-seven miles being performed in eleven hours. These boats weigh from seven to seven tons and a half, and are said to be fitted to stow ten tons of measurable goods, and afford accommodation to forty passengers. Taking the latter at fifteen to a ton, or equal to three tons, the cost of haulage, per ton, per mile, of goods, on these canals, is ·33 of a penny per ton, per mile, gross, or ·5 of a penny per ton, per mile, useful load, at an average rate of five miles an hour. The entire cost of conveyance, by fly boats, is about 3½*d.* per ton, per mile. Mr. Grahame states, that the outlay of money, expended by the boat owners, in carrying goods by these boats, is about five shillings and sixpence per ton for fifty-seven miles, or about 1·16*d.* per ton, per mile. Taking the cost of haulage at ·5*d.* per ton, per mile, we have, therefore, the cost of boats, &c., about ·66 of a penny per ton, per mile; and the general expenses charged, 2·34*d.* per ton, per mile. The aggregate cost being, for goods, 3½*d.* per ton, per mile, will be, for the gross load, including boat, 2·275*d.* per ton, per mile.

The resistance of the swift boats, at the rate of ten miles an hour, is 54·12 lbs. per ton. We have before noticed the extraordinary performance of horses dragging these boats, which was, that two horses drag along the canal, at the rate of nine miles an hour, on the average, a boat carrying three tons of useful load, and weighing, altogether, above five tons, the distance they travel being eleven miles. This will give a gross performance of fifty-five tons conveyed one mile, and of useful load thirty-three tons conveyed one mile, in a day, at the rate of from nine to ten miles an hour. Upon the Carlisle canal, the haulage of a swift boat is contracted for, the contractor finding horses and drivers; the price paid, for hauling the boat twenty-four miles, is twenty-one shillings, which is equal to 10½*d.* per mile. Mr. Grahame states the cost at eleven-pence per mile. This will give the haulage for the useful load about 3½*d.* per ton, per mile, or 2¼*d.* per ton, per mile, gross load; or, if forty passengers are taken in the boat, at a time, which we presume will be the utmost, on the average, the cost of haulage, per passenger, per mile, will be ·275 of a penny for each passenger per mile. The charges, for passengers, from Edinburgh to Glasgow, is six shillings, best cabin, and four shillings stowage passengers; or 1·3*d.* and ·86*d.* per passenger, per mile, conveyed at the rate of nine to ten miles an hour; and upon the Lancaster and Preston canal 1·26*d.* and ·34 of a penny per passenger, per mile; the average being about 1·08*d.* per passenger, per mile. Reckoning fifteen passengers to the ton, and each passenger twenty-eight pounds of luggage, the charge, per ton, per mile, will be 13·2*d.* useful load, or about ten-pence per ton, per mile, gross, which includes haulage, boat-hire, and general expenses; and as the cost of haulage is 3½*d.*, the general expenses and boat-hire will be 9·7*d.* per ton, per mile.

The following Table will, therefore, shew the result of these inquiries, on the cost of conveying goods and passengers on canals.

TABLE XVII.

Table of the cost of conveying goods, and passengers, on canals at different rates of speed.

Description of boats.	Rate of speed, in miles per hour.	Resistance, per ton in lbs.	Cost of haulage, per ton per mile.	Cost of boat-hire &c. per ton per mile.	General expenses per ton per mile.	Aggregate charges.	
						Useful load, per ton per mile.	Gross load, per ton per mile.
			d.	*d.*	*d.*	*d.*	*d.*
Slow boats	2½	2·73	0·18	0·32	0·86	1·36	1·02
Fly boats -	4	7·07	0·5	0·66	2·34	3·5	2·275
Swift boats	10	56·8	0·275 per passenger, 3·5 per ton.	- -	9·7	1·08 per passenger, 13·25 per ton.	10· per ton.

We have not, in our inquiries on the capabilities of canals, as a mode of transport, taken into consideration the application of steam as a motive power; all the attempts, hitherto made, have been unsuccessful, and have not yet superseded the use of horse power. Until, therefore, that description of motive power has been brought into such a state of perfection, or usefulness, as to be equal to, or more beneficial than, the present mode; we did not think any inquiry into that part of the subject, in this work, could be of any practical utility.

CHAPTER XIII.

COMPARISON OF DIFFERENT MODES OF INTERNAL COMMUNICATION.

§ 1.—*Railways and Turnpike Roads.*

We are now enabled to compare the relative value of railways, with common turnpike roads, and other modes of internal communication. Whilst railways were in a state of infancy, and their powers scarcely developed, this was a question of great difficulty, as the conclusions were, necessarily, almost entirely speculative, dependent upon the results of improvements, which this species of transport was deemed susceptible of; but now those improvements have attained a degree of perfection, which enables us no longer to present to the reader conclusions drawn from theory, or speculative reasoning, we can appeal to practice, to shew the value of railways, as a means of inland transport. We are aware, that, in appealing to the present state of railways, we offer them to the notice of the public under disadvantageous circumstances. We can only appeal to existing railways, which have, as it were, created this species of transport, and where, it will at once strike the reader, the cost and disadvantage of doing so, must have been very considerable; subsequent establishments, profiting by what has previously been done, will be enabled to commence the traffic upon their lines, under very much more favourable circumstances, and at considerably less cost. In comparing railways with other modes of internal transport,—when we take, as a basis for estimating the cost of working the former, the practical result of a few years, we do not present the comparison at the present state of improvement, which those works have attained; but we encumber that estimate with all the cost and expense, of bringing up a system, from a state of comparative insignificance, to that of its present perfection.

When the Liverpool and Manchester railway was established, it was made one of the stipulations, at the celebrated contest, that none of the engines should weigh more than five tons, and that the rate of travelling should not be less than ten miles an hour. We now find, the very engine for which the premium was obtained, discarded as useless, and doomed to drag coal along a private railway, and engines employed upon that railway weighing upwards of twelve tons, while the public are complaining when the rate of travelling is less than twenty miles an hour.

We may easily imagine the revolutions and alterations, which must have taken place, in all the arrangements and works of that concern, and that all these changes could not be effected, except at a very considerable sacrifice of capital, labour, and cost. The public, and, particularly, new railway companies, are deeply indebted to the Liverpool and Manchester railway, for the benefit which they have derived from the experience upon that great work; and for the very liberal manner in which the company have at all times communicated the result of their labours to the public, or allowed others to obtain that information, such liberality entitles them to the gratitude of all the promoters of that system of internal communication.

We deem the foregoing observations necessary to shew, that, in the comparison of other modes of transport with railways, deduced from past experience, we are scarcely acting fairly towards the system of railways; for there cannot be the slightest doubt, that the system is capable of very great and rapid improvement, and, therefore, in charging the expense of the cost of working up the system to its present state of perfection, we take no credit for such improvements as are, almost without a doubt, likely to take place in a very short period of time, and which might be fairly brought to bear, upon a comparison with other long established and complete systems of transit.

We must not, however, conceal from ourselves, and the public, that the accomplishment of all these improvements has entailed upon the construction and establishment of railways, an increase of capital, to a very considerable amount; railways, which might be constructed at 10,000*l.* to 12,000*l.* per mile, cannot now be properly formed, including the requisite establishment for carrying on the traffic, for less than 20,000*l.* or 25,000*l.* a mile. For it is now indispensable, that all the railway companies should, likewise, become the conductors or carriers of all the traffic upon the railways; and the recent order of Parliament, that no public road shall be crossed upon a level, has, likewise, increased the cost of masonry, to a very great amount.

Art. 1.—*Turnpike Roads and Railways, with Horses.*

The three descriptions of transit, which we have comprised under the head of turnpike roads, are waggons, with heavy goods, travelling at the rate of two, and two miles and a half an hour; fly-vans, or carts, with light goods, travelling at the rate of four miles an hour; and coaches, for the conveyance of passengers, at the rate of nine miles an hour.

The following Table will shew the relative quantity of work, which a horse will perform, and the comparative cost of conveying goods, upon turnpike roads and railways.

TABLE I.

Table of the comparative cost of conveyance of goods and passengers, upon turnpike roads and railways, with horses.

Description of traffic.	Rate of travelling in miles per hour.	Turnpike roads.			Railways.		
		Force of traction in lbs. per ton.	Cost of haulage per ton per mile.	Cost of conveyance per mile.	Force of traction in lbs. per ton.	Cost of haulage per ton per mile.	Cost of conveyance per mile.
Heavy goods	2$\frac{1}{2}$	73	3*d.*	8*d.* per ton	8·5	0·56*d.*	1·65*d.* per ton.
Light goods	4	73	4·5*d.*	12*d.* per ton	8·5	0·9*d.*	3$\frac{8}{27}$*d.* per ton.
Passengers and parcels	9	83	0·7*d.* per passenger. 10*d.* per ton	3*d.* per passenger. 3*s.* per ton	8·5	0·25*d.* per passenger. 2·24*d.* per ton.	1*d.* to 1$\frac{1}{2}$*d.* per passenger. 1*s.* 3*d.* per ton.

We see, therefore, that, for every description of traffic, whether for heavy, light, or bulky goods, or for passengers, railways present a system of transport very much cheaper than turnpike roads, even when horses are employed as the motive power; and, consequently, when the two come in competition with each other, all such traffic must be absorbed by the railway. We shall now give the relative utility, with horses on common roads, and locomotive engines on railways.

Art. 2.—*Turnpike Roads, and Railways with Locomotive Engines.*

TABLE II.

Table of the comparative cost of conveyance of goods and passengers, upon turnpike roads, with horses, and on railways, with locomotive engines.

Description of goods.	Turnpike roads.				Railways.			
	Rate of travelling in miles per hour.	Force of traction in lbs. per ton.	Cost of haulage per ton per mile.	Cost of conveyance per mile.	Rate of travelling in miles per hour.	Force of traction in lbs. per ton.	Cost of haulage per ton per mile.	Cost of conveyance per mile.
Heavy goods	2½	73	3*d.*	8*d.* per ton	8	8½	0·375*d.*	1·065*d.* per ton.
Light goods	4	73	4½*d.*	12*d.* per ton	12	8½	0·5*d.*	3·5*d.* per ton.
Passengers and parcels	9	83	10*d*	2*d.* to 4*d.* per passenger 3*s.* per ton	20	8½	0·25*d.* per passenger 0·73*d.* per ton	1*d.* to 1½*d.* per passenger. 12·37*d.* per ton.

On railways, with horses as the motive power, we find the cost, of conveying heavy goods, at two miles and a half an hour, is one fifth only of the cost of conveyance by horses on turnpike roads; with light goods, the comparative expense is, likewise, about one to five, and, for the conveyance of passengers, the cost of haulage is about one fourth, the comparative resistance being one ninth only. The difference, between the relative resistance and the charges, for the conveyance of goods, is important to consider. The charges are not the mere cost of conveyance only, but the interest of capital, for the construction of the road, and all the expenses of repairs, management, &c.; and, therefore, in the case of turnpike roads, we have, over and above the cost of haulage, to add the expense of cart-hire, &c., and the tolls for keeping up the roads. In the cost of conveying goods by railways, we have similar charges, we have, beyond the expense of haulage, the cost of finding carriages, the expense of maintenance of the railway, interest of capital, and other expenses of management, police, &c.; but when we see, that the cost of motive power or haulage, on turnpike roads, is more than five times the cost of haulage on railways, there remains a much greater surplus, for all these items of charge, upon railways, than upon turnpike roads. But the cost of haulage alone on turnpike roads is greater per ton, than the entire charges upon railways. We find, therefore, that turnpike roads cannot compete with railways, even when horses are employed as the motive power on the latter; and, consequently, all the traffic of passengers and goods upon turnpike roads must be absorbed by railways, between the termini when the two come in competition with each other.

But when we compare turnpike roads with railways, where locomotive engines are used as the motive power upon the latter, the superiority is still more striking. With heavy goods, we find the haulage on railways $\frac{1}{6}$th the cost of that on turnpike roads, and at more than three times the rate of speed. Light goods are, likewise, conveyed at $\frac{1}{4}$th of the cost of horse-hire on turnpike roads, and at nearly three times the rate of speed; and with passengers and parcels, the cost of haulage on railways is only ($\frac{1}{14}$th) of that upon turnpike roads, while the rate of travelling is more than double.

$\frac{1}{11}$ ÷

The conclusion resulting from these facts is, that, in every case where existing railways and turnpike roads come in competition, railways will absorb all the traffic, whether it be heavy goods, light merchandize, parcels, or passengers. If, therefore, a railway is once constructed, the company may safely calculate upon being enabled to compete successfully with the turnpike road carriers, for all the traffic between the two termini of the railway.

There is, however, a limit to this, which must not be overlooked, railways commence and terminate at certain points, to deliver goods, parcels, and convey passengers to different parts of the town, carts and carriages are required; and as the transferring of goods and passengers from one carriage to another is attended with expense and delay, the saving of conveyance by the railway may, in certain cases, where the distance is not great between the two places, be counterbalanced by the expense and inconvenience of transfer; and, therefore, in calculating upon the traffic which will be obtained by a railway, we must take this into consideration. Upon long lines of railway, where the saving of transport is great, the issue cannot be doubtful.

§ 2.—*Canals and Railways.*

We now have to compare canals and railways, as modes of transporting goods and passengers, from one place to another. The immense capital embarked in canals, and the very large sums in course of expenditure upon railways, alike render the subject of infinite importance; for, whether the result be in favour of one system or the other,—whether railways are enabled successfully to compete with canals, in the conveyance of all, or of any part of the traffic, which is now exclusively conveyed by canals, or which, by their nature, they are peculiarly adapted to convey,—it is alike necessary, that the question of their relative capabilities should be carefully, impartially, and, if possible, conclusively, determined. For if railways present a mode of transit decidedly superior, more economical, and more expeditious, than canals, for every description of traffic, then it is of the greatest importance, that the railway speculator should adapt the railway for the conveyance of every kind of traffic now conveyed by canals; but, if on the contrary, it were to be determined, that railways can successfully compete with canals for only a portion, or only for some descriptions of traffic, then it is of equal, if not of more, importance, that the line of demarcation should be drawn, and that the energies and capital of railway projectors should only be directed to that description of traffic, which legitimately belongs to the system they promote:—that, on the one hand, they should not be expending capital, and struggling for the acquisition of traffic which other modes of transit can convey more cheaply, while, on the other hand, the canal proprietors should not blindly plunge into schemes for the retention of traffic, which they have not the slightest power to withhold from other modes of transport.

We would not, however, for one moment have it understood that these observations are meant to check, or cramp the energies, of the promoters of either one system or the other. Nothing can tend more to develope and bring into prominence all the powers of any system, than competition with its rivals; and, therefore, both railway projectors and canal proprietors, are equally indebted to the exertions of their respective rivals for the developement of powers arising out of the competition of one system with the other. For although large sums of money may be spent upon schemes of unproductive competition, yet even these may produce useful results; as such a state of jealousy, watchfulness, and active competition, between one system and the other, however it may operate upon the pockets of the respective competitors, will, no doubt, be attended with beneficial effects, as regards the public.

We might illustrate the truth of these remarks, by the instance of the Liverpool and Manchester railway. When that line was first projected, it was held forth to the public, that almost all the traffic of the canals would be absorbed by the railway, and very lengthened evidence, for several days, was brought before the Committee on the bill, to prove that this result would be accomplished; and all this was deemed necessary to shew, that the railway projectors would realise a return for their capital of 10*l.* or 12*l.* per cent. Now, what has been the result? The traffic on the canal has not been materially diminished, and the railway projectors are receiving a return of 10*l.* per cent. upon a capital, many times the amount of the estimate laid before Parliament!

We see that railways do not, whether they can or not, is the question we are about to inquire into, successfully compete with canals, for all the traffic between the two termini of the railways; we see, also, statements made by canal promoters, that canals can successfully compete with railways for every description of traffic,—for heavy goods, light goods, and passengers; and that railways are nothing but insane schemes, bubbles, and an entire waste of capital; and, yet, we see millions of money either expended, or in the course of being expended, on railways, notwithstanding such denunciations.

We need scarcely, therefore, observe, that it must be of infinite importance to all the great interests concerned, if the question as to the relative capabilities of of the two systems cannot be so conclusively determined, as to be no longer a matter of doubt, that such information should be laid before the public, as the capabilities of the two modes present; in this, however, we meet with very great difficulties, some of which are almost insuperable. In the first place, the canal system, which has been slumbering and stationary, ever since its first introduction into England, has recently, by the competition of railways, been brought into great activity. Improved boats have been constructed, steam has been tried, and experiments made, which have proved that a rate of velocity may be attained, with horses, which, at one time, it would have been considered quite chimerical to entertain. Railways, likewise, have just emerged, or have scarcely emerged, from a system of comparative insignificance to that of the highest importance, and a rate of travelling established upon them, which, at one time, it was deemed impossible ever to arrive at. While, therefore, these systems, and more especially the latter, are, as it were, in a state of progressive improvement, or in their march towards perfection, it is difficult to fix upon any standard of comparison, which is not liable to be upset, by perhaps a start of improvement, even before the work is before the public. The most that can be done, therefore, is to present the two systems, in comparison with each other, in their existing state; leaving it to the relative exertions of the promoters of each, and to the inherent capabilities of each system, which of the two outstrips the other in the race of improvement.

Even to this extent, we meet with obstacles towards conclusively determining the existing capabilities of both the systems; we find, it is extremely difficult to obtain all the information upon all the points necessary to establish the powers of each mode of transport; and, more particularly, that which refers to the cost. The most powerful of canal promoters, Mr. Grahame, in all his publications, put forth with the express purpose of shewing the inferiority of railway to canal conveyance, has studiously avoided giving conclusive statements of the powers, and cost of working canals; although being an extensive canal proprietor himself, and in communication, we suppose, with all the canal interests of England and Scotland, and looked up to as their champion; and, consequently, when no doubt could exist, that it was in his power to give conclusive statements on the subject.

Again, as regards railways, although their present state of progressive improvement renders it extremely difficult to obtain a fixed standard of their powers and cost; yet, even amongst existing companies, there is a reluctance, perhaps justifiable, to a disclosure of the expenses of their several concerns; it is, therefore, almost impossible to obtain all the information necessary to establish a decisive standard of comparison, even of the existing state of the system of railways.

At the period of the publication of the first and second editions of this work, the cost of working railways, in the improved system, had not been sufficiently long established to warrant us in engaging with this part of the subject; since then seven years have elapsed, and the system of rapid travelling has been in operation on the Liverpool and Manchester railway during that period; considerable experience has existed likewise on the Stockton and Darlington, and other railways, as to the cost of working the improved engines; Mr. Grahame, too, has given us a good deal of information on canal navigation; these, together with such opportunities as have come within our reach, have justified us, in our opinion, in entering upon the question of the comparative cost of working the different systems of internal communication; and, therefore, with these explanations, we present to the reader such information as we have obtained on the subject.

Art. 1.—*Relative Resistance of Canals and Railways.*

In the first edition, we only compared canals with railways, in the relative resistances to bodies moved along them; at that period, few experiments had been made on the resistance of boats moved on canals, especially at high rates of speed; since that period a very valuable and extensive set of experiments has been made by Mr. M'Niel, the substance of which has been given in another part of this work.

It had previously been argued in favour of canals, that although, at certain rates of speed, they did offer to boats moved in them resistances according with the established theory of fluids, yet when these boats were moved at a high rate of velocity, the resistance did not increase in that ratio; or that, in fact, it did not increase at all, with the velocity. The experiments of Mr. M'Niel are conclusive on this part of the subject, as they give the actual resistances, at all the several rates of velocity, at which it is practicable to drag boats on canals.

We have endeavoured, in estimating the cost of conveyance on turnpike roads, to divide the traffic into three rates of velocity; viz. two miles and a half an hour, for heavy goods, four miles an hour, for light goods, and nine or ten miles an hour, for passengers. On canals we have adopted the same classification, although, in the resistance of canal boats, we have taken four different rates of speed, to illustrate the discovery of the diminution of resistance at high rates of velocity. The following table will, therefore, shew the relative resistances of canals and railways at different rates of velocity.

TABLE III.

Rate of velocity in miles per hour.	Canals.				Railways.	Ratio of resistances on canals and railways.
	Common boats.	Improved boats.				
	Average load 22½ tons. Resistance in lbs. per ton.	Maximum load 7·76 tons. Resistance in lbs. per ton.	Minimum load 3·53 tons. Resistance in lbs. per ton.	Average load 5·57 tons. Resistance in lbs. per ton.	Resistance in lbs. per ton.	
2½	2·73	—	—	—	8½	0·32 : 1
4	7·07	7·4	13·1	9·20	8½	0·83 : 1
8¾	36·8	49·8	74·9	58·53	8½	5·86 : 1
10¾	57·3	56·8	93·8	72·45	8½	6·68 : 1

On examining the above table, we find, that the improved canal boats do not present less resistance *per ton*, than the old boats, even under the most favourable circumstances, or when fully loaded; when partially loaded, we find the resistance much greater than in the old boats. The resistances of the old boats given in the table, up to four miles an hour, are the result of experiments detailed in Chapter XII. on canals; the resistances at 8¾, and at 10¾ miles an hour respectively, are calculated at the square of the velocity; and by this mode of calculation, we see the improved boats present a great increase, of resistance beyond that of the old boats.

It is perfectly true, as asserted by the canal promoters, that a diminution of resistance in the improved boats takes place below that which the theory would give, or below that of the square of the velocity, when the boats are urged beyond a certain rate of speed; thus we find, that between the rates of 8¾, and 10¾ miles the increase of resistance is below that of the simple rate of the velocity, instead of the ratio of the square of the velocity, which theory would give; but we must observe, that from 4 to 8¾ miles an hour, the *increase* of resistance is much beyond that of the square; so much so, as to more than compensate for the *diminution* between 8¾ and 10¾ miles an hour; so that with all the advantages of the improved boats, it does not appear that an actual diminution of resistance has been effected below that which theory would give, by the old boats, taking their resistance as that actually ascertained by experiment at two miles and a half, to four miles an hour.

We trust, that, in this place, we may be indulged one remark, in answer to what can only be called, by the mildest language, a most uncourteous attack, in 1832, on the second edition of this work, by Mr. Grahame, on the statement therein made of the comparative resistances of canals and railways. On referring to Table XIII. page 458, of that edition, it will be seen, that we make the comparative resistances between canals and railways, as 5·3 : 1 at eight miles an hour. We would direct Mr. Grahame's attention to the result of Mr. M'Niel's experiments, given in the table in the preceding page, which shews that the comparative resistances of the improved boats at 8¾ miles an hour is in the ratio of 5·86 : 1, with the maximum load, and 8·52 : 1, with the average load of these experiments. We did not think it necessary to answer this attack at the time, as any one interested in the inquiry might have seen a result equal to the above fact from Mr. Grahame's own references, viz. to the experiments detailed in Mr. Fairbairn's work; wherein it is shewn, page 60, that the resistance of a boat moved at the rate of 7·28 miles an hour, was equal to 66 lbs. per ton; or in the ratio of 7·7 : 1 of the resistance of railroads. We must not omit to notice, however, that Mr. Grahame laid considerable stress upon our statement of the power of horses, which was that of their ordinary work in other cases; and which he compared with the performance of horses dragging boats on canals, which we have already shewn are extraordinary efforts. We have given the experiments of Mr. M'Neil on the actual resistances of the boats dragged by the horses alluded to, which shew efforts very much beyond the generally conceived opinion of the capabilities of a horse, and which can only be accomplished by more than ordinary wear and tear to his physical powers. Taking, in the case of railroads, the *ordinary* powers of a horse, and contrasting these with the *extraordinary* powers to which the horses are urged in dragging the swift boats on canals; Mr. Grahame certainly shewed a discrepancy between, what he called, our statements, and his facts. But if the actual relative resistances of the two modes of transport were such as we then stated, and they are fully borne out by subsequent experiments, we see no reason, if such extraordinary performances are capable of being realized by horses travelling along the towing path of a canal, why the same effort cannot be made along the track of a railway; and, therefore, the comparison equally holds good in fact, however it may be distorted in argument, although horses have not been urged on railways, to such extraordinary efforts as they have been on canals.

With these observations, we now give the comparative cost of conveying goods and passengers upon canals, and by horses on railroads.

Art. 2.—*Comparative Cost of Canals and Railways with Horses.*

Table IV.

Table of comparative cost of conveying goods and passengers on canals, and by horses on railroads.

Canals.				Railroads.			
Rate of speed in miles per hour.	Resistance per ton in lbs.	Cost of haulage and boat hire per ton per mile.	Cost of conveyance per ton per mile.	Rate of speed in miles per hour.	Resistance per ton per mile.	Cost of haulage and carriages per ton per mile.	Cost of conveyance per ton per mile.
2½	2·73	0·5*d.*	1·36*d.*	2½	8·5	0·75*d.*	1·65*d.*
4	7·07	1·16*d.*	8·5*d.*	4	8·5	1·127*d.*	.3·627*d.*
10	56·8	0·275*d.* per passenger, 3·5*d.* per ton.	1·08*d.* per passenger, 13·25*d.* per ton.	10	8·5	0·25*d.* per passenger, 2·24*d.* per ton.	1 to 1·5*d.* per passenger, 15*d.* per ton.

We find, from the above table, that for the conveyance of heavy goods, canals present a cheaper mode of conveyance than railways, in the proportion of 1·36*d.* to 1·65*d.* per ton, per mile; this result takes place upon a level railway, and when the length of the canal and railway between the two places is precisely the same.

If the goods are to be conveyed between two places, which will admit of a descending line of railway, and the great bulk, or the whole of the goods are to be conveyed in that direction; and if the inclination be such as to enable a horse to drag one fifth greater weight than upon a level railroad, then the two modes of transport will be equal; and when the railway is such that a horse can drag more than that proportion, the balance will then be in favour of the railroad. And, on the contrary, if the situation of the two places is such, as that the inclination of the railway is ascending, in the direction the load is to be conveyed, then the balance will be in favour of canals.

In this latter case, however, we presume horses would not be employed, as the motive power would either be locomotive engines; or, if for the conveyance of minerals and heavy goods, probably, fixed engines, and, therefore, the comparison would not apply.

Again, if the length of the canal, between the two places is more than one fifth greater than the distance by the railway, this will throw the balance in favour of the railway, provided the gradients are not affected by taking the more direct line; having, however, the relative cost per mile, it will be easy to apply this to any case in practice.

With respect to light goods and merchandize, conveyed at about four miles an hour, we find the result a little in favour of canals, in the proportion of 3·5 to 3·627*d.* per ton, per mile, supposing the railway level; and the canal and railway, both the same length.

The same remarks, as to this result being altered by the circumstances above alluded to, apply to this description of traffic, as well as that of heavy goods.

In the comparison of quick travelling on railroads, and by the swift boats on canals, we have the resistance of the latter more than seven times that of the former; so far, therefore, as regards the motive power, the cost should be nearly in that ratio. We find, however, as previously remarked, the most extraordinary performances effected by horses dragging the swift boats; greater than assigned on railroads, to horses travelling at two miles and a half an hour. There can be no reason why, when horses are capable of such performances on canals, that they are not equally capable of doing the same on railroads; and, therefore, if such a performance was assigned them, then we have underrated the cost of conveyance by railways, at the speed of ten miles an hour. This, however, is of less importance, inasmuch as at that rate of travelling the balance is decidedly in favour of railways, and, consequently, any difference between the actual expenses of haulage, and the charges made, only adds to the profit of the railway, and does not strictly enter into the comparison of the two systems, in contrast with each other. In all cases, therefore, when the distances are equal, railways will be enabled to successfully compete with canals, for the conveyance of passengers, parcels, and all goods, or merchandize, conveyed at the rate of ten miles an hour, even when horses are the motive power.

We shall now give the comparison between canals and railways, when locomotive engines constitute the motive power on the latter.

Art. 3.—*Comparative Cost of Canals, and Railways with Locomotive Engines.*

TABLE V.

Table of the comparative cost of conveying goods and passengers, by horses on canals, and by locomotive engines on railroads.

Canals.				Railroads.				
Rate of speed in miles per hour.	Resistance per ton in lbs.	Cost of haulage and boat-hire per ton per mile.	Charges of conveyance per ton per mile.	Rate of speed in miles per hour.	Resistance per ton in lbs.	Cost of haulage and carriages per ton per mile.	Cost of conveyance per ton per mile.	Charges of conveyance per ton per mile.
2½	2·73	0·5*d.*	1·36*d.*	8	8·5	0·565*d.*	1·065*d.*	1·065*d.* 1·565*d.*
4	7·07	1·16*d.*	3·5*d.*	12	8·5	0·727*d.*	2·138*d.*	3·5*d.*
10	56·8	Haulage. 0·18*d.* per passenger, 3·5*d.* per ton.	1·08*d.* per passenger, 12·25*d.* per ton.	20	8·5	Haulage. 0·25*d.* per passenger, 0·73*d.* per ton.	0·675*d.* per passenger, 2·855*d.* per ton.	1*d.* to 1½*d.* per passenger, 12·37*d.* per ton.

On examining the above table, we find, that, with heavy goods, although the relative resistances of canals and railroads, are three times as great upon the former as upon the latter, the cost of haulage and boat-hire is nearly the same upon canals, as the cost of haulage and carriages upon railways; and that coals and minerals are conveyed on railways equally cheap, if not at a less rate, than upon canals. We have given cases on railways, of coals being conveyed at the rate of 1·065*d.*, and 1·09*d.*

per ton, per mile, in very large quantities, many hundred thousand tons yearly; and, in no instance, has it been shewn, that canal navigation is conducted at a cheaper rate, including every charge. Mr. Grahame, as one case of very cheap canal conveyance, cites the dues upon the Union canal at 2*s*. 3*d*. per ton, for 31½ miles, which is equal to ·86*d*. per ton; he likewise states the cost of haulage between Edinburgh and Glasgow, a distance of 56 miles, at 1*l*. 1*s*. for a boat of forty tons burden; but, as the boats are never fully laden, we may take this at ·15*d*. per ton, per mile, as the lowest rate of dragging boats; finding, in no other instance, the same work done at that cost. This would give 1*d*. per ton, per mile, exclusive of boat-hire; and, therefore, unless the boat-hire can be effected at ·065 of a penny per ton, per mile, canals cannot compete with railways in the conveyance of heavy goods; where such railways are constructed, and worked with a view of effecting the most economical conveyance of heavy goods, at moderate rates of speed.

It is not of so great importance, perhaps, as the economical transport of such goods, that they are conveyed on railroads, at three times the rate of speed, which they are conveyed on a canal; except that, where large quantities are to be transmitted daily, as upon some of the railways, where from 1500 to 2000 tons are conveyed daily along one line of road, a considerable saving of capital must be effected, between the carriages running at the rate of eight miles, and boats moving at the rate of 2, or 2½ miles an hour. We may, therefore, conclude, that where large quantities of minerals, coals, or other heavy goods are required to be transported from one place to another; that such minerals, &c. can be conveyed cheaper, and more expeditiously, upon a railway, constructed and worked for that purpose, than by a canal. And, in the determination of this question, it is not necessary to go into the relative distances by canal, and by railway; the superiority being in favour of the latter, in every case the railway will be the shorter length, and, therefore, the balance will be still further in favour of railways, when the relative distances are varied. Neither need we, in this case, go into the question of the gradients of the line of railway, as we see, in Chap. X., § 2, Art. 3, that coals and minerals are conveyed at the rate of 1·13*d.* per ton per mile by fixed engines, across a line of country, over which it would be difficult to carry a canal.

We now come to the consideration of, whether heavy goods or minerals can be carried upon public railways, on which a mixed traffic of merchandize, and passengers, is conducted, to compete with canals. On referring to the particulars of the cost of working the Liverpool railway, we find the total cost of conveying merchandise, 2·518*d.* per ton per mile; this includes a charge of 1·08*d.* for conducting the traffic of merchandize, loading, and unloading, &c., which, not being applicable to the cost of conveying coals, or minerals, should be deducted; leaving 1·51*d.* per ton, per mile, as the cost of conveyance of coals, &c., not required to be loaded, or unloaded, by the railway company. The expense of locomotive power, upon that railway, we have explained, will be greater than on future lines of railway. The cost of upholding waggons is, likewise, ·027*d.* greater than for the conveyance of minerals, and the charge for general expenses is likewise very high; with these reductions, and when trains of coals or minerals can be allowed to travel along the railway with a maximum load, we do not see why those articles cannot be conveyed along a public railway, with a mixed traffic, as cheaply as upon a railway constructed for the express purpose of conveying such articles. Taking the cost upon the Liverpool railway at 1·51*d.* per ton per mile; the cost on canals is 1·36*d.* per ton per mile; if the reductions for the saving of motive power be made, making railways 1.46*d.*, and, especially, if the length of the canal be greater than the railway, the balance will be in favour of the latter. And it may here be remarked, that, almost in every instance, where railways and canals have been constructed between two places, the railway has been very much shorter in length than the canal. From Liverpool to Manchester, the canal is fifty miles, the railway thirty-one miles; from Edinburgh to Glasgow the canal is fifty-six miles, and the projected railway forty-two miles; and several other instances might be given, where the length of the canals between the two places is much greater, but in no one instance, is it a shorter distance than the railway. By proper arrangements, therefore, upon public railways, with a mixed traffic; coals, or minerals, may be conveyed at a rate which would enable the railway company to compete with the rates at present charged by the canal companies. Upon the Newcastle and Carlisle railway, the coals for export are conveyed at 1·25*d.* per ton per mile, for railway dues and haulage, and ·25*d.* per ton per mile for finding waggons, (a superior description of waggon wheels being used for safety, with a mixed traffic,) being altogether 1·5*d.* per ton per mile. (Note L, Appendix.)

If the two systems of canal and railway come into active competition, and all regard to the receipt of dues be sacrificed by both parties, the case would be different; we would then have to ascertain upon which of the two the direct charges would be greatest, the cost of haulage and boat-hire, on the one hand, or the locomotive power, and waggons, on the other. The former, by Table XVII. Chap. XII. we find to be ·5*d.* per ton per mile; while the latter is ·565*d.* upon railroads, applied to the conveyance of minerals alone, and ·777*d.* per ton per mile, on the Liverpool railway. Between railways and existing canals, therefore, the length of each being the same between the two termini, the canal will be enabled to compete with the railway in the conveyance of *minerals*; but, in doing so, it will be observed, that it must be upon the principle of not making a remunerating charge for canal dues; still, if the canal company be determined to continue the traffic of coals, and minerals, it will not be in the power of the railway company, unless more favourably situated as regards the locale of the traffic, or as having a shorter line than the canal, to dispossess the canal company of the conveyance of such articles.

The next consideration, between the two systems, is that of the conveyance of *merchandize.* The comparison, in this case, lies between the goods trains on railways, and the fly boats on canals; the former travelling at the rate of twelve to fifteen miles an hour, and the latter at four to five miles an hour. On referring to the cost of railways, we find the charges the same as those on canals; this is easily accounted for; when parties can have their goods delivered in one third the time, they will prefer the quick delivery to the more protracted; and, therefore, although the charges are the same, the railway conveyance will be preferred, especially as, upon canals, the goods are more liable to pilfering; and these goods being generally valuable, a saving of time of delivery is of some consequence. If, therefore, the conveyance of merchandize upon railways, can be effected at the same cost as upon canals, the railway will monopolize all the traffic of such goods, facility of despatch being so great a desideratum.

We shall now ascertain upon which of the two systems of transport, such goods can be more cheaply conveyed. According to Table V. of this chapter, we find the cost of haulage and boat-hire on canals equal to 1·16*d.* per ton per mile, while the haulage and expense of upholding carriages on the Liverpool and Manchester railway is ·777*d.* per ton per mile; when, therefore, railways come into active competition with canals for this species of traffic, the struggle will be so decidedly in favour of railways, that we may suppose, unless other circumstances than the mere cost of conveyance, and facility of despatch, exist, the competition will never be brought into action. Railway projectors, as in the case of the comparison with turnpike roads, may, therefore, calculate upon all the traffic of merchandize, where cheapness of transit, and facility of despatch are combined, whether the comparison is against existing or projected canals.

We have now to enter into the comparison, with *passengers* and *parcels*, at higher rates of speed. In the chapter on canals, we have given sufficient information, obtained from Mr. M'Niel's experiments of the resistance of boats moved at rapid rates, to determine the actual force required to drag such boats, and we have taken from Mr. Grahame's publications, the cost of traction of the boats on some of the canals in England and Scotland; these data will not, therefore, be disputed by the advocates for canal navigation. For the results on railways, we have taken the actual cost upon the Liverpool railway, under circumstances which are far from favourable to that system; upon these, however, we purpose grounding the comparison of the value of the two modes of transit.

In the first place, with respect to the rate of travelling on each. In the case of canals, we have taken ten miles an hour, which is, we believe, at least one mile an hour greater than the average velocity constantly realized by the swift boats; at any rate, nine miles an hour, may be taken as the average velocity of the swift boats on canals. It will not, we presume, be questioned, that the rate of travelling upon railways by locomotive engines is overrated at twenty miles an hour. The distance between Liverpool and Manchester, (31 miles,) is run in an hour and ten or fifteen minutes. The distance between Birmingham, and Manchester, or Liverpool, is ninety-seven miles, the time, four hours and a half. So far, therefore, as relates to the rate of travelling, we may, in a general way, state that, at present, the rate upon railways, is more than double that by swift boats on canals.

Having ascertained, that the rate of travelling by railway is double that by any other mode, it will not be contended, if the fares are the same, the preference will not be in favour of railways; whatever may be said of the value of time as relating to goods and merchandize; it cannot be questioned, that time is valuable as regards individuals.

The time of the common labourer cannot be taken at less than *2d.* per hour, and when we come to the higher grades of mechanics, and from that to merchants, and others, engaged in trade, and other pursuits, we shall find, that the value of each hour, will pay for a considerable difference of fare, between travelling at the rate of ten and twenty miles an hour. This is amply exemplified by the canal companies themselves, otherwise, such extraordinary efforts would not have been made to attain a rate of speed with the swift boats, double that of the common fly boats; the trackage of which alone, according to Mr. Grahame, is in the one case 11*d.* per mile, and in the other 3½*d.* per mile, if they did not find, that such a rate of travelling was necessary to secure the traffic of passengers on canals.

We may, therefore, conclude, that, if the fares be the same on the railway and the canal, the rate of travelling on the former being twenty, and on the latter nine or ten, miles an hour, all the conveyance of passengers will be absorbed by the railway, the convenience of both being the same. But, we think, this may be carried further, and that greater fares may be charged by the railway, and still the traffic of passengers will be secured to that system of conveyance.

The fares on the Liverpool and Manchester railway have been often alluded to, as proving the high rate at which it is necessary to charge on railways; and the whole of the arguments of Mr. Grahame, in favour of canals, are founded upon, what he calls, the exorbitance of those charges, which are *5s. 6d.* by the best coaches, and *4s. 6d.* by the open carriages; or about *2d.* and 1½*d.* per mile, respectively. But it must be observed, that these are the fares which the company are *enabled* to charge, and yet to outstrip all competition from other modes of conveyance; not what they are *obliged* to charge, on account of the expenses of working the railway; and this fact, instead of telling against the system, goes to prove that such charges can be made per mile, and yet compete effectually against all other modes of conveyance. We must, however, remark, that the canal, in this case, is put out of competition by its increased length, being fifty-six miles, while the railway is only thirty-one miles; still the railway is subject to the competition of the turnpike road, thirty-three miles in length.

It is confidently asserted, that passengers can be conveyed in the swift boats at ¾*d.* per mile; if so, we have this conclusion, that the canal companies cannot induce passengers to travel by the canal at 3*s*. 6*d*. in preference to paying 5*s*. 6*d*. and 4*s*. 6*d*. by the railway, which can only be accounted for by the saving of time by the railway.

On examining the table of the relative cost of conveyance by canal and railway, we find the cost of haulage and boat-hire by canal, at ten miles an hour, equal to 3½*d*. per ton per mile; while, for parcels and light goods, conveyed by the railway coaches, the haulage and cost of carriages are 1¾*d*. per ton, at twenty miles an hour. In the case, therefore, of active competition between the two modes, we find the balance decidedly in favour of railways.

The result, therefore, of these comparisons of canal and railway communications is, with respect to heavy goods; where it becomes a question, whether a railway or a canal is to be constructed; that a railway is preferable, inasmuch as, while it affords as cheap a mode of conveyance for heavy goods, it presents a more economical and more expeditious means of transit, for all other descriptions of traffic. When the question relates to the construction of a railway, for the conveyance of heavy goods alone, to be brought into competition with an existing canal; unless there are other circumstances, in favour of the former, more than that of being a level railway, and of the same length as the canal, we find the latter will be enabled to compete with very great effect against such a railway. But when we are to determine as to the construction of a railway, for a mixed traffic of minerals, coals, or heavy goods, merchandize, and passengers, we find that a railway will be enabled to compete successfully with any existing canal; presuming that the interest of capital and amount of traffic are such, that the dues required to be charged on the railway, are not higher than those given in the cases upon which our calculations have been formed, of the comparative cost of working the two systems of communication.

In our comparison, however, of the two systems of transit, we must not lose sight of the very important consequences, resulting to the commerce of the country, by the rapidity of communication effected by railways, which far outweighs any trifling balance of economy in favour of canals, if such even do exist; and, therefore, we presume, whenever the balance between the two modes, in any degree approach each other, a preference will be given to railway communication.

CHAPTER XIV.

ON THE CONSTRUCTION OF THE GREAT WESTERN RAILWAY, AND THE LOCOMOTIVE POWER TO BE USED THEREON.

THE construction of this railway, being different from that of the Liverpool and Manchester, the London and Birmingham, the Grand Junction, and other great lines of railway laid down in this country; and being, in many respects, upon an entirely new system, and it being the intention of the proprietors of that railway to adopt a rate of speed much beyond that at present kept up upon the existing lines of railway; we have thought it advisable to give a short description of the mode of construction, and the plan of the locomotive engines to be used upon this railway. This should have followed the description of the plan of formation, of other lines of railway in Chapter IV., but as the Great Western railway is only at present in the course of formation, we deemed it advisable to obtain the latest information on the subject; and have, therefore, deferred obtaining it, as long as we could, previous to the work issuing from the press. Though this has caused a misplacement of this chapter, it has not been without its advantages; as it has enabled us to state the result of a trial upon a portion of the line, which, together with a description of the mode of construction, has been kindly communicated to us by Mr. Brunel the engineer.

§ 1.—*Principles of the old System of forming Railways.*

The plan of formation of all railways is, in the first place, to form a track or road of as nearly a uniform level, or rate of inclination, as can possibly be done, from one extremity of the line to the other. This is done by cutting down all those parts of the line of the country, which are elevated above the general inclination or level of the intended road, and filling up all those parts, the surface of which is below the general rate of inclination of the proposed line of railway, as shewn in *Fig.* 1, *Plate V.* The whole length of the railway is, therefore, almost entirely composed of a succession of cuttings and embankments from one end to the other; and the line forming the upper surface of these cuttings and embankments, which ought to be a uniform level, or rate of inclination, is called the "base," or "formation line," of the railway. Upon all those parts of the line which compose the cuttings, this base will be quite firm and solid, being, in fact, the undisturbed strata of the earth; but upon those parts which are formed by the filling up or embanking, the base will not be firm and solid, until the earth or material forming such embankment becomes completely consolidated, and incapable of compression or shrinking; and it will depend entirely upon the nature of the material, what length of time will be required to transpire before such embankments become perfectly consolidated, so as to form a firm and unyielding base, or formation line for the railway.

Upon this base or formation line, as previously explained, a coating of ashes, gravel, or broken sandstone, of from eight to twelve inches is laid, for the purpose of affording a dry and firm bed for the sleepers or blocks to rest upon; the ashes, gravel, or broken stone acting as drains to carry off the water into the main water-courses of the railway. The principle of construction of all railways being to form a continuous, uniform, firm, unyielding, and smooth surface for the wheels to run upon; it will at once be seen, that when the embankments yield, the uniform continuity of the line is disturbed, and, consequently, fresh material is required to be added from time to time, to raise the surface, until the embankment becomes perfectly consolidated.

Supposing the base or formation line of the railway perfectly firm, solid, and unyielding, then the rails are next required to be laid in such a manner, as that, when the engines and carriages roll along them, their weight should have no effect in depressing the sleepers or blocks into the coating, or of destroying the uniform level or line of the rails.

The mode of constructing the single and double wooden railways, at the early period of the formation of this kind of road, was, as previously explained, simply to lay down the longitudinal rails of timber, and the transverse sleepers, upon the surface of the coating of ashes; the timber of itself being very light, could have no effect in forming a solid and firm road, and, therefore, every time the carriages passed across the end of each sleeper, and along the rail, the coating would be compressed, the rails and sleepers would sink, and thus the level of the rails would be destroyed.

The mode of remedying this, was by constant manual labour, employed in pushing ashes or ballast underneath the rails and sleepers, until the coating became so firm, and solid, that the weight of the carriages had no longer any effect in compressing it; and until the rails did not yield, and sink to the pressure of the wheels. This, as may be supposed, would be very expensive in the first instance, and until the coating became perfectly firm, it would form a very imperfect railway. The long lengths of timber joined together, would render it very difficult to accomplish a uniform bearing throughout the whole length, and still more under each transverse sleeper; and, consequently, we find, that on the old railways, formed by continuous wooden rails, it required constant attention to preserve any thing like a firm or solid, and uniform line of railway.

These remarks apply to all the different descriptions of railways formed by continuous wooden rails, of which the majority of the American railways are composed; but the timber forming the rails and sleepers, in these cases in America, being of such greater scantling than the old wooden railways of England, a firm base is sooner obtained, and the rails are not so liable to buckle and bend under the wheels, as the common wooden railways.

When stone blocks were first used, the same system of forming a firm bed for the block to rest upon, was practised; the block was merely placed upon the coating or ballast of the road, and the weight of the carriages passing over it compressed the coating, and fresh ashes or ballast were pushed underneath the blocks until the whole became consolidated. On all the early constructed railways the blocks were much too small, and although, if the weight or pressure of the wheels acted smoothly upon the blocks, in time they would become firmly seated; yet the shocks and vibration of the motion of the carriages, acting against the sides of the rails, continually operated to destroy the seat of the block, and it, therefore, required the renewed and constant labour of packing and compression of the coating, to re-establish a seat for the blocks. We have before stated, that, in forming the Liverpool and Manchester railway, Mr. Stephenson adopted a new system of forming a firm and unyielding seat for the blocks. Besides making the blocks of larger dimensions, he employed a lever, by which he lifted the block a certain height, and then let it fall into its seat upon the coating, throwing in at the same time, upon the seat of the block, small ashes or sand, to form a uniform and even bed. The impact of the block, thus lifted up and let fall into its seat, was intended to be greater than the effect of the pressure of the wheels of the carriages in compressing the coating; and, therefore, he expected, when once a seat was formed by the block itself, more compressed and consolidated than it could be by the weight of the carriages, the latter in practice would have no effect in depressing the block; and, consequently, a uniformly level, and permanently unyielding road would be formed. If the size of the block be two cubic feet, the force of the impact, if the stone be lifted one foot high, will be equal to the pressure of two tons.

We must, however, in this place, observe, that great care is requisite to form a firm and solid seat for the block, the sand must be so spread amongst the interstices of the broken coating, as to make the block bear equally upon its entire base; otherwise, it will rest upon the points of the broken pieces of the coating, and, when once seated, the block must not, in the least degree, be disturbed in laying down and keying the rails. On embankments, not perfectly consolidated, this plan of seating the blocks is rendered abortive by the least shrinking; and, consequently, on such ground, transverse wooden sleepers and longitudinal wooden rails are, generally, laid down, until the embankment becomes perfectly consolidated. When the blocks are properly set, and the base of the railway perfectly solid, this plan forms a very firm and stable line of railway; yet, when the heavy engines pass over the blocks, we find, in practice, they yield or compress the coating, to a certain extent; and we likewise find, that the lurching or vibration of the carriages tends to displace the blocks from their seat, and that manual labour is still required, by forcing ashes or sand underneath, to keep them at their proper level. We have deemed these observations on the principles of the different modes previously practised of laying down railways, necessary, in order that we may shew the defects which it is the object of Mr. Brunel's plan to remedy.

§ 2.—*Description of Mr. Brunel's Plan of Railway.*

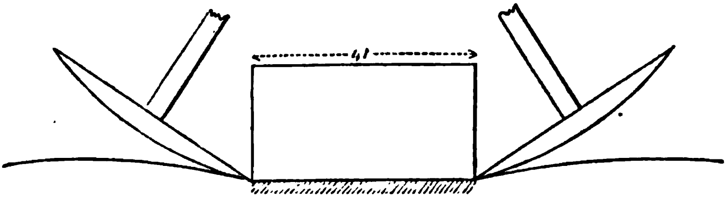
Figs. 1, 2, 3, and 4, *Plate XIII.* shew a plan and different sections of Mr. Brunel's plan of railway, which, it will be seen, in some degree resembles the plan of the old wooden railway. A, B, C, D, E, F, and G H, are the longitudinal rails forming the railway; these longitudinal rails are fourteen to fifteen inches broad, and six or seven inches thick, and are made of American pine, *a b′*, *a b′*, and *c d′*, *c d′*, are double transverse ties or sleepers, which are each six inches in breadth and seven inches deep; and *e f* single transverse ties or sleepers, which are six inches in breadth, and nine inches deep. These sleepers are stretched across the line of railway, and to them the longitudinal rails are secured; 1, 2, 3, 4, 5, and 6 are piles which in the cuttings are from nine to fourteen feet in length, according to the nature of the material, and in the embankments twelve to thirty feet, or of such a length as that they will reach from the base or formation line of the railway, six to eight feet into the original surface of the ground. The cross ties are American pine, and the piles of beech.

The plan of construction, or of forming the railway, is as follows; the piles are driven at intervals of every fifteen feet, as shewn in the drawing, and in the middle between the longitudinal rails. In cuttings, they are driven from eight to ten feet into the ground, below the level of the cross sleepers; and on embankments, they must be of such a length, as to be driven about the same depth, or seven or eight feet into the original ground. Upon an embankment of three feet, they must be, therefore, ten or twelve feet long; six feet, thirteen to fourteen feet long; and so on, according to the height of embankment, and the kind of subsoil into which they are to be driven. These piles are always to be driven to the exact depth required, no part of the head is allowed to be cut off, but if the pile does not drive to the proper depth, it must be drawn and driven again. This is for the purpose of being certain, that they have sufficient hold of the ground; near the head of these piles, as shewn at 1, 2, 3, 4, 5, 6, *Fig.* 1, and at *b b′ f*, and *d d′ Fig.* 2. A square shoulder, of 1½ inches, is made on one side of the piles, for the single ties, and on both sides of the piles, 1, 2, 5, 6, for the double ties. The ties or cross timbers are let into these shoulders, and they are firmly bolted to the piles, as shewn in the drawings. The double cross timbers, are laid down thirteen inches, and the single timbers nine inches, below the line of the rails. Between the double timbers, as shewn at *g g*, *Fig.* 1, and also at all the other points, where the longitudinal rails intersect the cross timbers, a piece of wood is interposed, which is pinned to the cross timbers, and upon which the longitudinal rails rest.

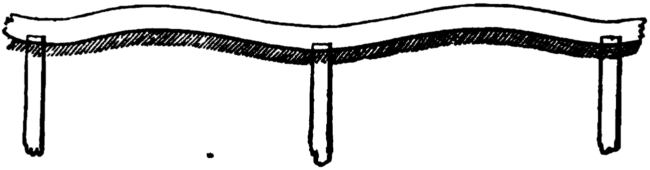
The longitudinal rails are then laid down upon the cross timbers, the upper surface of which is three inches below the surface of the iron rails; they are bolted to the cross timbers, with screw bolts, and washers, as shewn at *n n n n*, *Fig.* 1, and by a larger scale in *Fig. 5*; *e f* being the cross timber, and A B, the longitudinal timbers; the latter, it will be seen, is let into the cross timber a little, the single cross timbers being deeper than the double cross timbers. The head of the bolt and washer is countersunk into the upper surface of the longitudinal rail, as shewn in the figure. One of these bolts is put in at each of the points of intersection of the longitudinal rails with the single cross timbers, and two bolts at each of the points of intersection with the double timbers.

We see, therefore, that the longitudinal rails or timbers are firmly bolted to the cross timbers, or sleepers, and the latter to the piles. On all straight lines, the whole is laid perfectly horizontal, transversely, and in the plane of the proposed line of railway longitudinally. Upon curves, an inclination inwards is given to the cross timbers, depending upon the radius of the curve, or $\frac{5}{R}$ inches, R being the radius of the curve in miles.

When all this is accomplished, viz., when the piles are firmly driven, the cross timbers bolted to them, and the longitudinal timbers bolted to the cross timbers; then sand, or finely screened gravel, is beat, or packed underneath the longitudinal timbers, until a base or bed is made for them to rest upon, perfectly firm, solid, and compact. This is done with beaters, as shewn in the following sketch.



The packing being carried on by two men, working on the opposite sides of each timber, so as to beat against each other. The beating is continued until no more can be beaten in at any part, and until the timbers are strained up ½ inch or ¾ inch, according to their thickness, or until they assume something like the following figure.



The cross timbers are also well packed up underneath, and on the sides, and the spaces between the double timbers well rammed.

When the timbers have all been thoroughly packed up, and rammed, and strained to the utmost, and the general levels of the whole found to be correct, then the upper surface of the longitudinal timbers is adzed, or planed down to one uniform surface. A plank of hard wood, American elm, oak, or ash, about 1½ inches thick, and 8 inches broad, shewn at *r s'* Fig. 5, is then laid upon the longitudinal timbers, the upper surface being sloped inwards at an angle of 1 in 20. This hard wood plank is laid on with a good thick bed of tar, (the upper surface of the soft wood being scraped clean,) and nailed down with two, shilling nails, these nails being driven in two parallel rows 2½ and 5½ inches apart on each timber, so as not to interfere with the bolts; the heads of the nails are well punched in, to allow of planing the wood. The surfaces of all joints, and butts, and the whole of the bottom and sides of the longitudinal timbers; all bolts, washers, keys, spikes, and nails, and all other iron work, are well tarred.

Fig. 6. shews a section of the rail used, which weighs from 43 to 44 lbs per yard, and which rests upon, and is secured to the hard wood plank, and timbers of the longitudinal sills, in the following manner.

The upper surface of the hard wood is planed, and levelled; the iron rails are then laid down perfectly straight, and fitting each other at the joinings correctly. A space is allowed at each joint, for the expansion and contraction, and the joints are made to correspond with each other on opposite sides of the railway. The rail is fastened to the hard wood, and longitudinal sills, by screw bolts, a piece of felt being interposed between the base of the rails and the timber. The outside screws have square heads, but the inside screws are made with countersunk heads, on account of the flanch of the wheel. They vary in length, according to the thickness of the hard wood, the scroll of the screw, being very deep, to retain a firm hold of the timber.

The outside screw is tightened, until the rail fits close to the timber, the inner one is next screwed as tight as possible; a roller, weighing about ten tons, is then passed two or three times along the rails, which is followed close by the screwing, and, consequently, the bolts are thus much more firmly screwed than could be done by any screw-driver alone.

As shewn in *Fig.* 5, the rails have a slight bevel inwards.

The width, or gauge, of the railway, is 7 feet 2½ inches, from centre to centre of the rails; and the width, between the centres of the inside rails, is 6 feet.

On an examination of the details of this plan of forming a railway, it will be seen that, except in the piling, it does not materially differ from the principle of the old wooden railways, or from some of the wooden railways laid down in the United States. The plan of using piles, however, constitutes the difference in principle between those plans and that of Mr. Brunel, and it certainly is a most important difference. We have before remarked, that in the old wooden railways, and in those of America, the consolidation, and firmness of the base of the railway, depends upon the action of the weight of the carriages, and of the weight of the timbers, and sleepers. Mr. Brunel goes beyond this, he employs the retaining power of long piles, driven into the earth, to hold down the rails and sleepers; and relying on the retaining power of these piles, he throws an upright vertical strain, or pressure, against the base of the rails, to counteract the effect of the weight of the wheels of the carriages upon the rails. This is the principle of his railway, and it is necessary, for the perfection of this plan, that the timbers should be packed up, until they are considerably strained or sprung, or until they have a considerable pressure upwards; the whole stability, or superiority, of this railway, over other wooden railways, therefore, depends upon the retaining power of these piles. Mr. Brunel calculates, that he throws a pressure upwards, against the base of the longitudinal timbers, equal to about one ton to the foot forward; which will be nearly equal to one ton per square foot, or three tons for each three-feet length of rail. The weight of a stone block, containing four cubic feet, is only about equal to a quarter of a ton, which will be the pressure for each three-feet rail. The relative pressure, therefore, on the base of the support of each three feet of rail, is much greater in Mr. Brunel's plan, than in the common stone blocks. But we have previously seen, that the force of impact of the stone block, in forming the seat, is equal to two tons; and therefore, if these calculations are correct, and Mr. Brunel's piles are capable of sustaining a pressure of one ton upon each foot of rail, the relative degree of consolidation of the material forming the support for each rail is as 3 : 2 in favour of Mr. Brunel's plan, so long as the piles retain their hold of the ground. This calculation gives, reckoning one ton for each foot of rail, a pressure upon each pile equal to thirty tons, without taking into account any vertical pressure upon the cross timbers.

Until the embankments are perfectly consolidated, Mr. Brunel does not fasten the longitudinal timbers to the piling; although, out of twenty-two miles, laid down upon this principle, there are only two miles upon which this has been obliged to be left unfinished. The stiffness of the timber, in such cases, as in the old wooden, or American railways, forms the support to the wheels; but Mr. Brunel's rails, and cross timbers, being so firmly united together, constitute a more firm railway, than either the old wooden, or any of the American railways, that we have seen described. The whole of the timber is Kyanised, the consumption of pine timber, per mile, is about 420 loads, and forty loads of hard wood, six tons of iron bolts, and 30,000 wood screws, per mile, of railway.

The result of the trial, made upon a portion of this railway, has, we are informed, been most satisfactory; both as to its stability, and to the firmness with which it supported the locomotive engine, and carriages.

§ 3.—*Mr. Harrison's Engine for the Great Western Railway.*

It being the professed intention of the Great Western railway company, to travel with passengers, at a greater rate of speed than has been yet accomplished; it became necessary that the locomotive engines for that railway should be constructed somewhat differently from the ordinary engines, and should be adapted for higher rates of speed. The driving wheels of the engines upon the Liverpool and Manchester, Grand Junction, and London and Birmingham railways, are generally five feet in diameter, as will be seen in the table of the dimensions of engines. At high rates of speed, the piston moves at an extremely quick rate, far beyond that which gives a maximum effect; it, therefore, required, for the rate of speed proposed to travel on the Great Western railway, either that the driving wheels should be increased in diameter, or that the ordinarily sized wheels should move more than one revolution for each stroke of the piston. Mr. Brunel has had some of the engines made with driving wheels eight feet in diameter, and has ordered some with wheels ten feet in diameter.

To shew the velocity of the piston at different rates of speed, with differently sized driving wheels, we have made out the following table.

Table I.

Rate of speed in miles per hour.	Velocity of piston in feet per minute; with driving wheels of different diameters; stroke of piston 18 inches.						
	5 feet.	6 feet.	7 feet.	8 feet.	9 feet.	10 feet.	15 feet.
	feet.	*feet.*	*feet.*	*feet.*	*feet.*	*feet.*	*feet.*
20 miles an hour	336·3	280·2	240·1	210·1	179·7	167·7	112·0
25 ditto -	420·3	350·3	300·1	262·6	224·6	209·6	140·0
30 ditto -	504·4	420·3	360·1	315·1	269·5	251·6	168·0
35 ditto -	588·5	490·4	420·1	367·6	314·4	293·5	196·0
40 ditto -	672·6	560·4	480·2	420·2	359·4	335·5	224·0
45 ditto -	756·6	630·5	540·2	472·7	404·3	377·4	252·1
50 ditto -	840·7	700·6	600·2	525·2	449·2	419·3	280·1
55 ditto -	924·7	770·6	660·2	577·7	494·1	461·2	308·1
60 ditto -	1008·8	840·7	720·3	630·2	539·0	503·3	336·1

Considering that 220, or 240 feet per minute is assigned by Mr. Watt, and other engineers, as the rate of velocity for the piston of an engine working with a maximum effect, we see the great variation from that rate of speed, in locomotive engines, at the higher velocities, with wheels of five and six feet diameter; and we must not overlook, that Mr. Watt's standard of velocity was with engines, the length of stroke of which was very much greater than that of the locomotive engines, and, consequently, the number of alternations of the piston were much fewer.

With wheels of ten feet in diameter, the velocity of the piston is reduced nearly to the proper standard; but wheels of so large a diameter are very cumbrous, and heavy, and produce a very considerable strain upon the axles.

Mr. T. E. Harrison, engineer to the Stanhope and Tyne railway, has obtained a patent for an engine to obviate these inconveniences, and objections, the driving wheels of which make three revolutions for one entire stroke of the piston; and these wheels being five feet in diameter, they are equivalent in speed to one wheel fifteen feet in diameter. The last column in the table will, therefore, shew the velocity of the piston, at the different rates of speed of this engine, which, it will be seen, are not above the standard, when the velocity is under forty miles an hour. As this engine in many respects differs from those at present in use, we have given a drawing of one, built by Messrs. Hawthorn of Newcastle-upon-Tyne, for the Great Western railway.

Figs. 7 and 8, *Plate XIII.* are an elevation of part of this engine, the boiler, and apparatus for generating the steam, being placed upon one carriage, and the cylinders, and machinery, for propelling the engine, upon another carriage; each of which is supported by four wheels. B, *Fig.* 8, is a part of the boiler, which is, in every respect, the same as that shewn in *Fig.* 1, *Plate XI.*; *lal′l″* being the chamber, at the chimney-end of the boiler, *m* the chimney, and *t* the discharging or blast pipe. A, *Fig.* 7, is one of the cylinders, which is placed horizontally upon a bed plate, 12344′; the other cylinder being placed in the same position, parallel thereto, and on the same plane, and upon a similar bed plate on the opposite side. Upon the same plane, and in a line with the centre of the cylinders, an axle is placed, working up and down between the cheeks of the bed plates, 2 3, one end of which is shewn at *5″*. This axle has a crank at each end, corresponding with the line of centre of each cylinder, *5 5* exhibiting the piston and piston rod, and *5 5′* the connecting rod, *5′5″* being the crank at one end of this axle; the crank at the other end of this axle, and the connecting rod, being attached to the piston of the other cylinder, in the same manner; the two cranks being placed at right angles with each other. Upon the middle of this axle, the large cog-wheel, G, is fixed, which works the small wheel, or pinion, F, fixed upon the axle of one of the supporting wheels, W. When, therefore, the axle and wheel, G, are turned round by the pistons, the travelling wheels, W, are likewise turned round, and, of course, produce a progressive motion to the engine. The wheel, G, is three times the diameter of the pinion, F, and, consequently, the wheel, W, makes three revolutions, for one revolution of the axle, *5″*, and, of course, for one entire stroke of the pistons.

The travelling wheels, W, being five feet in diameter, the velocity communicated will, therefore, be the same as that of a fifteen-feet driving wheel, worked directly by the pistons.

The axle, *5″*, and chairs, on which it rests, are not fixed to the iron framing, 2 3, but slide up and down with the bearing axle, 6. To accomplish this, the chair of the axle, 5″, is connected with the chair of the axle, 6, of the travelling wheels, by an iron strap, passing round both chairs, shewn by the dotted lines at *ff*, the other end being secured by a key, *f′*. An upright stud, or pillar, *a*, supports the chair of the axle, 5″, and rests upon the upper side of the chair of the axle, 6; when the key, *f′*, is, therefore, driven, the strap firmly secures both the chairs, and the pillar, *a*, together; and by this method, the axle, 5″, partakes of the motion of the travelling axle, 6; and the teeth of the two wheels are thus always kept in contact with each other, and are not affected by the undulation of the road.

C, *Fig.* 8, is the steam pipe, leading from the steam chamber of the boiler, along which, and by the pipe, D, the steam is conveyed to the cylinders; *e e*, *Fig.* 7, is the slide for communicating the steam to the cylinders, as explained in *Fig.* 1, *Plate XI.*, *z* being the discharging aperture. After the steam performs its operation in the cylinders, it passes along the pipe, E, into the pipe, *t t*, through which it is discharged into the chimney. The plan of working the slides, for passing the steam into the cylinders, is by one eccentric for each cylinder, working upon the axle, 5″, and communicating with the arm, R T, which works the slide, *e e*. Upon the axle, R, the arm, or handle, H, is fixed, to enable the engine-man to work the slides by hand; and the eccentric is thrown in and out of geer, by the lever, K.

The two carriages are fastened together by the bar, *o*, but, to compensate for the motion between the two carriages, a peculiar kind of joint is used for the steam pipe, D, and the discharging pipe, E. *Fig.* 9 shews the form of joint used, which is a hollow universal joint;

b b is a short pipe, which is fastened to the cylinders by the flanch, *b b*; *h h* is the flanch of the pipe, fastened to the boiler; and these are connected by the two short pipes, *c c*, and *d d*, both of which are provided with a globular joint at *o o*, and *i i*. To compensate for any horizontal motion, or any lengthening or shortening of the coupling of the two carriages, the pipe, *d d*, is enlarged in diameter at *d′ d′*, leaving a space between it and the pipe, *c c*, which is filled with hemp packing. A gland, *n n*, working in the usual way, is screwed upon this packing, keeping the joint steam tight, and allowing a horizontal motion, or lengthening, or shortening, of the pipe, when necessary. To allow of a circular motion, the end of the pipe, *c c*, at *o o*, is globular, and also the end, *i i*, of the pipe, *d d*; the ends of the pipes, *b b*, and *h h*, have a vertical flange, to which are screwed the rings, *2′ 2* and *3′ 3′*; these rings are not, however, screwed close to the flanges of the two pipes, *h h*, and *b b*, but a space is left of about two inches, as shewn at *v v*. Within this space, metallic ring packing is laid, which is screwed down upon the outside of the globular end of the pipes, by the screws, *p p*, and thus forms a steam-tight joint; and the circular or globular end of the pipes, *o o*, and *i i*, allows of a motion in any direction, the same as in a ball and socket joint. The end, *v v*, shews the space, without the packing, and the end, *o o*, with the packing, screwed down by *p p*, and in contact with the pipe.

It being of great importance to the perfection of this plan of engine, that the teeth of the wheels, G, and F, should work smoothly, and without jarring or shaking; Mr. Harrison has adopted a plan to tighten the teeth, in case they become loose by being worn, and especially to counteract the effect of what is called the "back lash" of the teeth, in a change of motion, or to prevent the shock occasioned by any play in the teeth, when the motion is reversed. To accomplish this, Mr. Harrison adopts a double row of teeth, as shewn in *Figs*. 10 and 11; *g g* being one of the sets of teeth, and *m m* the other. *b* is the axle, upon which the wheel or pinion, F, *Fig*. 7, is fixed. But, it will be observed, that one only of the breadths of teeth is *fixed* to the axle, viz. that part shewn by *m m*, *m' m'*, and which is fixed to the axle by the keys, 4 4, seen also in *Fig*. 12. The other half of the teeth, *g g*, is fitted accurately to the part *m' m'*, but it is allowed to move round it, for the purpose of tightening the teeth; and this is done in the following manner. *b*, *Fig*. 12, shews the axle; *m' m'* is that part of the pinion fixed to *b*, by the driving keys, 4 4; a tapered key, 1, shewn also at 1 1 in *Fig*. 11, is fixed upon the part *m' m'*; two keys 2 2', and 3 3', work against the key 1 1, shewn in *Fig*. 11; the key 2 2' being *drawn outwards* by the screw 2', and the key 3 3' being *forced inwards* by the screw 3'. Both these keys, as will be seen in *Fig*. 11, are tapered or diminished in thickness, 2' outwards, and 3' inwards; the part *m' m'*, being fixed to the axle, and, likewise, the key 1 1, and the part *g g'* being at liberty to turn round. When, therefore, the key 2 2' is drawn outwards by the screw, 2', and the key, 3 3', is pushed inwards by the screw, 3', the part *g g'* will be turned round by means of the fixed key 1 1. This will throw the teeth, *g g'* a little out of the line of the teeth, *m m*, and, therefore, prevent any play which may take place by the wear of the teeth; the teeth, *m m*, working, or being driven by the wheel, G, in one direction of the motion, and the teeth, *g g*, in the other direction.

The wheels W and W', are coupled together, to obtain the adhesion of the whole weight of the carriage, *Fig*. 7; and they are supported by the springs, *s s*, in the usual way. The water tank, *x*, is placed underneath the boiler, and the pump for supplying the boiler, shewn at P, is worked from one of the axles, supporting the boiler carriage, by the cross head, *r r′* ; *p* being the pipe leading to the boiler.

Besides effecting a slow motion of the piston, at high rates of speed, Mr. Harrison expects, by this plan of engine, to effect a considerable reduction in the annual expense of repairs of the machinery. On examining the account of the repairs of the Stanhope and Tyne railway engines, (notes I and K, Appendix,) it will be seen, that a very large proportion of the expense consists of the labour of taking the machinery to pieces, and replacing it when repaired; and which is occasioned, almost entirely, by the machinery being crowded into so small a space underneath the boiler. By this plan the machinery is much more accessible, and constantly under the eye of the engine-man; therefore, when any part of the machinery gets out of order, it can easily be replaced; and when repairs are necessary, the whole of the machinery is quite accessible to the workmen. One of these engines, constructed as shewn in the drawing, and another without the cog-wheels, and with the driving wheel, w, ten feet in diameter, have been furnished by Messrs. R. and W. Hawthorn, of Newcastle, for the Great Western railway.

About twenty-four miles of this railway from London to Maidenhead having been completed, on the 1st of June an experimental trip was made by the directors, and several of their friends, preparatory to the opening of that portion of the line, to the public on the 4th.

The engine employed on this occasion was No. 150, Table, No. 1. Page 352, to which was attached a train of carriages containing nearly 200 passengers; with this train, the engine performed the journey in 47 minutes, the distance being 22½ miles, which is at the rate of 28 miles an hour. About an hour afterwards another train started, and performed the journey in 44 minutes, which is at the rate of 31 miles an hour nearly. In returning, the time occupied in accomplishing a distance of 21 miles and 2 chains was 35 minutes, which is at the rate of 36 miles an hour.

The railway was opened to the public on the 4th of June, and it is not only creditable to Mr. Brunel, the engineer, but also a proof of the stability of the road, and the perfection of the machinery, that the directors have been enabled to start eight trains in each direction every day, and that these trains perform the journey with the greatest regularity.

We had an opportunity of travelling along the railway on the 5th of June, from London to Maidenhead and back, with one of the regular passenger trains; being the Eton Montem, for the convenience of the public, an extra carriage was attached to the train, which consisted of three first class carriages, each capable of containing 24 passengers; two second class close, and two open carriages, containing from 24 to 30 passengers each; and one open carriage with six wheels capable of holding 50 to 60 passengers. With this train of carriages in which were upwards of 190 passengers we started from London, the following table will show the time of performing the journey there and back:

	Distance.		Time.		
	Miles.	Chains.	H.	Min.	Sec.
From London to Drayton - -	13	3	0	26	22
Stopped at Drayton Station - - -			0	3	55
Ditto at Water Station - - -			0	3	0
Ditto at Slough Station - - -			0	3	50
From Drayton to Maidenhead -	9	40	0	25	10
	22	43	0	51	32

	Distance.		Time.		
	Miles.	Chains.	H.	Min.	Sec.
From Maidenhead to Drayton -	9	40	0	27	50
Stopped at Slough - - - -			0	5	20
Ditto at Drayton - - - -			0	2	10
From Drayton to London -	13	3	0	26	50
	22	43	0	55	40

The average rate of travelling in both directions, in the above trip is about 25 miles an hour, but it must be considered that a great loss of time was occasioned by checking the speed on stopping at the intermediate stations, and again recovering the speed at starting; the rate being upwards of 30 miles an hour, when not checked.

Considering therefore the disadvantages under which the above experiment was made, the number of stoppages, and the short distance, that the engine had also to drag an extra carriage, and that no attempt was made to urge the engine to its utmost capabilities; it appears quite certain that, with such powerful engines, a much higher rate of speed will be accomplished upon this railway, than has hitherto been attained, especially as it did not appear to us that any obstacle existed to the higher rate of speed being kept up without difficulty.

APPENDIX.

NOTE A.

On 10th May 1831, on the Liverpool line, a malleable iron rail, fifteen feet long, carefully cleaned, and weighing 177 lbs. 10½ oz., was laid down. On 10th February 1833 the same rail was taken up by Mr. J. Locke, then resident engineer on the line, and well cleaned as before, and weighed 176 lbs. 8 oz. It had consequently lost, in twenty-one months, a weight of 18½ oz. The number of gross tons that had passed on the rail, during that time, was estimated at 600,000. Thus we see that with so considerable a tonnage, and with the velocity of the motion on that railway, the annual loss of the rail was only $\frac{1}{268}$ of its primitive weight; so that it would require more than a hundred years to reduce it to the half of its present strength.

NOTE B.

Given the area of section of a railway bar below the neutral axis, to find the dimensions of the lower flanch, so that the strength shall be a maximum; the breadth of the middle rib, and the depth of the lower flanch, being also given: let the whole of the sectional area below

$n n$ - - - - - - - $= a$
the breadth of rib $p q$ - - - $= b$
the depth $n s$ - - - - - $= d'$
the depth of lower flanch $r s$ - - $= e$
the tension of the lower fibre - - - $= t$

1. To find first the expression for the strength of the middle rib: take any variable distance x,

$$\text{then } d' : t :: x : \frac{t x}{d'} = \text{tension of fibre at } x;$$

multiply by the distance x, and breadth b, and we have, for the sum of all the resistances,

$$\int \frac{t}{d} b x^2 d x = \frac{t b}{3 d'} x^3;$$

this, when $x = d'$, becomes $\frac{1}{3} d'^2 b t$.

2. To find an expression for the strength of the lower flanch: let the breadth $= b'$; any distance from $n n = x$;

$$\text{then } d' : t :: x : \frac{t x}{d'} = \text{tension of fibre at } x;$$

multiply by the distance x, and breadth b'; we have, for the sum of all the resistances,

$$\int \frac{t}{d'} b' x^2 d x;$$

this taken between the values $x = d'$ and $x = d' - e$ gives resistance,

$$\frac{3 d' e^2 - 3 d' e^2 + e^3}{3 d'} b' t = \left(d' e - e^2 + \frac{e^3}{3 d'}\right) b' t;$$

therefore the resistance of the rib and lower flanch is,

$$\tfrac{1}{3} d'^2 b t + \left(d' e - e^2 + \frac{e^3}{3 d'}\right) b' t.$$

And the question is, to determine what value must be given to d', that this expression may be a maximum.

To effect this it is only necessary to consider d' as variable, to denote it by x, to find the value of the dependent quantity b' in terms of x, to substitute these quantities in the preceding expression, and to make its differential equal to zero.

Now since the depth of the middle rib is x, and breadth b, the area is $b x$, and consequently the area of the lower flanch $= a - b x$, and its depth being e, its breadth $= \frac{a - b x}{e}$, that is, $b' = \frac{a - b x}{e}$.

Substituting, therefore, $\frac{a}{e} - \frac{b}{e} x$ for b', and x for d', in the preceding expression, it becomes, rejecting t, which is common,

$$\tfrac{1}{3} b x^2 + \left(e x - e^2 + \frac{e^3}{3 x}\right)\left(\frac{a}{e} - \frac{b}{3} x\right) = a \text{ max.};$$

or,

$$d\left(\tfrac{1}{3} b x^2\right) + d\left(e x - e^2 + \frac{e^3}{3 x}\right)\left(\frac{a}{e} - \frac{b}{e} x\right) + d\left(\frac{a}{e} - \frac{b}{e} x\right)$$
$$\left(e x - e^2 + \frac{e^3}{3 x}\right) = 0; \text{ or,}$$

$$\tfrac{2}{3} b x \, d x.$$
$$+ \left(e - \frac{e^3}{3 x^2}\right)\left(\frac{a}{e} - \frac{b}{e} x\right) d x$$
$$- \frac{b}{e}\left(c x - e^2 + \frac{e^3}{3 x}\right) d x = 0;$$

$$\text{or, } \tfrac{2}{3} b x + \left(e - \frac{c^3}{3 x^2}\right)\left(\frac{d}{e} - \frac{b}{e} x\right) - \frac{b}{e}\left(e x - e^3 + \frac{e^3}{3 x}\right) = 0;$$

or,

$$\tfrac{2}{3} b x + a - b x - \frac{e^2 a}{3 x^2} + \frac{e^2 b}{3 x} - b x + b e - \frac{b e^2}{3 x} = 0.$$

Reducing every term to the denominator $3 x^2$, and rejecting it, this becomes

$$2 \underline{b x}^3 + 3 \underline{a} x^2 - 3 \underline{b} x^3 - e^{\underline{2}} a + b e^2 x - 3 \underline{b x}^3 +$$
$$3 \underline{e} b x^2 - b e^2 x = 0; \text{ or,}$$
$$-4 b x^3 + (3 a + 3 e b) x^2 - e^2 a = 0; \text{ or,}$$
$$x^3 - \frac{3(a + e b)}{4 b} x^2 = \frac{-e^2 a}{4 b};$$
$$x^3 - \tfrac{3}{4}\left(\frac{a + e b}{b}\right) x^2 = \frac{-e^2 a}{4 b};$$

from which x may be determined for any given values of a, b, and e.

NOTE C.

It may be convenient to shew the origin of these formulæ, particularly the third, which is not investigated, except that it has been shewn generally, that if d' denote the depth of the lower fibre below $n n$, and its tension be made $= t$, and any variable distance $= x$, that $\frac{t}{d'}\int x\,d\,x=$ sum of all the tensions to a unit of breadth,

that $\frac{t}{d'}\int x^2 d\,x=$ sum of all the resistance referred to the axis n,

and $\frac{t}{d'}\int\frac{x^2 d\,x}{\frac{t}{d'}\int .\,x\,d\,x}=\delta'$ distance of centre of tension;

from which it follows,

that $\frac{t\,\delta'}{d'}\int x\,.\,d\,x=$ sum of all the resistances for a unit of breadth, x being taken in its ultimate state.

Now in the rib, when $x=d'$, $\delta'=\frac{2}{3}d$, and $\int x\,d\,x=\frac{1}{2}d'^2$, whence the above becomes

$$\tfrac{1}{3}d'^2 t;$$

but to refer this to the centre of compression c, we have (called the whole depth d)

$$\tfrac{2}{3}d' : \tfrac{2}{3}d :: \tfrac{1}{3}d'^2 t : \tfrac{1}{3}d\,d'\,t,$$

and introducing the breadth $p\,q$, it becomes

$$\tfrac{1}{3}h\,s\,.\,n\,s\,.\,p\,q\,.\,t.$$

In the same way, calling the tension at $x=t'$, and the breadth $(n\,n-p\,q)$ we have, for the resistance of the head,

$$\tfrac{1}{3}h\,s\,.\,n\,x\,.\,(n\,n-p\,q)\,t',$$

but the tension at $x=\frac{n\,x}{n\,s}\,t$;

therefore, substituting this for t', we have

$$\tfrac{1}{3}h\,s\,.\,\overline{n\,x^2}\left(\frac{n\,n-p\,q}{n\,s}\right).$$

For the lower web,

$$\frac{t}{d'}\int\frac{x^2 d\,x}{x}=\delta',$$
$$\frac{t}{d'}\int x\,d$$

calling $n\,r=d''$, and x any variable distance below r, it becomes

$$\frac{\int(d''+x)^2 d\,x}{\int(d''+x)\,d\,x}$$

which, when $x=r\,s$, gives

$$\delta'=n\,m+\frac{r\,s}{12\,m\,n}$$

$$\text{and }\frac{t}{d'}\int(d''+x)\,d\,x=\frac{t\,\delta'}{d'}\,n\,m\,.\,r\,s;$$

whence the resistance referred to $n\,n$ is, for the breadth $(m\,m-p\,q)$

$$n\,m\,.\,r\,s\,(m\,m-p\,q)\frac{t\,\delta'}{d'};$$

and calling $\delta'+n\,c=\delta''$ it is, when referred to c,

$$n\,m\,.\,r\,s\,(m\,m-p\,q)\frac{\delta''\,t}{d'}$$

which is the formula in question.

NOTE D.

Extract from "Petition of proprietors of stage coaches employed on the turnpike roads within the county of Lancaster, and travelling in the following line of roads, viz.

Liverpool, through Warrington to Manchester.
——— to St. Helens.
——— to Newton and Wigan.
——— to Leigh and Bolton.

"The petitioners take leave to exhibit the following *facts* and statements of calculations, viz. of the taxes paid to government, and tolls paid to the commissioners of the turnpike roads, over which the thirty-three coaches travel between the points before stated, and the cost of working them for the year last past. Presented 3d May 1830."

Duty for thirty-three coaches for one year - -		£8,455 16 8	
Assessed taxes for coach servants - - -		261 0 0	
Mileage for twenty-six coaches to Manchester, at 13*l.* 4*s.* per day	£4,818 0 0		
Ditto for four coaches to Bolton, at 1*l.* 15*s.* per day - -	638 15 0		
Ditto for two coaches to Wigan, at 14*s.* 8*d.* per day - -	267 13 4		
Ditto for one coach to St. Helens, at 3*s.* per day - - -	54 15 0		
		£5,779 3 4	
			£14,496 0 0
Tolls for thirty-three coaches, at 18*l.* 10*s.* 8*d.* per day - - -			8,005 13 4
Duty and tolls - - -			£22,501 13 4

EXPENSES.

Harness for 709 horses, at 4*l.* per year each -	£2,836 0 0	
Iron and labour to blacksmiths for 709 horses, at 3*l.* per year each - - - - -	2,127 0 0	
Eighty-seven men as ostlers, &c. at 1*l.* per week each - - - - - -	4,524 0 0	
Rent of stables and coach-offices - -	1,418 0 0	
Consumption of horses, say 709 horses, at 15*l.* each *to be renewed every three years* - - -	3,545 0 0	
Hay and corn for 709 horses, at 15*s.* per week each - - - - - - - - -	27,651 0 0	
Straw, at 2*s.* 6*d.* per week each - - -	4,615 0 0	
	£46,716 0 0	
Deduct value of manure, which is calculated at the price of straw - - - - - -	4,615 0 0	
		42,101 0 0
		£64,602 13 4

NOTE E.

Memoranda relative to the Experiments made at Mr. Laird's works, at North Bickenhead, with the new Low Pressure Boiler, on the exhausting principle of Messrs. Braithwaite and Ericsson, by Alexander Nimmo, C. E., Dublin, and Charles B. Vignoles, C. E., London.

The exhausting apparatus consisted of a fan-wheel, with broad radial leaves, revolving within a close box or chamber, placed a little apart from the boiler, but connected with it by a passage leading from the flues traversing the boiler; a short tube above the exhausting chamber passed out to the atmosphere.

The furnace was attached to, and placed at the end of, the boiler, opposite to the exhausting apparatus, which latter being put to work, drew through all the turns of the boiler the hot air from the fire, which passed over the throat of the furnace through the bridge flue, and then successively through the other five turns of the flue arranged through the boiler, and finally, was drawn through the exhausting chamber, and passed into the atmosphere.

The heat, which in the furnace was extremely intense, was absorbed by the water in the boiler, as the air rushed through the flues, and, when passing up the tube or funnel from the exhausting chamber, was so far cooled, that the hand and arm might be placed, with impunity, down the tube, the temperature not exceeding 180° of Fahrenheit.

Not the slightest smoke was perceptible.

The following are the principal dimensions measured: —

	Ft.	In.		Ft.	In.	
Furnace.	2	0 deep.	Ash pit.	1	0 deep.	The openings of the fire-bars equal to about half the area of the bottom.
	2	6 long.		2	6 long.	
	2	6 wide.		2	6 wide.	

					ft.	in.
Exhausting Chamber.	2	6 high.	Outside dimensions.	Diameter of exhausting wheel	3	0
	3	6 wide.		Breadth of the same	0	10
	3	6 long.				

Bridge flue or throat, from the furnace, 2 ft. 6 in. broad, 4 in. wide, 2 ft. deep	5—16 in. iron plate.
First turn of the flue, 4 in. wide, 2 ft. deep, 2d, 3d, 4th, and 5th turns, 3 in. wide, 2 ft. deep	¼ in. iron plates.
Whole length of the flues through the boiler	45 feet.
Superficial area of the heating surface	247 square feet.
The contents of the water in the boiler, when filled, were from	85 to 90 cubic feet.
The superficial area of the evaporating surface, nearly	33 square feet.
The proportion of the heating to the evaporating surface, nearly	7½ to 1.

Steam Chamber.	3 ft. wide. 4 ft. 10 in. average depth. 4 ft. 6 in. long.	Containing about 65 cubic feet.

Diameter of the safety valve very nearly five inches, being nineteen square inches area, which was loaded for a pressure of 4 lbs. on the square inch. Giving seventy-six for the load. Of this, 66 lbs. of iron were placed in the boiler, and 10 lbs. allowed as the weight of the valve, rod, hook, handle, &c.

The water used was the salt water from Wallasey Pool, and filled into a large iron tank, the area of the surface of which measured 32½ superficial feet.

The boiler was placed under an open shed; the day was very cold, with thick rain. No engine being attached to the boiler, the exhausting apparatus was worked by a wheel and band from Mr. Laird's turning engine. The velocity of the circle of percussion of the leaves of the exhausting wheel was determined to be about seventy-seven feet per second, or upwards of fifty-two miles an hour. Mr. Laird's engine is stated to be a four-horse power. No determinate measurement was made, but the engineers present computed, that the power applied to turn the exhausting wheel, was equal to that of two horses.

The fire being lighted, the steam was got up to 4 lbs. pressure in forty-five minutes, with a consumption of 2½ cwt. of coke. The expenditure at first, was 8 lbs. per minute, and gradually decreased to 5 lbs.; averaging about 6¼ lbs. per minute for getting up the steam. The steam began to rise in twenty-seven minutes, after which the consumption of coke was little more than 5 lbs. per minute; and at this period there would have been a sufficient supply of steam to work the cylinders of an engine.

The coke employed was gas coke of very bad quality, of which 3½ cubic feet weighed 105 lbs., giving 30 lbs. for the weight of a cubic foot, or 3000 lbs. as the weight of 100 cubic feet. The same weight of St. Helens' coal (that principally used in steam-boats), measured sixty-three cubic feet. The cost of the coke used was 8*s*. 6*d*. per ton, delivered in Liverpool; the cost of smithy coke being 25*s*. per ton, of which 3½ cubic feet weigh 115 lbs., giving very nearly 33 lbs. for the weight of a cubic foot.

When the steam was up, the water in the thick glass-gauge attached to the boiler, standing at 7½ inches, the two men stationed for the purpose, began to pump, a fresh supply of weighed fuel was placed on the floor, and the following observations were made: —

	Hours.	Minutes.	
At	3	32	began to pump.
At	3	54—16	cubic feet of water were evaporated.
At	4	12—27	cubic feet of water were evaporated.
At	4	19—38	cubic feet of water were evaporated, And 2 cwt. of coke consumed.
At	4	32—41½	cubic feet of water were evaporated, With a consumption of 252 lbs. of coke.

From which it appears, that only 6 lbs. of coke per cubic foot of water per hour were consumed, and the evaporation of a cubic foot of water per hour being generally considered the measure of a horse power, the conclusion is, that the boiler was a forty horse boiler, and that the quantity of fuel requisite to work it is 2¼ cwt. per hour, the expense of which is 12¾*d*., and as the consumption diminishes after the first hour, the expense of fuel will probably not exceed 1*s*. per hour for the forty horse boiler.

(Signed) ALEXANDER NIMMO, C. E.
CHARLES B. VIGNOLES, C. E.

Waterloo Hotel, Liverpool,
29th May 1830.

NOTE F.

Section of the Stockton and Darlington Railway.

The part of this railway travelled by the locomotive engines, begins at the foot of Brusselton inclined plane, at an elevation of 383 feet, one inch above the quay at Stockton, where it terminates, after passing over the following inclinations:—

	0·46 Miles.	-	descent	-	- at $\frac{1}{311}$
	0·06	-	- ditto	-	- $\frac{1}{325}$
	0·92	-	- ditto	-	- $\frac{1}{144}$
	1·45	-	- ditto	-	- $\frac{1}{121}$
	2·25	-	- ditto	-	- $\frac{1}{528}$
	1·25	-	- ditto	-	- $\frac{1}{185}$
	1·01	-	- ditto	-	- $\frac{1}{352}$
	1·76	-	- ditto	-	- $\frac{1}{135}$
	0·20	-	- ditto	-	- $\frac{1}{166}$
	1·75	-	- ditto	-	- $\frac{1}{1584}$
	1·61	-	- ditto	-	- $\frac{1}{1408}$
	1·64	-	- ditto	-	- $\frac{1}{264}$
	0·23	-	- ditto	-	- $\frac{1}{718}$
	2·09	-	- ditto	-	- $\frac{1}{2192}$
	1·25	-	- ditto	-	- $\frac{1}{258}$
	0·03	-	- level	-	- —
	0·81	-	- descent	-	- $\frac{1}{226}$
	0·05	-	- ditto	-	- $\frac{1}{487}$
	0·80	-	- ditto	-	- $\frac{1}{1584}$
	1·16	-	- ditto	-	- $\frac{1}{164}$
Sum	20·78		Average inclination 383 feet on 109,692 feet, or $\frac{1}{286}$.		

Besides the principal line there are lateral branches, over which the locomotive engines also travel, but the level of which has not been taken. The aggregate space travelled over by the locomotive engines is twenty-four miles. The rest of the railway, consisting of sixteen miles more, is worked by horses and by stationary steam engines.

NOTE G.

STATEMENT of the WORK done by the LOCOMOTIVE ENGINES on the DARLINGTON RAILWAY, from 1st July to 1st December 1833.

Number of the engine.	Name of the engine.	Total number of miles travelled by the engine.	Tons of coals carried one mile by the engine.	Gross tons carried one mile on a level, including the waggons and return.	Number of days that the engine was		Amount of the repairs made to the engine during that time.			Amount of the repairs per gross ton carried one mile on a level.	OBSERVATIONS.
					In activity.	In repair.					
		Miles.	Tons.	Tons.	Days.	Days.	£	s.	d.	d.	
1.	Locomotion -	5,300	146,011	287,896	80	52	41	19	7	0·035	Boiler with a flue and two returning tubes.
2.	Hope - -	3,100	82,305	162,281	63	69	57	5	5	0·085	——— with a single flue.
3.	Black Diamond	1,000	26,920	53,078	27	105	14	0	5	0·063	——— with a single flue.
4.	Diligence -	80	1,906	3,758	2	130	13	18	3	0·889	Engine taken to pieces.
5.	Royal George	700	23,733	46,794	11	121	161	7	8	0·828	Boiler with a flue and one returning tube.
6.	Experiment -	4,400	122,442	241,420	70	62	53	1	2	0·053	Ditto.
7.	Rocket -	3,940	109,512	215,925	64	68	57	0	9	0·063	Ditto.
8.	Victory -	10,600	349,150	688,418	107	25	58	3	10	0·020	Ditto.
9.	Globe - -	3,120	70,683	139,365	60	72	36	4	6	0·062	Boiler with 120 returning tubes.
10.	Planet - -	1,200	20,429	40,280	27	105	53	7	5	0·318	——— with 88 ditto.
11.	North Star -	2,400	47,546	93,746	55	77	32	5	10	0·083	——— with 88 ditto.
12.	Majestic -	2,880	90,422	178,282	47	85	131	2	3	0·177	——— with 104 ditto.
13.	Coronation -	2,940	97,687	192,609	52	80	46	16	2	0·058	——— with 104 ditto.
14.	William IV. -	4,060	134,410	265,074	55	77	78	19	8	0·072	——— with 104 ditto.
15.	Northumbrian	4,480	143,885	283,698	59	73	67	14	11	0·057	——— with 104 ditto.
16.	Director -	5,860	202,492	399,253	91	41	107	19	11	0·065	Boiler with tubes on the model of Napier's patent.
17.	Lord Brougham	4,780	155,729	307,051	62	70	62	5	10	0·049	Boiler with 104 returning tubes.
18.	Shildon -	4,720	159,400	314,289	63	22	49	16	3	0·038	——— with a flue and two returning tubes.
19.	Darlington -	6,180	200,110	394,559	88	44	45	0	6	0·027	Ditto.
20.	Adelaide -	3,700	126,390	249,202	71	61	90	11	7	0·087	——— with 104 returning tubes.
21.	Earl Grey -	7,960	276,462	545,098	110	22	14	13	6	0·007	——— with a flue and two returning tubes.
22.	Lord Durham	6,480	213,737	421,424	84	48	67	13	8	0·039	——— with 104 returning tubes.
23.	Wilberforce -	4,220	141,534	279,062	55	9	51	17	11	0·045	Ditto.
	Sums -	94,080	2,942,925	5,802,562	1,403	1,518	1,393	13	0	0·058	

The greatest part of the machines were constructed by Mr. Timothy Hackworth of Shildon, near Darlington, and bear testimony to his skill. Twelve of them were almost new at the time this statement was made.

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		Lifting apparatus, with eccentric rods, straps, sheaves, Guage cocks.				Tools.			Painting engine.			Tender with tanks, boxes, box heads, horns, brasses, springs, spring pins, carriages, drag bars, drag springs, buffers, and foot steps.			TOTAL.		
		£	;	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Materials.		1	-		-	0	6	8½	-		-	1	15	1½	22	15	1¼
		0	1	8	4	1	3	11	-		-	6	4	7½	111	11	4
		0	[illegible]	4	0	0	15	2½	-		-	11	4	2½	83	7	11½
		0	[illegible]	0	6	1	0	6	-		-	32	16	7¾	63	0	11½
		0	-		-	0	19	10½	-		-	5	6	9¼	62	2	6¾
		0	-		-	0	4	3	-		-	0	14	10½	28	2	8
		0	-		-	0	6	7½	-		-	1	19	3	13	7	0¾
		3	[illegible]	12	10	4	17	7½	-		-	60	1	5¾	384	7	7½
Labourage.		7	-		-	0	15	1	-		-	1	19	4½	47	0	11¾
		3	[illegible]	8	8½	2	9	8½	1	14	1½	9	14	3½	106	12	7¾
		4	[illegible]	3	11	1	7	10½	0	7	6	12	3	9	101	3	2¾
		2	1	9	4½	2	8	1¾	0	7	6	5	10	3½	71	7	6½
		3	0	7	2½	2	5	4½	0	3	9	8	11	1	90	13	10½
		2	1	-	-	1	4	1½	0	0	6	5	0	0½	78	9	8½
		1	1	-	-	0	14	3	0	8	4½	2	17	3	22	12	11
		25	3	9	2½	11	4	6½	3	1	9	45	16	2	518	0	10¾

Eng

Materials.		4	-		-	1	10	1½	-		-	1	7	0¾	137	8	5½
	½	0	-		-	0	14	8½	-		-	0	12	7¾	172	19	11¼
	½	0	0	7	5½	0	15	2½	-		-	8	3	8	80	1	4¾
	½	2	0	0	10¾	0	10	6	-		-	1	16	8¾	141	8	11
	¾	0	-		-	0	7	11	-		-	36	12	7¼	150	14	4½
	½	2	0	7	6¼	0	7	5	-		-	0	3	11¾	64	6	1¼
	¼	0	0	4	10½	2	5	10½	-		-	6	4	9	34	16	3
		10	1	0	9	6	11	9	-		-	55	1	5¼	781	15	5¼
Labourage.		10	-		-	0	14	8½	1	3	4½	1	12	7	85	11	10¾
		3	0	3	1	0	2	6	2	9	10½	2	1	1	86	10	5½
		1	1	12	0	0	5	3¾	1	18	6	29	11	3½	120	5	6¾
	¼	1	0	11	11½	0	8	6	2	15	1½	2	6	0	88	12	10¾
		2	2	0	6	0	1	9	2	18	7½	25	7	1¼	117	2	11½
	¾	5	1	12	7½	0	9	4	2	1	3	1	11	1½	130	14	2¾
	½	4	2	6	8½	0	11	8½	1	16	8	0	7	10½	47	3	10½
	½	28	8	6	10½	2	13	9¾	15	3	5	62	17	0¾	676	1	10½

Note H.

The general average performance of the locomotive engines, on the Stockton and Darlington railway, is stated to us by Mr. Hackworth, to be, for thirteen engines, 441,038$\frac{3}{4}$ tons of goods, conveyed one mile by each engine, the engines being loaded in one direction only, and reckoning nothing for the empty carriages in either direction. The general load taken was twenty-four to twenty-eight waggons at a time, each waggon containing 53 cwt. of coals.

The average distance travelled by each engine annually was 13,493$\frac{1}{8}$ miles; which includes returning with the empty waggons.

The same engines, during the same period, worked on the average 251$\frac{2}{13}$ days, in the twelve months; and for want of a sufficient number of engines, the repairs were continued night and day, when an engine was taken off to repair.

The engine-men generally found fireman, coals, oil, hemp, tallow, and other stuff, for which he was paid different prices, according to the size and power of the engine, the average price being about ·175 of a penny per ton per mile.

We have given the contract price paid by the Stockton and Darlington railway company for the haulage of the coals at ·4 of a penny per ton per mile; this was, however, reduced before the termination of the contract, to ·34 of a penny per ton per mile; the contractor paying *5l.* per cent. on the capital of engines, &c., which, together with rents of premises, workshops, &c. amounted to nearly 1000*l.* per annum.

STANHOPE AND TYNE RAILROAD.

Note I.

Table giving a dissected Account of the Repairs done to the Locomotive Engines for the year 1835, with the expense of each item.—*See opposite.*

Note K.

Repairs done to the Locomotive Engines for the year 1836, with the expense of each item.—*See opposite.*

NOTE L.

Rates of tonnage and charges for conveyance of goods by the Newcastle-upon-Tyne and Carlisle Railway Company.

——	Tolls allowed to be charged for the use of the road, per ton per mile.	Charge for conveyance, including tolls per ton per mile.
	d.	*d.*
Dung, compost, and lime to be used as manure, and all other manures, and all materials for the repair of the public roads or highways - -	1	2
Coals for exportation, to be sea-borne - -	1	1½
Coals for home consumption - - - - -	1½	2¼
Coals passed through a screen not exceeding half an inch, lime, limestone, ironstone, iron ore, and all other mineral ores, building, pitching, and paving stones, sand and clay - - -	1½	2
Lime for exportation, to be sea-borne - -	1½	1½
Timber (hard wood 40 feet per ton, soft wood 50 feet per ton), deals, battens, staves, pitch, and tar	1½	3½
Lead, malleable iron, cast iron, and other metals -	2	3
Tiles, slates, flags, and bricks - - -	2	3
Corn, grain, flour, potatoes, butter in casks, and bacon	2½	3½
Corn in the straw, hay, and all other agricultural produce - - - - - -	2½	4
Coke and charcoal - - - - -	2	3
Sugar, dyewoods, raw hides, manufactured lead and paints, soap and tallow - - - -	3	3½
Groceries, oil, cotton and other wools, and bale goods, and tanners' bark - - -	3	4
Hats, glass bottles, and other light goods, per ton of 40 cubic feet - - - -	3	4
Dried hides, drugs, manufactured goods, and other merchandize, matters, or things not otherwise enumerated - - - - - -	3	4½
Wines, spirits, glass, and other hazardous goods, per weight or per ton of 40 cubic feet - -	3	
Vitriol - - - - - -	3	6¾
N.B. If tonnage shall not amount to 6*d.* per ton, the company may charge per ton -	6	—

Fractions of a quarter of ton or mile to be charged a quarter.

No waggon or other carriage shall carry at any one time along any part of the railway, including the weight thereof, more than four tons weight, for the tonnage of which waggon the company may take any rate not exceeding 4*d.* per ton per mile.

No piece of timber, stone, machinery, or other article exceeding four tons, including weight of the waggon, shall be carried without the licence of the company, for the tonnage of which they may charge as they please.

The company will carry goods from the station at Redheugh to the city of Carlisle, and from the station at the London Road, Carlisle, to Newcastle-upon-Tyne, on the following terms:—

		£	s.	d.
Goods rated as above, at	3½*d.* per ton per mile	1	1	0
Ditto	4*d.*	1	3	0
Ditto	4½*d.*	1	5	0
Ditto	5*d.*	1	7	0

Rate for the carriage of small parcels, for any distance not exceeding thirty miles.

lbs.		lbs.	s.	d.
	Not exceeding	14	0	6
	Not exceeding	28	0	9
	Not exceeding	56	1	0
	Not exceeding	112	1	3
Exceeding 112	and not exceeding	224	1	6
Exceeding 224	and not exceeding	336	2	0
Exceeding 336	and not exceeding	448	2	6
Exceeding 448	and not exceeding	560	3	0

*Tolls for passengers, &c. between Redheugh and Haydon Bridge.**

In respect of coaches, chariots, chaises, cars, gigs, landaus, waggons, carts, and carriages, used for the conveyance of passengers or cattle, &c. as follows:—

		s.	d.
For every person passing in or upon such carriage, for any distance—			
not exceeding	5 miles	0	6
not exceeding	10 miles	1	0
not exceeding	15 miles	1	6
not exceeding	20 miles	2	0
not exceeding	25 miles	2	6
not exceeding	30 miles	3	0
For every four-wheel carriage carried on the company's trucks, for any distance	not exceeding 20 miles	5	0
For - ditto - ditto,	not exceeding 30 miles	6	6
For - ditto, - drawn by one horse,	not exceeding 20 miles	3	6

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* Similar charges between Carlisle and Greenhead.

		s.	d.
For every four-wheel carriage drawn by one horse,	not exceeding 30 miles -	4	6
For every two-wheel carriage, - - -	not exceeding 20 miles -	2	0
For - ditto, - - - -	not exceeding 30 miles -	3	0
For every horse belonging to either of such carriages,	not exceeding 20 miles -	2	6
For - ditto - ditto, - -	not exceeding 30 miles -	3	0
The passengers in which to pay according to the rates for passengers conveyed in the company's carriages.			
For every carrier's cart to be conveyed by the company on trucks, after the rate of 3½*d.* per ton per mile, including the weight of the cart, and for every horse belonging to such carrier the sum of 1*s*. No charge made for the carrier.			
For every other horse, mule, ass, or other beast of draught or burden, and for every ox, cow, bull, or neat cattle carried by the company, for any distance - - - - -	not exceeding 20 miles -	2	6
For - ditto, - ditto, -	not exceeding 30 miles -	3	0
For every sheep, lamb, or pig, carried in or upon such carriage, for any distance - - - - -	not exceeding 30 miles -	0	6
If a score or upwards, ditto, - ditto,	- - - -	4*d.* each.	
For every calf - - - -	not exceeding 20 miles -	0	6
For ditto - - - - -	not exceeding 30 miles -	0	9

No gratuity to be allowed to be taken by any guard, porter, or other servant of the company.

JOHN ADAMSON, clerk to the company.

NOTE M.

(*a.*) LOAD OF LOCOMOTIVE ENGINES.

Horses' power for calculation of engines, 33,000 lbs. per minute, or 150 lbs. raised 220 feet per minute, or 2½ miles per hour, therefore $\frac{150}{4} = 37 \cdot 5$ lbs. = horses' power, at ten miles per hour, or 375 lbs. for ten horses, equal to friction of thirty tons, (taking friction at $\frac{1}{180}$ of weight;) say then - - - - - - -	30 tons.
Deduct weight of engine, tender, and water - - -	10½
Leaves for goods and waggons - - -	19½ tons,

or 13 tons of goods, and 6½ tons of waggons.

This assumption of the power is derived from the performance of engines in actual use, as follows:—

Work of DARLINGTON ENGINES, reduced to a level surface, the rise of this way averaging 1 in 246.

HACKWORTH'S ENGINE.

This engine's draught, as stated in the text, is equal to the following, upon a level surface:—

	SUMMER.			WINTER.		
	5 miles.	8 miles.	10 miles.	5 miles.	8 miles.	10 miles.
Goods - -	46·75	25·00	17·75	39·90	21·00	14·30
Waggons -	23·10	12·50	8·80	19·80	10·20	7·20
Engine and tender -	16·50	16·50	16·50	16·50	16·50	16·50
Tons -	86·35	54·00	43·05	76·20	47·70	38·00
	SMALLER ENGINES.					
Goods - -	34·66	18·66	13·33	28·75	15·00	10·33
Waggons -	17·33	9·33	6·66	14·50	7·50	5·20
Engine and tender -	12·00	12·00	12·00	12·00	12·00	12·00
	64·00	40·00	32·00	55·25	34·50	27·53

EXPERIMENT UPON BOLTON RAILWAY, REPORTED BY MR. SINCLAIR.

	Cwt.	lbs.
Weight of 1 waggon - -	30	0
Weight of its load - -	42	96
	72	96 = 8160 lbs. × 13 waggons = 106,080 lbs.

Add engine = 10 tons, 13 cwt. - - - - 23,856

Mass moved - - - - 129,936 lbs.

129,936 lbs. + 180 = 722 lbs. = friction.
129,936 lbs. + 440 = 295 lbs. = gravity.

1017 lbs.

1017 lbs. × 8·8 miles = 89,496 lbs. + 12·5 lbs. = friction of 1 ton - - - - - 71·6 tons.

Deduct engine - - - 10·6

Gross - - - 61·0 tons.

Deduct one third for waggons - 20·3

Goods - - 40·6 tons, or say 41 tons.

BOLTON ENGINE, WITH EIGHT WAGGONS, AT SIX MILES PER HOUR.

By experiment above, one load gross = 8160 lbs. which × 8 waggons = 65,280 lbs.
Add engine - - - - 23,856

Mass moved - - - - 89,136 lbs.

89,136 lbs. ÷ 180 = 495 lbs. = friction.
89,136 lbs. ÷ 440 = 202 lbs. = gravity.

697 lbs. = resistance.

697 lbs. × 6 miles ÷ 10 miles = 418 lbs. ÷ 12·5 lbs. = friction
of 1 ton - - - - - - 33·5 tons.
Deduct engine - - - 10·6

Gross - - 22·9 tons.
Deduct one third for waggons - - 7·6

Goods - - - 15·3 tons, or 15⅓ tons.

HETTON ENGINE, BY MR. WOOD'S REPORT.

In 30·00 chains falls - - 14 ft. 0 in. which is equal to - - 1 in 141
72·45 —— - - 9 3½ —— - - 1 in 514

102·45 —— - - 23 3½ —— - - 1 in 287

In summer takes down 16 waggons, containing 848 cwt. of coals.
Add waggon - - - 512
Engine, &c. - - - 210

Together - - - 1570 cwt.

20 journies = 51 miles per day, say 4½ miles per hour, for 12 hours; or, allowing for stoppages, 5 miles per hour.

1570 cwt. = 175,840 lbs. ÷ 180 = 977 lbs. = friction.
Deduct - 175,840 lbs. ÷ 287 = 612 = gravity.

Tons.
Resistance descending - 365 lbs. ÷ 12½ = - - 29 down.

512 + 210 = 722 cwt. = 80,864 lbs. ÷ 180 = 449 lbs. = friction.
80,864 lbs. ÷ 287 = 282 lbs. = gravity.

Tons
Resistance ascending - - 731 lbs. ÷ 12½ = 58½ up.

87½

Divide by 2 for averaging, or on level - - 43¾ tons.

But as the rise on part of the road is not favourable, say the work, on a level, is 50½ tons, at 5 miles per hour.

Upon this basis, the work, at different speeds, is as follows:

	5 miles.	8 miles.	10 miles.
Goods - -	23⅓	14	9 9/10
Waggons - -	16⅔	7	4 9/10
Engine - -	10½	10½	10½
	50½	31½	25¼

Now 50½ tons, at 5 miles = 101 tons, at 2½ miles, and 101 ÷ 12 = 8 5/12 horses power.

(*b.*) REPAIRS, &C. OF LOCOMOTIVE ENGINE.

	£	s.	d.
A tube and chimney breast every three years or annually - -	12	10	0
Occasional repairs to boilers - - - - -	3	0	0
New chimney each year, and deduct old - - - -	7	10	0
Set of chimney bars every two months - - - -	6	0	0
Axles and brasses, one set annually - - - - -	10	0	0
Wheels, three sets of wrought-iron tire every year, deducting value of old	36	0	0
Tender carriages, and tank - - - - -	2	10	0
Small repairs - - - - - - - -	12	0	0
	89	10	0
Add one fifth for spare engine - - -	17	18	0
	£107	8	0

(*c.*) COAL FOR EACH LOCOMOTIVE ENGINE.

A ten horse engine will take 13 tons of goods ten miles per hour, and will go between Liverpool and Manchester three times each day = 30 × 3 = 90 miles per day, and 13 × 90 = 1170 tons of goods one mile per day by each engine. 1170 tons of goods at 2½ lbs.* of coals per ton per mile = 2929 lbs. of coal per day, and 2925 × 912,600 lbs. per year = 380½ tons, or say 382 tons of coal for each locomotive engine per year.

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* The consumption of 2½ lbs. per ton per mile, was determined upon from the following data:—

The average of the experiments made at Hetton and Killingworth in January, 1825, gave, for one ton of goods conveyed at the rate of 4½ miles, per hour - - - - - - -	2·15 lbs.
Mr. Blenkinsop's account of the consumption of his engines - -	2·70 –
The Hetton account of the present engines on a level, at 4 miles per hour	3·00 –
The Hetton account of the engines near Sunderland - - -	2·00 –
Mr. R. Stephenson's report of an experiment on the Darlington line, at 11 miles an hour - - - - - - - -	1·60 –

But the data which were principally relied on, were the *actual* consumption on the Darlington railroad, furnished by Mr. Storey, from which it appeared, that 298 tons of coal were consumed by 4 engines in 2 months; and that the work done was 249,239 tons of coal conveyed one mile, or 2·16 lbs. per ton per mile. This was by engines with a single tube through the boiler.

(*d.*) ACCOUNT OF WORKING EXPENSES.

	£	s.	d.
Engine-man's wages, at 21*s.* per week -	54	12	0
Boy to assist - - - - -	26	0	0
Grease, oil, hemp - - - -	12	0	0
Total	£ 92	12	0

(*e.*) LOCOMOTIVE ENGINES FOR RAINHILL AND SUTTON INCLINED PLANES.

Resistance per ton on the Rainhill and Sutton planes: —

$2240 \div 180 = 12{\cdot}44$ lbs. friction.

$2240 \div 96 = 23{\cdot}33$ lbs. gravity.

35·77 lbs. per ton, and the engine, &c., being 10½ tons, is 375$\frac{1}{60}$ lbs. resistance. Now as (by *a*, note M) the power of the engine at ten miles, is 375 lbs., it is evident that an engine will just move its own weight up the hill at ten miles per hour.

If the same rate of speed and tonnage is to be kept up, the following calculation is given: —

Ten-horse engine upon these planes = 10½ tons at ten miles per hour, 13 tons of goods, or 19½ tons of goods and waggons.

If 10½ tons weight of one engine and tender require - -	10 horses' power.
Another engine, without tank or water-carriage, 8½ tons, will require - - - - - - -	8 horses'.
And on the same proportion, 19½ tons of goods and carriages will require - - - - - -	18½
Total power	36½ horses' power.

Or, if the same power of engine is kept, the following will be the performance, at the rate of five miles per hour: —

Horses' power at five miles = $150 \div 2 = 75$ lbs., or for ten horses - -	750 lbs.
Deduct gravity and friction of carriage - - - - -	375
Leaves applicable to load -	375 lbs.

375 lbs. ÷ 35·77 lbs. (resistance of one ton, text) give gross 10¾ tons, or goods only, 7½ tons.

Or, if eight miles be the rate of travelling on a level, the engine would take twenty-seven tons of goods and waggons up the plane, and,

Horse power at eight miles = $150 \times 2\frac{1}{2} \div 8 = 47$ lbs., or, for ten horses, 470 lbs.

Then $470 \div 12\frac{1}{2}$ (resistance of one ton) gives - - - -	37·6 tons.
Deduct engine, &c. - - - - - -	10·5
Leaves goods and waggons -	27·1 tons.

Or, goods eighteen tons, and waggons nine tons.

And with the assistance of another engine of similar power, would ascend at the rate of 4½ miles an hour, as follows: —

TIME OF LOCOMOTIVE ENGINE ON INCLINED PLANES.

27 + 10½ + 8½ = 46 tons = weight of load, and two ten-horse engines.
35·77 ÷ 46 = 1645 lbs. = total resistance to twenty horses.
1645 ÷ 46 = 82 lbs. = exertion for each horse.
82 lbs. : 150 lbs. : : 2½ miles : : 4½ miles per hour.

They therefore had recourse to the stationary system to work the two planes; and supposing to give nine miles clear an hour, the rate in motion should be twelve miles; and for 3,000 tons to be passed in each direction daily, the load for each journey will be fifty tons, and the power required.

FIXED ENGINES FOR RAINHILL.

52 tons, or 116,480 lbs. ÷ 96, the rise of the plane, give for gravity -	1,213 lbs.
Add 116,480 lbs. ÷ 180 for friction - - - - - -	647
Together -	1,860
Friction of rope = $\frac{1}{22}$ of its weight, or of 10,560 lbs. - - -	480
Gravity of rope = $\frac{1}{96}$ of its weight - - - - - -	110
	2,450

2,450 lbs. ÷ 31 lbs. (power of horse at twelve miles) = 80 horses, or allowing for surplus power, say two engines, each fifty-horse power.

(*f.*) EXPENSE OF ENGINES UPON RAINHILL.

		£
Two fifty-horse engines, at 1,500*l.* each - - - - - -		3,000
Machinery and drum-barrels - - - - - -		300
Engine house and chimney - - - - - - -		600
Engine-man's dwelling - - - - - - - -		100
Reservoir or well for water - - - - - -		100
Pullies, No. 330, for each line, or 660 for the two lines at 15*s.* - -		495
		£ 4,595

Interest on 4,595*l.* at five per cent. - - - - -				229	13	6
General depreciation at 1½ per cent. - - - - -				69	0	0
Boilers, say three, to last twelve years, difference of value 24*l.* per ton = 480*l.* to be expended at the end of twelve years, equal to an annual expense of - - - - - -				13	4	0
Fire bars annually - - - - - - -				5	0	0
Repairs to engine and machinery - - - - -				35	0	0
Oil, tallow, hemp, &c. - - - - - - -				20	0	0
Wear and tear of pullies - - - - - - -				25	0	0
Coals equal to eighty horses, working twelve hours per day, allow 15 lbs. of small coal per horse, per hour, which gives for 312 days 1872 tons, at 2*s.* 6*d.* (price given to us) - - - - -	234	0	0			
Add coal for raising steam, 377 tons, at 2*s.* 6*d.* -	47	2	6			
				281	2	6
Carried forward				£ 678	0	0

Brought forward				£ 678	0	0
Wages as follow:—	£	s.	d.			
Engine-man	54	12	0			
Fire-man	39	0	0			
Brake-man	39	0	0			
				132	12	0
Men to grease sheeves, one man to both planes, say for each plane				19	10	0
Oil, 150 gallons, at 2*s.* 6*d.*				18	15	0
				848	17	0
Similar engines and expenses for the other plane				848	17	0

Ropes; four ropes for these two inclines, each 2,640 yards long, 5½ inches circumference = 4 lb. to one yard each rope, therefore, 94 cwt. 1 quar. 4 lb., and the four ropes, 18 tons, 17 cwt. 16 lbs., which, at 42*l.* per ton, (being 51*l.*, less 9*l.* for old ropes,) gives 792*l.*

	£	s.	d.			
Interest upon 792*l.* capital, at five per cent.	39	12	0			
Annual expense of ropes, being for 4,000 tons, passed three miles daily for 312 days, at $\frac{1}{160}$ of a penny per ton per mile, upon a level, and adding for slope of 1 in 96, being nearly three times the wear upon a level	3,276	0	0			
				3,315	12	0
Making total				£ 5,013	6	0

(*g.*) WATER STATIONS.

	£	s.	d.
A two-horse power engine to each station	200	0	0
Pumps, kettle, and machinery	100	0	0
Engine-house and cistern	150	0	0
Cottage for man	60	0	0
Well or pond	50	0	0
	£ 560	0	0
Interest and depreciation on 560*l.* at 6½ per cent.	42	0	0
Wear of boiler and bars, grease, &c.	5	0	0
Coal for engine, kettle, &c. fifty tons at 2*s.* 6*d.*	6	5	0
Engine man	39	0	0
	£ 92	5	0

10 stations, at 92*l.* 5*s.* each - 922*l.* 10*s.* 0*d.*

NOTE N.

(a.) POWER OF STATIONARY ENGINE.

Friction of fifty-two tons $= 52 \div 180$ - - - - - -	647 lbs.
Friction of ropes, sheeves, and drums $= \frac{1}{22}$ of weight*, say of 3,400 (being weight of $1\frac{1}{2}$ mile of $3\frac{1}{2}$ inch rope) equal to - - - -	155
Friction of rope upon barrel - - - - - - -	13
	815 lbs.

Power of horse at 12 miles $= 150 \times 2\frac{1}{2} \div 12 = 31$ lbs., then $815 \div 31 = 26$ horses, or, say, allowing for spare strength, thirty horses, required in one direction, making two thirty-horse engines, at each end of the mile and half stages.

(b.) ENGINES TO WORK THE RAINHILL AND SUTTON PLANES.

The calculation in *e*, Note F. gave two fifty-horse engines requisite for working each inclined plane, but as the engines will now have to draw the waggons towards them for a mile upon the level, an increase of ten-horse power has been made to each engine, making two sixty-horse engines to each station.

	£
Two 60-horse engines, each 1800*l.* - - - -	3,600
Machinery, drums - - - - - - - -	500
Engine-house and chimney - - - - - -	700
Dwelling-house - - - - - - - -	100
Well and pond - - - - - - - -	100
	£5,000

Two engines at 5,000*l.* = 10,000*l.*

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* FRICTION OF ROPE ON THE BRUNTON AND SHIELDS RAILWAY.

By observation, seven empty waggons took down rope in 3′ 45″ ($= 8\frac{4}{10}$ miles per hour) which makes friction - - - - - -	$88\frac{3}{4}$ lbs.
Mr. Thompson says, eight waggons take it down in three minutes ($= 10\frac{1}{2}$ miles per hour) which gives friction - - - - - -	82
Average friction -	$85\frac{1}{2}$

Weight of rope $= 1,861$ lb. $\div 85\frac{1}{2} = 22$, or, say, friction of rope, sheeves, barrel, brake, &c., $= \frac{1}{22}$nd of weight of rope.

KILLINGWORTH. Sixteen empty waggons descended Killingworth plane, in four minutes, with $4\frac{1}{2}$ inch rope after them, of which the weight was 3,096 lbs. Inclination of plane 1 in $62\frac{1}{2}$. This leaves for friction of rope, &c., $143\frac{1}{2}$ lbs., or, say, $\frac{1}{22}$nd of weight nearly.

(*c.*) ENGINES FOR MIDDLE OF THE TWO MILES LEVEL, AND AT THE FOOT OF EACH PLANE.

	£
Two 20-horse engines, each 900*l.*	1,800
Machinery and drums	300
Engine-house and chimney	450
Dwelling-house	75
Well or pond	85
	£2,710

Three engines at 2,710*l.* = 8,130*l.*

(*d.*) ENGINES UPON 1½ MILE STAGES.

	£
Two 30-horse engines, each 1,200*l.*	2,400
Machinery, drum, &c.	400
Engine house and chimney	500
Dwelling-house	100
Well or pool for water	100
	£3,500

Fifteen engines at 3,500*l.* = 52,500*l.*

(*e.*) ENGINES AT MANCHESTER END.

	£
Two 12-horse engines, each 500*l.*	1,000
Machinery and drums	200
Engine-house and chimney	400
Dwelling-house	75
Well and pump, or pool for water	50
	£1,725

(*f.*) REPAIRS AND WORKING OF STATIONARY ENGINES.

	£	*s.*	*d.*
Repairs to boilers of engines, for the power of 1,354 horses, taken in the proportion of 13*l.* 4*s.* to 100 horses	178	14	6
Fire-bars, taken in like proportion, at 5*l.*	67	14	0
Repairs to engines and machinery, at 7*s.* for 1 horse's power	473	18	0
Oil, tallow, hemp, &c. for 1 horse's power	270	16	0
Coal in proportion to former estimate, for 100-horse engine, = 18·72 tons per horse, or 25,346 $\frac{88}{100}$ tons per annum, exclusive of coal for raising steam, at 2*s.* 6*d.*	3,168	7	2
Carried forward	£4,159	9	8

Brought forward - £4,159 9 8

Men required as follows:—

	Manchester engine.	Fifteen one and half mile engines.	Three 20-horse engines.	Two 60-horse engines.	Liverpool tunnel, extra.							
Engine-men	2	30	6	4	1	=43 at £51	12	£2,347	16			
Bank-men	2	30	6	4	2	=44 —	39	0	1,716	0			
Brake-men	1	30	6	4	1	=42 —	39	0	1,638	0			
Assistants	0	15	3	2	1	=21 —	39	0	819	0			
Ten men to oil pullies, at 39*l.*						- - - -			390	0			
											6,910	16	0
Oil, 30 miles at 50 gallons per mile = 1,500 gallons, at 2*s.* 6*d.*										-	187	10	0
											£11,257	15	8

(*g.*) EXPENSE OF ROPES.

"From an account kept by Mr. Thompson of the wear of ropes on the Shields and Brunton railway, apparently with great accuracy of detail; the mean average cost of ropes has been found to be $\frac{51}{1000}$ of a penny," or $\frac{1}{20}$ of a penny per ton per mile, nearly. The declination of the way being in the direction of the loaded waggons, and there being in some case no tail-rope, are both favourable to this line, as compared with a horizontal road; but as here the waggons are drawn back empty, the cost per ton of goods, as compared with the Liverpool and Manchester line, is increased.

Mr. Story reported to us, that the ropes upon the Brusselton inclined plane cost, by an account kept by him, one farthing per ton per mile upon all the coal conveyed over them, as follows:—

Rope on Brusselton plane.

1,851 yards, inclination 1 in 33½ ascended with load.
825 ditto 1 in 30½ descended with load.

Average taken at 1 in 33 which gives 69 lbs. gravity of 1 ton.

$$\begin{array}{rl}
 & \text{Tons.} \\
1{,}851 \times (69 + 12\tfrac{1}{2}) \times 1{\cdot}5 = 226{,}284 & \rbrace\ \text{loaded.} \\
825 \times (69 - 12\tfrac{1}{2}) \times 1{\cdot}5 = 69{,}919 & \\
825 \times (69 + 12\tfrac{1}{2}) \times {\cdot}5 = 33{,}618 & \rbrace\ \text{empty.} \\
1{,}851 \times (69 - 12\tfrac{1}{2}) \times {\cdot}5 = 52{,}292 & \\
\hline
382{,}113 \div 12\tfrac{1}{2} = 30{,}569 &
\end{array}$$

$$\begin{array}{r}
30{,}569 \div 1760 = 17{\cdot}37 \\
\text{Deduct } \tfrac{1}{3} = 5{\cdot}79 \\
\hline
11{\cdot}58 \text{ say } 11\tfrac{1}{2}
\end{array}$$

11½ miles : 1 mile : : 25 : ·0243 of a penny.

We have, by calculation, reduced this to a horizontal surface, and find that it would be $\frac{23}{1000}$, or under $\frac{1}{40}$ of a penny, per ton of goods, per mile, exclusive of the wear of tail-rope.

The reciprocating system being applied on the lower part of the Hetton road, Mr. Wood has informed us, that 301,800 tons of coal were conveyed over a distance of 2½ miles for an expense of 780*l.* in ropes. By reducing this to a level, and to suit our case, we find the cost to be $\frac{12}{100}$ of a penny per ton per mile, which very much exceeds either of the former results.

After fully considering this important subject in all its bearings, we fixed upon $\frac{8}{100}$ of a penny per ton of goods per mile, dividing it into $\frac{6}{100}$ for the head-rope, and $\frac{2}{100}$ for the tail-rope.

(*h.*) CAPITAL AND INTEREST UPON SPARE ROPE.

	£	s.	d.
114 miles of 3⅛ inch rope, at 1⅙ lb. per yard, is 104 tons 12 cwt. 3 qrs. 14 lbs., at 51*l.* for new - - - - -	5,336	16	8
Less 9*l.* for old - -	941	16	8
	£4,395	0	0

Interest on 4,395*l.* at 5 per cent. - 219*l.* 15*s.*

(*i.*) SUNDRY EXPENSES AND CHARGES.

				£	s.	d.
30 crossing by iron pipes, capital 300*l.* at 5 per cent. - - -				15	0	0
Coal each morning for raising steam, 28 lbs. per horse per day, for 1,354 horses for 312 days - - - - - -				616	2	6
Wear of pullies in proportion of 25*l.* for 3 miles - - - -				250	0	0
Interest upon duplicates, say 1,354 horses at 1*l.* = 1,354*l.* - - -				67	14	0
Ropes, capital as above note	£5,336	16	8			
For planes per locomotive estimate - - -	961	14	3			
	£6,298	10	11			
at 5 per cent. - - -				314	18	0
Interest upon signals, 550*l.* at 5 per cent. - - - - -				27	10	0
				£1,291	4	6

NOTE O.

(*a.*) The data for assuming this power of the engine, are as follow:—

Darlington railway.—The average fall is 1 in 246, but being undulating, some parts descend 1 in 100, and others are level, and the engines have to overcome the resistance of twenty loaded waggons on the level, and twenty empty waggons on 1 in 100, at the rate of four miles in an hour.

Weight of twenty loaded waggons - - -	80 tons
Engine and tender - - - - -	12
	92 tons.

92 tons ÷ 200 = 1,030 lbs. the maximum resistance at 4 miles an hour; and $\frac{1{,}030 \times 4}{10}$ = 412 lbs. at 10 miles an hour.

And with twenty empty waggons - - -	25 tons.
Engine and tender - - - - -	12
	37 tons.

37 tons ÷ 200 = 414 lbs. friction.
37 ÷ 100 = 828 lbs. gravity.

1242 lbs. the maximum resistance at four miles an hour;

and $\frac{1{,}242 \times 4}{10}$ = 497 lbs. at ten miles an hour.

Springwell railway.—The inclination varies from $\frac{1}{280}$ to $\frac{1}{80}$ the average being $\frac{1}{242}$. One engine travels with eighteen waggons weighing 22½ tons, or with engine thirty-three tons at an average speed of six miles an hour.

Average resistance. Gravity 606 lbs.
Friction 370

976 lbs. × 6 ÷ 10 = 585½ lbs., the effect at ten miles an hour.

Occasional resistance at $\frac{1}{80}$. Gravity 924
Friction 370

1,294 × 6 ÷ 10 = 776 lbs.

Bolton and Leigh railway.—From an experiment with the Lancashire Witch, fifty-eight tons were moved up an inclination of $\frac{1}{432}$ at the rate of $8\frac{8}{10}$ miles per hour, which is equal to 836 lbs. at ten miles an hour.

Liverpool railway.—Rocket engine traversed back and forwards with a gross load of 37½ tons *at the rate of thirteen miles an hour.*

Another engine, employed in leading marle, generally conveyed seventy tons (exclusive of its own weight) *at the rate of five miles an hour.*

From these experiments it was concluded, that a locomotive engine would convey twenty tons of goods, exclusive of carriages, at the rate of twelve miles an hour, which would require a force of 497 lbs.

(*b.*) This is derived from the actual expense of the Springwell and Darlington engines. *Springwell* furnished by Mr. John Wood of the cost in the years 1827—1828.

		£	s.	d.
1827.	Wrightwork - - - - - -	10	15	5
	Smithwork - - - - - -	40	17	3
	Sundry tradesmen's accounts - - - -	50	2	0
		101	14	8
	Deduct old materials -	9	19	3½
	Cost of two engines -	£91	15	4½

		£	s.	d.
1828.	Smithwork - - - - - - -	22	15	0
	Malleable iron bars - - - - -	27	8	3
	Wrightwork - - - - - - -	4	3	2
	Sundry tradesmen's accounts, including carting, stop-cocks, pumps, clacks, &c. - - - - - -	31	17	6½
	Cost of two engines -	£86	3	11½
	Darlington.—In 1829 the annual repairs of four of the Darlington engines as per account, carefully taken by Mr. Hackworth - - - - - -	154	8	0
	Fire-bars - - - - - - -	24	0	0
		£178	8	0

Cost of four engines, which say *50l.*

(*c.*) COALS.

According to the experiments on the Killingworth engines, detailed in the former edition of this work, Messrs. Stephenson and Locke state, that

No. 2 experiment, 2·13 lbs. of coal per ton per mile.
3 —— 2·05 ditto.
5 —— 1·60 ditto.

Darlington engine with a double tube.
1·60 lbs. of coal per ton per mile.

An experiment with the Lancashire Witch gave in twelve hours 1,031 tons conveyed one mile with 16 cwt. of coals = 1·73 lbs. per ton per mile.

From these experiments, the consumption is fixed at 1·75 lbs. per ton per mile for 1,800 tons per day, which is 3,150 lbs. per day, and, 312 days, is 439 tons, at *5s. 4d.*, equal to 128*l.* 10*s.*

(*d.*) Messrs. Stephenson and Locke propose, that the locomotive engines should, upon the other parts of the line, take twenty tons of goods twelve miles an hour, and that the same engines would take eight tons of goods up the plane at ten miles an hour; the respective resistances on the level and on the plane, being 497 lbs. and 656 lbs., referring to the experience of some of the engines previously noticed, which exert a power greater than this; and an experiment with the Rocket, weighing only 4¼ tons, gave 15¼ tons, including engine, moved up the plane in question, at the rate of sixteen miles an hour. Another experiment with the same engine, mounted the plane at the rate of 12½ miles an hour, with $20\frac{18}{20}$ tons, including engine.

And, calculating the effect of an engine having two ten-inch cylinders, with pistons moving 180 feet per minute, and an effective pressure of 25 lbs. per square inch, we shall have 157 inches area of cylinders × 25 lbs. × 180 ÷ 880 feet per minute, (being ten miles an hour) = 803 lbs., which exceeds the resistance of eight tons of goods on a plane ascending 1 in 96, by 147 lbs.

(e.) ANNUAL COST OF WATER STATIONS.

	£	s.	d.
Interest and depreciation on original cost of each water station, viz. 500*l.*, at 7½ per cent. - - - - - - -	37	10	0
Annual repairs, grease, &c. - - - - - -	5	0	0
Coals for each station, 100 tons, at 4*s.* 6*d.* - - - - -	22	10	0
Attendant - - - - - - - -	39	0	0
	£104	0	0

Note P.

(*a.*)—The power of the engines on the 1½ mile stages will be thus:—

Friction of fifty-two tons, at $\frac{1}{200}$ - - - - - -	582 lbs.
Friction of 1½ mile of 4½ inch rope, weighing 6,888 lbs. at $\frac{1}{12}$ * - -	574
	1,156 lbs.

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* The method which we adopted in investigating this part of the subject was, by placing so many empty waggons upon an inclined plane as would move a given length of rope at an uniform velocity; this being ascertained, it is evident that the gravity of the rope and waggons will be equal to their friction.

Experiment I.—Three waggons, weighing 72 cwt., maintained a speed of 1½ mile an hour, with 930 yards of rope, weighing 3,397 lbs., on a plane ascending one in thirty-three.

Experiment II.—Four waggons, weighing 96 cwt., maintained the same speed with 1,370 yards of rope, weighing 5,004 lbs.

Experiment III.—Five waggons, weighing six tons, maintained a speed of $1\frac{5}{8}$ mile an hour, with 1,810 yards of rope, weighing 6,600 lbs.

To reduce these to fractional parts of the rope's weight:—

1st.	Gravity of waggons - -	244½ lbs.
	Gravity of rope - - -	103
		347½
	Deduct friction of waggons -	39
	Leaves	308½ lbs., or $\frac{1}{12}$th of the weight of the rope for its friction.
2d.	Gravity of waggons - -	326 lbs.
	Gravity of rope - - -	152
		478
	Deduct friction of waggons - -	52
	Leaves	426 lbs., or nearly $\frac{1}{12}$th.

Power of a horse at twelve miles an hour = 150 × 2½ ÷ 12 = 31 lbs., then 1,156 ÷ 31 = 37-horse power, or, allowing for spare power, say forty-horse power for one line, or eighty horses for two lines.

(*b.*) POWER OF ENGINES FOR ONE MILE STAGES.

Friction of fifty-two tons, as above - - - - -	582 lbs.
Friction of one mile of rope, being ⅔ of the above - - -	382
	964 lbs.

But since these engines need not be made to propel the goods at more than eight miles per hour, because the space of one mile can only be travelled over in the same time, that the others are moving 1½ mile (on account of the necessary dependence of these engines upon the others); therefore, the power of a horse, at eight miles an hour, will be 150 × 2½ ÷ 8 = 47 lbs., which, divided into 964, gives the power of these engines = 20½ horses, or, for spare power, 24 horses, or double that for the two lines.

(*c.*) THE POWER OF THE ENGINES TO WORK THE TWO INCLINED PLANES WILL BE

52 tons ÷ 96 give for gravity - - - - - -		1,213 lbs.
52 ÷ 200 give for friction - - - - - -		582
Friction of rope (5½ inches circumference)	10,700 lbs. ÷ 12 - -	891
Gravity of rope - - -	10,700 lbs. ÷ 96 - -	111
		2,797 lbs.

2,797 lbs. ÷ 31 (power of a horse at twelve miles an hour) = 90 horses.

This would be the power of the engines in case no descending train was passing down the plane at the same time, but this, according to the regularity of the system, becomes a necessary consequence. We shall, therefore, assume the power requisite to work these planes, and the one mile stages, to be eighty horses.

(*d.*)—The power of the engine, at the foot of the inclined planes, will, by allowing ten horses to assist in overcoming the friction of the rope, be fifty horses, and the extra power at the tunnel forty horses.

3d.	Gravity of waggons - - -	407½ lbs.
	Gravity of rope - - - -	200
		607½
	Deduct friction of waggons -	65
	Leaves	542½ lbs., or nearly 1/12th.

(*e*.) ESTIMATE OF CAPITAL REQUIRED FOR ENGINES AND MACHINERY ON THE 1½ MILE STAGES.

	£	*s*.	*d*.
One engine of eighty-horse power	2,800	0	0
Four rope rolls and machinery	550	0	0
Engine-house and chimney	650	0	0
Dwelling-house reservoirs	200	0	0
	£ 4,200	0	0

Seventeen stations, at 4,200*l*. - 71,400*l*.

(*f*.) EXPENSE OF ENGINES AT THE BOTTOM OF THE TWO PLANES.

	£	*s*.	*d*.
One engine, of forty-eight horse power	1,600	0	0
Rope rolls	500	0	0
Engine-house and chimney	600	0	0
Dwelling-house and reservoir	180	0	0
	£ 2,880	0	0

Two engines at bottom of planes - 5,760*l*.

	£	*s*.	*d*.
(*g*.) One engine at Manchester, twenty-four horse power	960	0	0
Rope rolls	250	0	0
Engine-house, &c.	500	0	0
Dwelling-house, reservoir, &c.	180	0	0
	£ 1,890	0	0

(*h*.) ANNUAL EXPENSE OF STATIONARY ENGINES.

	£	*s*.	*d*.
Coals for engines, being altogether 1,572 horse power, working ten hours per day, for 312 days, at 17 lbs. per horse power per hour = 37,222 tons, at 4*s*. 6*d*.	8,374	19	0
Repairs of engines and machinery, including fire-bars, boilers, hemp, oil, &c., at 1*l*. per horse power, per annum	1,572	0	0
43 engine-men, at 54*l*. 12*s*.	2,347	16	0
21 assistants at 40*l*.	840	0	0
42 brake-men, at 40*l*. per annum	1,680	0	0
84 men to ride the trains, being one man to each rope, 40*l*. per annum	3,360	0	0
Wear and tear of rope sheeves, at 8*l*. per mile of double way	240	0	0
Oil for sheeves, 2,100 gallons, at 2*s*. 6*d*.	262	10	0
8 men to oil sheeves, at 30*l*. per annum	240	0	0
Annual cost of keeping the machinery in working order	£ 18,917	5	0

(i.) ROPES.

	£	s.	d.
108 miles of 4½ * inch rope on the level stages = 221⅓ tons, (after deducting value of old material) at 42*l.* per ton - - -	9,296	0	0
6 miles of 5½ inch head-rope for inclined planes, 19 1/10 tons, at 42*l.* -	802	4	0
6 miles of 3½ inch tail-rope for inclined planes, 7 tons 17 cwt. at 42*l.*	329	14	0
Grooves for ropes crossing road, 30 at 10*l.* - - - -	300	0	0
	£ 10,727	18	0

WEAR OF ROPES.

	£	s.	d.
Interest on 10,727*l.* 18*s.*, at 5 per cent. per annum - - -	536	7	10
Although the wear and tear on ascending the inclined planes will be increased, there will be a saving in descending, and we therefore take 30 miles at 1/10th of a penny per ton per mile†, on 4,000 tons, conveyed daily, equal to 37,440,000 tons over one mile per annum	15,600	0	0
	£ 16,136	7	10

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* The load which Mr. Walker has assigned to be conveyed by each engine is fifty-two tons, to be dragged by a rope 3½ inches in circumference; before estimating the cost, it will be necessary to examine whether such a size is adequate to such a load.

In this, as in most other cases, we can only refer to those railways where similarity of circumstances will warrant a comparison. The resistance of fifty-two tons will be 582½ lbs.

On the Hetton railway, a five-inch rope is used to drag twenty-four empty waggons, each weighing 28 cwt., up an ascent of 1 in 250. On this plane a 3½ inch rope was originally used, but it was so frequently broken that it was removed in four months.

Then 3,136 × 24 ÷ 250 = 301 lbs. gravity.
3,136 × 24 ÷ 200 = 376 friction.

Resistance requiring a five-inch rope 677 lbs.

On another plane, which is quite level, a rope 4½ inches in circumference is used to drag the same number of waggons; consequently 3136 × 21 ÷ 200 = 376 lbs., the resistance requisite for a 4½ inch rope, and, by reducing these to the resistance of 52 tons upon a level, we shall have by the former, for the requisite size of the rope, - - - - - - 4·6 inches.
By the latter - - 5·6

In the foregoing we have not taken the weight of the rope into calculation, as the length of the planes is nearly alike.

It is clear, therefore, that for such a line of railway as the Liverpool and Manchester, a rope of 3½ inches in circumference is too small; and in order to prevent as much as possible those delays arising from breakage, a 4½ inch rope is the very least in size that should be used, and on the inclined planes a rope not less than 5½ inches.

† The Brunton and Shields railway, on which the cost of ropes is said not to exceed the 1/20th of a penny per ton of goods per mile, is extremely favourable; but the

(*k.*) DUPLICATE ROPES.

	£	s.	d.
108 miles of spare 4½ inch rope, 221⅓ tons, at 51*l.* - - -	11,288	0	0
6 miles of 5½ inch head-rope for inclined planes, $19\frac{8}{18}$ tons, at 51*l.*	974	2	0
6 miles of 3½ inch tail-rope for inclined planes, 7 tons 7 cwt., at 51*l.*	400	7	0
Duplicates for engines, at thé rate of 1 per horse power - -	1,572	0	0
Signal stations, 22 at 25*l.* - - - - - - -	550	0	0
	£ 14,784	9	0
Interest on this amount at 5*l.* per cent. per annum, being the annual cost of duplicates - - - - - - - - -	739	4	5

NOTE Q.

Statement of the expense of ropes, on different planes.

	Description of plane.	Length in yards.	Inclination in feet.		Length of rope in yards.	Girt of rope in inches.	Number of tons conveyed by one rope.
			Ascent in feet.	Descent in feet.			
1	Engine plane - - C.	882	151	- -	1000	7¼	119·944
2	— do. - - S.	775	30	- -	810	5¾	205·621
3	— do. - - S.	775	115	- -	820	7¼	154·214
4	— do. - - C.	2530	- -	63½	2600	4½	171·349
5	— do. - - C.	1820	nearly	level	1900	4½	136·928
	— do. tail-rope of No. 5.	- -	- -	- -	1620	4¼	171·349
		- -	- -	- -	- -	- -	—
6	— do. - - S.	1864 836	68 - -	- - 33	1910	5¾	108·146
7	— do. - - S.	1104	42	- -	1200	5	168·805
8	— do. - - S.	1905	- -	89	2000	4½	218·625
9	— do. - - C.	964 1012	57½ - -	- - 33	1100	5	102·050
10	— do. - - S.	1263	- -	82	1500	5	134·000
11	Self-acting plane - C.	1302	- -	130½	1356	5¾	342·648
12	— do. - - C.	1224	- -	129½	1256	5¾	342·648
13	— do. - - C.	716	- -	54½	720	4¾	303·393
14	— do. - - S.	902	- -	76½	950	5½	325·565
15	— do. - - C.	325	- -	67¾	370	6½	193·071
16	— do. - - S.	715	- -	57	800	5	183·456
17	— do. - - C.	631	- -	77½	750	5½	168·340
18	— do. - - S.	704	- -	89	780	4½	126·200
19	— do. - - S.	942	- -	101½	1000	4½	169·000

chief portion of this line descends gradually with the load, and in favourable weather the reciprocating system is adopted on one plane only. The data, therefore, afforded by this railway cannot apply to the Liverpool and Manchester, where the whole is supposed level, or nearly so.

One instance, to which Mr. Walker refers in his report, as affording data on this

It is necessary to observe, that the gross weight taken at a time,
in Nos. 1 to 6 is about 32 tons.
7 and 8 — 48
9 to 15 — 32
16 and 17 — 24
18 and 19 — 16

The empty carriages, returning, being about one third of the gross weight. In Nos. 7, 8, 9, 10, 16, 17, 18, and 19, the quantity conveyed annually over the respective planes did not amount to more than one third of that which passed over the other planes. Where marked, C denotes that the plane is curved; and S that it is straight.

Note R.

Experiments detailed by Mr. James Walker, in a paper to the Royal Society, read May 31, 1827.

The experiments were made in the middle of the East India Import Dock, 1410 feet in length, 560 feet wide, and 24 feet deep.

A spring weighing machine was fixed near the bow of the boat, the dial laid horizontally; one end of a line $\frac{3}{8}$ inch in diameter, was attached to the hook of the spring; the other end was attached to a reel or barrel, 3 feet in diameter, the frame of which was firmly fixed in the ground, with handles of sufficient length for the necessary number of men to turn the barrel.

The velocities were calculated while the boat was dragged this 176 yards; but to obtain uniform velocity, the boat was, at each experiment, drawn over twice the length, and the 176 yards taken in the middle of the distance by two marks upon the line; an exact uniformity of motion was obtained by means of a pendulum hung up in sight of the men who turned the barrel, by the oscillations of which they regulated the revolution of the handles.

The experiments in Table A. were made in a full built boat, loaded with 2 tons 2 cwt., exclusive of the men; the length of the boat was 18 feet 6 inches; breadth, 6 feet; the depth of immersion, 2 feet; the whole depth of the boat being 3 feet, leaving 1 foot above water; the greatest immersed cross section, 9 feet.

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important point, is on a part of the Hetton railway, which is nearly level, where 301,800 tons are conveyed over $2\frac{1}{2}$ miles for an expense of 780*l.* in ropes, which gives, according to the most favourable mode of calculating, $\frac{13}{100}$th of a penny per ton per mile.

This part of the Hetton road is worked by the reciprocating system to a greater extent than on the Brunton and Shields, and the planes not varying widely from a level, it gives better data than either of the others; yet it does not seem to have influenced Mr. Walker's conclusions on this point, having fixed on $\frac{8}{100}$th of a penny per ton per mile, whereas the daily experience at Hetton indicates $\frac{13}{100}$ths.

Since, however, the curves which exist on that line may increase the wear of ropes in some degree, we shall take the cost, when applied to the Liverpool and Manchester, at $\frac{10}{100}$th of a penny per ton per mile.

The experiments in Table B. were made in the same boat, with about 2 tons of ballast.

The experiments in Table C. were made in a boat 28 feet in length, but, being light and more exposed to the action of the wind, the smaller boat already described was preferred.

TABLE A.

Number of Experiments.	Number of seconds in passing 176 yards.	Velocity per hour in miles and decimals.	Actual resistance indicated by the steelyard in lbs.	Calculated resistance at the different velocities in lbs., taking one experiment as a standard.	
1	124	2·903	15·75	15·04	
2	85	4·235	39·50	32·01	
3	146	2·465	10·00	10·85	
4	140	2·571	11·00	11·80	
5	145	2·483	11·00	11·00	Standard.
6	140	2·571	12·00	11·80	
7	120	3·000	14·00	16·06	
8	120	3·000	14·00	16·06	
		TABLE B.			
1	79	4·557	44·85	38·59	
2	80	4·500	40·32	37·64	
3	93	3·871	28·07	27·85	
4	94	3·830	27·26	27·26	Standard.
5	78	4·165	49·34	39·59	
6	141	2·553	10·03	12·12	
7	142	2·535	9·47	11·94	
8	142	2·535	9·52	11·94	
9	142	2·535	10·10	11·94	
10	143	2·517	9·23	11·78	
		TABLE C.			
1	162	2·222	13·08	13·08	Standard.
2	187	1·925	11·00	9·82	
3	89	4·045	47·26	43·34	
4	87	4·138	49·50	45·35	
5	137	2·609	18·10	18·02	

"The average resistance of Nos. 7, 8, and 10 (low velocities) is 941 lbs.; the corresponding velocity, 2,529 miles. The average resistance of Nos. 1 and 2 (high velocities) is 4,259 lbs., the velocity, 4,529 miles. The resistance calculated in the duplicate ratio of the velocities would be 38·11 lbs., in place of 42·59 lbs. Again, the same low velocities, Nos. 7, 8, and 9, compared with No. 3 (velocity 3·871), would give, by calculation, a resistance 22·04, while the actual resistance was 28·07."

A few experiments were also made in a small Thames wherry, the distance 80 yards. The average velocity of four of these experiments was 106 yards per minute, or 3·60 miles per hour; resistance, 10·4 lbs.; and of four others the velocity was 160 yards per minute, or 5·5 miles per hour, and the resistance 29 lbs., while the ratio of the square of the four preceding experiments would have given 24·27 lbs.

The small excess in the large boat, compared with the smaller and the wherry, Mr. W. considers to have been owing to the form of the bow of the former boat causing less heaping of the water in the front, than in the latter.

NOTE S.

Section of the Durham and Sunderland Railway, from Whitwell Colliery to the shipping places on the river Wear, at Sunderland.

506 yards	ascends	1 in 31.
176 ditto	ditto	1 in 65.
506 ditto	ditto	1 in 69.
990 ditto	descends	1 in 237.
1,738 ditto	ditto	1 in 209.
1,843 ditto	ditto	1 in 197.
836 ditto	ascent	1 in 68.
1,232 ditto	descent	1 in 462.
1,584 ditto	ascent	1 in 530.
1,342 ditto	ditto	1 in 60.
1,078 ditto	ditto	1 in 61.
2,376 ditto	descent	1 in 212.
3,058 ditto	ditto	1 in 43½.
1,232 ditto	ditto	1 in 60.
2,046 ditto	ditto	1 in 190.
2,420 ditto	ditto	1 in 230.

Siding twenty chains on the moor, and further on to the staith, descends about one eighth of an inch per yard.

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