TREATISE
ON
RAIL - ROADS

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A PRACTICAL

TREATISE ON RAIL-ROADS,

AND

INTERIOR COMMUNICATION IN GENERAL.

CONTAINING AN ACCOUNT OF

THE PERFORMANCES OF THE DIFFERENT LOCOMOTIVE ENGINES

AT AND SUBSEQUENT TO

THE LIVERPOOL CONTEST;

UPWARDS OF

TWO HUNDRED AND SIXTY EXPERIMENTS;

WITH TABLES OF THE COMPARATIVE VALUE OF CANALS AND RAIL ROADS; AND THE POWER OF THE PRESENT LOCOMOTIVE ENGINES.

ILLUSTRATED BY NUMEROUS ENGRAVINGS.

BY NICHOLAS WOOD,

COLLIERY VIEWER, MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS, &c.

"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 THE TRUSTEES OF

THE LATE EARL OF STRATHMORE,

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 Rail-road conveyance, and the intense anxiety existing in the public mind, respecting the relative value of Canals and Rail-roads, 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 Rail-roads, 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 my 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

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* See Note A. Appendix.

are entitled; my 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, I have rendered the work less suited to the taste of general readers, or have fallen into prolixity in the details; I trust that it will be attributed to my 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 me to assume that I have supplied all the information of which the subject is susceptible; on the contrary, I wish it to be understood, that what is herein contained must be considered only as an approximation. It will be sufficient, if what I 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, Rail-ways 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 Rail-way, 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 Rail-way, 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 Rail-ways for such purposes, when the mania of 1825 brought every scheme, alike good bad and indifferent, before the public, and, amongst the rest, Rail-ways. The re-action and languor which succeeded that year of excitement, involved Rail-ways 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 Rail-way, again, however, drew the public attention towards Rail-ways, 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 Rail-way 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 Rail-way, advancing towards completion, seemed, by a common unanimity of opinion, to be deemed as *the* experiment which was to decide the fate of Rail-ways. 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 Rail-ways of no ordinary importance, yet it is not necessary, perhaps, to pursue the history of the progress of that Rail-way 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 Rail-way, since the opening, have exhibited a result as astonishing as it is impor-

tant. Not only has the question been decided, and in the most conclusive and practical manner, that Rail-ways 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 Rail-way, 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 Rail-roads, 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 Rail-ways 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 Rail-way 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 Rail-ways 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.

It is not necessary to enter further into the uses to which Rail-ways, in their present state of improvement, may be applied, or the advantages which will accrue to commerce from their extension; such an enquiry not coming within the object of the work. We shall, therefore, without further comment, proceed to give an outline of the contents, with the various additions to the former edition.

Chapter I.—Contains an introduction, on the history of the various species of internal communication; with their successive and several transitions into the present modes.

Chapter II.—Comprehends an historical account of the introduction of Rail-roads, with a description of their gradual improvement, from wooden to cast and malleable iron rails, illustrated by several drawings.

In preparing this chapter, the remote date of the first application of Rail-roads to the transit of goods, has somewhat obscured this part of the subject, and rendered it not quite so perspicuous and clear as we could have wished. In following up the history, we have, however, endeavoured to trace the successive steps, from one improvement to another, which have been illustrated by requisite drawings. We have also given drawings of the several rails at present in use, in cases where general opinion seems to have concurred in pronouncing their superiority. Perhaps, some readers may find that no notice is taken of various kinds of rails, which they may think important; we have, however, given all those which materially differed from each other, and where such difference appeared to present a real improvement; but, in doing so, it will be necessary to state, that we have confined our observations

exclusively to those at present in use; and this remark will suffice for those who do not find, in any of the other parts of the work, notice taken of several schemes recently offered to the attention of the public.

Chapter III.—Contains a description of the form and construction of carriages used upon Rail-roads. To have given the particular form of the body of the carriages, for every species of goods, would have imposed upon our readers an endless, as well as an useless task; we have therefore, given, in addition to that of the common waggons used at the coal works in the north, a plan of the carriages used upon the Liverpool and Manchester Rail-way, which are intended to be transferred from the Rail-way wheels to others capable of travelling on the streets. We have given drawings of, and confined our observations, therefore, principally to, those parts of the carriages which were common to every form of body, and peculiar to the road.

In Chapter IV. we have introduced a division of the various lines of inclination of Rail-roads, into those suitable for each distinct kind of motive power; and, although we have found it extremely difficult to fix a proper line of demarcation between each, yet we trust the division will be useful, not only in practice, but also as the means

of conveying a more distinct idea of the degree of inclination, proper for each description of motive power.

Whenever the nature of the road permitted, as in the case of the self-acting and engine-planes, we have given formulæ for calculating the effect of carriages, dragged along the different planes; these, though perhaps not possessing strict mathematical correctness, will nevertheless be sufficiently accurate for practice: and, in illustration thereof, we have given drawings of the different lines of road necessary to carry those modes into operation.

In this chapter, we have also given a history of the various sorts of locomotive engines, as far as the extent of our enquiries enabled us; which we have followed up by particular descriptions, illustrated by drawings on a copious scale, of some of the different engines at present in use.

Chapter V.—Comprehends experiments on the strength and deflexion of cast and malleable iron-rails; from which is deduced a practical rule, for determining the strength necessary to carry different weights, on Rail-roads: to this are added experiments on the comparative resistance presented to the wheels of the carriages by

cast and malleable iron rails; with some observations and experiments on their comparative wear.

In CHAPTER VI. is given a series of extended experiments on the friction or resistance of carriages, and also on the friction on the axles of carriages, moved on Rail-roads. These experiments, being varied both with respect to weight and velocity, will, it is trusted, be found useful, especially as the want of the necessary data is justly acknowledged. They were multiplied until no doubt could be entertained of their accuracy; and the details are given with every minuteness, that the reader may be able to judge of the dependence which may be placed upon them. In the prosecution of these experiments, we have endeavoured to supply the information wanting in the first edition, the friction of the axles, and that of the wheels upon the rails, separately; and, in doing so, have, we trust, elicited some useful information on friction in general.

Some ambiguity having arisen, respecting the law of resistance of carriages moved at different velocities upon Rail-roads; we have attempted, by a comprehensive and minute illustration, assisted by diagrams, to define the proper ratio, and which, it is trusted, will be the means of elucidating the true law of such resistance.

Chapter VII.—Ropes being most generally employed in dragging carriages up ascents, or lowering them down from one level to another on Rail-roads, by the aid of fixed steam-engines, or by the force of gravity, the friction of these will form a subject of enquiry of considerable importance. This chapter contains, therefore, a series of experiments on the friction of ropes, on several engine and self-acting planes in actual use; from which are deduced theorems for ascertaining the friction of ropes employed in dragging carriages upon any Rail-road.

Chapter VIII.—Comprehends a set of experiments, observations, and deductions, on the various species of motive power used on Rail-roads, divided into four parts, viz.

Self-acting Planes,
Fixed Steam-engine Planes,
Horses, and
Locomotive Steam-engines.

In Self-acting Planes, the moving power being the force of gravity, the action of which is well known, and that action being communicated to the carriages by the medium of ropes; a practical theorem is given, founded on the friction of ropes, as ascertained by experiment.

The effective performance of fixed steam-engines

is also illustrated by four examples of engines dragging carriages up ascents on Rail-roads, from whence are deduced rules for practical application.

Some regard should, however, be observed, with respect to the effective power of high-pressure engines, acting solely by the expansive force of steam. In the elucidation of the locomotive engines, it will be found, that the effective energy upon the load, compared with the pressure upon the piston, (the latter being calculated by the elasticity of the steam in the boiler), depends, in a great measure, upon the velocity of the piston, compared with that of the load; and also upon the size of the aperture through which the steam issues from the boiler to the cylinder, compared with the elasticity of the steam in the boiler. In those engines, the size of the aperture was that which is most generally used, and which is about one twenty-fifth of the area of the piston. We have also given the velocity of the piston, so that, in the application of similar engines to practice, a comparison can be made.

To establish data for the performance of horses, we have given tables of the work of horses, upon three different lines of road; two of which may be considered as most favorable for the application of horses, where the whole of the goods are conveyed in one direction, and where the relative

weights are similar to those given in the Table. The horses of Table I. were very heavy and powerful; and those of Table II. rather more so. The horses of Table III. may be considered as moderately sized horses.

The average performances of these horses fall below the expression of Mr. WATT, and reach beyond that of Mr. SMEATON; but, as Mr. WATT's expression was assumed, more as a conventional standard for a horse's power, than the true measure of the energy which he is capable of exerting upon the load; perhaps those in the Table, being the result of long-continued practice, will be a more correct expression of his energy. Resulting from the data furnished by these performances, we have given a table of the load which a horse is capable of dragging upon Rail-roads, of different degrees of inclination.

In the case of locomotive engines, a sufficient number of experiments are given, we trust, to elucidate both the laws which regulate their action, and also the extent of their performance and utility, in the conveyance of goods upon Rail-roads. The uncertainty which exists, in general, respecting them, renders this extremely necessary; and if we have been too prolix in the elucidation of their several modes of action, it has arisen from a wish to satisfy public curiosity, and

render the illustration of their properties clear and comprehensive. In accordance with this, we have given the experiments, made on the Liverpool and Manchester Rail-way, at the memorable contest; the results arising out of those experiments, in the improvements subsequently effected in the engines, with the causes to which those improvements are attributable; and have, lastly, given tables of the performances which those experiments warrant us in expecting from the engines in their present state.

In this chapter, we have also added tables and observations on the comparative performances of horses and locomotive engines, together with a comparison of the value of fixed and locomotive engines, in moving goods on Rail-roads, which is illustrated by numerous calculations, derived from the reports of Messrs. WALKER and RASTRICK, and the work of Messrs. STEPHENSON and LOCKE.

CHAPTER IX.—Contains an outline of the comparative performance of the different available species of motive power, in the conveyance of goods by Canals and Rail-roads. Tables have been given, explanatory of the weight of goods which horses can convey, at different rates of speed, upon Canals and upon Rail-roads; and, also the weight which horses can convey on Canals, and which locomotive engines can drag

upon Rail-roads. The performance of the latter will also represent the effect with any other species of mechanical power on Rail-roads, the energy of which corresponds with that assigned to the locomotive engines.

These particulars, therefore, with an extensive Appendix, containing various tables and calculations, in explanation of the different subjects treated of in the text, and requiring further illustration, comprehend an outline of the matter contained in the work, which, we trust, will be found generally useful.

KILLINGWORTH, 22*d February*, 1831.

ERRATA.

Page 14, line 11, *for* Fig. I., Plate I., II., *read* Plate I., Fig. I., II.
Pages 64, 65, lines 14, 8, *for* Plate IV., *read* Plate VI.
Pages 92, 97, 98, 110, 111, and 118, *for* Plate III, *read* Plate IV.
Page 110, line 5, *for* $(P \underline{+} G \underline{+}) + g$, *read* $(P \underline{+} G) \underline{+} g$.
Page 119, line 35, *for* S, *read* g.
Page 121, lines 1, 9, *for* C, *read* g.
Page 135, line 5, *for* Plate IV, *read* Plate VI.
Page 152, line 21, *for* Plate VIII. *read* Plate VII.
Page 172, line 3, *for* 18, *read* 188.
Page 206, *for* Theorem 9, *read* Theorem 8.
Page 256, line 1, *for* Plate V., *read* Plate IV.
Page 265, line 14, *for* 367×23, *read* $367 + 23$.
Page 274, line 18, *for* $\times$ W′, *read* $+$ W′.
Page 281, line 23, *dele* 181.
Page 387, line 1, *for* Table IV., *read* Table VI.
Page 417, line 16, *for* 38, *read* 28.

DIRECTIONS FOR PLACING THE PLATES.

Plate I. facing Page 26.
—— II. —— 62.
—— III. —— 76.
—— IV. —— 112.
—— V. —— 122.
—— VI. —— 142.
—— VII. —— 154.
—— VIII. facing the Title Page.

Wood Engravings.—Rocket, facing Page 382.
Sans Pareil, —— 384.
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Table of Bridges, after Page 514.

Dues on Darlington Rail-way, after the Table of Bridges.

A PRACTICAL TREATISE

ON

RAIL-ROADS.

CHAPTER I.

INTERNAL COMMUNICATION.

THE Romans, it is 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. Their direction being from one station to another, which were 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.

For many centuries after the invasion of the island by the Romans, articles of trade were transported from one place to another, upon the backs of horses, which were called "Pack-horses." 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; 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 mode of transport.

The paved and hard roads of the Romans, would afford a comparatively good track for horses, but as the inhabitants advanced in civilization, 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 change 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 effort 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 civilization 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.

The next alteration, in interior communication, appears to have been the substitution of wooden Rail-ways, 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; but, as I intend tracing the history of this species of road, more particularly hereafter, I shall not, in this place, extend my remarks further, than merely to notice it.

Canals, another kind of conveyance, and which have been more extensively used in the conveyance of heavy goods, in most of the manufacturing countries, than any of the other species of internal communication, seem to have been the last introduced into Great Britain.

It appears, canals were used in Egypt long before the occupation of Great Britain by the Gauls; in China, their introduction is said to have taken place at a very early date. Into Great Britain their introduction is comparatively recent. The attempt to form the Sanky Brook into a navigable canal, from the river Mersey to St. Helens, 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.

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 it not only to carry on a successful competition with foreigners, but also to support a pre-eminence in the market, and constitutes almost the whole support of commerce.

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 I have prescribed to myself in the present work. It has already been recently discussed in every shape in the different periodical publications, and also in some works written expressly for the purpose. The only question which I 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 Rail-roads and Canals. It may be a question, in many cases, if Rail-roads can compete with existing common roads, in the economy and facility of the conveyance of goods and passengers; but whether Rail-roads 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 capability, as a mode of internal communication.

The sudden change in the public opinion, respecting the superiority of Rail-road 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 excess of capital in the country may have operated to accelerate the inquiry, 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, Rail-roads 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, they have attained such a feature of value, as to entitle 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, 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 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 Rail-roads; 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 Rail-roads, 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, perhaps, 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 in consequence might not have been so speedily brought into action, had not the present

prosperity of the country 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 Rail-ways 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 Rail-ways: but it is here, I presume, where the difficulty lies—we cannot perhaps find Canals and Rail-ways 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 mode. The want of proper data was felt, and it is with a view of furnishing these, that the present work was undertaken: which, by a concise, and, at the same time, comprehensive, description of the construction, uses, and advantages of Rail-roads, 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.

It is much to be regretted that a similar inquiry has not been made with respect to Canals; 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 mercantile prosperity to our facility of dispatch. The slow, tardy, and interrupted, transit by canal navigation must, therefore, of necessity, yield to other modes of affording a more rapid 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 given to the boats conveyed upon them. Experiments, to ascertain the amount of resistance, at different rates of speed, would be therefore highly valuable; and, it is to be hoped, that such will be made on a practical scale upon some of the canals, to shew how far they are capable of affording a more speedy transit.

CHAPTER II.

HISTORY AND PROGRESS OF RAIL-ROADS.

It is very difficult to trace the precise date when Rail-ways 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 a road suitable for all parties, and the expence of branching it 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 certain 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 in-

troduction of wooden rails the whole distance. Such is the practice in Russia, and it appears to have been as ancient as civilization in that country.

At the coal-works in the neighbourhood of Newcastle-upon-Tyne, the expence 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 horse-back. 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 expence.

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 p. 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 to 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 Rail-roads have been designated by the latter name; we may infer, that the "waggon" of Mr. Beaumont was applied upon a Rail-way, and that he was the first to introduce them into the north.

The date of the introduction of Rail-ways, 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 an 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 following description is given of them in Jaa's Voyages Metallurgiques, 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

* Life of Lord Keeper North.

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 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."

Fig. I. *Plate* I. II. represent a plan and elevation of this kind of Rail-road, which was called the "single-way;" a a, a a, are the rails laid parallel to each other, upon the sleepers or transverse bearings, 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 sleepers, and the pins driven through the rail and about half way through the sleeper. The rails six feet long, and the sleepers about two feet apart. The ends of the rails meet upon the sleeper, as at c′ c′; two pins being driven into the same sleeper fasten them down, and prevent them separating from each other.

This kind of Rail-road 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 sleeper, by the frequent perforation of the holes to fasten the rail 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 sleeper would be attended with considerable expence, 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.

Fig. III. *Plate* I. is a representation of this form of rail; a a are the rails fastened down upon the cross sleepers b b b b, similar to those of the "single way;" a′ a′ the rails laid upon the other, and firmly secured to them by wooden pins, in the same manner as the other rails are fastened to the sleepers. In the single-way, the joinings of the rails are necessarily upon a sleeper, as shewn at c′ c′; but in the double-way it is not so, for being fastened down upon the surface of the under rail, which in every part presents a proper bearing, they can be secured any where upon it; c″ c″ shews the joinings of the upper rail, which is midway between the sleepers, but which can be varied at pleasure. This prevents the under rail from being

destroyed by the frequent perforation of the pin-holes in receiving the upper or wearing rail, and saves the waste of timber thus occasioned by use of the single-way.

The sleepers in this description of road were generally formed of young sapling, or strong branches of the oak, obtained by thinning the plantations, and were six feet long by five or six inches in thickness, and about the same breadth. At their first introduction, the under rail was of oak, and afterwards of fir, mostly 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 almost always made of beech or plane tree.

The surface of the ground being formed pretty even, for about six feet in width, from the pits to the staiths, or the whole length of the intended Rail-road, 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 surface of the rail, which was thus strengthened and made more rigid. The upper rail was then placed upon the other, and firmly bound down by the pins or pegs of wood.

This combination had many very obvious advantages over the single rail, for, independent of the waste of timber before described, the

destruction of the sleepers in the single rail by the feet of the draught-horses was considerable. The double rail, by increasing the height of the surface whereon the carriages travelled, allowed the inside of the road to be filled up with ashes or stone to the under side of the upper rail; and consequently above the level of the sleepers, which thus secured them from the action of the feet of the horses.

This description of Rail-road 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 Rail-way 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 Rail-road, the general load for one horse was nineteen bolls, or about 42 cwt.

The formation of the Rail-road would certainly be attended with considerable expence: but the advantages derived from the increased load, would soon compensate for this, and also for an increase

of expence 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 Rail-roads would mostly descend in the direction of the load; except levelling down abrupt undulations, little care was taken to make the road with an uniform descent. For many years after the introduction of the wooden Rail-way, 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 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 equalize 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 I 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 expence 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. Rail-ways 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 Rail-ways 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 Rail-ways, 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 I 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 Rail-ways, 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 ones' 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; that it should require thirty years to discover, that, with a lighter load, they could be made to answer.

Mr. R. Stevenson, of Edinburgh, whose en-

quiries into Rail-road 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 Rail-ways 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 Rail-roads 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.

Fig. IV. *Plate* I. represents the form of Mr. Curr's cast-iron rails, which were used under-ground at the Duke of Norfolk's colliery, near Sheffield; a a a a, are the rails, which were six feet long, and in the form as shewn in *Fig.* V.: near each end of the rail small holes were cast, through which a nail was driven into the sleeper, which was of the same description as those of the wooden rails, *Fig.* II. and shewn by the dotted lines in *Fig.* IV.; at the joinings of the rail at c c c c, they were merely laid against each other at the ends, and nailed down to the sleeper, the intermediate sleepers having only one nailing. *Fig.* V. shews a section of this form of rail; a b, the horizontal bearing in which the wheel travelled; and b c, the upright ledge or projection to prevent the wheels from running off the road.

Various forms of this rail, which is called the "Plate Rail," appear to have been used with either wooden sleepers stretched across the whole breadth of the Rail-road, or short square wooden sleepers, as shewn in *Fig.* IV., 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 Rail-way at little Eton, in Derbyshire; introduced stone props instead of timber, for supporting the ends and joinings 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 iron Rail-road 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. VI. *Plate* I. is a ground plan; *Fig.* VII. a side view; and *Fig.* VIII. a section of the most improved form of this kind of rail;—c c c c, are the rails, four feet long, placed upon stone supports, about a foot square, and eight inches deep, as shewn in *Figs.* VI. and VII.; at the ends of each rail, where they are laid against each other on the stone support, a small square piece is cut, or left out, in casting the metal, increasing in size upwards; so that, when the two ends are laid together, these two holes form a sort of square hole through the ends of the rail, narrowing downwards; a perfectly level and horizontal grove is then made on the top of the stone, and the rail imbedded in it; a hole, corresponding with the square hole of the rails, is drilled into the stone, about half the depth; an iron pin is then driven into the stone through the hole in the rails, which having a bevilled head, fastens them down to thes tone, 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. VIII. is a section of the rail; a d, the bottom or wheel-track, about four inches wide and an inch thick, which is made quite level; d e, the flange or upright ledge to keep the wheel upon the part, a d, of the rail, and a f a, the flange projecting downwards to strengthen the rail; the upright flange is the same height throughout the whole length of the rail, as shewn in *Fig.* VII., 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 will necessarily be made as low as possible; hence we find it never exceeding three inches. This restriction in the height of the upright edge 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

cost, does not in the same degree add to the strength; the upright section, d i, 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.* VIII. and a f a, *Fig.* VII., the form of this, 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.

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 Rail-road at Loughborough with this kind of rail; the upper surface of which was level, and the under of an elliptical figure, with flanges upon the wheels to guide them upon the tracts of the road.

In the wooden Rail-ways, 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 wheel was brought

back to the same form as that for the wooden Rail-way.

Fig. IX. *Plate* I. represents an elevation or side-view of the edge-rail, as mostly used in late years; 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 half broad, for the wheel to run upon, and placed upright, within a sort of chair, upon the stone supports. These rails, when first used, were not secured upon the stone or wooden sleeper by a separate chair or pedestal; but had a flat bearing projecting outwards, on each side, at the end of the rail, through which were square holes for the pins or nails to pass, that fastened them to the sleepers.

It is evident that this form of rail combines the greatest strength with the least expenditure of material; for, being placed upright, it presents the greatest depth in the direction of the stress or strain. The form first used was nearly a parallelogram. *Fig.* III. *Plate* II. will show a section of those at present used; 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, they gradually diminished to three-quarters, tapering down to half an inch, near the bottom at *c*; this was the section of them for a long period, but they are now made again to swell out at the lowest extremity, as shown at *c*, *b*. The lateral thickness of the rail is generally the same throughout the whole length. The depth, as shown in the drawing, 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: they consist of a flat base, generally four inches by seven, and about $\frac{3}{4}$ inch thick; the upper surface, on which the rail rests, being also flat and horizontal: from this base two upright ledges 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 end of the rails, corresponding to similar holes cast in the chains, through which iron pins are driven; these pins thus fasten the ends of the rails to the upright ledges of the chair, which prevents their ends from starting upwards out of the cavity in the chair; and the sides or cheeks of the uprights prevent the ends of the rails from moving laterally or sideways. *Fig.* VII. *Plate* II. shews the mode of joining on a large scale.

These chairs are placed either upon a stone support, or a square piece 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 rail-road, 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, and 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 rail-ways.

To form a perfect and complete rail-way, the

Fig.I

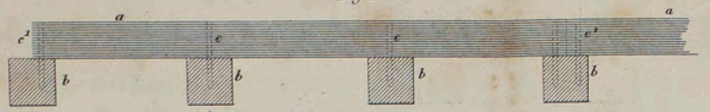


Fig.III

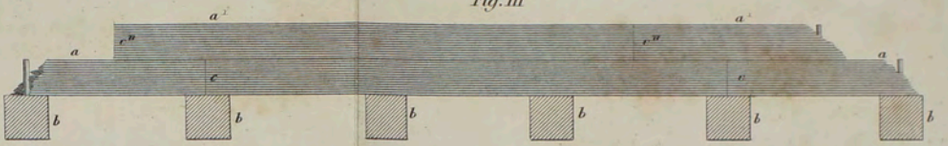


Fig.II

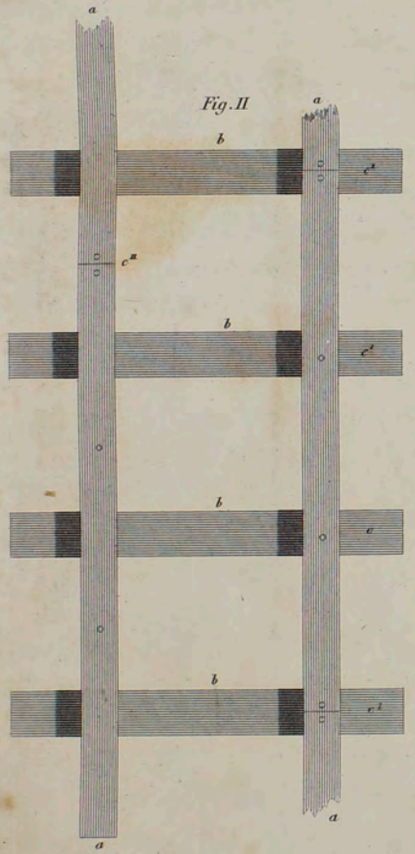


Fig.IV

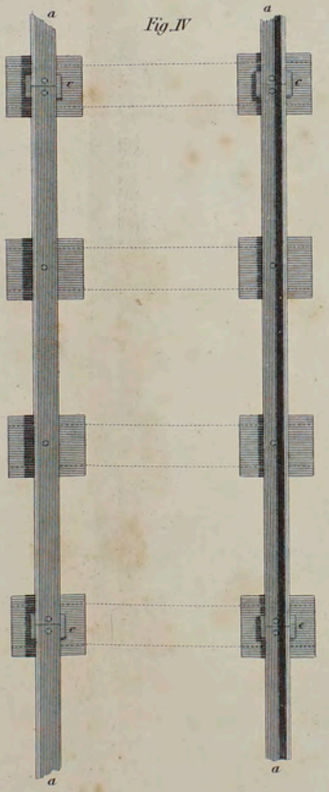


Fig.VI

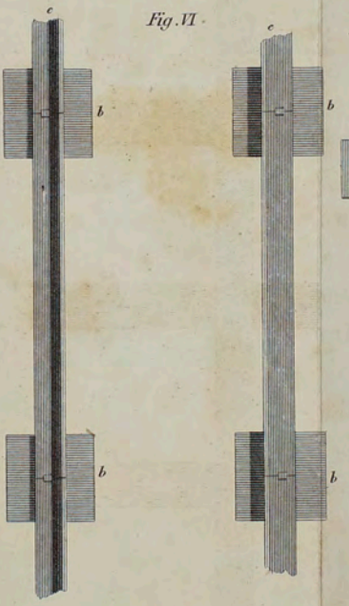


Fig.VII



Fig.V

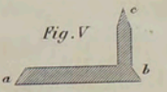


Fig.VIII

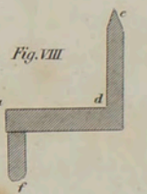
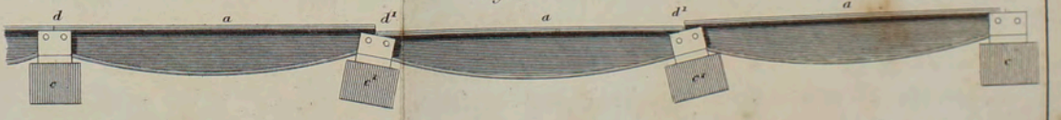
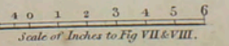


Fig.IX







Scale of Inches to Fig VII.&VIII.

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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 an uninterrupted line with the exception of the joinings at intervals, varying according to the length of the rails; and when the joinings are neatly fastened together, the interruption to the continuity will be scarcely visible; the carriage wheels, in rolling along such a road, will meet with little obstruction; and the friction or resistance will be comparatively trifling. To accomplish the formation and permanence of such a road, the bed of the chair should be formed quite parallel with the base of the stone, and consequently parallel with the line of the rails: and the chair should be placed precisely in the centre of the stone. The surface of the ground whereon the stone rests, should also be made firm, and hard, to secure the parallelism of the base of the stone, with the line of the rails; otherwise when the weight comes upon them, the parallelism of the rails will be destroyed.

We find in practice, however, that it is extremely difficult to form a surface upon which the stone is to rest, that is perfectly uniform in solidity, and which will not yield to the pressure when the carriages come upon it, and thus allow the stone to sink on one side or other, and destroy its parallelism with the general line

of road: now as the chair or pedestal is immovably fixed to the stone, and partakes of its displacement, we shall suppose that recourse is had to the mode of joining the rails to the chairs, to endeavour if possible to correct this.

In the old plan of joining, it is before stated, that the rails are 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 rail rests; and in the rails, they are at equal distances from the top, or bearing surface. 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 stone rests 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 stone, the weight of the carriages passing along the rail will displace the stones, by moving them from their parallelism with the

line of the road, and throwing them down on one side into the position represented at *c' c'*, *Fig.* IX. *Plate* I. 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 stones rest is considered, as also the difficulty of always compelling the workman 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 wondered that such a derangement frequently takes place; accordingly, we find in practice, that it is 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; and 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 which often occurs.

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 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 have been devised by different persons, to obviate this imperfection, and, in 1816, a patent was obtained for a form of rail and chair, by Wm. Losh, Esq. of Wallsend, and Mr. George Stephenson, of Killingworth, which appears to obviate, in a great degree, the evil arising from such a defect.

Fig. I. *Plate* II. is a side-view of their patent rail; shewing the rails *a 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 e e*, *Fig.* II. the side 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 pin-hole 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 d d d*, *Fig.* II. shew a plan of the chairs, and B, *Fig.* VII. a side-view on a larger scale; the half-lap extends the length of the chair 1-2, *g* shows the pin-hole, which passes through both rails; the base of the chair on which the rail rests, is shewn by the dotted line *h*, the bearing or under service of the rail being quite straight and parallel with the top of the rail. The patentees state, "our objects are, first, to fix both the ends of the rails, or separate pieces of which the ways are formed, immovable, 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 correspondent 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 rail-ways 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, and the pin or bolt of 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 the road, yet the rails will still rest upon the curved surface of the bearing without moving."

This plan of joining the rails is evidently a great improvement upon the common mode, and has been almost universally adopted on all new lines of road; the blows and shocks to which the carriage-wheels were exposed in the old plan of joining, have been almost entirely exterminated in the modern one; and the benefit is not confined to the carriages alone, for the reaction of those shocks was often 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, 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. C and D, *Fig.* VII. *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 a semicircular indentation is made, equal in diameter to the pin-hole in the chair; when the ends of the two rails are laid together, a circular hole is formed, through which the pin is driven, passing through the chair on each side of the rail; the pin has no effect in fastening them together in the direction of their length, but as, when they are laid down, they cannot separate in that direction,

the pin will prevent their rising up, being the only way in which they have a tendency to separate. D, 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, one end having a convex projection, which fits into a concave indentation cast in the end of the adjoining rail; and the sides or cheeks of the chair keeping the ends always opposite each other, the projecting piece keeps the ends of the rails in the same place.

In all chairs of these forms which I have seen, the base whereon the rails rested were flat. In C, *Fig.* VII. 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 rails and chair, 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 stone 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 modes, the ends are liable to rise and get out of the same plane.

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 rail rests 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.

E, *Fig.* VII. will shew the mode of joining, *a b* are two ends of the rail joining each other, supposing them cut off at the middle of the half lap; upon the outside of each rail a circular projecting nob, *c d*, is cast, on the inside of the rail *b*, a similar nob *c*, is cast, fitting into a corresponding concavity on the rail *a*; when the rails are kept together as shewn in the drawing, the nob *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 nobs *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 Rail-roads being 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; and, consequently, their formation must be on the principle of forming and preserving such a level and uninterrupted surface. The nature of the foundation upon which we have generally to form a Rail-way, renders this a task of no ordinary difficulty. Perhaps it is almost impossible to form an absolutely perfect Rail-way 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 embedded 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 pin-hole 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 semi-circular slit would allow it to turn longitudinally; when the stone then became depressed towards one side, the chair could move round without injuring the pin, or deranging the joints of the rails. The form of chair *d*, *Fig.* VII. if the bearance had been upon a point instead of a flat surface, nearly partakes of these properties without a pin; for in it 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 stones 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 stones are displaced from their proper position, and they 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 I not found that several, even of the most modern forms of chair, 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.

Mr. Stephenson has, in forming the greatest part of the Liverpool and Manchester Rail-way, adopted the latter mode, and has endeavoured to obviate those difficulties and imperfections, by making the blocks very large, and embedding them firmly upon the surface of the road; in the hopes that the weight of the carriages will have no effect in displacing them. Where stone is readily obtained, though expensive in the first formation, this mode will, no doubt, be found ultimately to be the most beneficial; especially if proper care is taken to keep the surface, on which the stones rest, dry, and free from water. Upon public lines of road, where the traffic is considerable, it is highly advisable to avoid the necessity of any interruption, by having displaced blocks to right again; and, therefore, it becomes the more necessary to secure their permanent stability in the first formation. The mode of fastening the rails to the chair is shewn in F, *fig.* VII.

About the year 1805, malleable iron rails were tried at Wallbottle 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 was not at that time extended; the narrowness of their surface cut the periphery of the wheels, and they were superseded by the cast-iron rails with a broader surface.

Mr. R. Stevenson of Edinburgh states, that malleable iron rails were first introduced about the year 1815, at Lord Carlisle's Coal-Works, on Tindale Fell, Cumberland; and, as above stated, they were used long before that period; he must also have been misled as to their introduction at Tindale Fell, as, acccording to the statement of Mr. Thompson, the present agent, they were laid down on that Rail-road in 1808. Since that period, they have been partially used in other places, but not to any extent, until very recently.

In October, 1820, Mr. John Birkinshaw, of the Bedlington Iron-works, obtained a patent for an improvement in the form of malleable iron rails. The shape of the malleable iron rails previously used, were bars from two to three feet long, and one to two inches square; but either the narrowness of the surface produced such injury to the wheels, or by increasing their breadth the expence became so great, as to make their cost greater than cast-iron, which consequently was preferred.

It was to remedy these defects in the malleable iron, and at the same time secure the same

strength as the cast-iron, that Mr. Birkinshaw made his rails in the form of prisms, or similar in shape to the cast-iron. *Fig.* IV. *Plate* II. shews a side-view of this kind of rail; *Fig.* V. a plan; and *Fig.* VI. a section of the same rail, cut through the middle.

These rails are formed by passing bars of iron, when red-hot, through rollers, with indentations or grooves in their peripheries, corresponding to the intended shape of the rails; the rails thus formed present the same surface to the bearing of the wheels, and their depths being regulated according to the distance from the point of bearing, they also present the strongest form of section with the least material. The mode of rolling these bars or rails, and giving them the gradual swell towards the middle, not only in the horizontal section, but also a lateral swell 1-2, commencing at each support, gradually increasing to the centre, and then again tapering away towards the point of support, is very ingenious; and has paved the way for a similar extension in the use of wrought-iron, in many cases where the simple form heretofore effected in rolling it, rendered it inapplicable. These rails are generally formed in lengths of twelve to fifteen feet, as represented in the drawing, and subdivided into bearing lengths of three feet each; but the patentee adds, in his specification, "the respective rails may be made of considerable length,

(eighteen feet I should recommend,) by which the inconvenience of numerous joints is reduced; and, consequently, the shocks or jolts to which the carriages are subject from passing over the joints (very much to the injury of the machinery) are also diminished. And in order still further to remedy the evil arising from the joints of the Rail-road, I propose to weld the ends of the bars together as they are laid down, so as to form a considerable length of iron rail in one piece."

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

F, *Fig.* VII. *Plate* II. will shew the mode of joining the wrought iron rails to the chair, or pedestals. In passing the rails through the rollers, a lateral projection is rolled upon one side, the upper part of which is parallel with the top of the rail, as seen in *Fig.* IV. On one side of the cheek of the pedestal a cavity is cast, equal in size with the projection on the side of the rail. On the other cheek a similar longitudinal cavity *b* is cast for the purpose of receiving an iron key. When the rail is laid into the chair, the key is driven into the cavity *b*, which pressing against the side of the rail, forces the projection *a* into the cavity on the opposite side, and thus effectually secures the rail from rising up. This is the mode of joining adopted by Mr. Stephenson on the Liverpool and Manchester Rail-way.

Another mode by Mr. Losh is shewn in G, *Fig.* VII. In this plan the projection is rolled upon both sides of the rail; on one side of the rail the projection fits into the cavity of the chair, as in the other plan previously described. On the other cheek of the chair a longitudinal cavity is cast to receive a key, but, as shewn in the figure, it is a double one, acting at the same time,

upon the upper part of the projection on the rail to force it down upon the chair, and against the side of the rail to steady it, and force the projection on the other side of the rail into the opposite cavity. By this mode of keying, if the rail works loose upon the chair, by driving the key it can again be tightened.

H. *Fig.* VII. shews the mode of joining adopted by Mr. Steel in forming the Clarence Rail-way. This rail differs from those previously described, in being formed of a parallel bar rolled into the section shown at H. *Fig.* VII. *Plate* II. and a side view in *Fig.* IV. *Plate* III. One side of the chair is cast to fit the side of the rail as shewn in the drawing; the other side is made wide, with a plane cheek, between which and the rail a cast iron key, *a a*, one side of which corresponds in shape with the rail, is driven; thus forcing the circular part of the rail into the cavity of the chair, and keeping it down.

The plan of fastening the rails by keys is infinitely preferable to pins; as in every case, where the latter have been used, that has come under my observation, I have found them work loose, especially at the joints of the long lengths of wrought iron; and when once they become loose, it is extremely difficult to fasten them securely again; while the working soon wears down the ends of the rails, thus still further increasing the evil.

These two kinds of rails, cast and malleable, represented in *Plate* II. are the best at present in use, and each have their advocates. Without attempting to decide upon the merits of each, I have, as the subject is of considerable importance, extracted, out of some published reports, the opinion of some engineers, which may not be uninteresting to the reader.

Mr. CHAPMAN, in his report on the Newcastle

and Carlisle communication, states, "the Railway may either be formed of cast-iron or malleable iron. The latter may be somewhat less expensive, and has been found eligible in rolley-ways below ground, in which the weight on each wheel is not considerable: but, above ground, with heavy waggons, their utility, or rather their duration, is not likely to be so great as rails of cast-iron of due strength; because with heavy carriages, and case-hardened wheels, (which are much in use except for locomotive engines, as it would diminish their adhesion to the way), the following effect is produced from the softness of malleable iron, viz., the rails formed of it being drawn out between rollers, and consequently fibrous, the great wheels, rolling on those ways, expands their upper surface, and at length causes it to separate in thin laminæ. The injury from oxydation is comparatively small."*

This report caused a reply from Mr. LONGRIDGE, one of the proprietors of the Bedlington Iron-works, defending the utility of those rails, who produced a letter from Mr. Thompson, Lord Carlisle's agent at Tindale Fell, stating that the malleable iron rails, which had been laid down there for sixteen years, had no appearance of lamination. "The whole of the wrought-iron,"

* Chapman's Report on the Communication between Newcastle and Carlisle.

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 to carry near a Newcastle chaldron, viz., 53 cwt."—*Newcastle Courant, Dec.* 18, 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. 6, p. 139.)

Mr. G. STEPHENSON, of Newcastle, the patentee of the cast-iron improved rail, has allowed me to insert a copy of a report made by him on the subject. " The great object in the construction of a Rail-road 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 expence, admit of a greater 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 engineers, 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 cohesive 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 producing 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 consequence 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 unchanged by chemical agency. A remarkable difference, as to uniformity of condition or texture in the two bodies, produces a corresponding want of uniformity 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 Rail-way has oxydization 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 Rail-ways, by the pressure upon them. To account for their extraordinary 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 carbonic 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 rolled iron, appears to act as a defence against the oxydizing power of the atmosphere, or water. This is the reason why the rail does not rust on its sides."

Practice seems to have established the fact since the above was written, that there is no waste or destruction from oxidation or exfoliation, and that the wear is less than in cast-iron, subjected to the same action. A more severe test of comparison in the wear of wrought and cast-iron, exists in wheels made of the two materials; locomotive engine-wheels of the latter material generally become, by wear, unfit for use in nine months, while the wrought-iron tires have worn in some cases three years, and are not yet unfit for use.

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

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

The first cast-iron rails were by far too weak. Scarcely any of the rails laid down twenty years ago are in existence; this is partly owing to the increased weight now carried upon the rails, and partly to the mistaken policy in the saving by the

lightness of rails, to keep the cost below that of the wooden way.

It seems necessary that the rails should be made considerably stronger than merely to support the weight they have to carry. The blows they are subjected to, from the unevenness of the road, transferring the weight alternately from one side of the carriage to the other, and the side-shocks from projections upon the sides of the rails, all have a tendency to snap in two the cast-iron, or bend the malleable iron rails.

Upon public, or other Rail-roads, where the carriages move with great velocity, the breakage of the rails should be carefully guarded against, as the most dangerous consequences might ensue, by such fractures setting the carriages off the road; and the velocity with which the carriages travel, would render it difficult, perhaps, to stop them in time to avoid accidents.

Having thus described, and pointed out some of the properties of the different rails at present used, both of cast and malleable iron, it may be necessary to mention a plan of rail composed of both these kinds of iron. Mr. John Hawks, of Gateshead, in 1817, obtained a patent for a rail, which he stated, in his specification, "to be a compound of malleable and cast-iron, so connected, as to be stronger than if made of either alone," and which consisted of a bar of malleable

iron formed into the proper shape of the under part of the rail, the flat part on which the carriages run; the upper side of the malleable iron was then made rough and uneven, or dovetailed, and the cast-iron top run upon it in a state of fusion, thus forming the rail for about three quarters of an inch down of cast-iron, and the remainder of malleable iron. In all rails, or bars of iron, supported upon the ends, and loaded in the middle, the under part is in a state of tension, and the upper part subjected to compression. It is known that malleable iron resists tension with greater force than cast-iron, and, on the contrary, that cast-iron resists compression in a greater degree than malleable iron. By forming, therefore, the upper part of the rail, or that subjected to compression, of cast iron, and the under part, which is exposed to a state of tension, of malleable iron, Mr. Hawks expected to secure greater strength by his combination, than if formed of either material separately, and also to present the hardest material to the wheels of the carriages. The great care required, in accomplishing a proper and firm joining of the two, rendered the making of them very difficult; the wrought-iron requiring to be entirely free from the least damp, otherwise the soundness of the cast-iron was injured; this, added to the circumstance of the malleable iron part being made too weak, and by yielding to the weight, causing the cast-iron to crack, and

eventually work loose, prevented, I believe, the extension of their use, though, if properly manufactured, they might have become useful.

Various other kinds of rails, both of cast and malleable iron, have been used; but it would be swelling the work to, perhaps, an unnecessary size, to attempt the description of them. The kinds figured in the drawings constitute those most extensively used in the Northumberland and Durham Rail-ways, where certainly the experience of their utility has been very considerable, from their extensive use in the application to the conveyance of goods, and on those public lines of road enumerated.

It seems to me a matter of great astonishment, that the plate-rails have yet many advocates; and what seems more unaccountable, is the mistaken notion of the friction being less upon them than upon the edge-rail. I should have thought that the number of Rail-ways 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 wheels in the plate-rails be equal in breadth to the surface of the rails in the other,

and that the former would always roll along the rail without rubbing against the sides of it, more than the ledge of the wheel rubs against the side of the edge-rail, then the friction in the two cases might be equal; but the rubbing of the wheels against the plate-rails is considerably greater than the rubbing 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 ledge of the wheels of the other, one inch, and as the tendency to rub against the ledge is the same in each, nay, as will be hereafter shown, is greater in the flat than in the edge-rail, the friction will be as the height of the ledges, and consequently greater in the plate-rail. This is supposing 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 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 Rail-way, gives a very interesting experiment on the obstruction caused to the carriages by the dust upon the plate-rails,

which I 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 5264lbs.; 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 wear was considerable at first, owing to the narrow surface of the rails; 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 would almost amount to the difference between the two rails, and this might cause an uncertainty which of the two ought to be preferred. This having ceased, 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.

Having thus given a minute description of the various kind of rails used upon the different Railways, it is now necessary to give a sort of brief outline of the form of single and double lines of road, with their passings, as they may be required for the general conveyance of goods.

In most of the Rail-roads in the neighbourhood of Newcastle-upon-Tyne, and other districts of Great Britain, which I have visited, one main line of road is laid the whole distance, with short pieces 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, perhaps, in many cases, double lines of road the whole distance may be preferable: but this will, in all instances, be regulated by the peculiar circumstances of each particular line of road. Dividing them into two kinds, viz., single lines with different kinds of passings, and double lines with common passings from one to the other.

Fig. XII. *Plate* II. will represent a double road, with the crossings from one line to the other, for the carriages to pass each other; A A′ is one line, which may be for the carriages going in either direction, say from A to A′, and B B′ the other line, for the carriages traversing the opposite

direction, say from B′ to B; those two lines are supposed to extend the whole distance traversed, from one end to the other. When the goods to be conveyed are to travel 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, then it will be necessary to have certain passings, so that the carriages moving faster can cross to the other road, and pass those moving slower; when the latter can again come upon their own road, and so proceed. Thus, suppose a train of heavy goods travelling along the road A towards A′, and another train of lighter 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, and the heavy one will again resume its former track, by proceeding along the crossing *c d*. In like manner, a light train of carriages proceeding along the road B′ B towards B, encounters a heavy train travelling in the same direction; by the proper signal, the heavy train proceeds along *f e* into the road A′ A, until the other train passes it, when it again gets upon 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) the carriages will 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 ones making a point of giving way to those proceeding at a swifter rate, will always keep clear of those travelling with passengers and light goods.

The mode of causing the carriages to cross from one road to the other, is effected as follows: suppose through the crossing *c d*, a moveable rail, similar to *a b*, *Fig.* X. is placed at the junction, *c*, of the passing with the main line of road: when this moveable rail is thrown back in the position shewn in the drawing, the carriages proceed along the main line, *c d*, *e f*, without interruption: but when put close to the other rail, as shewn by the dotted line in the drawing, this rail acting against the projecting ledge on the wheels of the carriages, prevents them from continuing along the main line, and diverts them into the passing; the rail on the opposite side having an opening at *g* for the ledge to pass through. *Fig.* IX. shews the sort of rail laid at the point where the four rails meet together, *a* being the point where two of the rails meet, and *b c* where they branch into two separate rails again; the upright ledges, *d d* and *e e*, standing up about $\frac{3}{4}$-inch, prevent the wheels from running off the road at the junction of the rails, where the projecting ledge on the wheels has no effect in keeping them upon the road; at the junction, *d*, of the crossing with the

main line of road, rails, similar to those shewn in *Fig.* XI., are used ; *a b*, *c d*, being the main lines, and *e f*, *g h*, the rails of the crossing. By attentive examination of these rails on the larger scale, *Figs.* IX. X. XI. and applying them to the lines of road shewn in a smaller scale, in *Fig.* XII., it will be seen in what manner the wheels of the carriages are directed into the proper road. The moveable or switch rail, is always to be put into the proper position by the attendant of the train of carriages, to divert them into the right track, otherwise they would always continue along the main line.

Figs. XIII. and XIV. *Plate* II. will shew two single lines of road, with passings of a different kind; A A′, *Fig.* XIII. is the main line, extended the whole distance, along which the carriages travel, in both directions; B B′ is a siding or passing, 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 does not so frequently occur. In this form of road the carriages will always continue along the main line of road unless diverted into the passing by the moveable rail, previously described, the attendant having to put it into the proper position, whenever the carriages are likely to meet each

other. 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 situation, when the empty train proceeds either along *a* B, or *b* B′, as the case may happen, and the carriages pass each other.

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 coal-pits to the shipping places. In these cases, the loaded carriages always keep the main line, and the empty carriages pass into the siding; the moveable rail being placed on that end of the crossing towards which the empty carriages are proceeding. These moveable rails are very inconvenient, requiring the constant precaution of putting them in their proper places, whenever the carriages are to pass each other; it is true, they do not affect the loaded carriage passing on the main line; the projecting ledge of the wheels always displacing them from their position in contact with the rail, into that which allows of the free passage of the carriages without interruption. *Fig.* XIV. *Plate* II. will shew a mode of obviating these 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. A, will represent the main line proceeding in one direction, and A′ the same line passing in the opposite direction. The carriages having always a tendency to continue moving in a straight line, will, in passing along from A towards *d*, keep the road, A *d c;* and, in like manner, the carriages proceeding in the opposite direction A′ *a*, will keep the road A′ *a b;* the two trains will thus proceed into different roads, and, passing each other, will join the main line again, the former by the road *c a*, and the latter by the road *b d*.

This form of passing will be very useful upon public lines; where any neglect of placing the moveable switch in the proper place might occasion many inconveniences.

The form of crossing *Fig.* XIV., though obviating the use of switches, is objectionable, from the turns in the line which the loaded carriages must necessarily make, whether there be any carriages to pass or not. I have lately adopted a form of crossing, upon the Killingworth railway, by which the main line of way is not obliged to be diverged as in the last mode; and yet the empty carriages are obliged to pass through the siding when necessary.

Fig. XV. and XVI. *Plate* II. *a b, c d,* will represent the main line at one end of the crossing, and *e f, g h,* the main line at the other, *l m, h p,* being the rails passing into the

crossing at the latter end, and *n k*, *o c*, those at the other. Suppose the loaded carriages always to pass along in the direction of the darts, the empty ones returning in the other direction; and the latter always going into the siding, or passing place to allow the former to pass them. *i k*, *d r*, are two tongues or switches, working freely upon the pins *i* and *d*, and resting upon flat pieces of iron at *k* and *r;* these two switches are joined together by a chain *r k*, and a small chain is fastened to *r*, which, passing over a pully placed by the side of the road, a weight is attached to the other end, sufficient to keep the switches always in the position shewn in the drawing; and likewise sufficient to bring them back into that position when the carriages pass. At the other end of the crossing, similar switches are worked by a pulley and weight placed by the side of the road, by which they are kept in the position shewn in the drawing, and are joined together by a bar of iron, *s*. On an examination of this crossing, it will be seen, that the loaded carriages passing along *a b*, *c d*, meet with no obstruction, as, when well fitted up, the rails appear as an unbroken line. When the carriages arrive at *e f*, *g s*, the flanch of the wheel acting against the rail *e f*, pushes the moveable rails, *s* and *l*, into their proper position, and the carriages pass on without the least jolt. The empty carriages, in returning, are diverted into the siding by the rail *l m*, while an opening is made by the position of the rail *s g*, and when the loaded carriages pass, they proceed along the rails *o c*, *n k*, out of the siding, the flanch of the wheel acting against the rail *o c*, pushing the moveable rails *i k* and *d r* into their proper position. It was stated that the rails *s l* were connected by a bar, while the rails *r k* were connected with a chain; the reason is this, the wheel of the loaded carriage, in passing along *a f*, pushes the switch *s* right, by the flanch of the opposite wheel, acting against *e f*, and therefore the switch *g s*, *pulls m l* into its proper position: but the wheels of the empty carriages, in coming out of the siding, *pushes* the switch *d r* out of the position in the drawing into the proper one; and the weight of the carriages being at the same time upon *k i*, a bar would be bent; a chain is therefore used, allowing the wheel acting against *o c*, to push the switch *k i* right. This form of crossing

is not more useful for the purposes just stated, than for presenting an unbroken level surface for the wheels to travel upon. In the old form of crossing, *Fig.* XI. *Plate* II. it will be seen that a considerable break exists at *f* and *h;* and as the wear is generally greater upon *b a* than *f*, the latter soon becomes higher, and thus produces a jolt to the carriage passing over it. This takes place to a great extent upon the crossing or X rail, *Fig.* IX. *Plate* II. *a b* is the track of the loaded carriages, and *a c* that of the empty; the wheels of both carriages therefore pass over *a*, which is thus soon worn down below *b*, and still more below the level of *c*. It is scarcely necessary to state, that this must produce a jolt to the carriages; and that all such jolts are very objectionable. *Fig.* XVII., *Plate* II., shews a plan, on the principle of the siding previously alluded to, for the purpose of obviating those jolts; *a b*, *c d*, shews the main line of road; *e f*, *g h*, the crossing; two moveable rails, or switches, are placed on the rails *e* and *c*, working with weights, as previously explained; *d f* are two rails joined into one, and terminating in a point, against which the switches *i* and *k* rest, *i* in the same manner as *k*. Suppose a loaded carriage proceeding from *a* to *b*, when it arrives a little beyond the joint of the switch, the wheel pushes it into the position shewn in the drawing; and it will be seen that the wheel has a level and smooth surface to pass over: in like manner, in returning the reverse way, the wheel strikes against *i*, and pushes it into the position shewn. The carriage also, in passing along the crossing rails from *f* to *e*, pushes the switch *k* out, or into the position of *i*, while the switch *i*, resting close against the rail *d e*, forms a continued line for the wheels to pass over. The pullies are fixed in boxes, and are placed below the surface of the Rail-way; which, keeping them out of sight, prevents them from being damaged.

Fig. I. *Plate* III. represents a mode adopted by Mr. Stephenson upon the Liverpool and Manchester Rail-way, for diverting the carriages from one line of road to the other. Let *e f* be the road into which the carriages are to be made to pass. *ab*, *cd*, being the main line of road, two rails are made moveable upon the joints *a* and *c;* these two rails are joined together at the other end by an iron rod, which is extended to one side of the

road. This end of the rod is terminated by an oblong box as shewn in the figure, and within this box an eccentric cam, or wheel, is placed with an upright axle, on which is fixed the handle *h*. The difference between the radii of this wheel, from the centre of motion, is precisely equal to the distance between the ends of the two rails; when, therefore, the eccentric wheel is in the position shewn in the drawing, the carriages will pass along the main line; but on turning the handle round to *k*, and with it the eccentric wheel, the latter pushes the rod and rails into the position shewn by the dotted lines. This mode of turning the carriages into another road is quite safe, and can admit of no mistake, if the handle be turned sufficiently round, as the eccentric wheel is made to move it the proper distance and no further.

PLATE II

Fig. I

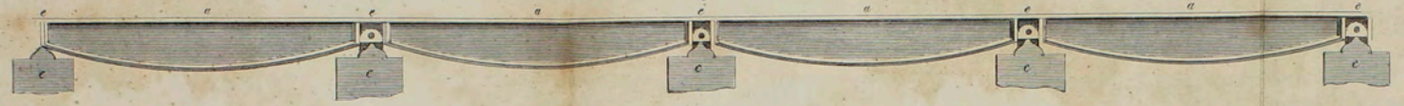


Fig. II

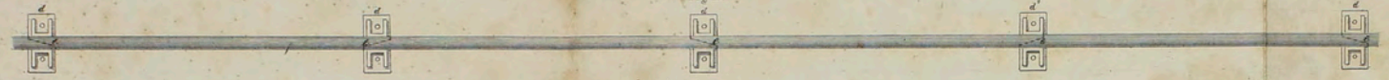


Fig. IV

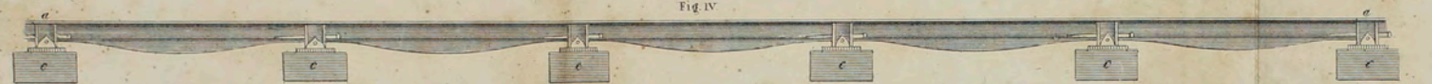


Fig. V.



Fig. XII.

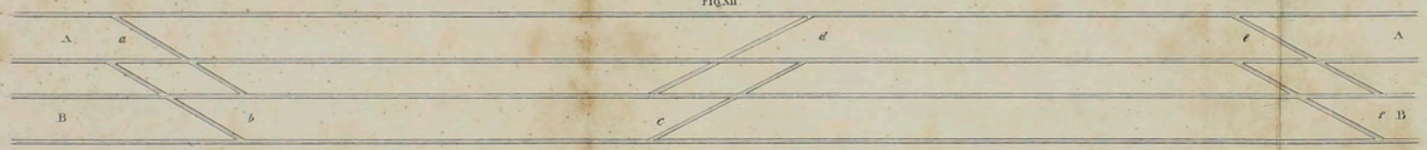


Fig. XIII.

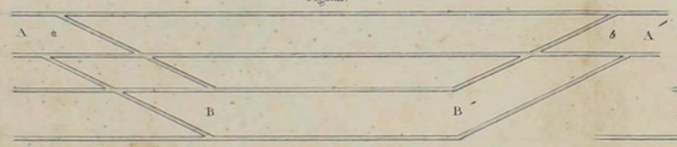


Fig. XIV.

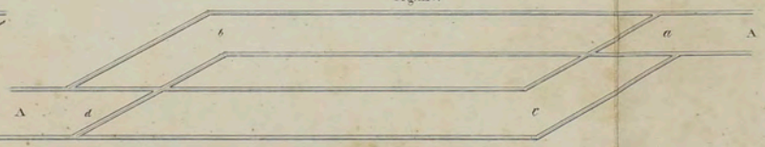


Fig. III.

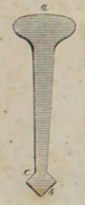


Fig. XV.

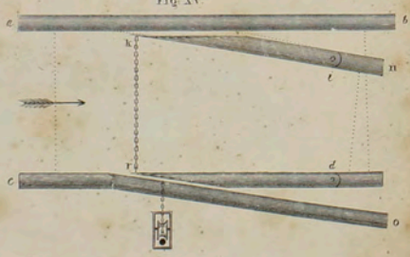
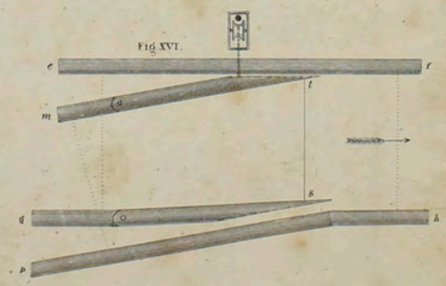


Fig. VI.



Fig. XVI.



E Fig. VII.

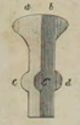


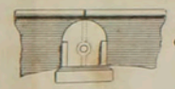
Fig. VII.



A



B



C



D



F



G



H

Fig. X.

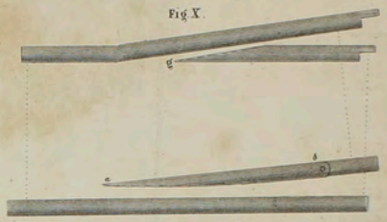


Fig. XI

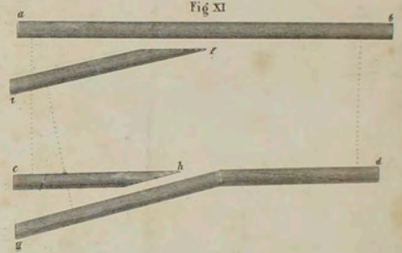


Fig. IX.

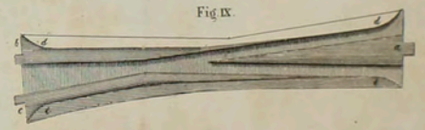
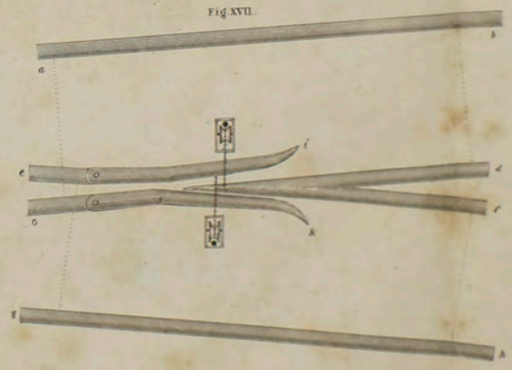


Fig. XVII.



Published by Hurst. Chance & Cº London. Jany 1831.

CHAPTER III.

OF CARRIAGES ADAPTED TO RAIL-ROADS.

It is very obvious that the form of the carriages will depend, in a great measure, upon the nature of the goods to be conveyed in them; many kinds of goods requiring a different sort of carriage. To attempt to give plans of the different forms of the body of carriages to be used upon Rail-ways, would be an endless task; I shall, therefore, confine myself principally to the description of the wheels and axles, or other parts, which the nature of the road requires should be always of the same form and construction.

The carriages, or, as they were termed, "waggons," used at the first introduction of Rail-ways, were, and still remain, where employed in conveying coals, the frustrum of a pyramid, or in the shape of a hopper; being much broader and longer at the top than at the bottom: the Rail-roads 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 waggon in a horizontal position; the fore end of the waggon, resting on the large wheels, was also made to project considerably further beyond the perpendicular line of the axles of the fore 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, laying a greater weight 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 square, and placed equally upon the two axles, as shown in *Fig.* VII. *Plate* IV.

The wheels were, for a long period, made of wood, composed either 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, 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 a sort of

jolting or undulatory motion to the load, and thus increase the draught.

To one side, or, in some instances, when steep declivities were to be descended, to both sides of the waggon a brake or lever was attached, which was made to press upon the wheels of the carriage, and regulate the velocity.

a, *b*, *Fig.* VII. *Plate* IV. Is the brake or lever, which is called a "convoy;" it is fixed upon the bolt or pin *d*, projecting from the frame of the carriage A B, which serves as a fulcrum; upon the brake at *c c* are attached two pieces of wood, which, when the end *b* of the lever is depressed, acts against the wheels and checks their velocity. At first, these convoys did not extend beyond *d*, acting upon the hind-wheels only as a lever of the second kind; and when very steep declivities were to be passed, there were two, one on each side, united together at the end *b*, by a bar of wood or iron extending across that end of the waggon, thereby enabling one man to work them both: it was a comparatively modern improvement to extend the lever beyond *d*, and thus embrace both wheels.

The arm or lever of these convoys is either made of wood or of iron; when of wood, pieces of beech, *c c*, called "breasts," are nailed on, which are renewed when worn away: when of iron, they are bolted, as shewn in the drawing, the iron being flattened for that purpose. The end *b* is kept up by a hook, when the convoy is not used, to prevent the parts *c c* from touching the wheels. In some cases, another lever is used, to give additional power to the man in pressing down the end *b;* this is accomplished by fixing it with a chain upon the frame of the carriage, the chain acting as the fulcrum; another chain, a little from this, reaches to the end *b*, to which it is attached, so that by pressing down the end of the second lever, which is prolonged for some distance behind the end of the waggon, the required purpose is effected.

It seems uncertain at what precise period cast-

iron wheels were first introduced. In a Dictionary of the 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 waggon-ways made use of at the coal-mines near Newcastle;" from whence we may suppose they had not been used there at that period. How long after this they were adopted, I cannot learn; but, in 1765, two wooden and two cast-iron wheels were mostly in use, the wooden ones 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 the others, their liability to break, to cut the rails, their insufficiency to present an adequate hold to the brake. At first the cast-iron wheels do not appear to have been properly formed, to avoid the contraction in cooling, 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.

The cast-iron wheels, now formed for the plate-

rails, are generally of one entire piece, being thicker in the middle to retain the axle, and about two to three inches broad on the rim, and much thinner towards the middle, or nave; many of the carriages, used upon the plate-rails, have wheels, loose upon the axles, the latter being either fixed upon the carriage, or running loose upon a bearing or chair. Many different forms of wheels are used, some with spokes, similar to the common cart-wheels, and some solid, with holes cut in them to reduce their weight. The cast-iron wheels for the edge-rail are almost universally made with six or eight spokes, with a nave about seven inches broad, through which is a square or round hole to receive the axle, and a rim of about four inches in breadth.

Fig. II. *Plate* III. will give an idea of their form; *f* is the nave, *a* the rim, with the projecting ledge *b*, called by the waggoners "the crease," to keep the wheel upon the rail.

The rim of the wheel is mostly made a little conical, rather increasing in diameter towards *b*: this is for the purpose of keeping the wheels from rubbing against the sides of the rail with the ledge, *b*: the increase in diameter, when the wheel rolls near the inner side of the rim, tends to throw it off towards the other side, and consequently from the side of the rail. It is evident that this ought not to be carried too far, otherwise the motion of the carriage will be very

irregular, and the inclined position of the bearing would tend to press the rail outwards, and throw a sort of oblique strain upon it. The height of the ledge is generally about an inch, and practice has shewn this to be sufficient to prevent the carriages from running off the rails.

A very formidable objection to the use of iron wheels was, that the rails, especially when their surfaces were narrow, tended to form, or rub an indented groove around each of 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 upon them, and frequently were broken off, on the interior side, for the whole length of the rail. After this, the breadth of the surface of the rails was increased, which remedied the evil to a certain extent: but the expence of repairs was still considerable.

A complete remedy for this was, however, effected a few years ago, by what is called "case-hardening" the rim of the wheels. This is done by running the metal, which forms the exterior surface of the rim of the wheel, against a cold cylindrical piece of iron; the rapid abstraction of heat by the cold iron produces such a degree of hardness to the metal, that the file has no effect upon it, and this hardness effectually prevents the action of the rail from wearing it 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, 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, prevented the uniform contraction of the metal in all the parts, and made them frequently fly in pieces. The rim being first cooled, did not yield to the contraction of spokes in cooling: which, if it did not cause them to separate immediately, 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, in the expectation that the latter would cool sooner; in others, the nave was formed in two parts, and afterwards secured with iron hoops.

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.

Fig. II. *Plate* III. 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. When the arms or spokes are joined to the nave and rim, the dovetailed form, by the contraction in the cooling, causes them to be drawn very firm, and produces a degree of combination which 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 are preferable; and they are also now made of a serpentine form, so as to yield to the contraction of the rim in cooling.

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; 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. I have often examined, very carefully, their action upon the rails, but could never find any tendency in them to cut the rails; 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 is frequently the case, as may be seen on all those Rail-roads upon which the common wheels have been long used. The universal adoption of case-hardened wheels on all the principal Rail-roads, in preference to the common wheels, is, however, the best criterion which can be adduced of the general belief of their superiority. The case-hardening is, as previously explained, effected by running the metal against a cold cylinder of cast iron. I am inclined to think, that this tends to form the wheel more perfectly cylindrical than casting in the ordinary way: which will lessen the resistance by remedying any resistance arising from the undulatory motion produced by the imperfect circular form of the rim.

The very great rapidity at which it is now proposed to travel upon some of the public Railways, renders 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—an object of very serious consideration; various plans have already been devised to obviate this objection. It will be subsequently seen that the cast-iron wheels of the Killingworth engines had

been hooped with wrought-iron tires, which was not only found to be quite practicable, but also a great saving in the wear, compared with common cast-iron wheels; since that time the wheels of the engines made by Messrs. STEPHENSON and Co. have been either made of cast-iron, hooped with wrought; or with wooden spokes, on which was laid a malleable iron tire: wheels, thus hooped, though more expensive, seem quite necessary for the rapid rate at which some of those engines are propelled. The same plan of hooping the cast-iron wheels with wrought-iron tires, has also been adopted with respect to the common carriages; which, like the engine-wheels, though more expensive, is strictly necessary.

Messrs. JONES, of London, have a patent, which is described in the sixth Volume of the "Repertory of Patents," p. 279, where the spokes are screwed into the nave, and thereby any strain by the unequal expansion of the rim is obviated.

The axles of the carriages used at the coal-works are universally made of wrought-iron, being square at the ends, to fit the square hole *d*, through the nave of the wheel. Upon the frame of the carriage is fixed a chair, which rests upon the axle, the latter being turned smooth, to reduce the friction as much as possible. Upon the side of this chair a projection is cast, extending beyond the side of the frame of the carriage,

which projection, by rubbing against the faced flange, *f*, in the nave of the wheel, prevents the carriage from coming in contact with it; and, being kept well greased or oiled, reduces the friction, when, by one side of the road being lower than the other, the body of the carriage is thrown to one side; or this is sometimes effected by putting a loose ring upon the axle, which rubs against the flange, *f*; the latter I consider more preferable, as rubbing nearer the centre of motion, and more likely to keep lucubrated with oil. These chairs have successively been made of wrought-iron, brass, and cast-iron; the latter I consider the most eligible, for reasons which I shall hereafter assign. The size of the axles will necessarily depend upon the diameter of the wheels, and the weight they have to sustain. Upon the waggons used to carry the coals from the collieries in the neighbourhood of Newcastle, the diameter of the axles is from two inches and a half to two and three-quarters, and the diameter of the wheels about three feet; the weight of the carriage and load amounting to above three tons.

Upon public lines of road, the form of the carriages will, as before stated, vary with the nature of the goods they are required to convey; bulky goods of course requiring larger carriages. The drawing of the carriages previously given, is for the conveyance of coals; in these, the

sides of the carriage come between the wheels, and the upper part projects in the form of a hopper: this plan for coal waggons is very convenient, where, as in the north, the coals are to be emptied out at the bottom, at the shipping places. For the conveyance of coals into towns a different form is necessary; as in this case, the carriage used for the rail-way must either be so constructed, as to travel upon common roads, or the body of the carriage must be of such a form that it can be transferred to wheels suitable for the streets.

Figs. IV. and V., *Plate* III. represent the form of those intended to be used upon the Liverpool and Manchester Rail-way for coals; *Fig.* IV. being a side view, and *Fig.* V. an end view. A A is thebody of the carriage, which is a square box, capable of containing about 25 cwt. of coals. Upon the frame *a a* of the carriage are fixed the cross sills *b c d*, *Fig.* IV. and *d*, *Fig.* V.; on these, angular plates of iron rest, forming short pieces of plate railway along the cross framing. An end view of these plates are shewn in *Fig.* IV.; and *e f*, *Fig.* V. is a side view of the plate resting on the sill *d*. On the under side of the framing of each of the boxes, four small vertical sheeves are fixed, which support the boxes, and which run upon the plate rails, shewn also at *n o*, *Fig.* V. To prevent the boxes from rubbing against the sides of the plate, small horizontal sheeves are fixed to the same frame work, shewn at *r s*, *Fig.* V. which run against the upright edge of the plate. The body of the carriage can thus be moved readily back and forward along the plate rail. To prevent the boxes from moving, and to keep them steady upon the frame while the carriages are travelling, two catches, *g g*, are made use of, working upon a joint at one end, and resting upon the end of the frame-work of the carriage on the other. Carts, drawn by one horse, are used to convey one of those boxes from

the Rail-way through the streets. Plate rails, similar to those upon the Rail-way carriage, are fixed upon the frame-work of the cart, so that when the cart is backed against the side of the Rail-way carriage, with the plate rails of both forming a line, the boxes are easily run from off the Rail-way carriage upon the frame of the cart. The empty ones, being similarly transferred from the cart, to the Rail-way carriage.

Although the drawing shews only the form of boxes used for the conveyance of coals, yet it will readily occur that the form can be varied to suit the carriage of any kind of articles; the frame-work or body of the carriage being raised above the wheels, the breadth can be extended to any width which the distance between the Rail-way will admit.

The body of the carriage is supported upon springs resting on the middle of the chairs of the axles; and the axles being projected beyond the sides of the frame-work, the diameter at the bearing is consequently diminished; *t t*, *t t* are the springs resting on the chairs *i i;* the other end working upon plates of iron fixed to the frame of the carriage. *m m* are the guides that the chair works between, the extreme ends of which form a sort of cap projecting beyond the guides. The chair has a cover on the under side, to prevent the waste of the oil, being screwed tight to the upper part with a leather washer between. The oil is fed into the top of the chair, by a syphon wick, inclosed within a tin box, which holds a sufficient quantity of oil for supplying the axle for several hours; and by means of the syphon the oil is continually feeding upon the axle.

CHAPTER IV.

DESCRIPTION OF MOTIVE POWER, AND DISPOSITION OF RAIL-ROADS.

In the early periods of the history of Rail-roads, the disposition of the general line of the road into proper, or uniform degrees of inclination, seems to have been an object of little moment. Most of the Rail-roads, 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 easily 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 waggon-ways, the horse was sometimes very heavily strained, and his action was, at other times, not

Fig. I.

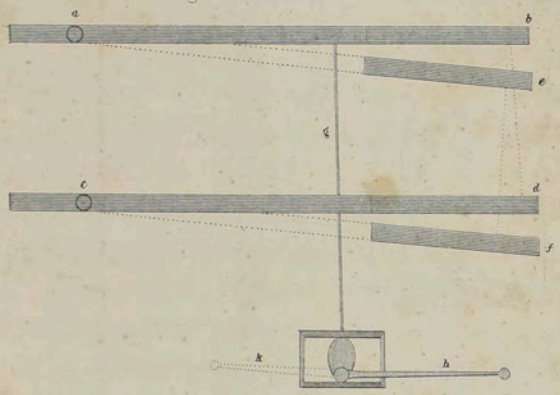


Fig. II

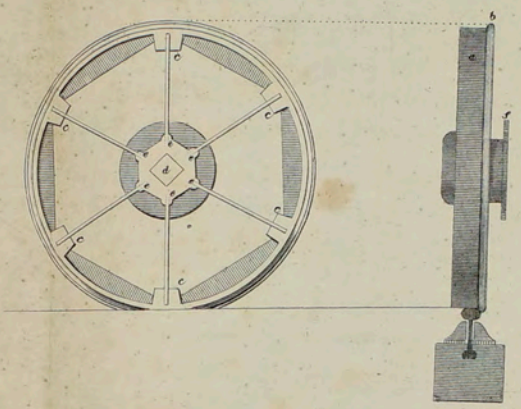


Fig. IV.

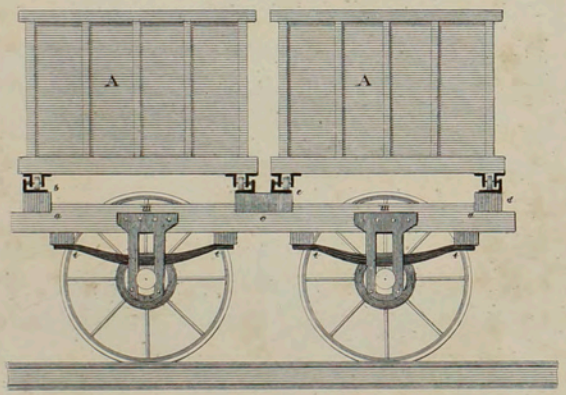
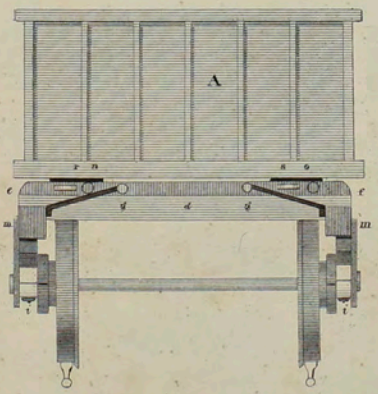


Fig. V.



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required at all. When the waggon came to some of the descents, it was the custom to unhook him 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, when 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 Rail-ways 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 declivities; and the most disastrous effects were occasionally produced by the waggons running "a-main," down the steep declivities. A brake, or convoy, being used, as before described, 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, where very steep descents occurred,

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 their 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 occasional ascents intervened, more care was taken in forming the road, and a horse was enabled to take a chaldron waggon, containing 53 cwt. 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.

And when the cast-iron wheels were brought into use, 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; I presume they found its action upon the cast-iron wheels sufficiently powerful, on such descents as they tra-

versed, to secure the proper hold: and the wooden wheels were therefore relinquished.

The next improvement was, the adoption of iron rails, and then 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 disposition 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 of 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 was:— 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 Rail-roads; 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 loco-motion was given to the steam engine; and it was in that manner

applied to drag the waggons along the more level parts of Rail-roads, without the intervention of a rope.

Having thus given an outline of the various species of motive power, successively employed in transporting goods along Rail-roads, I shall now, for the sake of greater perspicuity, treat of 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.

I.—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 Rail-road, 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 this 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 200lbs., moved at the rate of two and a half miles an hour for eight hours a day; or 200lbs. 20 miles a day. Mr. SMEATON found his performance less. Mr. WATT states it at 150lbs., moving two and a half miles an hour. I shall not, at present, enter into this question, further than what is necessary to determine the degree of inclination of road; beyond which it would not, on any account, be prudent, or even practicable, to employ the action of horses.

I shall assume 150lbs. as the amount of a horse's power, at that velocity which should be kept up in conveying goods along a Rail-road. I am 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. A moderately-sized horse will weigh about 10cwt., or 1120lbs. Taking this 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′; and, upon this acclivity, 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 Rail-road, therefore, with a view of employing the motive power of horses, all ascents should be carefully avoided; the diminution of his power being so very rapid, that very little effective power will be left for the action upon the load. Even on moderate acclivities, the road should, if the level of the two places 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.

II.—GRAVITY.

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, were 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 Rail-road, by which a loaded boat, in passing down a frame constructed for the purpose, drew up some boats which were empty. Since that time many inclined planes have been made upon Rail-roads, for the purpose of drawing up the empty carriages, by the gravitating power of the loaded carriages down the plane.

On public, and other Rail-roads, 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 Rail-road 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 Rail-road, 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. I shall, therefore, first of all, endeavour to develope the laws which govern bodies descending inclined planes, and afterwards give such practical illustrations, as I 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 falling down 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

$$G = \frac{WH}{L} \quad (1)$$

Or, making I the inclination of the plane, we have

$$G = W \text{ sin. } I.$$

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,

$$\text{Then } S = \text{sin. } I\, rt^2 \text{ or } S = \frac{G}{W} \times rt^2 \quad (2)$$

$$\text{and } t = \sqrt{\frac{S}{Gr}} \quad \text{or} \quad t = \sqrt{\frac{S}{\text{sin. } Ir}} \quad (3)$$

For instance, if the height of the plane be equal to the 36th part of its length, or the descent be 1 inch in a yard; then by (th. 1) the force by which the body is urged down the plane, will be equal to the 36th part of its weight; and (th. 2) the space which it will describe in the first second of time, will be the 36th 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

$$\frac{SG}{SO} \times \frac{H}{L} \text{ or } G = \frac{SG}{SO} \sin. I \quad (4)$$

The friction of carriages moved on Rail-roads, 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,

$$\text{we have } S = \frac{SG}{SO} \sin. I - F \times rt^2 \quad (5)$$

$$\text{and consequently } F = \frac{SG}{SO} \sin. I - \frac{S}{rt^2} \quad (6)$$

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,

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

$$S = G - F \times rt^2 \qquad F = G - \frac{S}{rt^2} \quad (7)$$

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

$$F = W + w \sin. I - \frac{\left(W + w \frac{SO}{SG}\right) \times S}{rt^2} \quad (8)$$

and consequently $t = \sqrt{\frac{\left(W + w \frac{SO}{SG}\right) \times S}{W + w \sin. I - F \times r}}$ (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 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 affected 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, consequently, 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.

$$\text{Then } S = \frac{G - F'}{W + w\frac{SO}{SG} + W'} \times rt^2 \quad (10)$$

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

$$\text{Thus } F' = G - \frac{W + w\frac{SO}{SG} + W' \times S}{rt^2} \quad (12)$$

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*; SR the distance of the centre of gyration, from the axis of motion; and SD the distance from the axis, at which the force is applied to communicate motion to the sheeve; then $\frac{W \cdot SR^2}{SD^2}$ supposed to be placed at the distance SD, 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 SR; if we take $\frac{W \cdot SR^2}{SD^2} = \cdot 5$, W being 1. it will be sufficiently near for practice.

If therefore a = the inertia of the ascending train = $a' + a'' \frac{SO}{SG}$; 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 = $\frac{1}{2}$ their weight.

Then $W' = a + b + c + c'$

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.

$$\text{Then } F' = G - \frac{(W + w\frac{SO}{SG} + a + a'\frac{SO}{SG} + b + c + c') \times S}{rt^2}$$

consequently $F' = F + f + g + \phi$.

And therefore having the friction of the carriages, and their gravitating force, the friction of the rope, &c., will be

$$\phi = F' - F + f + g \qquad (13)$$

In the application 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 exist, 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. I shall, therefore, pass over these considerations at this time, and refer to them again when I shall have detailed the experiments made to ascertain these *facts:* and shall now proceed to describe the mode of action upon the Rail-roads, in the neighbourhood of Newcastle, where their use has been very extensive.

Fig. I. *Plate* III. 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 cast-iron, about six feet 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 Rail-road; the wheel is then placed between two frames of timber, the upper of which, *a b* and *c d*, is 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 nearly 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, or slightly-inclining ground, furthest from the top of the plane, the wheel is placed, and small horizontal sheeves, *s s s s s s*, are placed in the direction the rope runs, to prevent its being injured by dragging along the ground, and also to diminish its friction. These horizontal sheeves are placed at intervals of every eight or ten yards upon the plane, from one end to the other. The drawing will show the form of the periphery, of two kinds; the one being flat, and the other circular, and of a width just sufficient to admit the rope upon it; their diameter about eleven inches, with a flange on each side to prevent the rope from running off: they are made most frequently to run upon pieces of wood, and sometimes upon cast-iron stands, placed upright upon the middle of the road; the axles are made of wrought-iron, and where they run upon the upright bearings, about three-quarters of an inch diameter. The plane is then made into a proper slope, between the platform or level on which the wheel is placed, and the lower extremity, when 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 flat platforms. The narrow parallel lines in the drawing will show the rails as laid down upon the platform; the wheel being placed below the level of the rail: the square hole is covered up, and the rails pass over upon the cover. In the drawing, the rails are broken off at *k k*, the cover being removed to show the wheel.

The dotted line A A, 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 nearly half way down the plane, of the requisite width between each rail, for the carriages to run upon, so that both the ascending and descending train pass upon the

middle, and upon one of the outer rails: these 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, for a certain distance, sufficient to allow the 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. 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′.

In this form of plane, it will be seen, that the loaded carriages pass alternately down the sides D′ D and E′ E. For instance, if they commence their descent at D, one end of the rope being attached to them, and the other end being at E′ E, at the foot of the plane, and fastened to the empty carriages, the loaded carriages will pass down D′ D, and when they arrive at the bottom, the empty ones will arrive at the top, at E. Upon the other side of the plane, the loaded carriages, in the next operation, pass down the side E′ E of the plane, and the empty ones up D′ D.

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, with a double line of rollers or sheeves: 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 double to a single 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 the 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 equalize 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. The declivity of the plane should never be so great as to cause such an excess or preponderance of gravity, when such a wheel as this is used.

Many other plans of employing gravity as a moving power have been resorted to by different persons. In very steep planes horizontal rollers, similar to A B, *Fig.* II. *Plate* II. have been used: where the descending train unwinds the rope from its barrel, and, at the same time, winds the rope upon the barrel of the returning carriage, which 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 is one machine, and the rope cannot move round without moving the barrel round also.*

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. I 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 the road, that the empty ones traverse upwards, and *vice versa*.

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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 at the summit, a plummet of considerable weight: which plummet, in its descent, drew the empty carriages up the plane.

The mode by which the carriages are made to pass from one kind of road to another, upon the plane described in *Plate* III. *Fig.* I. is at once simple and effective, and is done without the aid of manual labour.

The ledge, or projecting flange, which directs the wheels of the carriages upon the rails, is upon the inner side of the rim of both the wheels, and, consequently, travels on the inner side of the Rail-road. When the rails diverge into four, and thus form two separate roads, as from A A to B B, 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 E E′, towards C C, 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 B B and B′ B′, some contrivance is necessary to direct the carriages into the proper track: for this purpose rails, moveable on a centre, as *f f′*, *Plate* III. or shewn on a larger scale at *f*, *Fig.* X. *Plate* II. 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 D D′; then the moveable rail, "switch," or "pointer," *f*, will be thrown out from the rail, *c*, 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, D′ D: 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 E E′; when it arrrives 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 shewn by *f*. The dotted lines will represent the position of these rails, after the descending train has passed, which will be perceived is that 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.* I. *Plate* III, will, I am 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 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 sufficient to drag the ascending carriages up the plane with the requisite velocity, and always upon descending lines of road.

III.—STEAM-ENGINE,

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 little inclination: and when we descend planes, 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 carriage 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. I shall, therefore, now describe the means which have been employed to surmount such ascents with the loaded carriages.

I 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 chapter 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.

I shall, therefore, first of all, describe the different methods of surmounting those ascents which occur in some of the principal Rail-roads that have come under my 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 Rail-road is to be carried.

The dragging of 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 Rail-roads, 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 Rail-roads in the neighbourhood of Newcastle.

The following are the different kinds of planes with which I am acquainted, and the manner of surmounting 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 planes 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, when the descending carriages reach the bottom, 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 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 kind of planes is principally used in private Rail-roads, 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 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

$$G + \tfrac{1}{2} b \sin I = F' + \frac{\left(W + w\frac{SO}{SG} + b + c + \frac{c'}{2}\right) S}{rt^2} \quad (14)$$

$$\text{or } \operatorname{Sin} I = \frac{\frac{\left(W + w\frac{SO}{SG} + b + c + \frac{c'}{2}\right) S}{rt^2}}{W + \frac{b}{2}} + F + \phi \quad (15)$$

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

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

$$P = G + F + \phi + \overline{\tfrac{1}{2}b \sin I + \left(W + w\frac{SO}{SG} + b + c + \tfrac{1}{2}c\right) S} \qquad (17)$$
$$\overline{\qquad\qquad rt^2}$$

$$\text{and } t = \sqrt{\frac{\left(W + w\frac{SO}{SG} + b + c + \tfrac{1}{2}c\right) S}{P - (G + F + \phi\,\overline{\tfrac{1}{2}b \text{ sine } I}) \times r}} \qquad (18)$$

Second. Where goods are to be conveyed on a 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 after, or opposite end of the trains, to that to which the other 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 other 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,

$$P = \left(g + F + \phi + f + \frac{\left(W + w\frac{SO}{SG} + a' + \overline{a''\frac{SO}{SG}} + b + c + \frac{1}{2}c'\right) S}{rt^2}\right) - G \quad (19)$$

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

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

$$P = F + \phi + f + \frac{\left(W + w\frac{SO}{SG} + a' + \overline{a''\frac{SO}{SG}} + b + c + \frac{1}{2}c'\right) S}{rt^2} \quad (21)$$

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

Third. 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 is 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 carriage up either plane will be the same as (17), the time being (18); and the degree of inclination necessary to cause the carriages to descend the plane in the time t will be (15). In the case No. 2, for the descending train of carriages,

$$\text{Let } G + \overline{\tfrac{1}{2}b \sin I} - F' + \frac{\left(W + w\frac{SO}{SG} + b + c + \tfrac{1}{2}c'\right) \times S}{rt^2} = P' \quad (23)$$

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

Fourth. 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, which has been made the subject of a patent by Mr. B. THOMPSON, late 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 returning 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—

$$P = F + \phi + f + \frac{\left(W + w\frac{SO}{SG} + a' + a''\frac{SO}{SG} + b + c + \frac{1}{2}c'\right) \times S}{rt^2} \quad (24)$$

$$\text{and } t = \sqrt{\frac{\left(W + w\frac{SO}{SG} + a' + a''\frac{SO}{SG} + b + c + \frac{1}{2}c'\right) \times S}{P - F + \phi + f \times r}} \qquad (25)$$

When the planes are not horizontal—

$$\text{Then } \left(P = F + \phi + f + \frac{\left(W + w\frac{SO}{SG} + a' + a''\frac{SO}{SG} + b + c + \frac{1}{2}c'\right) \times S}{rt^2} \pm g\right) \pm G \qquad (26)$$

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

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

I shall now attempt, with the aid of the drawing, *Fig.* II. *Plate* III. to describe more particularly the mode of action of the different planes above enumerated; but, first of all, I 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 my object is to illustrate the different modes upon extensive lines, where traffic is considerable, and celerity

the great desideratum, I 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, as described by Mr. SCOTT, in the Transactions of the Highland Society, vol. IV.; as also other matter on Rail-roads 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 these are 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. I shall, therefore, suppose that

a b, *Fig.* II. *Plate* III. Represent 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 giving motion to the rope-rolls A B, by means of the cog-wheels *g h*. These rolls are alternately thrown out of geer, or disengaged from the action of the cog-wheels, by any of the common methods of disengaging machinery. The axles of the rolls are round, so that when the axles are fixed, the rolls are at liberty to turn, or revolve freely round; there are levers each moveable upon a steady fulcrum at *i i*, one end of which can be moved at pleasure. The other end passes within, but does not touch, (when the machinery is in action,) the two parallel flanches fixed upon the side of the roller, 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 equalise the twist upon the axle, but which are not shewn in the drawing. The whole is placed upon the bearings *l l*, &c., resting on a frame of wood upon the wall of the building, and elevated sufficiently high for the carriages to move along the Rail-road immediately underneath without touching, and is covered over to preserve the whole from the action of the weather.

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, 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*, *Plate* IV. The sketch, *Fig.* I. *Plate* V. 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 Rail-way is made to diverge, so as to pass on one side of the engine-house. 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 them, 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

Fig. II.

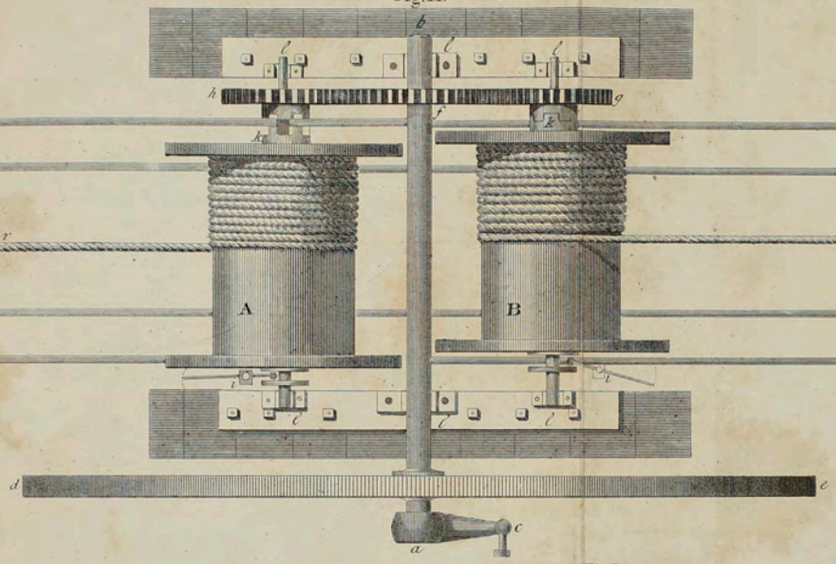
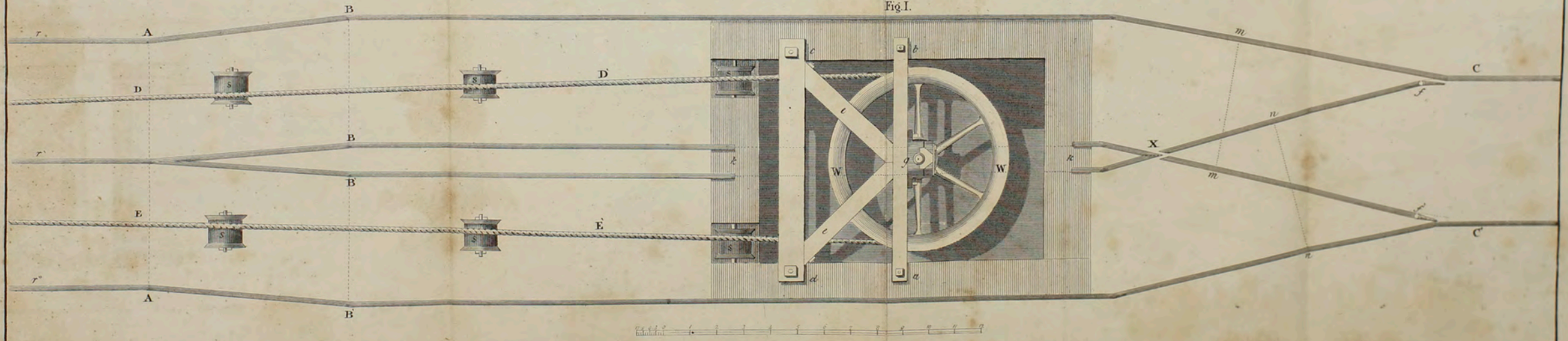


Fig. I.



Drawn by E. Galloway.

W. Read sc.

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the same time; and this may be effected either by laying two 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 require any drawing to explain the first of these modes. *Fig.* II. *Plate* V. will shew the plan of laying the rails down in the latter one. 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 of 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.* I. *Plate* IV. is placed horizontally, or a like wheel fixed perpendicular to the axis of the engine, which being turned by the engine, is thus made to drag the carriages up the plane. This 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 them to pass down the opposite sides of the plane, with which the centre of the wheel, on which they wind, is in a line. Thus, in *Fig.* I. *Plate* IV., if the rope D′ be made to pass round a vertical sheeve placed at *s* on the opposite side, and the rope E′ round a similar sheeve on the other side; then the rope will 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 leading sheeve, which acting upon the rope embracing the wheel also, 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, as it precludes the necessity of having two ropes, which with rolls, where the rope winds upon itself as in *Fig.* II. *Plate* IV. is indispensible. In both these cases, however, whether the rolls A B, *Fig.* II. *Plate* IV. or the single wheel, *Fig.* I. 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.* II. *Plate* IV. The road may either be formed of two separate and distinct lines of road, or in the manner shewn in *Fig.* III. *Plate* V. 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 may represent 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*, 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* 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 dragged into their places, 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 Rail-way, and is in every respect the same as that of the self-acting plane, *Fig.* I. *Plate* IV.

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.* IV. *Plate* V. 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 C, 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 *b*, 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 as 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 when 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.

Upon the Liverpool and Manchester Railway, Mr. Stephenson effects the transit of goods up and down the large tunnel, being a plane similar to *Fig.* III. *Plate* V., by means of an endless rope. *Fig.* V. *Plate* V. will shew the plan of effecting it, a

double line of road is laid the whole distance, and at the bottom of the plane a sheeve B is fixed similar to *c Fig.* III.; *e* and *f* represent the rope passing around it. At the top of the plane, a horizontal wheel A is fixed, worked by two engines, one on each side of the Rail-way; 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, crossing between that wheel and *a*; passes over the side of the latter, around *b*, and leading past *a*, crosses again, and winding round A upon the other groove, leads down the road to the train at *f*, and so round the wheel B. The rope thus passing twice round 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 equalise the tension of the rope, a heavy weight is attached to the framing of the wheel *b*, by a rope passing over the vertical pully *c*. This weight is at liberty to ascend or descend in a well sunk for the purpose, as the tension of the rope becomes greater or less, or as the rope becomes longer or shorter by any variation of humidity to which it is exposed. By this plan the carriages ascending the plane always traverse the same road, the descending carriages traversing the other, and no alteration of the machinery is required.

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.* VI. *Plate* V. 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.* II. *Plate* IV. 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 the 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.* VII. *Plate* V. 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.* II. *Plate* IV. 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.* VI.; 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.* III., 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.* IV. *Plate* V.

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 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 Rail-way. *Fig.* VII. *Plate* V. will shew the operation by a single line of road. It may be supposed to be one extremity, or an intermediate station of the line, at which an engine is erected. The line is then divided into stages of suitable lengths, about $1\frac{1}{2}$ miles 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.* II. *Plate* III. At the extremity of the stages the single line of Rail-way is made to branch into two separate lines *a b*, *c d*, the former descending from *a b* to *c*, 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 toward 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 engine being set to work, drags by means of the ropes *g* and *i* the train of carriages to B

and A, 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 declivities occur, giving the train of carriages a greater gravitating force than what is necessary to drag the rope; then the rope roll is 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 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 engines, 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 S 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. *Fig.* VIII. *Plate* V. will shew a scheme of performing this, recommended to the notice of the directors of the Liverpool and Manchester Rail-way, in the report of Messrs. Walker and Rastrick, and said by the latter to be struck out by him. A B C represents the engines at the end of three stages, each of those engines are furnished with four rope rolls similar to those shewn in *Fig.* II. *Plate* IV. 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 shewn, 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 toward their respective stations. When the train D arrives at *g*, the ropes are disengaged, and the train pro-

ceeds to *o*, where it stops; meanwhile the train C 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 C arrived 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 crossing *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, which is very objectionable. This might probably be avoided by a modification of the plan of Mr. Stephenson's endless rope, by which the carriages going in an opposite direction always keep their respective roads.

By one or other of these modes of working double lines of road, a constant transit is effected, except the delay at the various stations; as we have always the trains of carriages passing in both directions at once, at intervals equal to the length of the stages. In this mode, as well as in the other modes of working lines of Rail-way by engines reciprocating with each other, it is necessary that the nature of the traffic be constant and regular, or that an uninterrupted supply be kept up. As by a slight consideration of the operation of those engines, it will be seen that a delay at one of the stages affects the whole line of engines, unless the reciprocation be kept up with dragging skeleton carriages back and forward.

We have, in the previous description of the different modes of conveying goods by fixed engines, we trust, explained the manner by which the con-

veyance 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 stant transit.

IV.—STEAM-ENGINES,

BY LOCO-MOTION.

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.

Fig. I.

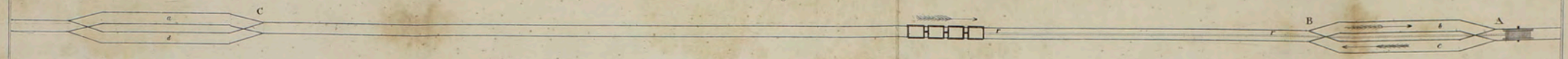


Fig. II.

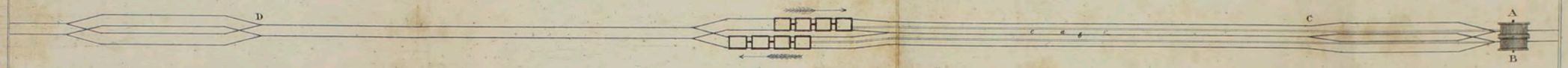


Fig. III.

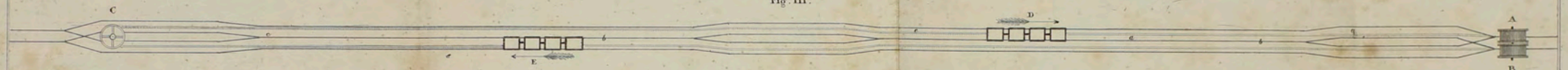


Fig. IV.



Fig. VIII.

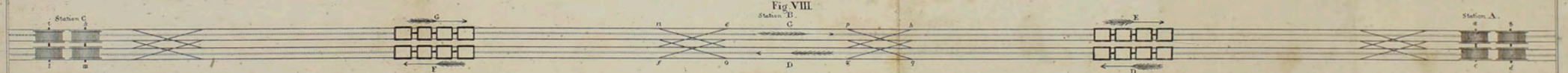


Fig. VI.

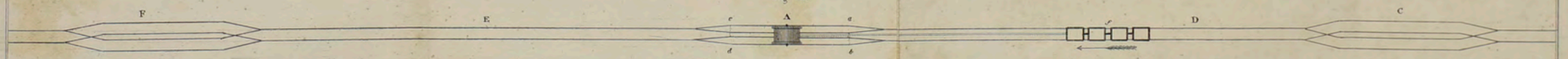
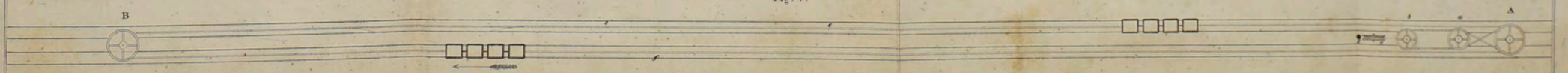


Fig. VII.



Fig. V.



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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 Philosphy," 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, 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 intro-

duction 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 Rail-roads.

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; and, since that time, high-pressure steam-engines have been much used, in many places to economise the fuel.

Messrs. Trevithick and Vivian, in the specification of their patent, give a drawing of their engine, applied to move a carriage upon the common roads, which may be seen in the 4th 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 which directed public attention to the subject, it is entitled to great commendation.

The many objections to its application upon public turnpike roads, may, I presume, have operated in preventing the patentees from carrying it into practice in the manner described in their specification; they, therefore, very properly, directed their attention to its use upon Rail-roads.

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 Rail-road. The engine is stated to have had an eight-inch cylinder, with a four-feet six-inches stroke, and "drew after it upon the Rail-road 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 I can learn, did not materially differ, in construction, from that previously described, except in the form of the carriage.

The great obstacle to their introduction 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 said wheels, 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.

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 wheels, turned by the engine, worked, and thus produced a progressive motion in the carriage.

Fig. I. *Plate* VI. will convey a pretty correct idea of the mode of action of this kind of engine. R R is a piece of iron of the rails constituting the Rail-road, on the side of which are cast the semi-circular protuberances or projections 1, 1, 1, &c. These semi-circular teeth project from the side of the rail two or three inches, thus forming a longitudinal toothed rack, which is extended the whole length of the road. *a a* are the cylinders, placed within the boiler. The action is communicated by the pistons to the connecting rods *b b*, which transfer the motion to

the cranks *c c*, turning upon axles attached to the frame of the carriage. Upon the axles on which these cranks are fixed, are also fixed the pinion-wheels *d d*, which are turned round by the cranks; these two pinion-wheels communicate with a larger cog-wheel *e*, in such a manner that both contribute in producing a rotatory motion in it. The axle of this cog-wheel *e*, extends to the outside of the frame of the engine, and upon the end of it is affixed the larger toothed wheel *f*, which is 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 is thereby effected. The steam, after performing its office in the cylinder, is allowed to escape into the atmosphere, through the pipe *e*. The boiler is cylindrical, and is heated by a circular tube passing through it, terminated at one end by the chimney. The toothed or rack-rail is only laid on one side of the road, the other being common rails. The cog-wheels can be varied in size according to the different velocity with which it is required to travel.

By the use of this rack-rail the engine is enabled to ascend acclivities which Mr. TREVITHICK's engine, from the want of adhesion, could not surmount; accordingly its use is extended.

Mr. BLENKINSOP, soon after the date of his patent, erected some of his engines, and employed them upon the Middleton colliery Rail-road, in sending coals to Leeds, where they have ever since been used.

The engine erected by Mr. TREVITHICK had one cylinder only, and 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

Rail-road, but 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 Rail-road, 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.

In December, 1812, Messrs. WILLIAM and EDWARD CHAPMAN obtained a patent for a mode of effecting the loco-motion of the engine, by means of a chain stretched along the middle of the Rail-road, 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, it could not be drawn forward by the wheel, and therefore the carriage was 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 Rail-way.

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 part of 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 Rail-road, near Newcastle, but it was soon abandoned; the great friction, by the use of the chain, and also its liability to get out of order, operated considerably against it.

In 1813, Mr. BRUNTON, of Butterley iron-works, also obtained a patent for a mode of accomplishing the loco-motion of the engine without the aid of the adhesion of the wheels upon the rail; and of which, as it displays great ingenuity, I have given a drawing.

Fig. II. *Plate* VI. 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 line *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 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 Rail-way, 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 loco-motion of the engine upon Rail-roads approaching nearly to a level, or with a moderate inclination. His Rail-road 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 loco-motion 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 loco-motion; and hence we find the engineers attempting to produce other means of loco-motion. Mr. BLENKINSOP, by means of a cog-rail; Mr. CHAPMAN, by the chain; and Mr. BRUNTON, by means of moveable legs.

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 Rail-road, that this question was decided: and it was proved that, upon Rail-roads nearly level, or with very moderate inclination, the adhesion of the wheels alone was sufficient, in all the different kinds of weather, when the surfaces of the rails was not covered with snow.

Mr. HEDLEY informs me 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 Rail-road, a requisite number of waggons.

The first engine applied upon the Wylam Rail-road 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 Rail-road by this kind of 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 Rail-road. This engine had two cylinders, each eight inches

diameter, and two feet stroke: the boiler was cylindrical, eight feet long, and thirty-four inches diameter; the tube, twenty inches diameter, passing through the boiler.

Fig. III. *Plate* IV. 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 is fixed; *a b* and *c d* are the connecting rods, similar to *b c*, *b c*, *Fig.* I., 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 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 diameter, and the cog-wheels upon the axles of the travelling wheels twenty-four inches diameter: so that the cranks made two revolutions for one revolution of the engine-wheels.

This engine was tried upon the Killingworth Colliery Rail-road, July 27, 1814, upon a piece of road with the edge rail, ascending about one yard in four hundred and fifty; 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, con-

taining 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 sufficiently adequate to produce the desired effect.

The communication of the pressure upon the piston, through the means of the crank to 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 the one upon the wheels became greater or less than the pressure of the other, when the teeth became at all worn, caused a rattling noise. For, when the leverage of the one crank became greater than the other, the latter was propelled by the other through the intervening wheels; but when the former approached towards the extremity of the stroke, its leverage became less and less, and the leverage of the latter became greater as the angle between the connecting rod and the crank increased; and, at a certain point, the latter preponderated. When a change in the action took place, the former was then the propelled, and the latter the propelling power. 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 between each other greater.

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, by which it travelled upon the Rail-road, the lower end of the connecting rod being attached to it by what is termed a ball and socket joint; the other end of the connecting rod being attached to the cross-beam, worked up and down by the piston.

a b, *Fig.* IV. *Plate* VI. represents the connecting rod, the end *a* attached to the cross-beam, and the end *b* to one of the spokes of the wheel; in like manner the end *d* of the connecting rod *c d*, is attached to the beam of the other piston, and *h* 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, which has been much used upon these kind of engines, consisted at first of one broad and two narrow links, alternately, fastened together at the ends with bolts: the two narrow links were always 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, (otherwise perfectly circular and flat,) about an inch or one and a half inches. When the wheel turned round, these projecting cogs entered between the two narrow links, having a broad link between every two cogs, 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.

The mode of communicating the action of the

engine, from one wheel to another, is shewn in the drawing of *Fig.* IV. *Plate* VI.; 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 could be moved back to tighten it again, until a link could be taken out, when the chair was moved back again to its former situation.

An engine of this construction was tried upon the Killingworth Rail-road, 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, respecting the improvement in the rails and wheels. 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 Rail-road conveyance; and, indeed, than many on any other subjects, and it certainly confers great credit upon the patentees. The contrivance is very minutely described, in the specification of their patent; and the advantage derived is very

judiciously and very clearly stated; I shall give it in their own words:—

"In what relates to the loco-motive 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."

e e e, *Fig.* IV. *Plate* VI. 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 *Fig.* IV. *Plate* VI., 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 loco-motive engine, its gradual and successive improvements, and, in doing so, described many of the detached parts entering into its construction, I shall now proceed to describe the whole combined, as forming the engine in use upon the Killingworth Rail-road.

Figs. I. and II. *Plate* VII. represent a side and end view of one of the engines used upon the Killingworth Rail-road.

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 put, and the other end is terminated by a chimney. The grate,

Fig. I

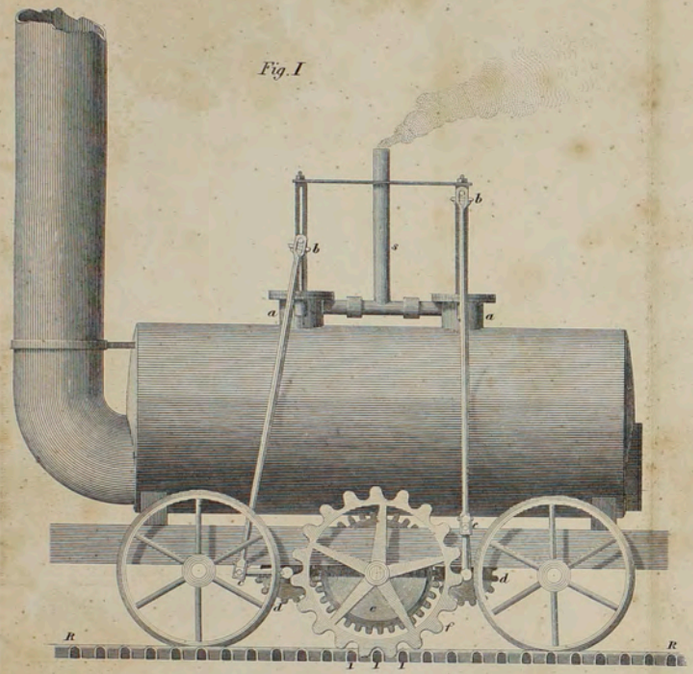


Fig. II

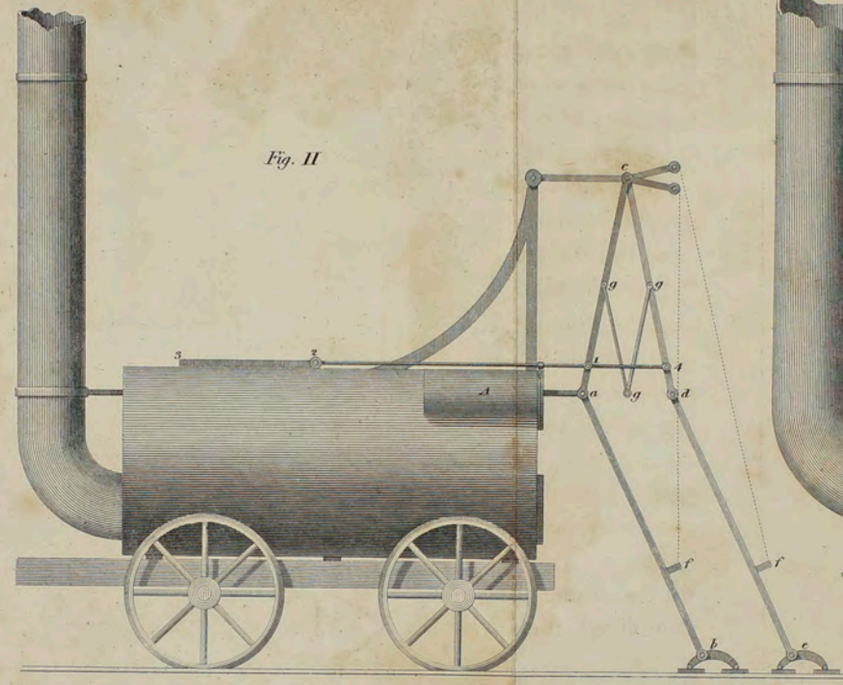


Fig. IV

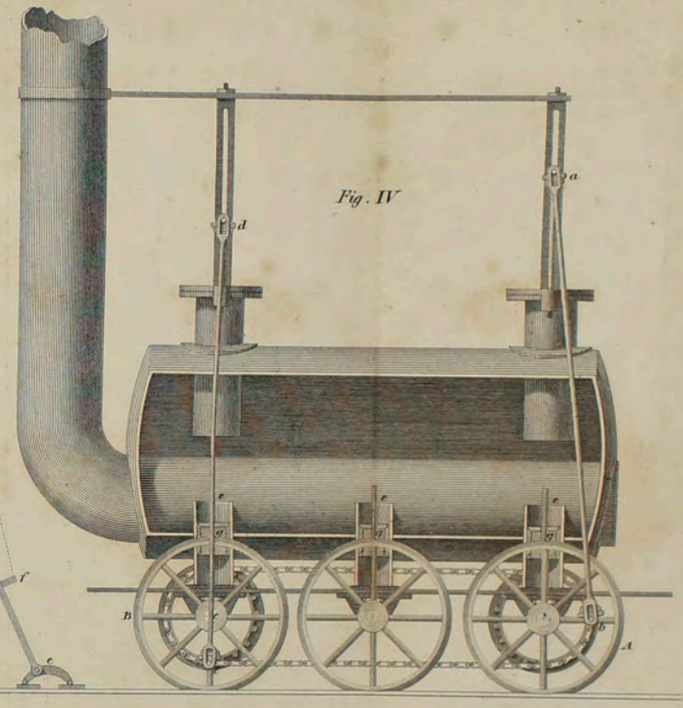


Fig. III

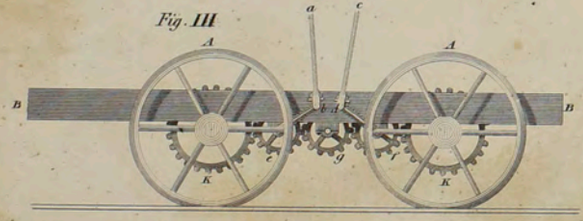


Fig. V

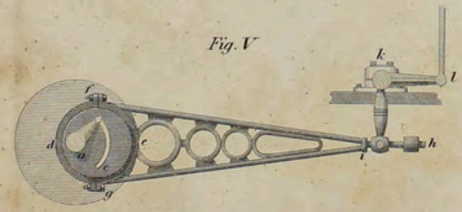


Fig VI

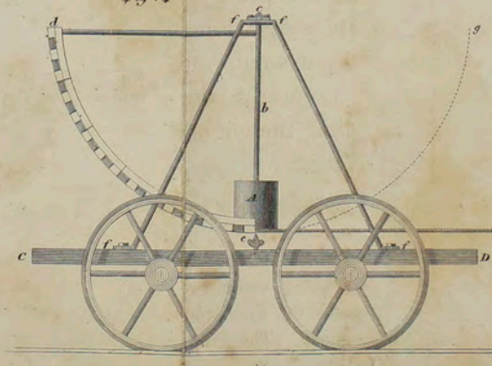
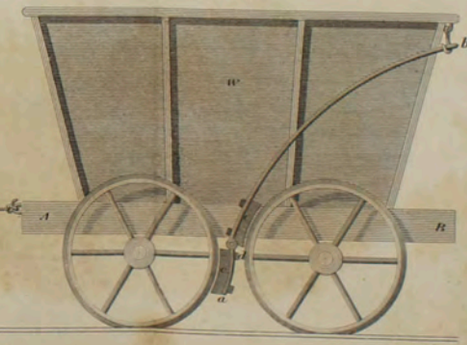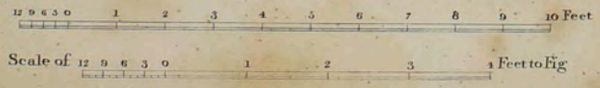


Fig. VII





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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, *Fig*, II. 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. 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 drawing. They are generally nine inches diameter, and 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 *Fig.* II. The rectilinear motion of the piston-rod is secured by the slides, *s s s s*, fastened to the projecting arms *c 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, a circular piece of metal is cast, which attaches the two adjoining spokes with it.

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 pre-

viously 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 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; and the rotation of the latter wheels, at that period of their evolutions depended upon the action of the chain; if the chain was 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 connection was thus effected. 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 *Fig.* II. 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 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, about four years ago, I had a rim, or tire of wrought-iron put upon one set of the Killingworth engine wheels; this tire was made by the hammer of the workmen, and not being of uniform thickness, produced considerable resistance to the engine; we were, however, enabled to pursue the experiment a sufficient length of time to prove that very little actual, and certainly very considerably less relative wear, took place than with cast-iron. The trial being so very satisfactory, the Bedlington Iron Company were induced to erect a pair of rolls for the purpose of rolling the tires by machinery: the first set of tires from which are still at work upon one of the Kilingworth engines; and since that time similar tires have been extensively used, not only for locomotive engine wheel, but also for the wheels of common carriages on public Rail-ways. 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, 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, *e*, *Fig.* I. 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 who have 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*, *Fig.* V. *Plate* VI., 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 a 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 turns round; as this lever is moved, its motion is communicated to the arm *i k*, as shewn in *Fig.* I. *Plate* VII. 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.

p 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 prevent 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 easy, and when the pressure, or elasticity of the steam, is not required to be very great.

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; when 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 turns or curves in the line of the road occur.

Having, in a subsequent part of the work, given a detailed history of the great improvement of the Locomotive Engine, compared with the one just described, induced by the memorable contest at Liverpool; and in elucidating the principles of the different engines exhibited there, given such drawings and explanations of these engines, as will convey to the reader a perfect knowledge of the progress of improvement, from the engine above described, to those at present in use; we shall therefore at once proceed to describe the construction of one of the most improved engines of Messrs. Stephenson and Co. intended for public railways. It was our wish, if possible, to have given drawings and descriptions of both kinds of engines, viz. both Stephenson's, and Braithwaite and Ericsson's; but having been unsuccessful in our application to obtain a drawing of the latter, we are obliged to content ourselves with giving a drawing of one of the most improved of Messrs, R. Stephenson and Co.'s, with which we have been favoured.

Figs. I. and II. *Plate* VIII. shew a side and end view of this engine. The boiler itself is of the same construction as that of the Rocket engine, being cylindrical, and filled with copper tubes (reaching from one end to the other), from the bottom up to the semi-circumference of the boiler, through which the heated air and flame passes from the fire-place to the chimney. The length of the boiler and tubes being 7 feet, and the number of tubes 82,

$1\frac{1}{2}$ inches diameter. Upon one end of the boiler, as shewn in the drawing, a chamber is fixed which contains the fire-box; this chamber is square at the bottom, but cylindrical at the top to embrace the end of the boiler: within this chamber a square fire-box is placed, having a space of two inches between it and the chamber on the sides, for the water to surround the fire; the top of this box of course reaches to the middle of the boiler, in order for the flame and heated air to pass through the tubes, leaving a considerable space above the fire-box for water and steam; and a communication at top and bottom of this fire-box with the boiler supplies it with water, and allows the steam to pass off into the boiler. The fire-bars are placed near the bottom of the box, which is open at the bottom to receive the air; the size of the fire-place being 3 feet 8 inches wide, 2 feet long, and 2 feet $10\frac{3}{4}$ inches high. The whole of the fire-box is surrounded by water, thus presenting a surface of nearly 19 feet, exposed to the radiation of the fire: after which, the flame passes through the tubes, exposing a surface of 225 feet to the action of the flame and heated air; the area of the fire-grate being 7 feet 4 inches. A similar chamber to this is fixed to the other end of the boiler, from the top of which the chimney proceeds: the bottom of this chamber is water tight, and contains a quantity of water reaching to the waste tube, into which any cinders passing through the tubes are thrown, by cross plates of iron, similar to Venetian blinds. The two cylinders are placed horizontally within this chamber, shewn in the end view *Fig.* II., and also by the dotted line at *a b c d*, *Fig.* I. The axle of the large wheels is double cranked, resting on four bearings. The piston-rod works within, and is kept in a rectilinear motion by the guides *e*; the connecting rod *f*, proceeds in the same line, and produces a rotatory motion of the large wheels of the engine, by the cranked axle; one of the cranks of which may be traced by the dotted lines at *g h*; and it is scarcely necessary to say, that the cranks of the axle are at right angles to each other. The weight of the engine is equalized upon the respective wheels, and any jolts or shakes of the road counteracted by the adoption of springs, *s s*. The chairs of the large wheels are fastened to the springs, but the springs of the small wheels rest on the back of the chair, The plan of the chairs are similar to those described in the ac-

count of the carriages, the regularity in the supply of oil being kept up in them, as well as in all the other joints of consequence, by means of cotton wick syphons. The cylinder receives the steam by means of sliding valves in the usual way, which are worked by an eccentric wheel on the axle of the large wheels; the motion is communicated from the eccentric to the slides by rods working the arms *i i*, and *n n*, fixed upon the cross axle *o o*. The engine is worked or the motion changed by the handles shewn at the end of *Fig.* I., by means of the cross heads 11 and 22, and the rod 33, communicating with the axle working the slides. The engine is supplied with two safety valves, one to which the engineman has no access, or which is locked up. The wheels are made with wooden spokes and fellies; a thin hoop of iron embraces the fellies, and upon this is laid a tire rolled into the proper form for travelling upon the rails. The engine is fixed to the frame of the carriage by the iron knees 4, 4, 4, *Fig.* I., shewn more particularly by the dotted lines in *Fig.* II.

The convoy carriage, containing the requisite quantity of water, and coals or coke, is attached to the end of the engine next the fire, and the boiler is supplied with water by means of a forcing pump, worked by the engine. The height of the water in the boiler being shewn by glass tubes.

The necessary draught of air through the fire is obtained in this engine, by the rarefaction of the heated air in the chimney: but this would, of itself, be insufficient, from the low temperature to which the flame and heated air is reduced in its passage through the tubes; and therefore, the steam, after it has performed its office in the cylinder, is thrown into the bottom of the chimney as a jet, which, at the great velocities that the engines now travel, effects a sufficient draught of air through the fire.

The effect, in the economy of fuel, and in the

facility of raising steam, by the system of tubes, adopted in the construction of these modern engines, must be obvious to every mechanical reader; the importance of which, in the general application of this species of engine, as a moving power upon Rail-ways, will be afterwards shewn, with some remarks on this mode of raising steam. It does not, however, require any consideration to see that the system of tubes of small diameter, is infinitely superior to the old plan of one tube, as shewn in *Plate* VII. In works where the latter kind of engines are already in use, it may be inconvenient or inexpedient to discard the old engines, even although we are convinced of the superiority of the modern plan; I shall therefore shortly describe a plan of altering the old engines with a single tube, an alteration made at a trifling expence, and which embraces almost all the advantages of the small tube engines.

The tube passing through the boiler of the engine in *Plate* VIII. is above 9 feet long. Suppose we cut it off 3 feet from the fire end, close it up with a flat plate where cut off, and take away the 6 feet length altogether, and make the boiler end perfect. The 3 feet length of tube being strengthened at one end by the boiler, and at the other by the plate, may then be made of an oval shape, as shewn by the dotted outline in *Fig.* II. The fire-grate in that case may be made 3 feet long by $2\frac{1}{2}$ feet wide. Small tubes, similar to those of the engine, *Fig.* VIII., may then be inserted into

the flat plate at one end, and pass out at the end of the boiler at the other: these tubes would then be 6 feet long, and thus give a very considerable area of surface, more than four times larger than the single tube. We only then require a sufficient area of opening, below the grate bars, which the space in the tube does not supply. One or two oval or square openings, similar to manhole doors, may be cut through the tube and boiler; and as the tube may only be about one inch from the under side of the boiler, it only requires a ring an inch thick, riveted around this opening, to keep the space between the tube and boiler, water and steam tight. With a trifling alteration, therefore, we increase the facility of raising steam, and the economy of fuel, nearly three-fold: an alteration which I am at present making in one of the Killingworth engines.

The locomotion of these engines, as will be perceived, is effected by the action of the wheels upon the rail, without the aid of any extraneous mechanism, and consists of the hold or adhesion of the surface of the wheels, against the surface of the rail. The rationale of the action will be very evident, by an inspection of the drawings; the power of the steam in the cylinders is employed to turn the wheels of the engine round, acting as a common crank; these wheels, resting on the rail, press upon them with a force equal to the weight of the engine, divided by the number of wheels; thus, suppose there are four

wheels, then the pressure of the periphery of each wheel, upon the surface of the rail, is equal to one-fourth of the weight of the engine. Now it is well known, that when two surfaces are in contact, and subjected to pressure, it requires a certain force to cause them to slide upon each other; that property in bodies, to resist sliding, is called the adhesion of the surfaces. Suppose, then, the power of the cylinders be employed to turn the wheels of the engine round; this property of bodies, in contact with each other, will prevent the wheels of the engine from sliding upon the rail, with a force proportionate to their weight or pressure, and they will necessarily roll along the surface. If, however, the progressive motion be opposed to a retarding force, greater than the force or power of adhesion, then the surfaces will slide upon each other; and the rotatory motion of the wheels will be continued, without effecting a progressive motion of the engine.

The power by which the engine propels itself forward, or by which the progressive motion of the engine is effected, is, therefore, the adhesion of the surface of the wheels upon the rail; and the reader will perceive that this power is acquired without in the least affecting, or adding to, the resistance. The resistance, or friction of the wheels upon the rail, would be the same upon the wheels of any other carriage, of the same weight, as upon the wheels of the engine when propelling itself forward; and this is not mere

Fig II.

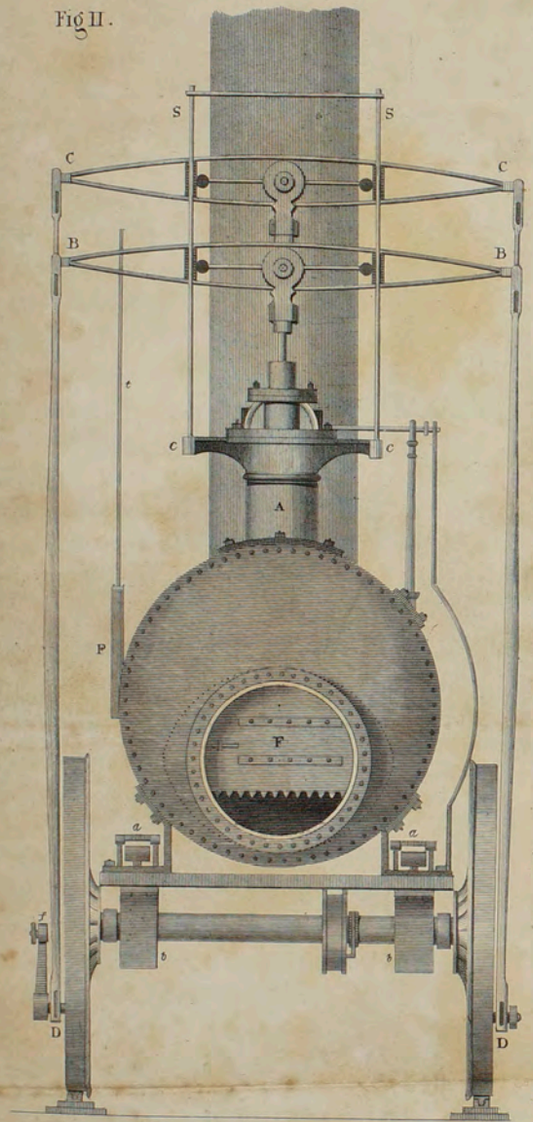
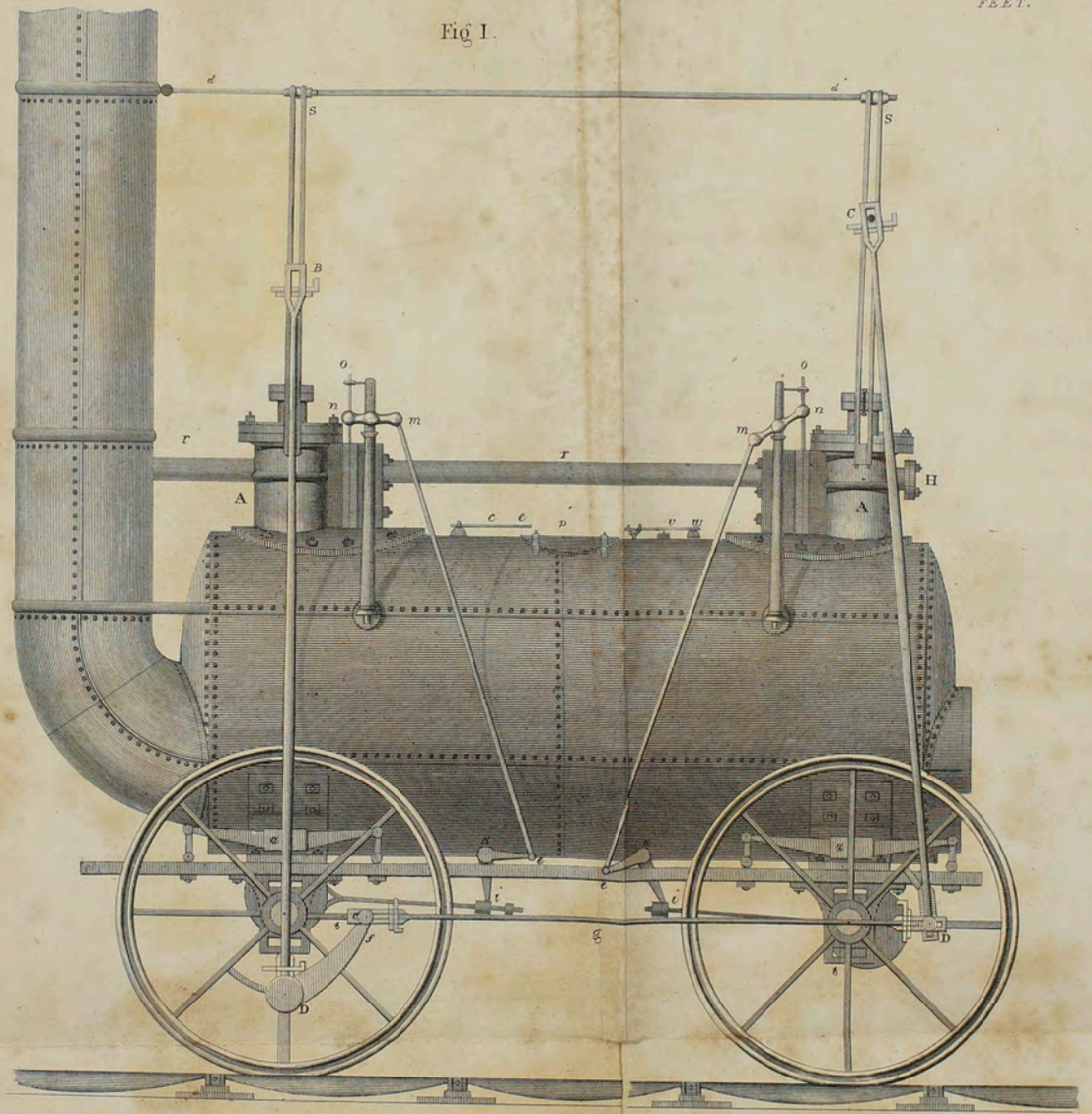


Fig I.





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J. Rose



supposition, for, on comparing the space passed over by the engine, with a given number of revolutions of the wheels, no sensible distance was lost, which proved that no sliding took place.

By knowing the amount of adhesion upon surfaces in contact with each other, we might deduce the power of adhesion presented by the rail to the wheels of the engine, and this would be the power required to cause the engine to slide along upon the rail, supposing the wheels were prevented from turning round. This, however, is by no means constant; at one time the rails are quite dry, at another quite wet, at other times partly both, and sometimes slightly covered with a film of mud; in all of which cases the amount of adhesion varies; to deduce any data of practical utility, we must, therefore, ascertain the amount in all the different states of the weather; and we shall afterwards give an account of some experiments made to ascertain this point.

From the nature of this kind of motive power, it will occur to the reader, that the ascent in the line of road must never be such as will present a resistance to the engine, equal in amount to the adhesion of its wheels upon the rail; the limits of the action of this kind of engine will, therefore, be within certain lines of road, nearly approaching to a level, or receding little from it. When the amount of adhesion shall have been ascertained, we shall be able to fix this limit.

CHAPTER V.

ACCOUNT OF EXPERIMENTS ON THE STRENGTH OF CAST AND MALLEABLE IRON RAILS.

Since cast-iron superseded the use of wooden rails, it has been most extensively used in the construcion of Rail-roads. 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 organization; yet still we are enabled to form a Rail-road with it, on which weights of considerable magnitude can be conveyed, without much risk of breakage.

It is a consideration of paramount importance, in the construction of a Rail-road, to form it of such materials as combine strength and durability with economy. 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 this, as it cannot be obviated without increasing the section of the rail, and adding to the weight, and consequently to the cost, has lately produced an innovation in the material, by the substitution of a particular form 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 Rail-roads, we have previously given the opinion of some engineers, on the comparative merits of cast and malleable iron rails, offered previous to 1825. Since that period wrought-iron rails have been more extensively, or almost exclusively, used upon public lines of road; and the prejudice which then existed against their adoption, experience has dispelled. There were then wanting experiments on the *comparative strength*, *durability*, and the *resistance* to the carriages moved along them. We have endeavoured, so far as in our power, to determine

these points; and shall first of all give some experiments made on the strength and flexibility of the two kinds of rails.

The most general form of the edge-rail is that of a parabola on the under side, the upper side being straight. When a beam is supported at each end, as is the case with a rail, and loaded in the middle, the upper being quite straight, the line, bounding the under side in the form of section usually considered the strongest, is that of two semi-parabolas, the vertex being the point where the force acts; but, in the case of a weight rolled along the Rail-road, the pressure is occasionally acting throughout the whole length. On that account, the line bounding the under side should be that which presents the greatest strength, when the beam is supported at each end, and loaded equally throughout the whole length, which is a semi-ellipse.

The want of a practical treatise on the strength of cast-iron, and on the various forms of section, suitable for beams, acted upon in different ways, was, until lately, very much felt. Mr. TREDGOLD, in his treatise on the strength of cast-iron, has supplied that want, and given numerous practical examples on the subject. The reader, who wishes to inform himself further on the subject, will find some very useful information in that work.

Account of some Experiments on the strength of Cast Iron Rails, made at Walker Foundery, near Newcastle-upon-Tyne, the property of Messrs. LOSH, WILSON, *and* BELL.

The rails were all cast from the same pattern, the difference in weight being accidental. Section similar to *Figs.* I. and III., *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 supports, 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, nine and a half inches.

EXPERIMENT I.

Number of Experiments.	Description of metal.	Weight of each rail.		Weight which produced fracture.			Average weight of each kind of rail.		Average strength of each kind of rail.			Relative strength of mixed and unmixed metal, specific gravity considered.	
		lbs	oz	cwts	qrs	lbs	lbs	oz	cwts	qrs	lbs		
1	No. 1, metal A...	56	6	126	3	0							
2	——— Ditto. ...	56	0	99	3	0	55	9	114	1	14		
3	——— Ditto.....	55	8	108	3	0							
4	——— Ditto.....	54	7	122	1	0						146	122
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		
8	——— Ditto.	57	1	99	3	0						156	108
9	No. 1, B, mixed	57	13	162	3	0	57	10	156	0	0		
10	with old metal	57	7	149	1	0							
11	No. 1, metal C...	55	8	150	3	0	55	4	140	2	14		
12	——— Ditto.....	55	0	130	2	0						173	128
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		
16	——— Ditto.....	56	1	117	3	0						194	119
17	No. 1, D, mixed	59	9	207	3	0	58	4	194	1	0		
18	with old metal	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		
24	——— Ditto.....	57	2	135	0	0						137	144
25	No. 1 E, mixed	55	6	148	2	0	55	8	137	2	0		
26	with old metal	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	—— 3 feet long, No. 2, metal	33	0	98	2	14							
31	—— 3 ft. Welsh metal.....	33	0	100	3	14							
32	—— 3 ft. No. 1, metal.....	33	0	107	2	14							

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 could otherwise 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 deflexion 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 re-action will transfer those to the rail, 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 adviseable 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 for a Rail-road, 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 throws 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 Rail-road 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*, art. 148.

$$\text{consequently } d = \sqrt{\frac{3\,W\,l}{850\,b}}\,(1 - q\,p^3)$$

$$\text{and } W = \frac{850\,b\,d^2}{3\,l}\,(1 - q\,p^3)$$

Account of some Experiments on the strength and flexure of malleable iron-rails, made at Bedlington Iron-works, Dec. 6th, 1824.

Section of rail similar to *Fig.* IV. and V. *Plate* II.; distance between the supports three feet; depth in the middle $3\frac{7}{16}$ inches, tapering away, at each end, to $2\frac{1}{4}$ inches; breadth at top $2\frac{1}{4}$ inches; thickness about $\frac{5}{8}$ths of an inch; weight per yard 28lbs.

The rail was nine feet long, fastened to the chairs three feet a part, in the same way as in forming the road; the rail was inverted, and the extreme ends rested upon two blocks of timber, the direction of the strain being upwards, and applied at the middle of the bearing.

The rail was made of Welsh iron re-manufactured, and taken promiscuously out of a heap of rails intended for the Darlington Rail-road.

EXPERIMENT II.

Weight in cwts.	Deflexion in inches	REMARKS.
28	.06	
56	.11	
84	.2	On the weight being removed it immediately resumed its original form; and to ascertain if any injury had taken place, the following experiments were made.
112	.35	
126	.47	
56	.11	When the weights were taken off, the bar again returned to its original form; the weights were then replaced, and the successive deflexions corresponded with the respective weights as in the former experiment.
126	.47	
131.5	.57	When unloaded it came back to its original form.
56	.115	The weights were again applied, and the respective deflexions found as described; the weights were allowed to remain on for some time, and, on being removed, a permanent deflexion had taken place of .0035 inches.
126	.48	
140	.63	
154	.92	On the weights being again added, the deflexions were nearly similar to those previously observed. When loaded with 154 cwt. the deflexion was found as stated; the weights were then removed, and it was found that the bar had acquired a permanent bend of .24 inches. The rail did not appear otherwise injured.

The following experiments, made on the flexibility of different sections of rails, will, it is trusted, be useful. The weights were applied by means of a steelyard, and the deflexion was measured by a screw, 17 threads to an inch, with a dial-plate showing the 64th part of a revolution of the screw, and thus exhibiting the 1088th part of an inch deflexion.

The form of the whole of these rails was similar to those given in *Fig.* VII. *Plate* II., consisting of the *top* or surface whereon the wheels traverse, and which constitutes the wearing part of the rail; the

rib or middle part; and the *keel* or under part, where the breadth is increased to present the strongest form of section: we shall therefore, for the sake of brevity, retain these terms of *top*, *rib*, and *keel;* the meaning of which will be understood by the above explanations. In all the experiments, the distance between the centre of the supports was precisely 3 feet; but each end of the rail rested upon the chairs intended for their use, the width of the base of which is stated in the account of each experiment. They are stated either to have been *fixed* or *loose;* when *loose*, the two ends only of the 3 feet were firmly fixed to the two chairs forming the supports of the apparatus; but when stated to be *fixed*, the rail was firmly screwed down to the apparatus, at each of the remaining divisions of the rail, or at every 3 feet.

The first column shows the weight applied to the middle of the rail in cwts.; the second column shows the deflexion in the middle of the rail while the weights were resting upon it; and the third column shows the deflexion after the weights were removed. The deflexion when the weights were removed and again applied is also shown; thus, in Experiment III., 4 weights were successively applied, amounting to 68 cwt., when the deflexion was found to be. 0386 of an inch; they were then taken off, and no permanent deflexion observed:

they were then applied again, and the deflexion found to be the same as before. This was the case with 5 weights, but on 6 being applied, equal to 102 cwt., the deflexion was .0615; they were then removed, and a permanent set of .0027 had taken place: the weights were again applied, and the deflexion was found to be greater than when the same weights were first applied, or .00624, show- that the rail had been injured.

EXPERIMENT III.

Wrought iron rail, 14 feet 11⅛ inches long, of five lengths, weight 167 lbs. Breadth of top 2¼ inches, depth 1 inch:—depth of rib 1 5/16 inches, breadth ⅝ inch;—depth of keel ¾ inch, breadth ¾ inch:—extreme depth in middle 3 1/16 inches, tapering away in a semi-elliptical curve to 2⅜ inches at each end. Breadth of chair 3¼ inches.

	SUPPORTS FIXED.				SUPPORTS LOOSE.	
Weight applied in cwts.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.
17	.0091		.0091		.0147	
34	.0183		.0193		.0294	
51	.0284		.0303		.0432	
68	.0386	.0	.0413	.0	.0579	.0018
	.0386		.0413		.0579	
85	.0468	.0	.0468	.0	.0744	.0036
	.0468		.0468		.0744	
102	.0615	.0027	.0624	.0027	.0919	.0101
	.0624		.0634		.0956	
119	.0753	.0055	.0762	.0055	.1149	.0202
	.0753		.0762		.1149	
136	.0900	.0122	.0910	.0091	.1470	.0367
	.0910		.0910		.1499	
153	.1107	.0165	.1106	.0156	.1801	.0615
	.1108		.1107		.1930	
170	.1126	.0248	.1124	.0275	.2573	.1264
	.1127		.1127			
187	.1158	.0477	.1168	.0496		

EXPERIMENT IV.

Wrought iron rail 14 feet 10 inches long, of five lengths, weight 157 lbs. Breadth of top $2\frac{1}{4}$ inches, depth $\frac{3}{4}$ inch:—depth of rib $1\frac{3}{8}$ inches, breadth $\frac{3}{4}$ inch;—depth of keel $1\frac{3}{16}$ inches, breadth 1 inch:—extreme depth in middle $3\frac{1}{8}$ inches, tapering away in a semi-elliptical curve to $2\frac{1}{2}$ inches, within $1\frac{1}{2}$ inches of each end*. Breadth of chair $3\frac{1}{4}$ inches.

	SUPPORTS FIXED.				SUPPORTS LOOSE.	
Weight applied in cwts.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.
17	.0110		.0128		.0174	
34	.0229		.0219		.0358	
51	.0367		.0312		.0523	
68	.0477	.0018	.0450	.0018	.0698	.0036
	.0477		.0450		.0707	
85	.0643	.0036	.0588	.0036	.0891	.0082
	.0643		.0588		.0891	
102	.0818	.0073	.0716	.0055	.1110	.0147
	.0827		.0726		.1112	
119	.1102	.0128	.0863	.0091	.1158	.0404
	.1106		.0882		.1163	
136	.1147	.0367	.1108	.0165	.1290	.1159
	.1152		.1112		.1310	
153	.1233	.1102	.1143	.0404	.1474	.1217
	.1246		.1147			
170	.1415	.1268	.1189	.0716		

* In this, and the two following rails, a convex projection, at the end of each 3 feet length, about $\frac{3}{8}$ inch depth, and 3 feet long, is rolled upon the under side, which fits into a corresponding concavity in the base of the chair.

EXPERIMENT V.

Wrought iron rail, 14 feet, 8 inches long, of 5 lengths, weight 162lbs. Breadth of top $2\frac{3}{16}$ 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 $1\frac{1}{2}$ inches from the end;—breadth of chair $3\frac{1}{4}$ inches.

	SUPPORTS FIXED.				SUPPORTS LOOSE.	
Weight applied in cwts.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.
17	.0064		.0064		.0091	
34	.0174		.0183		.0220	
51	.0294		.0312		.0340	
68	.0376	.0	.0422	.0	.0459	.0
	.0376		.0422		.0459	
85	.0487	.0	.0533	.0	.0606	.0
	.0487		.0533		.0606	
102	.0606	.0	.0634	.0	.0726	.0018
	.0615		.0634		.0707	
119	.0698	.0036	.0762	.0027	.0818	.0036
	.0698		.0762		.0836	
136	.0781	.0055	.0910	.0055	.0955	.0073
	.0781		.0919		.0955	
153	.0919	.0128	.1112	.0220	.1123	.0211
	.0974		.1115		.1130	
170	.1123	.0303	.1151	.0496	.1277	.1156
	.1125					
187	.1161	.0616				

EXPERIMENT VI.

Wrought iron rail 15 feet $\frac{1}{2}$ inch long, of five lengths, weight 196lbs. Breadth of top $2\frac{1}{4}$ inch, depth 1 inch;—depth of rib $1\frac{3}{4}$ inches, breadth $\frac{6}{8}$ inch;—depth of keel $1\frac{5}{16}$ inches, breadth 1 inch;—extreme depth $4\frac{1}{16}$ inches, tapering away in a semi-elliptical curve to $3\frac{3}{8}$ inches, within $1\frac{1}{2}$ inches from the end; breadth of chair $3\frac{1}{2}$ inches.

	SUPPORTS LOOSE.				SUPPORTS FIXED.	
Weight applied in cwts.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.
17	.0036		.0035		.0082	
34	.0110		.0110		.0174	
51	.0184		.0165		.0285	
68	.0275	.0	.0248	.0	.0386	.0
	.0275		.0248		.0386	
85	.0358	.0	.0294	.0	.0459	.0027
	.0358		.0294		.0459	
102	.0432	.0	.0386	.0	.0569	.0055
	.0432		.0386		.0569	
119	.0496	.0018	.0459	.0027	.0689	.0110
	.0496		.0459		.0698	
136	.0579	.0045	.0542	.0045	.0836	.0184
	.0579		.0551		.0836	
153	.0670	.0082	.0625	.0064	.1102	.0303
	.0670		.0634		.1106	
170	.0790	.0128	.0726	.0110	.1156	.0716
	.0799		.0735			
187	.0965	.0229	.0882	.11		

EXPERIMENT VII.

Wrought iron rail 14 feet $11\frac{3}{4}$ inches long, of five lengths, weight 18 lbs. Breadth of top $2\frac{1}{4}$ inches, depth $\frac{3}{4}$inch;—depth of rib $1\frac{15}{16}$ inches, breadth $\frac{5}{8}$ inches; keel round $1\frac{3}{16}$ inch diameter;—extreme depth $3\frac{7}{8}$ inches, parallel the whole length. Breadth of chair 5 inches.

	SUPPORTS FIXED.				SUPPORTS LOOSE.	
Weight applied in cwts.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.
17	.0073		.0064		.0082	
34	.0128		.0122		.0173	
51	.0173		0183		.0257	
68	.0239	.0	.0248	.0	.0349	.0
	.0239		.0248		.0349	
85	.0321	.0	.0312	.0	.0459	.0018
	.0321		.0312		.0459	
102	.0386	.0	.0386	.0	.0569	.0055
	.0386		.0386		.0569	
119	.0459	.0021	.0459	.0021	.0661	.0101
	.0459		.0459		.0661	
136	.0522	.0045	.0542	.0045	.0774	.0202
	.0522		.0542		.0774	
153	.0606	.0064	.0606	.0055	.0863	.0386
	.0606		.0606		.0882	
170	.0670	.0082	.0670	.0073	.1165	.0808
	.0670		.0670			
187	.3735	.0101	.0772	.0110		

These experiments being made upon rails of different sectional areas, will be useful in showing their relative strength and rigidity; a very great increase of effect will be seen to have taken place, when the rail was fixed at the joints beyond those at each end of the compartment on which the weights were applied. In all the cases, whether *loose* or *fixed*, the rail was keyed firmly down to the apparatus at each end of the 3 feet length on which the weights were applied; and when said to be fixed, the same effect took place when the next joints only, beyond those of the length on which the weights were applied, were keyed down, as when the remaining joints were fixed. This shows the advantage of long lengths of rail, and the necessity of adopting such a mode of securing the ends of the rails to the chairs, as will effectually prevent their rising up; a security of fastening of which pins seem incapable, and which keys alone, acting as a wedge, seem capable of effecting.

The section of all the rails experimented upon, except that in Experiment VII., were of the same principle; the under side between each of the supports being semi-elliptical; while in Experiment VII. the under side was straight, and parallel with the bearing surface. Experiments VI. and VII. will show the relative strength of the two forms, the weight being nearly alike in each; proper re-

gard must, however, be paid to the extra width of chair of the latter, and also to the circumstance of the top of the latter being .25 inch thinner than in the former. This thickness of iron laid along the top adding very little to the strength, would make the rail of 15 feet, 28lbs heavier; which would make the former 39lbs., and the latter 43lbs. per yard.

As the inquiry seemed of some importance, the following Experiment was made to ascertain the relative rigidity of the two forms. The rails rested upon the edge of a prism, and were in both cases precisely the same distance asunder (3 feet $\frac{1}{4}$ inch), and the experiment was conducted with the strictest regard to accuracy.

EXPERIMENT VIII.

Rail, No. 1. similar to that of Experiment I; length 15 feet 2 inches; weight 197lbs.			Portion of a rail, No. 2. similar to Experiment VII.	
Weight applied in cwts.	Deflexion with weights applied.	Permanent deflexion.	Deflexion with weights applied.	Permanent deflexion.
17	.0064		.0064	
34	.0156		.0165	
51	.0248		.0321	
68	.034		.0422	
85	.045	.0	.0523	.0
	.045		.0523	
102	.0561	.0	.0615	.0
	.0561		.0615	
119	.0716	.0	.0744	.0
	.0716		.0744	
136	.0873	.0036	.0919	.0042
	.09		.0919	
153	.1182	.09	.1111	.0257
	.1198		.1116	
170	.1351	.1193	.1246	.1154

We find from the above experiment, that the rail No. 1, is more rigid than No. 2, until the weights to which it was subjected became very great, and produced permanent injury; after which the rail No. 2, became less deflected by the

weights applied, and with a less permanent set. The rail No. 1, was, however, more rigid with weights, far beyond any to which it is likely to become subjected on a rail-road; and, therefore, on this account, the difference, if any, is in favour of the rail No. 1. The weight of No. 1, is 39lbs. per yard; and No. 2, 37½lbs. per yard; but on observing the section it will be found that the top, or wearing part of the rail No. 1, is 1 inch, while in No. 2, it is .75 inch; the former rail will, therefore, allow the wear of .25 inch on the top, and still have the same wearing depth of section as No. 2. Or if we lay .25 inch on the top, it would make No. 2, as before stated, equal to 43 lbs. per yard, without adding much to its rigidity.

On comparing Experiments VII. and VIII. it will be seen, that, as might be expected, when the rails merely rested upon the supports, as in the latter case, the deflexion is greater than in the former case, with the same weights. But it will be observed, that in the latter case, the rail bore a considerably greater weight without permanent alteration; a similar effect will likewise be observed on comparing experiments VI. and VIII.

We come now to the question of comparative durability between cast and malleable iron rails. The introduction of the latter being comparatively recent, the opportunity to subject 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 almost 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, adduce such as our experience enables us, 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, are 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 showing 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 common 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 3 tons each, with 3 feet wheels, the relative wear of the wheels and rails are as 53 : 1 nearly.

The average wear of the cast-iron wheels was above $\frac{1}{2}$ inch in 9 months; and with the wrought-

iron tire, the wear of one pair of wheels has been ¼ inch in 3 years, and with three other engines ⅛ inch in 12 months; making the wear at least as 5 to 1 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.

The very great difference of wear in the wheels, proves, beyond any doubt, that if rails of the proper degree of strength be used, the durability must be decidedly in favour of wrought-iron rails; and we have before observed, that practice has shown, that in rails properly manufactured, none of the exfoliation, lamination, or oxidation originally dreaded, exists.

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

* See Note B, Appendix.

slight; and observation showed that, to a certain extent, the resistance appeared greater than upon cast-iron; and this, as may be supposed, was owing to the bending.

To ascertain, if such was the fact, to what extent, and to what strain they 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 close to each other, upon the same balks, 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 unequally loaded, became like a pendulum, by the centre of gravity being thrown near the periphery on one side; and they would of course only remain at rest, when the line of gravity passed through the centre of the axle joining the two wheels, and that point of the periphery resting on the rails: the wheels were then rolled along the rails, until the centre of gravity was several inches beyond the point of bearing, and when let go, it of course vibrated backwards

and forwards, until the resistance of the periphery upon the rails brought it to rest. This mode of experimenting was preferred to trying the relative resistance by carriages; as, in this way, there was 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 became very delicate. A scale was used to measure the extent of each vibration from the centre, and the observations made by a telescope: the number of oscillations were thus counted, while the extent of the vibrations were diminished each inch. Thus, at the commencement, the extent of the vibrations from the point of rest was 5 inches; and the wheels made 56 vibrations before this was diminished an inch, or until the extent of vibrations from the centre was 4 inches. The cast-iron rails were 3 feet 9 inches long, and weighed 56lbs.; section shown in *Fig.* III. *Plate* II. The wrought-iron rails weighed 28lbs. per yard, the bearings 3 feet apart; section same as Experiment II. on the strength of rails.

EXPERIMENT I. EXPERIMENT II.

Extent of vibrations.	Weight of wheels, &c., 10 cwt.				Weight of wheels, &c., 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 to 3	74	78	68	80	64	70	64	66
3 to 2	88	22	84	100	84	82	92	86
2 to 1	87	86	98	84	99	110	142	150

EXPERIMENT III. EXPERIMENT IV.

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

These experiments will shew, 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 the rails of wrought-iron, upon which these experiments were made, were only sufficient for carriages of four wheels, weighing three tons. The deflexion with 30 cwt. was .032 inch, with 40 cwt. .043 inch; so that we find it will not be advisable to use rails, the deflexion of which when loaded amounts to .032 inch, especially when the rails are laid down of this strength; as when they become worn, the deflexion 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 sup-

pose 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, their rigidity should be such, as that, by carriages with springs, one-fourth; and by carriages without springs, one half of the weight will not cause a deflexion in the middle of the rail equal to .032 *parts of an inch.*

And considering that, in the experiment, the weights were applied carefully upon the rail; and that in practice, the weight, especially in carriages without springs, will be occasionally imposed with great abruptness, it will always be advisable, independent of making proper allowance for wear, to adopt rails of more than sufficient rigidity to resist any injurious deflexion by the weight of the carriages. The tables of experiments on the rigidity of different sections of rails, will be useful in determining the proper strength for practice; both for single lengths, and with rails of several compartments in one length.

The experiments on the comparative resistance of cast and malleable iron rails, 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 these experiments is, therefore, that no increase of resistance 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 VI.

ON THE FRICTION, AND RESISTANCE OF CARRIAGES MOVED ON RAIL-ROADS.

In all carriages, moved on rail-ways, 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 wheel upon the road; 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 obstructions 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 whole weight of the body is subjected to the action of attrition, over the whole surface of the plane, 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 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 diameter of the respective circles.

We have, therefore, 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: whenever two surfaces are brought into contact with each other, and subjected to a determinate pressure, it requires a certain force to

cause them to slide over each other, and the obstruction to the free motion of the carriage, arising from this cause, is called the *friction* of, or resistance by, *attrition;* and the retardation by the action of the periphery of the wheels rolling upon the rails, the *rolling friction* or resistance; and as in general, in all wheel carriages, the two species are in motion at the same time, where it is not particularly expressed to the contrary, the term friction will be understood to comprehend both kinds of friction combined. It will be afterwards necessary, when treating of loco-motive carriages, to speak of that property of bodies in contact, the surfaces of which resist sliding over each other, as employed for a mechanical purpose; the employment of that force, 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 these 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 after-

wards, when treating of rapid motion, recur to these obstructions.

Let f = the resistance opposed to the free motion of a carriage upon a Rail-road, 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 be preferable.

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, independent 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 as circumstances will permit.

In order to obtain a correct knowledge of the resistance of carriages moved on Rail-roads, 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 Rail-roads; but in the latter, and in all rubbing surfaces, it is a subject of the utmost importance, to ascertain what extent of bearing surface, in proportion to the weight, produces the least friction. The opinions of different men of science, on this point, are very various, and the experiments made, have not settled the question satisfactorily. These reasons, therefore, induced me, since the publication of the first edition of this Work, to institute a set of experiments for the solution of the difficulty; from which it results, that there is a certain size of bearing compared with the insistant weight, when the friction is a minimum.

Previously, however, to entering into a detail of the experiments on the resistance of wheel carriages

moved on Rail-roads, it may be necessary to explain a little more fully the laws which regulate the action of bodies, moved upon Rail-roads, about which considerable ambiguity has existed.

It is a well known law of dynamics, that every body has a tendency to continue, either in a state of rest, or of uniform rectilinear motion, unless disturbed by some extraneous mechanical force. Let, therefore, a carriage be placed upon a Rail-road, and a certain velocity be given to it, by any force or pressure whatever;—if we suppose the body and plane perfectly void of friction, and free from the action of any other force, then the body will continue to move on uniformly with the velocity given to it; for the body has no power in itself to change that velocity, and it is not supposed to be effected by any other mechanical force whatever. Suppose, now, instead of the body being perfectly free from friction, that its motion is continually opposed by a certain determinate force or pressure, which is always acting with the same intensity in retarding the progressive motion of the body; then the body, instead of continuing in a state of uniform motion, will, by the constant retardation of this force, be soon brought to a state of rest.

Suppose, however, when it is in a state of uniform velocity, and subjected to the action of this retarding force, we apply, or cause a force continually to act upon the body to urge it forward

with the same intensity of pressure, that the retarding force or friction of the body opposes to its progressive motion; then the body will still continue to move on in a state of uniform velocity, and with the same velocity originally given to it.

When, therefore, a carriage is placed upon a Rail-road, and a continual pressure is exerted upon it to urge it forward; and it is found with whatever velocity the carriage is moved, (supposing the moving force to proceed with the same velocity), the pressure required to keep it in a state of uniform motion, is the same at any velocity; then the friction is said to be a constant or uniformly retarding force, of the same intensity, whatever be the velocity with which the body is moved. The force or intensity of pressure, therefore, required to act upon the body to move it over any determinate space at different velocities, will be the same at each instant of time: consequently, the aggregate amount of power required to drag any body over a given space, will always be the same, whatever be the velocity with which it is moved; for if we traverse that space in half the time, it will, of course, require the moving power to travel at twice the velocity, and the aggregate effort of mechanical power will, therefore, be double; but as it only acts half the time, the aggregate amount of force will consequently remain the same: and the intensity of power required to continually keep the body in motion, at twice the velocity, will, of

course, be twice that required to keep it constantly moving at half the velocity; which will, perhaps, be more clearly explained by the following diagrams:—

I.

Velocity V, at which the body is moved .	1	2	3	4
Resistance of carriage, or body, B. . .	10	10	10	10
Spaces passed over, S	1	1	1	1
Then the mechanical force required to propel the carriage B, over the space S, at the velocities V, will be	10	20	30	40
But the time T, during which the above force is required to act, is	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
And, therefore, the total quantity of power expended in moving the body B, over the space S, will be	10	10	10	10

OR

Velocity V, at which the body is moved .	1	2	3	4
Resistance of carriage, or body, B . .	10	10	10	10
Times T, during which the force acts . .	1	1	1	1
Then the mechanical force, required to act continually (or in the time T,) upon the body B, to cause it to move at the velocities V, will be	10	20	30	40
And consequently the spaces which the body B, will be impelled by the above force, during the time T, will be	1	2	3	4

If, again, experiment proves that the intensity of force required to urge the body forward is not the same at all velocities, but increases in the ratio of the velocity; as, for instance, if, when the body is moved forward at twice the velocity, the pressure indicated by a dynamometer be twice as great as

when moving at half that velocity, then the aggregate amount of force required to move the body over the same space, will be twice that required to move the body over a given space at half that velocity; and consequently, by traversing that space in half the time, the moving power will also travel at twice the velocity, and therefore, the mechanical power required will be four times the amount acting half the time; and the undermentioned diagram will shew the mechanical force required at different velocities.

II.

Velocity V, at which the body is moved .	1	2	3	4
Resistance of carriage, or body, B, . .	10	20	30	40
Spaces passed over, S, ...	1	1	1	1
Then the mechanical force required to propel the carriage B, over the space S, at the velocity V, will be	10	40	90	160
But the time T, during which the above force is required to act, is	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
And, therefore, the total quantity of power expended in moving the body B, over the space S, will be	10	20	30	40

OR

Velocity V, at which the body is moved .	1	2	3	4
Resistance of carriage, or body, B, . .	10	20	30	40
Times T, during which the force acts .	1	1	1	1
Then the mechanical force, required to act continually (or in the time T) upon the body B, to cause it to move at the velocities V, will be	10	40	90	160
And, consequently, the spaces which the body B, will be impelled by the above force, during the time T, will be . . .	1	2	3	4

Again, if experiment proves that the resistance increases in the ratio of the square of the velocity, then the amount of mechanical force required to move the body forward at different velocities, will be as follows:—

II.

Velocity V, at which the body is moved .	1	2	3	4
Resistance of carriages, or body, B, . .	10	40	90	160
Spaces passed over, S, ...	1	1	1	1
Then the mechanical force required to propel the carriage B, over the space S, at the velocities V, will be	10	80	270	640
But the time T, during which the above force is required to act, is	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
And, therefore, the total quantity of power expended in moving the body B, over the space S, will be	10	40	90	160

OR

Velocity V, at which the body is moved .	1	2	3	4
Resistance of carriage, or body, B, . .	10	40	90	160
Times T, during which the force acts . .	1	1	1	1
Then the mechanical force required to act continually (or in the time T) upon the body B, to cause it to move at the velocities V, will be	10	80	270	640
And, consequently, the spaces which the body B, will be impelled by the above force, during the times T, will be . . .	1	2	3	4

It would not have been necessary, to be thus particular in the elucidation of the effects of friction, or resistance to bodies moving in obstructing mediums, had not considerable ambiguity existed in the amount of force necessary to move bodies, at different velocities in the several cases. I trust

the foregoing explanation, if it do not entirely dispel the ambiguity, will at least acquaint the reader with the sense in which I shall hereafter wish it to be understood in the work.

It has 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 Rail-roads : 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 have been made on the weight which a horse could drag upon a carriage on a Rail-road, but, as we had no measure of the force exerted by the horse, the resistance of the carriage could not be thereby ascertained.

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 I have been favoured. He laid a cast-iron rail-way down upon beams of wood, and placed upon this Rail-way 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 Rail-way, states the result of some experiments, made on the friction of carriages, moved along different kinds of Rail-roads: he makes the resistance considerably greater than Mr. Grimshaw, amounting to the eighty-seventh part of the weight, as found upon the Edge Rail-road, from the Penryn slate quarries; but, as this must have been owing to some difference in the construction of the Rail-way 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.

Impressed with the importance of knowing the precise amount of resistance opposed to the motion of carriages along Rail-roads, 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 Rail-road, 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, A, *Fig.* VI., *Plate* VI., was suspended by the arm *b*, from a well turned and perfectly smooth axle *e*, moving freely upon a brass carriage or chair, which was kept well oiled, and moved with very little friction. A grooved quadrant, *d e*, accurately formed, was fixed at the extremity of the pendulum, and moved with it, as shewn in the drawing. 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 at *e*, 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 pointer should indicate *o*.

It will be easily seen, from an inspection of the drawing, that when the pendulum was left at liberty, it would assume a position perpendicular to the horizon, or hang freely down; and that it would require a certain force to remove it from that position, which force would range according to the different angles it was made to form with respect to the horizon. The dotted line *eg*, will represent the arc of the circle, which the pendulum would describe; and the greatest force, which it

would present to any power drawing it out of the position it would assume, would be when it arrived at *g*, or become 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 steel yard, 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 horizontal arm known weights were suspended, and from the end of the perpendicular arm a rope proceeded, which passed round the grove of the quadrant, and was fastened at *d*. 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 index. The same rope was used in the experiments, that was made use of to adjust the instrument.

This instrument, which is a perfect dynamometer, was firmly fixed to the carriage CD, by the frame *ffff*, 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 by which they are usually drawn along the Rail-road.

The carriage containing the dynamometer was placed upon the Rail-road, and the rope fastened to the carriage, the friction of which was the subject of experiment, in the same manner as represented in the drawing, Manual labour was then applied to the dynamometer carriage to push it along the Rail-road, and the rope being fastened to the waggon, it was also drawn forward. 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 Rail-road.

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 dynamo-

meter, 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 Rail-roads.

The rails were of cast iron. — Edge-rails of Messrs. Losh and Stephenson, *Fig.* I. *Plate* II. Flat bearing surface 2½ inches broad, 3 feet 9½ inches 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 *Fig.* VII. *Plate* VI. The wheels were fixed upon the axles, and turned with them; their diameter was 34 inches, with a projecting ledge of ¾ 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, 2¾ inches 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.
		lbs.	lbs.	lbs.
1	Loaded carriage, weighing 23¼ cwt., and containing 53 cwt. of coals, total weight 76¼ 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
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
3	Four empty carriages, each weighing 23¼ cwt. Three with case-hardened wheels, and one with wheels not case-hardened. Same kind of bearings as No. 1. .	74	32	53
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
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, 1¼ inches broad	112	70	91
6	The preceding twelve empty carriages together	277	149	213
7	*Four empty carriages, and weighing 23¼ cwt., all with case-hardened wheels, and cast-iron bearings, similar to No. 1. .	72	29	50
8	Four empty carriages, same weight, with case-hardened wheels, and brass bearings, same as No. 2. . . .	75	33	54
9	Four empty carriages, same weight, wheels not case-hardened, half worn. Bearings similar to No. 7.	90	48	69
10	Four empty carriages, same weight, wheels same as preceding, or No. 9. Brass bearings, similar to No. 8. . . .	96	54	75
11	Four empty carriages, same weight, case-hardened wheels. Wrought-iron bearings same as No. 5.	89	47	69

* 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 these experiments in the construction of these carriages. The carriage No. 1, was of the most modern construction, and the resistance upon a level plane amounted to no more than 39lbs. The carriage No. 2, required 63 lbs., 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 21lbs., which must arise from the wheels alone. The whole weight of those carriages was 93 cwt.; 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 4 lbs., 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 size, compared with the pressure upon them, and shews that the brass is considerably below that size; 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 I 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 19 lbs. between that kind of bearing and the cast iron, and 15 lbs. 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 these two causes is very considerable, and when properly estimated, are of great moment in the economy of Rail-road conveyance. The two together, amount to the 275th part of the weight of the carriage, and equal to 43 per cent. of the whole amount of friction.

The following are some experiments, which I made upon the Hetton Colliery Rail-road, 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 11 feet, 2 inches, in the whole distance; edge-rail, of Losh and Stephenson's patent, $2\frac{1}{2}$ inches 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 W = 8906 and $w \frac{SO}{SG}$ (as per experiment)2095 lbs.

We have by 9 $F = W + w \sin. I - \frac{W + w \frac{SO}{SG} \times S}{r\, t^2} = 1574$ lbs.

And $\frac{1574}{4} = 39.35$ 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, 1266 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 rather to one side, and causing the projecting ledge of the wheels to press or rub against the side of the rail, and thus, consequently, augment the friction. The increase of resistance or retardation caused by the wind is sometimes very considerable, especially when the direction is oblique to the line of the road; as then, the wind not only acts by its direct impulse upon the carriages, but also by forcing the wheels against the side of the rail, and increasing the friction by the projecting ledge rubbing against the rail. In the last three 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.

By comparing the friction of the empty with the loaded carriages, we might have found if the friction increased in the direct, or any other, proportion with the weight; as, however, the carriages experimented upon were not all the same, though of the same construction, it was necessary to try the friction directly, by loading the same carriages

with different weights, and the following experiments were made for that purpose, with the dynamometer.

EXPERIMENT VII.

Number of experiments.	DESCRIPTION OF CARRIAGES.	Resistance up the plane.	Resistance on a level.
1	Carriage with common wheels and cast-iron chairs, four inches broad, wheels thirty-four 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, loaded 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

Having thus ascertained the friction relative to the weight, the following experiments were made

with the dynamometer, to ascertain the friction or resistance of carriages, moving at different velocities on a plane rising 1 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, thirty-four inches diameter; and wrought-iron axles two and three quarter 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 their passage 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.

To determine this question by a method different from the preceding, and where, perhaps, the liability to error was less, I lately made the following experiments upon a stage, or piece of Rail-road, selected for the purpose. A perfectly straight plane, of the Edge Rail-road, 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 inertia. The descent of the plane, was 1 yard in 104, or 134 inches, in 13968 inches.

EXPERIMENT IX.

No. I.			No. II.			No. III.		
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	1045.
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 $2\frac{3}{4}$ 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 the Edge Rail-road.

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 being 1.	Ratio of diameter of wheels to diameter of axles, or of rolling to rubbing action dia. of axles being 1.
1	By dynamometer. Exp. I. No. 1	8540	7280	39	219	12.36
2	Ditto . . . . . No. 7	2604	1344	12.5	208	12.36
3	Ditto . . . . . No. 8	2604	1344	13.5	193	12.36
4	Ditto . Exp. VII. No. 1	4816	3584	26.	185	12.36
5	Ditto . . . . . No. 2	7056	5824	34.	207	12.36
6	Ditto . . . . . No. 3	8512	7280	40.	213	12.36
7	Ditto . Exp. VIII. . .	8456	7224	39.	217	12.36
8	By inclined Plane. Exp. II. . . .	9408	8096	39.35	239	11.6
9	Ditto . Exp. III. . . .	9408	8096	39.35	239	11.6
10	Ditto . Exp. IV. . . .	9408	8096	41.46	226	11.6
11	Ditto . Exp. V. . . .	9408	8096	44.19	212	11.6
12	Ditto . Exp. VI. . . .	3472	2160	12.73	272	11.6
13	Ditto . Exp. IX. . No. 1	9408	8096	41.45	226	11.6
14	Ditto . . . . . No. 2	9408	8096	44.18	212	11.6
15	Ditto . . . . . No. 3	3472	2160	12.75	272	11.6
16	Ditto . Exp. X. . . .	9160	7840	39.	238	12.36

By the above table, it will be seen that the least amount of resistance is equal to the 279th part of the weight of the carriage; and the greatest equal to the 185th, the average being more than

the 200th part of the night. By a comparison of the resistance of the carriages of different weights, the friction does not appear to be precisely in the ratio of the weight. As previously shewn, the whole resistance is resolvable into two parts, that which acts upon the axles, and that upon the rails. The whole of the weight of the carriage is subjected to the action of the latter resistance, while only that part which rests upon the axles is subjected to the action of the former; the wheels and axles only partaking of the rolling action. When, therefore, we place different weights upon the same axles, the ratio which the weight subjected to rubbing, bears to that of rolling, will vary; and therefore the aggregate ratio of resistance will vary in carriages of different weights. Thus, in Experiment VII., where the carriage was loaded with different weights, the weight subjected to attrition in Nos. 1, 2, and 3, is to the weight subjected to rolling as 1584, 5824, and 7289, to 1232. The total resistance, in these cases, is equal to the 185th, 207th, and 213th part of the weight respectively; and this proves, that the resistance by rolling is, as might be expected, considerably less than that by attrition; and hence, as the ratio of the latter increases, the aggregate resistance is greater.

These considerations shew the necessity of determining the resistance of each species of friction separately; not only to render our information on this important part of the subject more com-

plete, but because we cannot otherwise calculate "*a priori*," the friction of any carriage, by experimenting upon a carriage of a different weight. Impressed with the importance of obtaining this correctly, since the publication of the former edition of this work, I instituted the following set of experiments, on the resistance of the wheels alone, upon the rails, for the purpose of ascertaining the amount of that species of friction separately, and from which we might also deduce the resistance by attrition.

By causing a carriage to descend an inclined plane, or otherwise ascertaining its aggregate resistance, and loading it with different weights; 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 causing the wheels and axle to descend inclined planes alone; and thus to ascertain the resistance of rolling friction, independently of the resistance of attrition.

To accomplish this, I took two wheels, connected together by an axle, in the usual way; and loading those wheels with various 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.

The rails were cast-iron, with half lap joints, bearing surface 2½ inches 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	2.0645
400	3.9853
500	4.9228

EXPERIMENT XI.

Weight of wheels and axle ..... 595 lbs.
Case-hardened, diameter, 34.5 inches, nearly.
By experiment SO = 26.49 inches; and SG = 17.248 inches.
By formula (6) $F = \frac{SG}{SO} \sin. I - \frac{S}{rt^2}$

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 inch. nearly.
By experiment, SO = 26.51 inch.
SG = 17.248 do.
By formula (6) $F = \frac{SG}{SO} \sin. I - \frac{S}{rt^2}$.

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, SO = 22.447 inch.
SG = 17.248 inch.

EXPERIMENT XIV.

Weight of wheels and axle, 2072 lbs.
Same wheels as Expt. XII.
By expt. SO = 26.70 in.
SG = 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 second.
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 . . SO = 26.10 inches.
SG = 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 II.

	FRICTION IN PARTS OF THE WEIGHT.				
Terminal velocity in feet per second.	Weight of wheel, 595lbs.	Weight of wheel, 656lbs.	Weight of wheel, 2095lbs.	Weight of wheel, 2472lbs.	Weight of wheel, 4480lbs.
550 to 625	.001181	.001157	.001278	.001129	..
809 to 894	.001377	.001350	.001255	.001015	..
10 to 1127	.001400	.001479	.001258	.001075	..
1133 to 1287	.001440	.001490	.001201	.000985	..
1248 to 1445	.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 864th, to the 640th part of the weight; the former, however, are lighter than the presure of almost any wheel carriage on a Rail-road, and, therefore, we ought to take the latter as the resistance generally. These vary from the 800th to the 1000th part of the weight. When, however, we consider that, in making the experiments, there was nothing to

confine the wheels to move in a straight line, except their periphery, being formed a little conical; that the least difference in the diameter of either of them, would destroy their parallelism, 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 securing 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, 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 1000 part of the weight. We find from these experiments, that this ratio 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; so 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 III.

	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 in lbs.	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	239	12.36	19.
2	2604	1344	12.5	2.60	9.90	136	12.36	11.
3	2604	1344	13.5	2.60	10.90	123	12.36	10.
4	4816	3584	26.	4.81	21.19	169	12.36	13.6
5	7056	5824	34.	7.05	26.95	216	12.36	17.4
6	8512	7280	40.	8.51	31.49	231	12.36	19.
7	8456	7224	39.	8.45	30.55	236	12.36	19.
8	9408	8096	39.35	9.40	29.95	270	11.6	23.2
9	9408	8096	41.46	9.40	32.06	252	11.6	21.7
10	9408	8096	44.19	9.40	34.79	232	11.6	20.
11	3472	2160	12.73	3.47	9.26	233	11.6	20.
12	9100	7840	39.	9.10	29.90	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 20th 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.

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 sufficient in many cases for practical purposes, yet by no means tend to bring the enquiry into any more settled state. In Nos. 1 and 6, and the following experiments, the ratio only varies (except in one instance) from the 19th to the 21st 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, —might 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; yet still this ratio is greater than shewn by former experimentalists.

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. Under these circumstances, and considering the importance of obtaining the most correct information on the subject, 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 Rail-road. 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 are conducted with the utmost care, and repeated several times to obtain correct results.

Experiments made on an edge Rail-road, half lap-joints, surface $2\frac{1}{4}$ inches broad, carriage with brass bearings three inches broad, wrought iron axles 2.9 inches diameter, and case-hardened cast-iron wheels 34.497 inches 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, semi-circular, 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	41.25	.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.		.0 02218	. . . .	.002061	. . . .	.001978	. . . .	.001854	. . . .	.002033

TABLE IV.—Brass Bearings three inches broad.

	Total weight of carriage on rails, 10972 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
Total resistance { equal to the	434th	472nd	489th	516th	468th
Total resistance { 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
Friction on axles { in parts of weight	.01779	.01600	.01611	.01771	.02936
Friction on axles { equal to the	56th	62nd	62nd	56th	34th

TABLE V.—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	452nd	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	62nd	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 10272lbs., equal to 22.78lbs.; the rolling resistance of the wheels is supposed to be equal to the 1000th part of the weight or 10.72lbs., which leaves 12.5lbs. 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 $716 + \frac{2.9}{34.497} = 60$th 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 any carriage along a Rail-road $P = \frac{W}{f} + \frac{W'}{f'\frac{d}{D}}$

where, by the above experiments, $f = .001$, or the 1000th part of W, the whole weight of carriage and wheels; and $f' = .01666$, &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 Rail-roads; 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 Rail-road, with the axles lucubrated with the best neat's foot oil; may account for the great reduction, compared with that of the former experiments, and in this case, good neat's foot oil was used, and applied at the commencement of each experiment; whereas, in the former experiments, 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 had an axle fitted up, which was placed upon two chairs, or bearings; by which the rubbing friction 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 had 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 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 30 feet; a wheel was fixed in the middle of the axle, 2 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 thus elevated precisely 30 from the platform: by withdrawing a pin, the weight was then let free, and, falling 30 feet, unwound the cord, and put the axle and lead weights into rapid motion ; the cord then detached

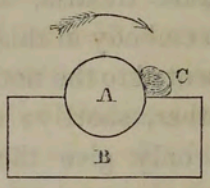
itself, and left the axle to turn freely round, until the friction of the axles brought it to rest. By a proper apparatus, the time occupied, during each 10 revolutions, of the axle, was measured, as also, the whole time, until it came to rest; by which means, not only the absolute amount of friction was obtained; but, also, the friction at different velocities; and, by varying the weights, from 1331lbs. to 4140lbs., 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, what size of bearing, subjected to a given pressure, produced the least resistance. With this view, bearings of 3, $4\frac{1}{2}$, and 6 inches, respectively, were used; the diameter of the axle being 3 inches; and, on each of which, the successive weights of 1331, 2465, 3622, and 4140lbs., were placed. With these materials, the number of experiments made, were more than 600, and varied in every possible way, to leave no doubt, as to the accuracy of the result; the weight, in each experiment, falling precisely 30 feet.

It would be carrying the subject too far, to give a 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 sub-

ject, 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, shortly; and I shall therefore, at present, only give the result of those, which seem to apply more particularly to the subject of our inquiries.

As before stated, the weight which put the axle in motion, was made to fall in every experiment, precisely 30 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. 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 VI.

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.	Vibration of pendulum.	Number of revolutions.	Number of experiments.	Vibration 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 30 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 time in 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 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 were found, as shewn in the Table, until the end of the 300th experiment, when the number of revolutions, by the same moving force, was only 37; 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, when the nnmber 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 36; 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 36 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, 5 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 12 times that of the axle, the distance traversed in the above number of revolutions would be about $3\frac{1}{2}$ miles.

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 the surfaces, diminish the friction, by causing the surfaces to roll, instead of 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 will most effectually prevent the contact of the surfaces, will be that which is the least fluid; while that 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, therefore, 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 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,—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 the 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 III., and those in Tables IV. and V.; the former were made with the common coal waggons, where, from their construction, an unguent of a viscid nature was obliged to be used, which, no doubt, operated to increase the resistance; while those in Tables IV. and V. 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 IV. and V. 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 III., 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 IV. and V., and hence the diminution of effect.

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 neatsfoot oil.

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	148.12	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 between 58.60 and 86.12, and at 87.90 lbs. pressure, per square inch of surface, respectively. In the first column, the effect had not attained its maximum; as the pressure was only 73.82 lbs. per square inch. The former experiments gave the pressure, 98 lbs. per square inch of surface; which agrees pretty well with the above experiments.

Supposing, therefore, 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 $1\frac{1}{2}$ 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.

Having thus entered into the various phenomena of friction, and developed the laws which govern its action, upon the axles of carriages; it will be seen that we are far from having attained a maximum effect; this, however, will require time to accomplish, and we must, therefore, determine upon some data for practice.

We have previously given experiments upon the carriages used at the collieries in the north, but public attention having been recently so intensely directed to this subject, many plans of carriages have been suggested to the public companies of rail-ways; and we have been favoured by the directors of the Liverpool and Manchester Railway, with some experiments, made by Messrs. HARTLEY and RASTRICK, on three plans 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 20 inches diameter, which ran upon the rails; the axles of these projected though the naves, the ends being 1½ inches 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 1½ inches long. No. 2, did not differ from this in construction, except the travelling wheels, which were in this case 30 inches in diameter, 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, 30 inches in diameter; the axles 3 inches in diameter. One of the axles rolled upon the apex of the rim of two friction wheels, 12 inches in diameter, and 3 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 2 inches diameter, and $2\frac{1}{2}$ inches 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.* IV. and V., *Plate* III., consisting of a platform resting on four travelling wheels, 3 feet diameter, case hardened; the axles, as shewn in the drawing, passed through the nave, were turned down to $1\frac{3}{8}$ inches in diameter, and rested upon bearings of brass $3\frac{1}{4}$ inches in length, working upon springs.

Knowing that the friction of rolling is less than that of attrition, Messrs. Brandreth and Winan expected, by disposing a much greater portion of the motion 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 $2\frac{1}{4}$ inches 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, along which, the momentum acquired

in their descent of the other plane, caused them to run until the friction brought them to rest. The difference of level betwcen the two planes, (in the space passed over), with the distance traversed, giving the amount of friction.

The following Table will shew the result:—

TABLE VIII.

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.	1	1467	12	119.75	1166	2633	11.61	1/227	9.88
	2			116.75	1433	2900	11.33	1/256	8.75
	3	2.220	20	145.50	1865	4085	18.91	1/216	10.37
	4			145.00	1989	4209	18.81	1/214	10.10
	5			141.00	2711	4931	18.32	1/269	8.32
	6	2.604	24	149.50	2957	5561	22.15	1/251	8.92
	7			149.50	3221	5825	21.95	1/265	8.44
	8	3.364	32	176.00	3877	7241	29.30	1/247	9.06
	9			175.00	4013	7377	29.19	1/253	8.86
Wind scare of carriage, 10 square feet.									
Mr. Winan's carriage, No. 2, weight 13½ cwt., loaded to 4 tons.	10	3.364	32	193.50	2486	5850	30.43	1/192	11.65
Mr. Brandreth's carriage, No. 1, loaded with stones to 4 tons.	11	1.467	12	123.25	1101	2568	11.66	1/219	10.21
	12			123.25	1115	2582	11.65	1/222	10.11
	13	2.220	20	147.00	1914	4134	18.87	1/219	10.23
	14			146.00	2025	4245	18.78	1/226	9.92
Wind scare of carriage, 12 square feet.									
Mr. Brandreth's carriage, No. 2, loaded with stones to 4 tons.	15	2.982	28	177 50	2175	5157	26.66	1/193	11.58
	16			177.00	2448	5430	26.45	1/205	10.91
	17	3.364	32	185.00	2925	6289	30.18	1/208	10.75
	18			187.00	2648	6012	30.36	1/198	11.31
Wind scare of carriage, 18 square feet.									
Mr. Stephenson's carriage, on springs, with 3 feet wheels, loaded to 4 tons.	19	1.467	12	115.25	1744	3214	11.00	1/292	7.67
	20			115.25	1706	3173	11.03	1/288	7.79
	21	2.220	20	148.00	2427	4647	18.48	1/251	8.91
	22			142.50	2418	4638	18.46	1/251	8.92
	23			140.00	2517	4737	18.42	1/257	8.71
	24	2.604	24	159.50	3007	5611	22.12	1/254	8.83
Wind scare of carriage, 13 square feet.	25			156.00	3008	5612	22.12	1/254	8.83
	26	3.364	32	177.00	3809	7173	29.36	1/244	9.17
	27			176.00	3839	7203	29.34	1/246	9.17

In making these experiments, the rails were swept quite clean, and kept free from any extraneous matter, that would have the effect of diminishing the friction; though when worn bright with use, the surfaces will be much smoother than the state in which the rails were when the experiments were made, and therefore 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 the road; sometimes with a velocity equal to three miles per hour, and at other times quite calm. Temperature varying from 32° to 35°.

On examining these experiments, it will be seen, that the reduction of friction which was anticipated, by the adoption of 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.

Supposing the rolling friction, equal to the 1000th part of the weight, and the weight of the wheels and axle to 12 cwt., the rubbing friction in No. 19, will be the $\frac{1}{13.5}$ and in No. 26, the $\frac{1}{11}$ of the insistent weight, or $f' = .074$ and $.0948$. In Table III. we have $f' = .05$, and in the experimental carriage of Tables V. and VI. $f = .0166$. In the experiments with Mr. Stephenson's carriage, the maximum velocity was much greater

than in the other experiments, being about 17⅓ and 26⅓ miles per hour. But that, it is presumed, will scarcely account for the difference of effect. Probably the area of bearing is too small for the insistent weight, rendering the oil incapable of preventing the contact of the rubbing surfaces.

The pressure per square inch of bearing surface, we have previously found should be, when the friction was a minimum, about 98 lbs. In these carriages, the pressure would be about 273 lbs. which will probably account for the diminished value of f'.

On an attentive consideration, of all these experiments, upon the friction of carriages; we arrive at the following conclusions, viz.

That, in practice we may consider the friction of carriages, moved along Rail-ways; 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 see, however, from the previous experiments, that at present no settled standard can be assigned to the actual amount of friction. Considerable improvements have already been made upon the old carriages, and these experiments shew that still further improvements in the reduc-

tion of friction may yet be effected. We have entered somewhat largely into this part of the subject, which perhaps requires an apology: but when it is considered, that it embraces that part of the economy of rail-roads, which relates to the *only obstacle opposed to the free motion of the carriages used upon them;* it is trusted, that if these experiments have a tendency to elucidate the principle, on which we must proceed to effect a further reduction of this obstacle to the moving power, it will be a sufficient apology for having extended our enquiries to such a length.

We shall now endeavour to deduce, from the foregoing experiments, some data which may be relied on in practice. In the former edition of this work, we assigned the $\frac{1}{200}$ part of the weight as the friction in practice; we have no reason for altering this in common carriages; but considering the improvements that have since taken place, and the results shown in the subsequent experiments, we are induced to suppose, that the resistance may be taken in practice at the 240th part of the weight, when the carriages are in good working order. We may, therefore, adopt the formula $P = \frac{W}{f} + \frac{W'}{f'}\frac{d}{D}$ where f $= .001$, and according to Table III. $f' = .05$, when the pressure per square inch of bearing does not exceed 100 lbs.; but if this ratio is either exceeded or diminished, we must make corres-

ponding allowances, the necessity of which is shewn in Table III.

The following Tables will then shew the resistance of a carriage, on different inclinations of road; taking the friction at the 200th, and 240th, part of the weight respectively.

TABLE IX.

Shewing the resistance of a carriage, on different inclinations of plane. Friction equal to the 200th part of the weight.

	INCLINATION OF THE PLANE, EQUAL TO 1, IN.									
	0	100	200	300	400	500	600	700	800	900
0	.005	.015	.01	.00833	.0075	.007	.00666	.00643	.00625	.00611
10	.105	.01419	.00976	.00822	.00744	.00696	.00664	.00641	.00623	.0061
20	.055	.01333	.00954	.00813	.00783	.00692	.00661	.00639	.00622	.00609
30	.03833	.01269	.00935	.00803	.00733	.00689	.00658	.00637	.0062	.00607
40	.03	.01214	.00917	.00794	.00727	.00685	.00656	.00635	.00619	.00606
50	.025	.01166	.009	.00786	.00722	.00682	.00654	.00633	.00618	.00605
60	.02166	.01125	.00885	.00777	.00718	.00678	.00652	.00632	.00616	.00604
70	.01928	.01088	.0087	.0077	.00713	.00676	.00649	.0063	.00615	.00603
80	.0175	.01059	.00858	.00763	.00708	.00672	.00647	.00628	.00614	.00602
90	.01611	.01026	.00845	.00756	.00704	.0067	.00645	.00627	.00613	.00601

TABLE X.

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	.01416	.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

The following experiments were made to ascertain the resistance of carriages moved along the *plate-rail*, with the same dynamometer used in the previous experiments, and shewn in *Fig.* VI. *Plate* IV.

The rails were each 4 feet long, and $3\frac{5}{8}$ inches broad, where the wheel runs upon them; and the height of the upright ledge, 3 inches.

Number 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 $39\frac{1}{4}$ inches diameter, $1\frac{3}{8}$ inches broad, upon the rim which runs upon the rails, brass bearings $1\frac{3}{4}$ inches broad, diameter of axle $2\frac{5}{8}$ 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 VII.

EXPERIMENTS MADE ON THE FRICTION OF ROPES ON INCLINED PLANES.

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 Rail-roads; 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 ropes, 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 I have been allowed to make upon the different Rail-roads in the neighbourhood of Newcastle-upon-Tyne; and are such as appeared to me 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 XVIII.

Upon the Killingworth Rail-road: 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 57 feet 6 inches. Five loaded carriages, each weighing 8764 lbs., descended by their gravitating force, and drew up 6 empty carriages, each weighing 2800 lbs., on a mean of several times, in 200 seconds; wheels 34 inches diameter, axles $2\frac{3}{4}$ inches diameter, size of rope 5 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. I. *Plate* V., the line of road perfectly straight. Number of sheeves in action at once 73, weight 3297 lbs., diameter of sheeve where rope runs 11 inches, and diameter of the axles $\frac{3}{4}$ of an inch, ratio 14.65 : 1 ; weight of wheel W W 4636 lbs., diameter 10 feet, and diameter of axles 6 inches, ratio 20 : 1.

We have then

$$F' = G - \frac{\left(W + w\frac{SO}{SG} + a' + a''\frac{SO}{SG} + b + c + c'\right) \times S}{rt^2}$$

$$\text{And } \phi = F' - (F + f + g)$$

The gravity of the loaded carriages will be

$$G = W + w\frac{H}{L} = \frac{8764 + 5 + 57.5}{2145} = 1175 \text{ lbs.}$$

and the gravity of the empty carriages will be

$$g = a' + a''\frac{H}{L} = \frac{2800 \times 6 \times 57.5}{2145} = 450 \text{ lbs.}$$

Taking the friction of the carriages at F = 38 lbs., and f = 12 lbs., W = 7452 lbs., w = 1312 lbs., $\frac{SO}{SG} = \frac{27.07}{17.25}$ and $w\frac{SO}{GS} = 2059$. Therefore $W + w\frac{SO}{SG} = 9511$ lbs., $a' = 1488$ lbs., and $a'' = 1312$, consequently $a' + a''\frac{SO}{SG} = 3547$ lbs., b = 3884 lbs., $c = \frac{1}{2}$ W W = 2318 lbs., and $c' = 1648$ lbs. Therefore

$$1175 - \frac{(9511 \times 5 + 3547 \times 6 + 3884 + 2318 + 1648) \times 2145}{16\frac{1}{12} \times 200^2} =$$

920 lbs.

Whence by Theorem 13, $\phi = F' - (F + f + g) = 920 - (190 + 72 \times 450) = 208$ lbs. The friction of the rope, sheeves, and wheel, at top of plane.

EXPERIMENT XIX.

Same plane, and similar carriages; six loaded carriages drew up the plane seven empty carriages in 180 seconds.

Theorem $G = \frac{\overline{8764 \times 6 \times 57.5}}{2145} = 1410$ lbs.

and $g = \frac{\overline{2800 \times 7 \times 57.5}}{2145} = 525$ lbs.

also $F' = 1410 - \frac{(57066 + 24829 + 3884 + 2318 + 1648) \times 2145}{16\frac{1}{12} \times 180^2}$

$= 1041$ lbs.

and $\phi = 1041 - 525 + 228 + 84 = 204$ 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 3 to 4 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 XX.

Self-acting plane, with wheel, similar to *Fig.* I. *Plate* IV., 6 feet diameter. Length of plane 3906 feet, height 130 feet, 4 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 6 feet, diameter of axle 3 inches; number of sheeves in action at once 144, weight 4448 lbs.; circumference of rope 5 inches, weight 4807 lbs.; ratio of diameter of sheeves, to diameter of axle 14 : 1.

Five loaded carriages, same as Experiments V. and VI., each weighing 9408 lbs., in descending, drew up seven empty carriages, similar to Experiment IX., each weighing 3472 lbs., in 300 seconds.

$$\text{Theorem } G = \frac{9408 \times 5 \times 1564}{46872} = 1570 \text{ lbs.}$$

$$g = \frac{3472 \times 7 \times 1564}{46872} = 811 \text{ lbs.}$$

$W = 9408 - 1312 = 8096$ lbs. and $w \frac{SO}{SG} = 2059$. Therefore $W + w \frac{SO}{SG} = 10155$ lbs., $a' = 2160 + a'' \frac{SO}{SG}$ (2059) $= 4219$ lbs., $b = 4807$ lbs., $c = 227$ lbs., and $c' = 2224$ lbs.

Then $F' = 1570 -$

$$\frac{(\overline{10155 \times 5} + \overline{4219 \times 7} + 4807 + 227 + 2224) \times 3906}{16\frac{1}{12} \times 300^2} = 1134$$

and $\phi = 1334 - \overline{811 + 91 + 200} = 232$ 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 $G = 2198$ lbs., and $F' = 1343$ lbs., which is more than necessary to effect the requisite velocity.

EXPERIMENT XXI.

Self-acting plane-wheel, same as preceding; 6 feet in diameter, weight 454 lbs., ratio of diameter to diameter of axle 24 : 1, length of plane 3672 feet, height 129 feet 6 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 5 inches.

Five loaded carriages, similar to the last experi-

ment, each weighing 9408 lbs., descended against seven empty carriages, each weighing 3472 lbs., in 360 seconds.

$$\text{Theorem } G = \frac{\overline{9408 \times 5} \times 1554}{44064} = 1659 \text{ lbs.}$$

$$g = \frac{\overline{3472 \times 7} \times 1554}{44064} = 857 \text{ lbs.}$$

$$F' = 1659 - \frac{(\overline{10155 \times 5} + \overline{4219 \times 7} + 4468 + 227 + 4874) \times 3672}{16\frac{1}{12} \times 360^2.} = 1501 \text{ lbs.}$$

and $\phi = 1501 - \overline{857 \times 200 + 91} = 353$ lbs. the resistance of the rope, &c.

The same number of carriages are usually employed on this plane as on the preceding, which leaves a considerable surplus of gravity to effect their motion upon the plane.

EXPERIMENT XXII.

Self-acting plane, similar to the two last; length 2706 feet, height 76 feet 5 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, $4\frac{1}{2}$ inches 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.

Theorem $G = \frac{\overline{9408 \times 5} \times 917}{32472} = 1328$ lbs.

$$g = \frac{\overline{3472 \times 7} \times 917}{32472} = 686 \text{ lbs},$$

$$F' = 1328 - \frac{(\overline{10155 \times 5} + \overline{4219 \times 7} + 2927 + 227 + 2086) \times 2706}{16\frac{1}{12} \times 280^2} = 114 \text{lb.}$$

and $\phi = 1145 - \overline{686 + 200 + 91} = 168$ 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 XXIII.

Fixed-engine plane, where a steam-engine of 60-horse power is erected, to drag the loaded carriages up; length 2646 feet, height 154 feet 6 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 40 yards. Rope-roll similar to A, *Fig.* II. *Plate* IV., on which the engine winds the rope, and which, during the experiment, was thrown out of gear, as shewn in the drawing, the descending carriages unwinding the rope; weight of rope-roll with cog-wheels 8960lbs., ratio of diameter to diameter, of axle 10 : 1, number of sheeves 161, weight 10,278lbs., ratio of

diameter to diameter of axle 14 : 1; length of rope 1000 yards, $7\frac{1}{4}$ inches circumference, 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,

$$F' = \overline{G + \tfrac{1}{2} b \sin I} - \frac{\overline{\left(W + w\frac{SO}{SG} + b + c + \tfrac{1}{2}c'\right) \times S}}{rt^2}$$

and $\phi = F' - f$

therefore $G = \overline{3472 \times 3} \times \frac{1854}{31752} = 608$ lbs., and $\frac{1}{2} b \sin I$ $= 3483 \times \frac{1854}{31752} = 203$ lbs. And $F' = \overline{608 + 203} -$ $\frac{\overline{(4219 \times 3} + 6967 + 4480 + 2569) \times 2546}{16\frac{1}{2} \times 174^2} = 666$ lbs.

whence $666 - 39 = 627$ lbs., the friction of the rope, &c.

EXPERIMENT XXIV.

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, $7\frac{1}{4}$ inches circumference, weight 6157 lbs.

Four empty carriages, each weighing 3472 lbs., descended the plane, and dragged the rope after them in 115 seconds.

$$\text{Theorem G} = (3472 \times 4) \times \frac{1380}{27900} = 686 \text{ lbs. } \tfrac{1}{2} b \sin \text{I} = 153 \text{ lbs.}$$

$$\text{Then F}' = \overline{686 + 153} - \frac{\overline{(4219 + 4 + 3078 + 4480 + 1131)} \times 2325}{16\frac{1}{12} \times 115^2} = 560 \text{ lbs.}$$

whence 560 — 52 = 508 lbs., the friction of the rope, &c.

EXPERIMENT XXV.

Fixed-engine plane, with rope-roll similar to A, in the drawing, *Fig.* II. *Plate* IV.; 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.

$$\text{Theorem G} = (2688 \times 8) \times \frac{691}{34704} = 428 \text{ lbs. } \tfrac{1}{2} b \sin \text{I} = 37 \text{ lbs.}$$

Then $F' = \overline{428+37} - \frac{\overline{(3435 \times 8 + 3696 + 2250 + 1322) \times 2892}}{16\frac{1}{12} \times 320^2}$

$= 408$ lbs. whence $408 - 120 = 288$ lbs., the resistance of the rope.

N.B. 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 XXVI.

Fixed-engine plane, similar to the above; length 3165 feet, height 42 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 $4\frac{1}{2}$ inches.

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.

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 carrriages 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 carrriages 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.

Recapitulation of the preceding experiments of the friction of ropes on inclined planes.

TABLE II.

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	$4\frac{1}{2}$	168	8529	16.9:1	503	1:3.00
XIX	Fixed-engine	882	$7\frac{1}{4}$	627	21666	12:1	1810	1:2.90
XX	Ditto	775	$7\frac{1}{4}$	508	17378	12:1	1584	1:3.11
XXI	Ditto	964	5	288	9840	11:1	934	1:3.24
XXII	Ditto	1055	$4\frac{1}{2}$	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 sur-

face 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 same proportion as 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 my 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.

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 $3\frac{1}{2}$: 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 $\phi = \frac{R + R' + R'' + P}{3.5\,r \text{ or } 3\,r}$ for the self-acting-plane,

and $\phi = \frac{R + \frac{1}{2}R' + R''}{3.5\,r \text{ or } 3\,r}$ 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, I 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 I have here given, there is one which I 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;) I shall, therefore, make that the foundation of my 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 XVIII., is one which, when six loaded carriages are employed in dragging six empty carriages up by the rope there described, I can safely state, from a daily opportunity of witnessing its action, has just sufficient preponderancy to produce the required effect; and I 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 $G - \overline{g + F + f + \phi}$ will be equal to 369 lbs. nearly.

Whence we have, if W denote the inertia of the whole mass in motion,

$$\frac{WS}{rt} = 369 \text{ lbs.}; \text{ or } G - F' = 369 \text{ lbs.}$$

Then by Theorem (11) $t = \sqrt{\frac{(W + \frac{SO}{SG} + W') \times S}{G - F'\ r}} = 176$

By Experiment XVIII., 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 VIII.

OBSERVATIONS AND EXPERIMENTS, ON THE VARIOUS KINDS OF MOTIVE POWER EMPLOYED ON RAIL-ROADS.

This chapter will comprehend practical illustrations 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 Rail-roads.

For the sake of making a better comparison of their various effects, by classing those following the same laws, together, I shall divide them into the following order:—

1. Self-acting planes.
2. Engine-planes.
3. Horses.
4. Locomotive-engines.

I.—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. F and f, by Table I. and ϕ by Table II. p. 266.

Then, taking the friction and resistance of the several moving parts, as deduced from the foregoing experiments, and making T = the required time of descent of the carriages down the plane $= \frac{8}{7}t$, we have

$$T = \frac{8}{7}\sqrt{\frac{(W + w\frac{SO}{SG} \times W') \times S}{(G - F') \times r}}$$

whence the preponderance of gravity necessary to effect the descent in all states of the weather, in the time T, will be

$$G - F' = \frac{(W + w\frac{SO}{SG} + W') \times S}{12{,}31\ T^2}$$

and having the weight of the ascending and descending trains of carriages, the inclination of the plane will be

$$\frac{H}{L} = \frac{\frac{(W + w\frac{SO}{SG} + W) \times S}{12{,}31\ T^2} + \phi + F + f}{W - w}$$

or, adopting the notation used in calculating the result of the previous experiments, we have

$$\frac{H}{L} = \frac{\frac{\left(\overline{W + w\frac{SO}{SG}} + \overline{a' + a''\frac{SO}{SG}} + b + c + c'\right) \times S}{12{,}31\ T^2} + \phi + F + f}{(W + w) - (a' + a'')}$$

It is impossible in a case of such a compound nature, to give tables of the inclination required in practice for all the different lengths of plane: we shall therefore give one example, which will render any other a matter of easy calculation, and shall give one about to be laid out upon the Killingworth Rail-way.

Example. Suppose a descending plane, the length of which is equal to 1800 yards, down which it is intended to pass 9 loaded carriages at a time, each weighing 4 tons; which drag up 9 empty carriages, each weighing 24 cwt., required the height of plane or inclination that will cause the descent in 400 seconds.

Supposing w = 1312, and $w\frac{SO}{SG}$ = 2059, we have $W + w\frac{SO}{SG}$ = 99171lbs.; and consequently $a' + a''\frac{SO}{SG}$ = 30905lbs. Let the rope be $4\frac{1}{2}$ inches circumference, then 1900 yards will be 5562lbs. = b. If the sheeves be placed 10 yards apart, and weigh 30lbs. each, then 180 sheeves will be 5400lbs; whence

$c' = 2700$ lbs.; $c = 227$ lbs. The value of $\phi = \frac{R + R' + R'' + P}{3.5\ r}$ $= \frac{454 + 5400 + 5562 + 1696}{3.5 \times 16} = 234$ lbs.; F = the 200th part of the weight = 403 lbs., and $f = 120$ lbs. Then $\frac{H}{L} = \frac{(99171 + 30905 + 5562 + 227 + 2700) \times 5400}{12{,}31 \times 400^2} + 234 + 403 + 120$ $\overline{80640 - 24192}$ $= \frac{1}{50}$ nearly.

We may depend upon this in practice, where the apparatus is well fitted up, and kept in good order; 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 $\frac{H}{L} = \frac{1}{45}$ 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 subject 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 nearly 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.

II.—FIXED STEAM-ENGINES.

To elicit the performance of steam-engines, fixed, and dragging carriages up planes inclined or parallel to the horizon by means of ropes, I have selected the four following experiments on engines that have been in use for some time, and which, I 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, I have taken two low-pressure, or condensing engines, and two high-pressure engines.

EXPERIMENT XXVII.

Boulton and Watt's low-pressure condensing engine, with two 30-inch cylinders, steam 4½lbs. per square inch above the ordinary pressure of the atmosphere; rope-roller similar to A, *Fig.* II. *Plate* IV., rope 7¼ inches circumference, same as employed in Experiment XXIII.; length of plane 2646 feet, height or ascent 154 feet 6 inches, being the same as Experiment XXIII.

Time of drawing up 7 loaded carriages, each weighing 9408lbs., similar to those employed in Experiments II. and III., 620 seconds, the engine making 374 single strokes, 5 feet each.

Then $(30^2 \times 2) \times .7854 = 1413.72$ area of cylinders, and 1413.72×19.5 the pressure of steam in the boiler $= 27567$ lbs. pressure upon the piston, which, in the experiment, was moved through $374 \times 5 = 1870$ feet; hence $27567 \times 1870 = 51550290$ lbs. moved one foot, *the power of the engine.*

The resistance will then be according to Formula 17,

$$G + F + \phi + \overline{\tfrac{1}{2} b \text{ Sin. } I} + \frac{(W + w\frac{SO}{SG} + b + c + \frac{1}{2} c') \times S}{rt^2}$$

$$\text{Then } G = \overline{9408 \times 7} \times \frac{1854}{31752} = 3845 \text{ lbs.}$$

Also, by Experiments II. and III. $F = 40 \times 7 = 280$ lbs.
And, by Experiment XXIII. $\phi = 627$ lbs.
Likewise, by ditto, $\frac{1}{2} b$ Sin. $I = 203$ lbs.

Also $\dfrac{(W + w\frac{SO}{SG} + b + c + \frac{1}{2} c') \times S}{rt^2} = 36$ 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 × 2646 = 13206186 lbs., the resistance moved one foot.

Therefore { 51550290 power of engine,
13206186 effect of resistance,

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,
——————— load, 256 feet per minute.

EXPERIMENT XXVIII.

Fixed engine, Boulton and Watt's double power, similar construction to the preceding, and same power, viz. with two 30-inch cylinders, steam $4\frac{1}{2}$ lbs. per square inch above the pressure of the atmosphere; rope $7\frac{1}{4}$ inches circumference, same as Experiment XXIV.; plane the same also, length 2325 feet, height or ascent 115 feet, carriages same as preceding experiment.

Time of drawing up 7 loaded carriages 550 seconds, making 320 single strokes of the piston, 5 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, 7 loaded carriages, of the same weight, up another plane in extension of the other; length 770 yards, and height 25 feet 6 inches.

Then $(30^2 \times 2) \times .7854 = 1413.72$, area of cylinders $\times$ 19.5, the pressure of the steam = 27567 lbs. pressure on the piston, which, in the experiment, was moved through $320 \times 5 = 1600$ feet.

Therefore, $27567 \times 1600 = 44107200$ lbs. moved one foot, the impelling power of the engine.

$$\text{Then } G = \overline{9408 \times 7} \times \frac{1380}{27900} = 3264 \text{ lbs.}$$

$$G = \overline{9408 \times 7} \times \frac{25.5}{2310} = 726 \text{ lbs.}$$

And, by Experiment II. $F = 40 \times 14 = 560$ lbs.

Also, by Experiment XXIV. $\phi = 508$ lbs.

And, by another experiment, not here detailed, $\phi = 127$ lbs.

Likewise $\frac{1}{2}\, b \sin I$ by Experiment XXIV. = 153 lbs.

Also $\dfrac{\overline{(W + w \frac{SO}{SG} + b + c + \frac{1}{2}\, c') \times S}}{rt^2} = 38$ lbs. the force required to overcome the inertiæ.

And for the other plane the inertiæ = 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 $5474 \times 2325 = 12727050$ lbs. moved 1 foot, the resistance.

Whence { 44107200 power of engine
12727050 effect produced.

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.
——————— load 253 feet per minute.

EXPERIMENT XXIX.

High-pressure engine; cylinder 21 inches diameter, elasticity of steam in the boiler 30 lbs. per square inch, above the pressure of the atmosphere; length of plane 3165 feet, height 42 feet, being the same as detailed in Experiment XXVI. Rope $4\frac{1}{2}$ inches, also the same.

Time of drawing 12 loaded carriages, each weighing 9010 lbs., up the plane, 570 seconds; the engine making 444 single strokes, 5 feet each.

Then $21^2 \times .7854 = 346.36$ area of the cylinder $\times$ 30 lbs. $= 10390.8$lbs. pressure of steam upon the piston, which, in the experiment, was moved through $444 \times 5 = 2220$ feet; therefore, $10390.8 \times 2220 = 23067576$ lbs. moved 1 foot, the impelling power of the piston.

Then $G = \overline{9010 \times 12} \times \frac{42}{3165} = 1434$ lbs. the gravity of the load; and $F = 42 \times 12 = 504$ lbs. friction of the carriages; also ϕ, by Experiment XXVI. $= 213$ lbs. resistance of the rope; likewise, $\frac{1}{2}\, b \sin I = 23$ lbs.;

and $\dfrac{\overline{(W + w\frac{SO}{SG} + b + c + \frac{1}{2}\, c') \times S}}{r\, t^2} = 77$ lbs. force required 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 $2251 \times 3165 = 7124415$ lbs. the total resistance moved 1 foot.

Whence $\left\{\begin{array}{l} 23067576 \text{ power of engine,} \\ 7124415 \text{ effect produced;} \end{array}\right.$

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,
——— carriages 333 feet per minute, or 3.78 miles per hour.

EXPERIMENT XXX.

High-pressure steam-engine, cylinder 16 inches, pressure of steam in the boiler 50 lbs. per square inch; length of plane 2892 feet, height 57 feet 7 inches, being the same as Experiment XXV.; rope also the same, 5 inches circumference.

Time of drawing 8 loaded carriages up the plane, each weighing 8624 lbs., 390 seconds; the engine making 400 single strokes, 5 feet 6 inches each.

Then $16^2 \times .7854 = 201$, area of piston, multiplied by 50 lbs., the elasticity of the steam, is 10050 lbs., the pressure of the steam upon the piston, which, in the experiment, was moved through $400 \times 5.5 = 2200$ feet.

Therefore, $10050 \times 2200 = 22110000$ lbs. moved 1 foot, the power of the engine.

And $G = \overline{8624 \times 8} \times \frac{691}{34704} = 1373$ lbs.

Also $F = 40 \times 8 = 320$ lbs.; and, by Experiment XXV.,

$\phi = 304$ lbs.

Likewise $\frac{1}{2}\ 6 \sin I = 37$ lbs.

Also $\dfrac{(W + w\dfrac{SO}{SG} + b + c + \frac{1}{2}\ c') \times S}{r\ t^2} = 96$ 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 = 6159960 lbs. moved 1 foot, the resistance.

Whence { 22110000 the power of the engine.
6159960 the effect produced.

From which we find the effective power equal to 27 per cent. of the pressure upon the piston.

Velocity of piston 333 feet per minute,
——— load 445 feet per minute, or 5 miles an hour.

The same engine was tried with 9 loaded carriages, which were drawn up in 420 seconds.

The resistance in this case would be G = 1544 lbs.; F = 360 lbs.; ϕ = 304 lbs., $\frac{1}{2}$ 6 sin. I = 37 lbs., and the *inertiæ* = 94 lbs.: which, added together, is 2339 lbs. × 2892 = 6764388 lbs. moved 1 foot.

Whence { 22110000 the power,
6764388 the effect;

and the effective power equal to 30 per cent.

Velocity of piston 314 feet per minute,
——— 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 - { 27. / 30. } per cent.

And the velocity - - - - - { 338 / 314 } feet per minute.

Whence we find the relative performances with respect to time and effect { 9126 / 9340

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. The velocity of the piston was, however, very great, and this would have the effect of diminishing their performance, compared with the elasticity of steam in the boiler, otherwise we might have expected a greater amount of effective power. I 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.

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, the inclination of which is sufficient to cause the descending carriages to drag the rope after them, the formula 17 will apply, where

$$P = G + F + \phi + \tfrac{1}{2} b \sin. I + \frac{\left(W + w\frac{SO}{SG} + b + c + \tfrac{1}{2} c'\right) \times S}{rt^2}$$

From the above experiments we find, that P, being the effective power of the engine, should not exceed 30 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 60 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 $G = 9408 \times 8 \times \frac{60}{3000} = 1505$ lbs.

$F = \frac{9408 \times 8}{200} = 376$ lbs.

Then $\phi = \frac{R + \frac{1}{2} R' + R''}{3.5r} = \frac{4500 + 1500 + 40765}{3.5 \times 16}$

$= 180$ lbs. supposing the weight of the rope roll $R = 4500$ lbs. the sheeves placed 10 yards apart, and each weighing 30 lbs., consequently $\frac{1}{2} R' = 1500$ lbs., the weight of the rope $R'' = 4065$ lbs. and $r = 16 : 1$

Then $\frac{1}{2} b \sin. I = 40$ lbs.

And $\frac{\left(W + w\frac{SO}{SG} + b + c + \frac{1}{2} c'\right) \times S}{rt^2} =$

$\frac{(10155 \times 8 + 4065 + 2250 + 750) \times 3000}{16\frac{1}{12} \times 300^2} = 183$ lbs.

whence $P = 1505 + 376 + 180 + 40 + 183 = 2284$ lbs. which, to be moved 3000 feet in 5 minutes, is equal to 1370400 lbs.

moved 1 foot in a minute; consequently $\frac{1370400}{33000} = 41\frac{1}{2}$ 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 $\frac{8}{7}\frac{H}{L}$ 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

$$P = (G + F + \phi + f + \frac{(W + w\frac{SO}{SG} + a' + a''\frac{SO}{SG} + b + c + \frac{1}{2}c') \times S}{rt^2})-g$$

Let the weight of the empty carriages, be 3472 lbs. each.

Then, G = 1505 lbs., F = 376 lbs., ϕ is, in this case, $= \frac{R + R' + R'' + P}{3.5\,r} = 274$ lbs.

And $f = \frac{3472 \times 8}{200} = 138$ lbs.

Likewise $g = \sqrt{3472 \times 8} \times \frac{69}{3000} = 555$ lbs. and the inertiæ $= 252$ lbs.

Whence $\sqrt{1505 + 376 + 274 + 138 + 252} - 555 =$ 1999 lbs. which moved 3000 feet in 5 minutes, or 600 feet in 1 minute, is = 1199400 lbs. moved 1 foot.

Therefore $\frac{1199400}{33000} = 33\frac{1}{3}$ horse 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 9 horses' power.

III.—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 Rail-road 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.

The following Tables will show, on different Rail-roads, 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 Experiment IV. *No.* 1.; and returns with six empty carriages, each weighing 2604 lbs. same as Experiment IV. *No.* 7.—Edge-rail, Killingworth Colliery Rail-road, friction loaded carriages 40 lbs., empty carriages 14 lbs.

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 6 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	0.	0	240	0	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-rail-road, where a horse takes six loaded carriages, each weighing 9,010 lbs. down the plane; and returns with six empty carriages up the plane, each weighing 3,080 lbs.

Friction of loaded carriages 42 lbs. and of empty 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 Rail-road; these horses, like those employed on the Killingworth Rail-road, are 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 traverse 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 show 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-rail-road, 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 8,540 lbs., friction 40 lbs., empty carriages 2,604 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	342	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
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 Rail-road are not so strong and heavy as those upon the roads shown 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 is traversed 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 are 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 as the mean 100 lbs., which may be taken 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-rail-road, will be 24,000 lbs.; as, however, the resistance of the carriages in winter would be

greater than that shown in the Table, we may perhaps take the power of a horse as equal to 112 lbs., the mean of Tables III. and IV., travelling at the rate of two miles an hour, or twenty miles a day, which, on a level Rail-road, 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. I 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 I am 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.

I am not acquainted with any experiments made on the performance of horses, travelling at different rates of speed.—The rapid diminution of their power, from the great portion of their muscular exertion required to move themselves along, is observable upon the coaches and other vehicles upon the common roads.

To obtain a sort of approximation to the energy of the power of horses at different rates of speed, I formed a kind of rule, on which I founded my 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., I made this a general expression, for his accumulated performance.

I 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; I 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 effect would be the greatest; as I invariably found, on pushing a horse at a more rapid rate, he was more distressed in performing the same work. I 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 of speed, his effect would not be greater; at least, I 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 Rail-road at any other velocity.

Since forming these calculations, I find Professor LESLIE, in his Elements of Natural Philosophy, had previously given 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."

The above rule, I find, has been lately adopted by some writers on the subject; but having pre-

viously formed my calculations from the other, and as it does not materially differ from that given by Professor LESLIE, up to that rate of speed at which horses are generally made to travel; I shall not now alter them, but shall, in the Table below, give the respective weights by each formula, which the reader will have an opportunity of comparing together.

TABLE IV.

Miles per hour.	Force exerted upon the load in lbs. by the formula $\frac{224}{v}$.	Load which a horse can draw upon a level Rail-road in cwts. by formula $\frac{480}{v}$ twenty miles a day.	Force exerted upon the load in lbs. by Professor Leslie's formula $(12-v)2$.	Load which a horse can draw upon a level Rail-road, by Professor Leslie's formula.
2	112	240	100	214
3	$74\frac{2}{3}$	160	81	173
4	56	120	64	137

Columns 3 and 5 are calculated on the supposition that the friction is equal to the 240th part of the weight, and that the horse travels 20 miles a-day.

Since the former edition of this work was published we have found, by experiment, that in carriages well constructed, we may take the friction at the 240th part of the weight; and as it may become a subject of enquiry, how far horse power is capable of competing with mechanical, at the greater velocities, for the conveyance of passengers; we shall

endeavour to ascertain their performance, at the greatest velocity at which they have hitherto, or which, perhaps, they are capable of travelling, with a load, viz. in the stage coaches; retaining the conclusions of the foregoing Table for ordinary carriages, at low rates of speed upon private Rail-ways.

According to the formula $(12—v)^2$ of Professor LESLIE, the relative performance at $2\frac{1}{2}$ and 10 miles per hour, is as 9 : 1. Mr. TREDGOLD, in his work on Rail-roads, gives the effect as 4 : 1.* Mr. RASTRICK, in his report on the Liverpool Rail-way, gives his opinion also as 4 : 1; † while Mr. WALKER, in his report on the same occasion, gives 6.4 : 1. ‡

Our formula of $\frac{224}{v}$ 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.

We have a very important document on this subject, furnished by the coach proprietors on the

* Tredgold on Rail-roads, page 169.
† Report on the Liverpool Rail-way, page 50.
‡ ——————————————— page 41.

Liverpool and Manchester turnpike roads; from which we shall be able to determine, what deduction is necessary, at the more rapid ratio of travelling. It appears from a petition presented to the House of Commons, May 3, 1830, that there were at that period, 33 coaches upon the different roads in that neighbourhood, running from Liverpool; viz. 26 to Manchester, 4 to Bolton, 2 to Wigan, and 1 to St. Helens. 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 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; making the effective performance at 2½, and ten miles per hour as 6 : 1 nearly. Perhaps, therefore, if we

retain the formula $\frac{224}{v}$, and make a deduction of five per cent. from the performance for every mile per hour increase of velocity, from three miles per hour upwards; though not strictly, or theoretically correct, we shall be pretty near the truth in practice.

The following Table will, then, show the weights which a horse can drag upon a level Railway, of the best construction; and with carriages, the resistance of which is equal to the 240th part of the weight; with the diminution of effect by an increase of velocity.

TABLE V.

Velocity in miles per hour.	Force capable of exerting in lbs.	Performance in Tons drawn one mile per day.	Effect at the different velocities.
4	53.2	114	3.56
5	35.8	87	2.72
6	31.7	68	2.12
7	25.6	53	1.65
8	21.	45	1.4
9	18.	37	1.12
10	14.6	32	1.

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; 112

lbs. is taken as the average effect; but the Tables of performances in the Colliery Railways show, 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. If we, therefore, assume 180 lbs. as the greatest performance he is capable of exerting, on an average, in one direction, and 60 lbs. in the other, making a mean of 120 lbs.; and take the friction equal to ten lbs. per ton, or the 224th 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.

TABLE VI.

Inclination of plane.	Loaded carriages up and empty carriages down.	Loaded carriages down and empty carriages up.	Load equal in both directions.
	Tons.	Tons.	Tons.
Level . . .	18.	18.	12.
1 in 4480	17.14	18.46	——
—— 3360	16.74	18.62	——
—— 2240	16.36	18.95	——
—— 1680	15.65	19.5	——
—— 1120	15.	20.	——
—— 1000	14.7	20.30	——
—— 900	14.41	20.56	——
—— 800	14.04	20.94	——
—— 700	13.62	21.43	——
—— 600	13.11	22.15	——
—— 500	12.42	23.21	——
—— 448	12.	24.	——
—— 400	11.53	25.	11.53
—— 350	10.96	26.50	10.96
—— 300	10.30	27.38	10.30
—— 250	9.48	28.44	9.48
—— 200	8.50	25.50	8.50
—— 150	7.21	21.63	7.21
—— 100	5.55	16.65	5.55

The above Table is estimated upon the average performance; 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 road, 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 twelve 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 120 lbs., twelve 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 horses' 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. Story, 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, has 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. Story has favoured us with the following particulars, of the increase of effect, by the adoption of this expedient.

"Previous to carriages being used for the horses to ride on, a week's work of 6 days, was 87 miles with 12 tons of coals; and $5\frac{1}{2}$ tons empty carriages.

87 miles with $5\frac{1}{2}$ tons of empty carriages

Total.... 174 miles.

"A week's work after using the horse carriage, was 120 miles with 12 tons of coals and $5\frac{1}{2}$ tons empty carriages.

120 miles with $5\frac{1}{2}$ tons of empty carriages.

Total . . 240 miles."

And Mr. Story observes—"this is nearly $\frac{1}{3}$rd more work, and the horses improved in condition, whereas formerly the horses grew worse 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 the carriage side by side, and turned round with their feet a sort of endless chain, furnished with narrow boards like scales, which bent round the 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 4 miles an hour, they would propel the carriage at the rate of 12 miles an hour. Independent of the injury to his physical powers, the horse, at 12 miles an hour, is not capable of exerting a force equal to one-fourth of what he is capable of doing at 4 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.

IV.—LOCO-MOTIVE ENGINES.

In my investigations respecting loco-motive engines, I shall confine myself wholly to those, which effect their progressive motion, by means of the adhesion of their wheels upon the rails; the only engines of that kind at present in use, which do not, are those of Mr. BLENKINSOP, at Leeds, with the rack-rail; and as I have not had any opportunity of ascertaining their performance by the test of experiment, I shall not, therefore, attempt to give any opinion of their utility, compared with the other, founded only on report, or on bare supposition.

I have before explained the nature of the action of the engine-wheels upon the rails, and the principle by which the loco-motion 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.

This may either be ascertained, by continued observation of their performance upon certain lines of roads; 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 experiments made in the two extremes, in order to obtain a mean result. I shall, therefore, give the particulars of two experiments, one in the most favorable, and the other in the most unfavorable 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 surface 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, toward 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 to slide along with its wheels 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 Rail-road, 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, perhaps, be so accurate a standard for practical application. The force of the steam, at different periods of the stroke, being very irregular upon each wheel, might occasion the result, in practice, to vary from that deduced by the foregoing methods; and the following experiments were therefore made upon engines in actual use, to ascertain the amount of adhesion.

EXPERIMENT I.

Loco-motive engine, with cast-iron wheels, 3 feet diameter, weighing 6½ tons, and containing 1 ton of water, = 7½ tons; dragged 12 loaded carriages, each weighing 9408 lbs., up a plane ascending 134 inches in 1164 feet, and also the convoy-carriage, weighing 1½ tons, the wheels not

slipping. Rails quite dry. Cast-iron edge-rail $2\frac{1}{2}$ inches broad at the top.

Then, weight of the engine 16800 lbs.

12 carriages $= \overline{9408 \times 12} = 112896$

Convoy-carriage ..... $\frac{3360}{133056} \times \frac{134}{13968} =$ 1277lbs. gravity.

Friction of 12 carriages, at 43 lbs. each .... = 516

Friction of convoy-carriage .... = 17

1810lbs.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 is dry, equal to the 9.28 part of the pressure on the rails, exclusive of the friction and resistance of the engine, which if we take equal to 568lbs., the proportion will be equal to the 7th part of the weight.

EXPERIMENT II.

Same engine, with 29 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 4 miles an hour.

Then, as before, $16800 + 3360 + \overline{3472 \times 29} = 96128 \times \frac{1}{324} = 296$ 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 part of the weight, and taking the resistance of the engine at 568 lbs. as before, the adhesion will be equal to the 13th 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 70 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 to the rails. The load should not, therefore, be so great as to produce such an effect.

From several years' observation of their performance upon the Killingworth Rail-road, I am inclined to think the above rather too high, without incurring the risk of slipping. There they travel sometimes with 9 and sometimes with 12 carriages, amounting to 36 and 48 tons respectively. The greatest ascent, upon any part of the Rail-road with the load, is 1 in 330; and in returning, with the empty carriages, 1 in 80. The wheels, in very bad weather, slip sometimes with 12 carriages; but the engines, in the worst weather, are never prevented travelling with 9 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 $\overline{16800 + 3360} \times \frac{1}{330}$ = 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-rail-road without slipping.

The weight of the engine is about 16,800 lbs., *whence the amount of adhesion will be equal to the 25th 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 *Figs.* I. and II., *Plate* VII., without springs, and with a chain to connect the two cylinders with each other. When the engines were improved, and the connection made, as shewn in the drawing, and springs adopted, it was found that the amount of effective adhesion was increased. I had frequent opportunities of observing this; and some experiments 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 I 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, $2\frac{1}{4}$ inches broad at top, with half lap joints: the inclination of which was as follows:

No. 1.	110 yards	1 in 132
2.	110	1 in 97
3.	110	1 in 113

4. 110 ..... 1 in 120
5. 110 ..... 1 in 114

EXPERIMENT III.

Engine weighing 6 tons, without springs, cast iron wheels, 3 feet diameter, water and tender 3 tons.

No. 1. Dragged 4 carriages each weighing 4 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 3 carriages of 4 tons each, wheels did not slip.

EXPERIMENT IV.

Engine weighing $7\frac{1}{2}$ tons, convoy-carriage and water, $2\frac{1}{2}$ tons, wheels 4 feet 2 inches diameter, with wrought iron tires, "which had been at work twelve months, but did not appear worse," 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
2	27
3 and 4.....	53
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 until it made 68 revolutions, with six carriages attached; it made 69½ revolutions 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 20th 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 24th part of the weight of the wheels upon the rails: and the adhesion was sufficient to overcome that resistance without slipping.

In Experiment IV. No. I., the resistance amounted to the 16th part of the weight, and with this resistance the engine travelled 574 yards, with 133 revolutions of the wheels; this would make about 6 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 ½ a revolution of the wheel, or 6½ feet. The resistance opposed to the engine, in this experiment, amounted to the 18th 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 would take place, probably 20 to 25.

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 one rule for practice. *This would give the adhesion equal to the 20th 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, *Plate* VII., *each of the cylinders 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 rail-road are different, *both cylinders working the same pair of wheels,* as shewn in *Plate* VIII.; and as there appears some difference of effect in the amount of adhesion, it will perhaps be necessary to explain the cause.

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The action of the power of the cylinders upon each of the wheels of the engine, *Plate* VII., is extremely irregular. When the piston, for instance, is at the top of one of the cylinders, say No. 1, the power has no effect in turning the wheels round, and the circumvolution is effected by the other cylinder, No. 2, through the connecting rods 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. 1, gradually becomes greater, then equal to No. 2, and then the predominant moving power, when the other pair of wheels, No. 2, is *dragged* round by the action of the cylinder, No. 1; 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, 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 always commences with the wheels on which the piston is descending, and is then communicated to the other by the horizontal

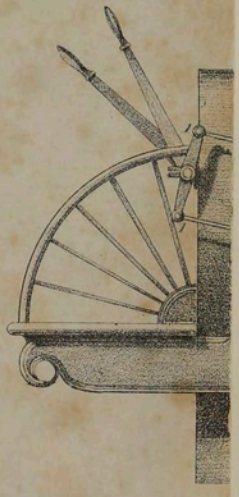


Fig. 1.



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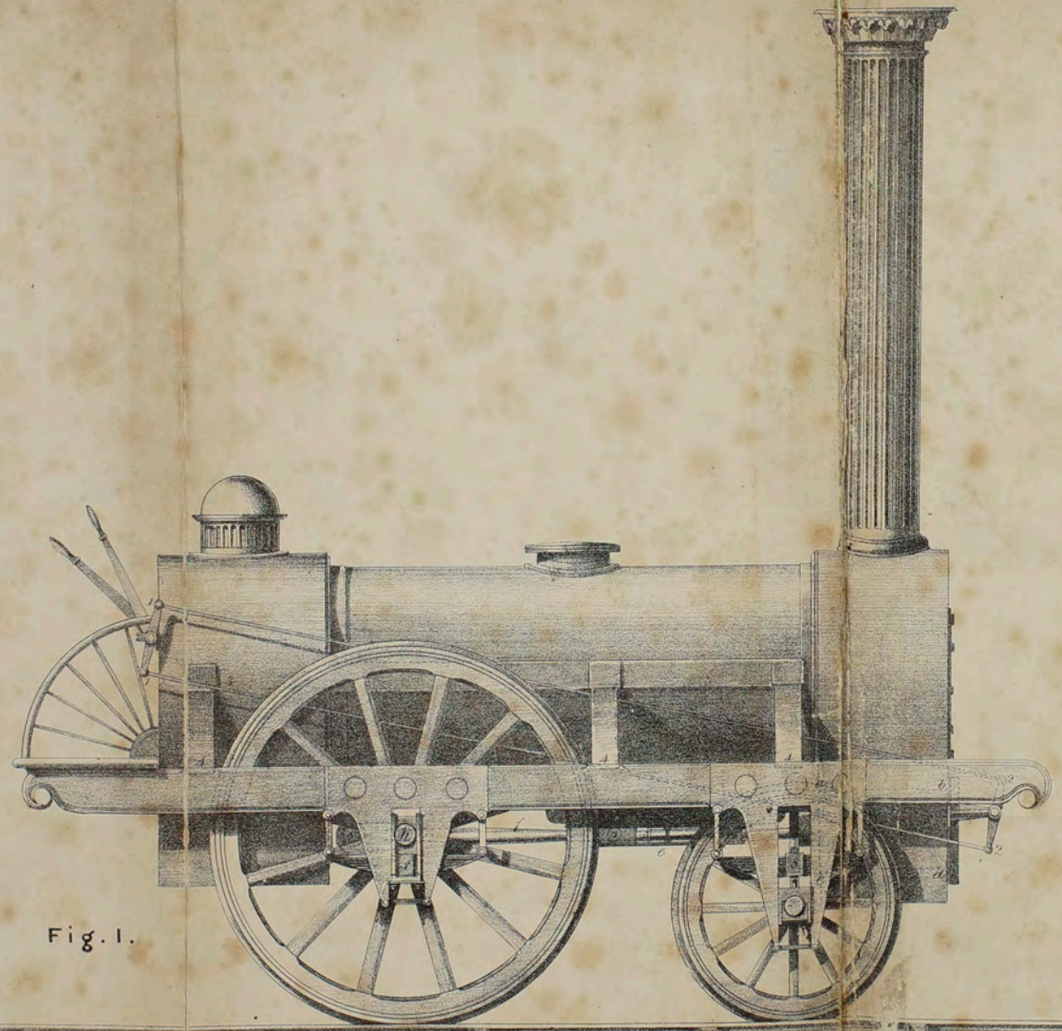


Fig. I.

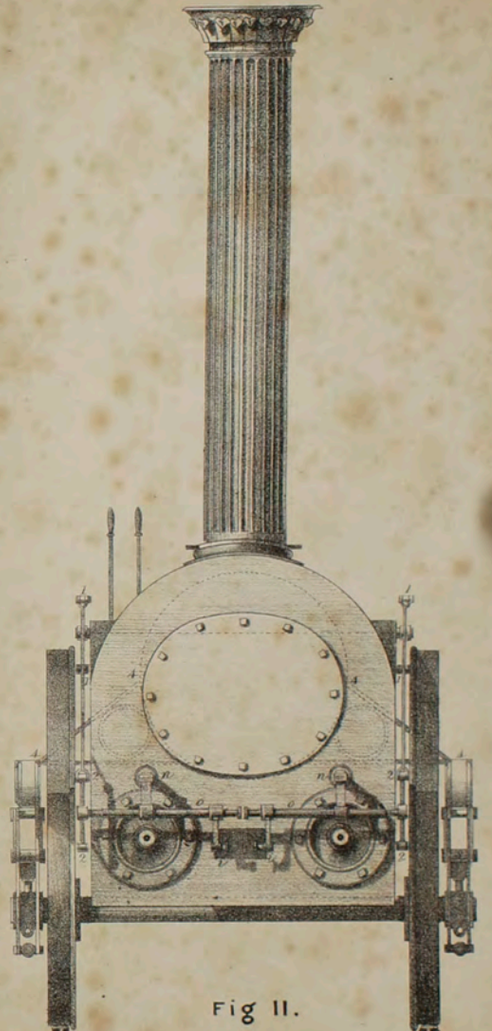


Fig II.

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Day & Haghe Lithers to their Majesties

connecting rods. It is likewise very difficult to procure two sets of wheels strictly or mathematically of the same diameter, and if not so, there must be a partial slipping. All these causes have a tendency to *induce* a commencement of slipping, and especially the action of 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 Mr. Stephenson's engine, *Plate* VIII., none 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 to 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 realise a greater amount of

adhesion, compared with the insistent weight, than the 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, that, supposing the whole weight of the engine equally divided upon the four wheels, we have only one-half 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 convinced, in the change from three to four feet wheels, that an increase of adhesion was effected; for greater speed of travelling, still larger wheels have, and will be applied, whereby a still further increase may be expected; and the injury to the Rail will 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, therefore, we may, 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.

No very accurate experiments have as yet been made, to ascertain the amount of adhesion of the engines working one pair of wheels: indeed, almost every engine yet made, varying in construction in some way or other, we have not yet arrived at any settled standard, and perhaps it would be premature, at present, to assign any fixed limit. Sufficient has been done upon the Liverpool and Manchester railway, to prove that the proportionate amount of adhesion is considerably greater than in the old engines; and from the weights, which we have seen those engines take up the planes rising 1 in 96, we are disposed to estimate this, at least, as equal to one-third more than with an engine of the same weight on the old construction. In the absence of experiment to prove the precise amount, we shall give a table of the weights, which may safely be calculated upon in practice, as being that which the engines will drag up planes of the different inclination, in the worst state of the rails.

Column 1, is the inclination of the plane. Column 2, is the weight which an engine, weighing 6 tons, will drag upon the different planes, supposing only two of the wheels are worked by the cylinders, or applied to effect the locomotion of the engine; and that $\frac{3}{5}$ of the weight rests upon

those two wheels—the amount of adhesion being taken as the 15th part of the weight. Column 3, is calculated upon an engine of the same weight, the four wheels of which are all worked by the cylinders, or applied to effect the locomotion of the engine,—the adhesion being taken as equal to the 20th part of the weight. The diameter of the wheels is supposed to be equal to 4 feet; and we have before stated our conviction, that an increase of the diameter of the wheels, independent of causing less injury to the rails, is productive of a greater amount of adhesion; probably with wheels of the diameter under discussion, nearly in proportion to the increase of diameter. We shall, therefore, with wheels of 4 feet diameter, take the power of adhesion as equal to the 15th and 20th part of the weight or pressure on the rails respectively.

Having thus 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, the amount of which is equal to the 15th and 20th part of its weight respectively: or, taking the friction of carriages the 224th part of their weight, a load equal to $\frac{224}{15}$ or $\frac{224}{20}$ of its weight. If the acclivity of the plane, on which the engine is made to tra-

vel, be such, that the height is equal to the 15th or 20th 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; and, in all the intermediate degrees of elevation, between a dead level and the above inclination of plane, the amount of adhesive power which the engine can spare to the load, above that required to propel itself forward, will be inversely as the sine of the angle of inclination, or as the height of the plane to its length.

TABLE I.

Inclination of the plane.	Load which the adhesion of the wheels will drag, in Tons.	Load which the adhesion of the wheels will drag, in Tons.
Level....	53.8	67.25
1 in 4480	50.85	65.52
——2240	48.18	60.36
——1680	45.74	57.43
——1120	43.5	54.66
——1000	42.48	53.43
—— 900	42.25	52.22
—— 800	40.28	50.75
—— 700	38.58	49.
—— 600	37.	46.76
—— 500	34.68	43.93
—— 448	33.2	42.13
—— 400	31.61	40.20
—— 350	29.63	37.8
—— 300	27.38	35.07
—— 250	24.46	31.66
—— 200	21.15	27.47
—— 150	16.8	22.11
—— 100	11.07	15.21

The above will give the limits to which the nature of their action restricts the application of this kind of engines, and will show 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. 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.

It may be necessary to observe, with respect to this standard, 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, while 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 will be more than double that assigned.

Those engines may therefore be often made to work with loads beyond that which the power of adhesion assigned 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 the instance adduced, of the wear of the wheels of the Killingworth engines; the wear of the light engines being greater, in the proportion 1.5 to 1, than the heavier engines with larger wheels.

The leading object of all machines, especially of this kind, is to perform a definite quantity of work in a given time; to do this with the least expenditure of power, there will be in every case a certain load compared with the weight of the engine, which, when used, will make the performance a maximum: it will, however, be impossible to ascertain this, without a perfect knowledge of all the phenomena of their action, and this again, perhaps, cannot be ascertained, without subjecting them to the test of experiment. Observation and experience may guide us in forming a judgment of the performance of any engine, but it is only by subjecting them to experiments, in all their various modes of action, that their general law of action is developed.

To accomplish this, I commenced a series of experiments on the Killingworth Rail-road, with the engines there used; and, by applying different engines with the same load, and also the same engine with different loads, I was enabled to

ascertain, with nearly perfect accuracy, the relative performances, both with respect to weight, and also to velocity.

With the expectation of reducing the friction, and also to obtain the performance at different rates of speed, I affixed larger travelling wheels to the engine, and, by experimenting upon the same engine, with different-sized wheels, I was not only enabled to prove the relative performances of wheels of different diameters, but also to ascertain the actual amount of friction inherent in the engine itself.

The following Tables will shew the result of these experiments.

Account of some Experiments made on the performance of locomotive engines upon the Killingworth Rail-road in 1824.

Length of plane 2260 yards, with an ascent in one direction of 6 feet 5 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 diameter, axles 2¾ inches diameter.

No. I.—Loco-motive engine of the construction represented in *Fig.* 1 and 2, *Plate* VII., length of boiler 8 feet, diameter 3 feet 9 inches, diameter of tube in which the fuel is placed 20 inches, with two cylinders 9 inches diameter each; wheels of different diameters, as explained in the following Table; steam 50 lbs. per square inch.

TABLE II.

Number of Journies.	Experiment I. 3-feet wheels, 9 carriages, weighing 73$\frac{1}{4}$ cwt.				Experiment II. 4-feet wheels, 9 carriages, weighing 73$\frac{1}{4}$ 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 min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.
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	33	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	33	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	3
	Distance traversed, 36 miles in 9 hours 35 min.; coals consumed 2,534 lbs.; water 890 gallons. = 93 gallons per hour.				Distance traversed, 48.8 miles in 9 hours 27 min.; coals consumed 2,534 lbs.; water 854 gallons. = 90.4 galls. per hour.				Distance traversed, 23 miles in 4 hours 48 min.; coals consumed 1,546 lbs.; water 452 gallons. = 94 gallons per hour.			

No. II.—Loco-motive engine, similar construction as the preceding, except in the dimensions of the boiler and tube. Length of boiler 9 feet 2 inches, diameter 4 feet, and diameter of tube 22 inches, cylinders each 9 inches, wheels as per following Table, steam 50 lbs. per square inch.

TABLE III.

Number of Journies.	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 6 hours 32 min.; coals consumed 1487lbs.; water 490 gallons.				Distance each journey 2002 yards. Total 11.375 miles; distance passed over in the above time, 1663 yards 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 Rail-road, 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; my object being to ascertain the relative performances with different wheels and different loads. I therefore endeavoured to keep up a speed as equable as possible, and in doing so, I 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 velocity, 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 it 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 space, 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 3-feet wheels from off the axles of the engine, and replacing them with wheels 4 feet diameter. The experiments were made upon the same stage of the Rail-road, 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 / 4-feet wheels } traversed the respective distances of { 36 miles / 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 remains the same, being as the space passed over; then, as 63280 yards, (the space passed over in Experiment I) : 2534 lbs. (the coals consumed) : : 85880 yards, (the space passed over in Experiment II.) : 3439 lbs. the coals which would have been consumed in Experiment I. in traversing 85880 yards; the relative consumption of coals will then be

No. I. 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 3 *and* 4*-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 whole

retarding forces opposing the motion of the engine, viz. the friction of the engine, and the friction of the carriages. The latter I have previously shewn; I shall, therefore, give an experiment made to ascertain the former.

EXPERIMENT VI.

Upon the same plane or piece of Rail-road described in Experiment II. p. 205, with a descent of 11 feet 2 inches in 388 yards, I allowed five loaded carriages, each weighing 9408 lbs., to descend freely, as explained in that experiment, which they performed in 120 seconds. I 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 alernately 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 30 seconds.

The weight of the engine and convoy-carriage together was 9 tons=20160 lbs., to which add for the rotatory motion of the wheels, 1800 lbs.=21960 lbs. The carriages weighed 9408 lbs.,

and for resistance of the rotation of wheels, 747 lbs.=10155 × 5 =50785+21960=72735 lbs., the mass in motion.

Then the retardation, caused by the friction of the whole, will be

Theorem (8) $F=W+w.\ \sin.\ I-\frac{(W+w\frac{SO}{SG})\times S}{r\,t^2}=410.7$ 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.

The resistance of the engine, when moved along, and not subjected to the pressure of the steam, will then be 214 lbs.; of this, taking the friction at the 200th part of the weight, 100 lbs. will belong to the axles and the action of the wheels upon the rails, leaving 114 lbs. as the friction of the pistons, connecting chain, and other rubbing parts of the engine.

The total friction of the engine, however, when employed in dragging a load after it, or that part of the power required to produce a progressive motion of the engine itself upon the road, when loaded will be different, and will be greater than when the simple motion of its parts only is concerned. When the engine is loaded with a certain pressure, by having to drag a train of carriages after it, the whole of that weight, or pressure, 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 3-feet wheels we remove them, and substitute 4-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 3 and 4 feet respectively; and hence the proportionate effect.

It is not necessary, at present, to notice the force required to give motion to the machinery, which will always be as the diameter of the wheels directly, and will not therefore be diminished by an increase of size; as we shall have occasion to recur to this when treating on the proper velocity with different sized wheels.

We shall, therefore, endeavour to obtain from the preceding experiments, the absolute friction, or force required to move the engine itself.

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, or 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 4-feet wheels; the friction of 3 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 4-feet wheels the distance travelled was 37.7 miles, while with the same fuel, the distance by the 3-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 lb. each carriage) we have $480 \times \frac{37.7}{36} =$ 502 lbs., the resistance overcome, exclusive of that of the engine with 4-feet wheels; the weight taken by the 3-feet wheels was 731¾ cwt. = 360 lbs. resistance, whence 520—360 = 142 lbs., the increase of effect by the substitution of 4-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; the wheels were respectively 3 and 4 feet diameter; hence we may suppose, that in the application of 4-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 3-feet wheels, and as 4 : 3 : : 568 : : 426 lbs., the friction of the engine with 4-feet wheels.

We see, therefore, the reason why the same quantity of fuel produced different effects with 3 and 4 feet wheels : in the former, the friction was 568 lbs. ; increasing the wheels to 4 feet diminished that friction to 412 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 3 and 4-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 other working parts of the engine, subjected to an increased strain, must also be strengthened, so as to compensate for the additional strain ; and in the direct ratio of the strains, which will cause the friction of the axles and those parts to remain the same, and consequently produce no diminution of resistance by the enlargement of the wheels. But, as the friction of the axles, and those parts required to be enlarged by the use of wheels of greater diameter, form only a small part of the whole friction, the previous experi-

ments will, I trust, shew, that, *when an increase of velocity is required, it ought to be effected by an increase in the diameter of the wheels.*

We shall now endeavour to ascertain, from the foregoing experiments, the quantity of fuel consumed by those engines, both as regards the absolute quantity, and also the comparative quantity with different loads.

An inspection of the result of the experiments given in the Tables will shew this; 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 shewing a very important discovery, in the construction of these engines, for diminishing the quantity of fuel.

The experiments were made with two engines, which I have termed No. I. and No. II., the first affording the experiments of Table II. and the latter of Table III. 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, 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 Experiment I. with IV., where the same load was taken, we find the quantity of fuel consumed by the former, in travelling 63280 yards, to be 2534 lbs., and, in the latter, for travelling on the same ground, 45200 yards, equal to 1487 lbs. Then, as 63280 : 45200 : : 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 narrow tubes to keep up a constant supply of steam, which, by producing a more rapid combustion of the fuel, throws it off imperfectly consumed, and at a very high temperature. 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 knowledge of this fact, will unquestionably lead to a further diminution in the consumption of the fuel, even in the same engines. It would not, therefore, perhaps be treating the subject fairly, to fix at present the basis of actual consumption, for the performance of a definite quantity of work; 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; 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 9 carriages, weighing 731¼ cwt., and, in the latter, with 12 carriages, weighing 975 cwt., the consumption was, with 9 carriages in travelling 85880 yards, 2534 lbs.; and with 12 carriages 1546 lbs. in travelling 40680 yards. Then, as 85880 : 4680 : : 1546 : 3263 lbs., which would have been consumed in conveying 12 carriages 85880 yards. Therefore, the relative consumption of fuel, with 9 and 12 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 $426 + \overline{39.35 \times 9} = 780$ lbs., the resistance of the 9 carriages and engine. And $426 + \overline{39.35 \times 12} = 898$ lbs., the same with 12 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 an increase of resistance through all the working parts of the engine, would create an additional 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 rail 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 20020 : 45200 : : 587 : 1325 lbs. consumed by Experiment V., in traversing the same distance as Experiment IV. The two were performed with wheels whose respective diameters were as 3 : 4; but it has been before shewn, that the effects are in the inverse ratio of the size of the wheels; we then have 4 : 3 : : 1487 : 1115 lbs., the weight of fuel which would have been consumed by Experiment IV., if 4-feet wheels had been used. The relative quantities with 9 and 12 carriages will, therefore, be as 1115 : 1325; the relative resistances, as above stated, were 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 rail, 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 resistances 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, 20020 yards upon a horizontal plane.

Reducing this to the consumption per mile, viz.

As 20020 : 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 200th 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 $\frac{51.55 \times R + P}{898}$

the quantity of coals required to convey any given weight of goods, whose friction or resistance is equal to R, the distance of one mile upon a level Edge-rail-road.

The formula $\frac{51.55 \times \overline{R + P}}{898}$ will then represent the consumption of coals with any load R; 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.

The reader will scarcely expect that I should again recur to the subject of friction, after the experiments already detailed. It may appear, however, to some, and I know it has already been made the subject of discussion, that, when the steam in the boiler is of a degree of elasticity equal to 50 lbs. per square inch of surface, in estimating the power of the engine, the same degree of pressure should be assumed as acting upon the surface of the piston; and that the difference between the amount of such pressure, and the actual performance of the engine, is the measure of the friction, or, as it is termed, of "the power lost." I must confess, the difference between the two effects at first appeared great; but, on considering the method by which the steam is transmitted from the boiler to the cylinders, and by also subjecting the engine to experiment, the cause soon became very evident; and, when I found that the same amount of difference existed

in other high-pressure engines, the reason could then no longer be the subject of mystery.

In all high-pressure engines, acting solely by the elasticity of their steam; and indeed in all elastic fluids whatever, when those fluids are subjected to great degrees of pressure, and are thus made highly elastic, there is a tendency in them to resume their original elasticity, or the density of the surrounding atmosphere.

Steam, when confined in a close vessel or boiler, is made highly elastic by the continual addition of successive particles, produced by the evaporation of water;—and air, from the expansion or compression of the same particles; but the law of their elasticity when subjected to pressure remains the same, and each has the same tendency to expand, when the pressure, which kept them in that state, is removed. And it is a well known law of pneumatics that air rushes into a void, with the velocity which a heavy body would acquire by falling from the top of a homogeneous atmosphere; and that the velocity, with which a fluid of greater density, rushes into another fluid of less density, is as the respective densities of the fluids.

When, therefore, an aperture is made in a vessel or boiler containing steam highly elastic, the tendency which fluids of different densities have to assume a state of equilibrium, will cause the steam in the boiler to rush out into the atmosphere; and the velocity of efflux, will be propor-

tional to the difference between the density of the steam in the boiler, and that of the medium into which it rushes.

It is thus that the steam of the high-pressure engines acts, in its passage from the boiler to the cylinder; a passage is made between the two, the area of which is made greater or less by opening or shutting the throttle valve, by means of a regulator: when the opening is made, the steam issues through it into the cylinder, with a force proportionate to its density; and acting upon the piston, causes it to move up and down, with a velocity equivalent to that which steam, of a density equal to that in the boiler, would flow through such an aperture, into a medium, equal in density to the intensity of pressure upon the piston. If the machinery of the engine is so arranged that the piston moves with a velocity nearly equal to the rate of efflux, then the steam will exert little pressure upon it; and the nearer the two velocities approach to each other, the less effective pressure will be exerted upon the piston:—and again, if the arrangement of the machinery be such that the piston moves with a moderate velocity, then the effective pressure upon the piston, compared with that in the boiler, will be greater, the relative pressures continually approaching towards the same; and will, when the piston does not move at all, become equal. During all these cases, the reader will perceive that the elasticity of the

steam in the boiler, and that in the cylinder, are widely different, the one being indicated by the pressure on the safety valve of the boiler, and the other by the intensity of the load upon the piston.

Again, if we suppose a certain resistance opposed to the motion of the piston, which will be represented by the intensity of the load, we shall require a pressure upon the piston equal to this, merely to balance the resistance; but to give motion to the piston and machinery, we must increase the pressure of the steam beyond that which merely balances the opposing resistance; and this additional pressure must, as previously explained, be increased, the quicker the piston is required to be moved.

We have all along supposed the production of steam in the boiler, to afford a constant and regular supply; adequate to supply steam in sufficient quantity to keep up the same degree of density in the boiler, whatever be the rate of efflux into the cylinder, by the different velocities of the piston. But, if this be not the case; if the formation of steam in the boiler be not equal to the quantity escaping through the throttle valve, then the density in the boiler will be diminished, and the rate of efflux, and consequently the velocity of the piston, will also be proportionably lessened.

Let W = the load upon the piston.
F = the friction of the engine.

V = the velocity of the piston, in feet per second.
g = $32\frac{1}{6}$ the velocity of gravitation in one second.
t = time in seconds.

Then, from the laws of accelerated motion, $\frac{\overline{W + F}\, 2\, V}{gt}$ the power required to give to the piston the velocity V, in the time t; and as we require a force = W + F, to balance the resistance opposed to the motion of the piston, we have $P = W + F + \frac{(W + F) \times 2\, V}{gt}$ the effective pressure upon the piston, to move it at the velocity V.

Two causes thus operate, in limiting the velocity of these engines, viz. the intensity of pressure required to act upon the piston, compared with the density of steam in the boiler; and the quantity of steam capable of being constantly raised; and both these operate in bringing the engine to a state of uniform velocity.

We might, indeed, by enlarging the aperture between the boiler and the cylinder, increase the velocity of efflux, and consequently that of the piston; but this would again be rendered futile, if the supply of steam cannot be kept up; the latter, therefore, will be the principal regulator of the velocity.

We shall endeavour afterwards, to ascertain the extent to which these operate, in restricting the velocity of this kind of engine; but it will first of all be necessary to inquire a little further into the capabilities of these kind of engines, and ascertain if their particular mode of action, prevents them from attaining so high a maximum effect, as other

high-pressure engines. We are the more inclined to retain this inquiry, from knowing that the apparent "loss of power," as it is called, has already been made a subject of discussion, and objection to the use of such engines; calculated by taking the elasticity of steam in the boiler, as the measure of pressure upon the piston; and calling the difference between the pressure so estimated, and the actual performance of the engine, as the "power lost." The difference between the effects appears at first sight, as before stated, great; but by paying a little attention to the mode by which the steam is transmitted from the boiler to the cylinders, the cause is very evident; and the two following experiments, made with a view of illustrating this, will show, not only the characteristic properties of locomotive engines, but also of high-pressure engines in general.

EXPERIMENT VII.

Locomotive engine, with two cylinders, each 9 inches diameter; boiler, 9 feet long, 4 feet 8 inches diameter; density of steam in the boiler 50 lbs. per square inch; length of stroke in the cylinder, 2 feet; diameter of travelling wheels, 37 inches, same construction as *Fig.* I. and II. *Plate* VII.

Up a plane, ascending 134 inches in 1164 feet, the engine dragged 12 loaded carriages, the same as described in Experiment I., (on the adhesion of

the wheels,) the distance of 388 yards in 430 seconds.

Then $9^2 \times 7854 \times 2 = 127.2$ square inches, the area of surface of the two pistons; which, multiplied by 50 lbs., the elasticity of steam in the boiler, is 6367 lbs., the power applied on the pistons. The diameter of the wheels of the engine is 37 inches = 116.24 inches circumference; and, as during one double, or one complete stroke of the pistons, the wheels make one revolution, the number of strokes will be $\overline{1164 \times 12} \div 116.24 = 120$ of $2 \times 2 = 4$ feet each; consequently, the piston will have moved through $120 \times 4 = 480$ feet, while the engine moved over 1164 feet. The pressure on the piston is 6367 lbs., the power expended is, therefore, 6367 lbs. moved 480 feet = 3053280.

The gravity and friction of the engine and carriages, as per Experiment above named, is 1774 lbs., and the vis inertiæ $\frac{W + w\frac{SO}{SG} \times S}{rt^2} = 55$ lbs., making 1829 lbs., the resistance, which was moved over 1164 feet; consequently $1829 \times 1164 = 2128956$, the effect produced, exclusive of the friction of the engine.

Therefore { 3053280 power.
2128956 effect.

Whence we find the effective performance equal to 70 per cent. of the pressure of the steam, (of the density in the boiler) upon the piston; when the velocity of the piston, is 80 feet per minute.

EXPERIMENT VIII.

Same engine, and every other circumstance the same as in last experiment, except the load. The engine was taken down the plane, and 5 of the waggons used in the last experiment, attached; the time of drawing them up was 175 seconds. The

pressure of the steam, and the space passed over, being the same as the preceding experiment, we have 3053280, the power expended, at 50 lbs. pressure per square inch.

The resistance will be = 16800 lbs., (the weight of the engine) + 3360 lbs., (the weight of the convoy-carriage;) + 9408 × 5 = 47040 lbs., (the weight of the carriages;) $= 67200 \times \frac{134}{1396} =$ 645 lbs., the gravity of the whole train; and 40 × 5 = 200 the friction of the carriage, then $645 + 200 + \frac{W + w\frac{SO}{SG} \times S}{rt^2} = 167$ = 1012 lbs., the resistance; which, in the experiment, was moved through 1164 feet; whence 1012 × 1164 = 1177968, the effect produced.

Therefore { 3053280 power. / 1177968 effect.

Whence we have the effective power equal to 38.6 per cent. of the pressure of 50 lbs. per square inch upon the piston, when the velocity of the piston is 165 feet per minute.

The above experiments will shew how vague an idea we have of the performance of those engines, by expressing it in terms of horses' power, calculated by applying to the area of the piston the pressure of the steam in the boiler. The first of these experiments gives 70 per cent. effective power, and the other 38.6; while in each the elasticity of the steam in the boiler is supposed to remain the same.

We shall now endeavour to ascertain the cause of such an apparent difference in the effective performance between the two

Experiments. In the first Experiment, we have the resistance of the load = 1774 lbs., the friction of the engine 568 lbs., the vis inertiæ of the load 55 lbs.; and by the formula $\frac{\overline{W + F} \times 2R}{gt}$ we have the force requisite to give a velocity of 80 feet per minute to the piston 129 lbs.;—hence 1774 + 568 + 55 + 129 = 2526 lbs., the total resistance of load, machinery, &c. which moved 1164 feet, gives 2940264, the effect produced by a power of 3053280, or 98 per cent. The piston was moving at the rate of 80 feet per minute, at which velocity little loss of effect would arise, from the difference of elasticity of the steam on the cylinder, and boiler. But as, even at this slow rate, it would require some force to cause the steam to flow through the valves, the area of which, compared to that of the cylinder, is as 3 : 50; we may attribute the trifling loss of 2 per cent. to that cause, or perhaps to some error, in estimating the amount of friction.

Enough is shewn by this experiment, that no defect in principle arises from the particular nature of the application of this kind of engine; and that as high a maximum effect is attained, as in similar engines acting in a different manner; that if not a greater, at least as great an effect can be produced upon the load with these engines as with any other; and that no "loss of power," if we may apply a technical expression, is occasioned in the application of engines to *move with the load*, than what takes place in *ordinary engines fixed*, of the same kind; except what arises from the power required to move the engine itself upon the road.

In the second Experiment, the resistance of the load, including its vis inertiæ, is 1012 lbs., the friction of the engine 568 lbs.;

and $\frac{\overline{W + F} \times 2 R}{gt} = 375$ lbs.; whence 1012 + 568 + 375 = 1955 lbs. moved 1164 feet = 2275620 the effect produced, which is equal to 74.5 per cent., and 25.5 per cent. below the pressure on the piston, at 50 lbs. per square inch. The steam would be partially reduced in density, in its passage through the valves; but as the piston only moved at the rate of 165 feet per minute, the diminution by that cause, is not sufficient to account for the apparent loss of effect. We shall, therefore, endeavour to ascertain if the elasticity in the boiler has been kept up constantly at 50 lbs. per square inch during the experiment. In examining the Experiments in Table I., we find the evaporation of water about 94 gallons per hour; which, at the density of the atmospherical pressure, would produce 742574 cubic inches of steam per minute, the two pistons moved at the rate of 165 feet per minute, expending 251831 cubic inches of steam per minute; supposing the bulk of steam to be in the inverse ratio of its density, 742574 cubic inches of steam, at 30 inches of mercury when compressed into 251831 cubic inches, will therefore be of a density equal to 90 inches of mercury, or 30 lbs. per square inch, *above* the pressure of the atmosphere. We find from this therefore, that at the velocity with which the pistons moved in this Experiment, the boiler was only capable of furnishing steam of an elasticity equal to 30 lbs. pressure per square inch, which would be incapable of moving the pistons, constantly, at the rate of 165 feet per minute. The pressure at the commencement of the Experiments was, however, 50 lbs.; which might make the average somewhere about 40 lbs.; in which case, the power would be 5088 lbs., moved 480 feet = 2442240, while the effect was 2275620, which is equal to 93 per cent.

The above experiments shew, in a clear point of view, the mode of operation of these engines; in the first experiment, by the slow motion of the piston, the engine performs an effect equal to 98 per cent. of the pressure upon the pistons; and if we suppose the boiler capable of evaporating 94

gallons of water per hour, which would yield 171,363 cubic inches of steam per minute, at 50 lbs. per square inch, while the cylinder required, for a rate of 80 feet per minute, 122,112 cubic inches; there would always be an abundant supply of steam, and the pressure upon the piston, from its slow motion, would thus be kept at nearly the full intensity.

In the second experiment, we find the piston moving at the rate of 165 feet per minute, requiring a supply of steam at 50lbs. per square inch pressure of 251,831 cubic inches per minute; the supply which the boiler was capable of raising, was only, however, 171,363 cubic inches at that degree of elasticity. At the commencement of the experiment, therefore, the elasticity being at 50 lbs., would put the engine into rapid motion; but the boiler not being able to keep up the requisite number of cylinders full per minute, the elasticity would be gradually diminished, until an equilibrium was effected between the supply of steam and the expenditure, when the velocity would be uniform, and the engine would then be working with a pressure of 30 lbs., at a rate of 251,831 cubic inches per minute. The performance of those engines, therefore, depends entirely upon the quantity of water, which can be evaporated into steam of the required degree of elasticity in a given time; it is of no use to increase the size of the cylinder, unless the evaporating power of the

boiler can be correspondingly increased, so as to form the necessary quantity of steam. The quantity of water, or weight of steam, which can be evaporated in a given time, will therefore give the true measure of effect: and having once in any engine, ascertained the greatest quantity of steam which can be raised per minute, we can then calculate the effect which can be produced. This will be $R = 4\sqrt{\frac{l P}{W}}$; where R = velocity of the piston per minute, l = the length of the stroke, P = the pressure acting upon the piston, over and above what balances W; and W = the resistance, acting against the free motion of the piston.

We shall now endeavour to ascertain, from the foregoing experiments, the actual performance of loco-motive engines, with respect to the quantity of goods which they may be expected to drag upon Rail-roads.

On examining Experiments II. and III., we find one engine take 36 tons of goods, at the rate of five miles per hour; and 48 tons, at the rate of $4\frac{3}{4}$ miles per hour. This was effected by an engine, the area of the fire-place of which, was $6\frac{2}{3}$ square feet; the surface exposed to the radiant heat of the fire, being $10\frac{1}{2}$ square feet; and to the flame and heated air, 21 square feet.

In Experiment V., the area of the fire-place of which was 7 square feet, the surface exposed to radiant heat, $11\frac{1}{2}$ square feet; and to the commu-

nicative heat of the flame on its passage to the chimney, 29¾ square feet, being above one-third more; and hence we find the effect correspondingly increased. The performance of the latter engine is 48¾ tons, conveyed at the rate of 6,6 miles per hour, which, 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, 40 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 this 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 same 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,

40 tons conveyed at the rate of six miles an hour, was the maximum performance of those kind of engines; which is little more than an effective performance of seven horses, exclusive of the motive power required to propel the engine.

From the construction of the engines 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 one hour; and that a bushel of coals, i. e. 84 lbs., would evaporate 10 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 IV.

Experiment.	Cubic feet of water evaporated per hour.	Surface of tube in 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 a 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 Rail-way, 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 another experiment detailed by Messrs. Stephenson and Locke,* with an engine upon the Bolton and Leigh Rail-way, gave in twelve hours, 158 waggons of marl and

* On the Comparative Merits of Locomotive and Fixed Engines, p. 18.

sand, each weighing 4 tons, exclusive of carriages, conveyed over a distance of $1\frac{4}{10}$ miles, equal to 884 tons, over one mile, with a consumption of 15 cwt. of coals by the engine, and 1 cwt. in heating water, 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 Rail-way, deduct $\frac{1}{4}$th, making the consumption 1.60 lbs. per ton, per mile.

In the former 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 resistances of the friction of engine and load; the friction of 48.75 tons, was 472 lbs., and the engine 426 lbs.

Let P = the friction of the engine = 426 lbs.
R = the friction of the load.

Then $\frac{51.55 \times R + P}{898}$ = the quantity of coals required to convey any given weight of goods, whose friction or resistance is equal to R, along a level Rail-road, the distance of 1 mile; when loaded in both directions. Or $\frac{66.78 \times R + P}{898}$, 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 5 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 1.60lbs. per ton, per mile.

We have before stated, that in 1825, the power of these engines was rateable at about 40 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 an 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 Rail-way, 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.

In the spring of the year 1829, the Liverpool and Manchester Rail-way 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 Rail-ways 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 Rail-ways 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 Rail-ways, carefully to examine the

* On the Liverpool and Manchester Rail-road, p. 69.

working of the two species of mechanical power, and report to the Board of 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 Rail-ways 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 Rail-ways which they visited.

TABLE V.

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 Rail-way, and also of the Work that the Ten-horse Engine proposed by Mr. J. Walker and myself will be capable of doing :—

ENGINES.	RAIL ROADS.	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 Weight.	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	9⅛	12	40	13⅓	6⅔	12	32	28¾	14½	12	55¼	15	7½	12	34½	10 4/10	5 3/10	12	27 6/10
Engine on four 4-feet 2-inch wheels, under Mr. Nich. 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. Thos. Wood .	Hetton Colliery.	24¼	12	10½	46¾	12½	6¼	10½	29¼	8⅓	4⅓	10½	23½	19¾	9¾	10½	40	9¾	4¾	10½	25	6¼	3¼	10½	20
Engine on four wheels, rack rail, under the care of Mr. Blenkinsop	Middleton Colliery, near Leeds.	22¼	11	6¼	39½	12¼	6¼	6¼	24¾	9	4½	6¼	19¾	19¼	9½	6¼	35	10¼	5¼	6¼	21¾	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	32¾	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 Rail-way, is nearly the same as previously deduced in the former 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 Rail-way 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 Rail-way 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 :—

Rail-way Office, Liverpool, 25th April, 1829.

STIPULATIONS AND CONDITIONS

On which the Directors of the Liverpool and Manchester Rail-way 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 Rail-way Act, 7 Geo. IV.

2nd, The engine, if it weighs six tons, must be capable of drawing after it, day by day, on a well constructed Rail-way, 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 50lbs. per square inch.

3rd, 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 lbs. 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 45 lbs. per square inch.

7th, The engine to be delivered complete for trial at the Liverpool end of the Rail-way, 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 Rail-way; and any engine not approved to be taken back by the owner.

N. B. The Rail-way 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 Rail-way 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 Rail-road.

" *Liverpool, Oct.* 5, 1829."

The part of the Rail-way, 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 merit 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 RAIL-WAY.

The following is the ordeal we have decided each Locomotive Engine shall undergo in contending 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 50 lbs. 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.

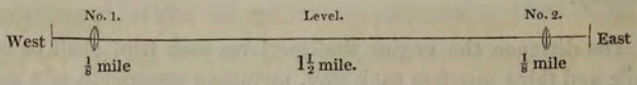
The time of performing each trip shall be accurately noted, as well as the time occupied in getting ready to set out for the second journey.

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,
John Kennedy, Manchester,
} Judges.

Liverpool, Oct. 6th, 1829.

The ground was then marked out according to the diagram below.—



And the mode of conducting the Experiment agreeable 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 proceeding 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.

The "Rocket" being first ready, was put upon trial, and having got a proper supply of water, was weighed, and found to be 4 tons 5 cwt.; the load affixed agreeable to the resolutions of the Directors, was therefore three times that weight, or 12 tons 15 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 50 lbs. per square inch, was 57 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 35 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 IX.

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 in going downfrom 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	.....	Greased the Pistons.
							0 4 35	
	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	.....	Took in 16 Imperial Gallons of Water.
							0 4 2	
	9	.....	1 33 35	0 7 5	.....	1 26 30	.....	
		0 2 15						
		.....	1 35 50	.....	0 4 12	1 40 2	.....	
H. M. S.							0 2 1	
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	
					+		0 28 34	
Total time 3 11 48							0 57 40	
			Time in going 30 miles at full speed	2 14 8		Time in starting, stopping and going 5 miles ..		

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 $14' 34^s$, and the precise time of starting, upon the second journey, was $2^h\ 3'\ 12^s$. After performing the assigned number of trips, as shewn in the following Table, the engine arrived at the west-end of the stage, at $5^h\ 0'\ 21^s$, the steam being found to be at the same elasticity as at starting, and the same quantity of water in the boiler.

EXPERIMENT X.

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 3 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	.....	Greasing waggons.
							0 3 40	
	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	.....	Took in 16 imperial gallons of water.
							0 3 38	
	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	.....	
Totaltime 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
	30 miles in	2	6	9		$14\frac{2}{10}$	per hour.
Ends of stage	5 miles in	0	57	40	equal to	$5\frac{2}{10}$	Miles
	5 miles in	0	50	20		6.	per hour.

Maximum velocity in performing one trip — 1st journey $19\frac{1}{7}$; 2nd journey 20 — Miles per hour.

Minimum velocity in performing one trip — 1st journey $11\frac{4}{11}$; 2nd 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 $29\frac{1}{2}$ 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.
Exclusive of ditto .....1.63 lbs. } per ton, per mile.

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.

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 $14\frac{1}{2}$	}	miles, per hour, or average
2nd journey	0	57	12, or $15\frac{3}{4}$	}	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 70 miles travelled in the observed time occupied between the inner stations, and half the time at each end. This would make the performance 17 tons, including the engine, or 9½ tons, exclusive of the engine, conveyed 70 miles in about five hours, or at the rate of 14 miles per hour. And this would give the evaporation of water, 114 gallons per hour, and the consumption of coke, 217 lbs. per hour.

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 50 lbs. 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 4 tons, 15½ cwt. On perusing the conditions issued by the Directors, it will be seen, that if any engine should be more than 4½ tons 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 agreeable 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 XI.

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 8 imperial gallons of water.
							0 2 34	
	7	.....	0 15 12	0 8 1	.....	0 7 11	.....	
One of the waggons got loose.		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	
					+		0 19 47	
Total time, 2 17 11			Time in going 22 and a half miles 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
	12 miles in	0 40 27		$15\frac{5}{10}$ per hour.
Ends of stage	$1\frac{7}{8}$ miles in	0 19 47	equal to	$5\frac{7}{10}$ Miles
	2 miles in	0 20 08		6. per hour.

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 lb.,

which is { including the engine and tender 2.41 lbs. } per ton
{ exclusive of .. ditto .. 4.2 lbs. } 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.

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 $19\frac{1}{2}$ tons, or 11 tons exclusive of the engine and tender, conveyed at the rate of about 15 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.

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 ERICSSON'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 66lbs., 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 XII.

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.		
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 2 34	
					0 6 40			
				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. ERICSSON 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 10 tons $6\frac{1}{4}$ cwt. traversed the eastward trip of $1\frac{1}{2}$ miles in 4 minutes 39 seconds, being at the rate of $17\frac{1}{2}$ miles per hour, and the westward trip in 5 minutes 54 seconds, being at the rate of 15 miles an hour. The loaded carriages being detached, the engine made a trip with passengers, going at the rate of between 20 and 30 miles an hour. Two or three days being allowed to get

the engine into complete working order, (as many as Messrs. BRAITHWAITE and ERICSSON 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 XIII.

Observations.	No. of Trips.	Time of getting up and stopping the speed of 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						
H. M. S.		.....	1 48 44	.....	0 6 14	1 54 58	.....	
Boiler joint blew out and stopped the Engine above the bridge at.. 2 1 45							0 1 7	
	2	.....	.....	.....	.....	1 56 5	.....	
				0 5 35	0 17 22			
					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. ERICSSON 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.

The "Rocket" engine, of Mr. R. Stephenson, shewn in the engraving No. I. 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, 6 feet long, and

3 feet 4 inches diameter. To one end of the boiler is attached a square box, or furnace B, 3 feet long, by 2 feet broad, and about 3 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 3 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, supplying it with water; and another pipe D, at the top, allowing 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 this part of the boiler, copper tubes reach from one end of the boiler to the other, shewn in No. 2, being open to the fire-box at one end, and to the chimney at the other. In the boiler of the "Rocket," there were 25 tubes, 3 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 8 inches diameter, with a stroke of 16½ inches; diameter of large wheels, 4 feet 8½ inches. 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 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 20 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 6 square feet. The end view, No. 2, will shew the disposition of the tubes in the end of the boiler, with the fire-box surrounding the end.

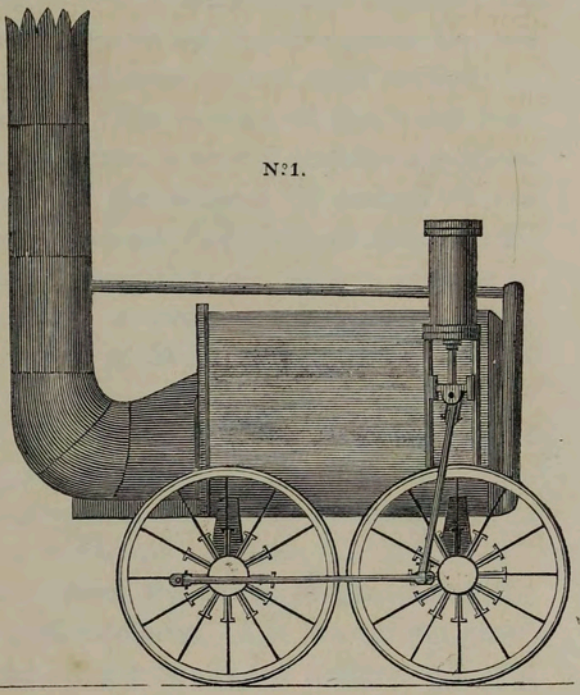
The "Sans Pareil," of Mr. Hackworth, is of the same principle as the "Rocket;" the combustion of the fuel being effected by the *exhausting power of the chimney*, and the ejection of the steam from the cylinders into the chimney. The accompanying sketch, No. 1, will shew the form of boiler, which is cylindrical, 4 feet 2 inches diameter, with one flat, and one hemispherical end, and 6 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, 7 inches; length of stroke, 18 inches; diameter of wheels, 4½ feet.

The steam is generated by means of a double tube, as shewn in the sketch No. 2, 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. 2, shews the grate-bars, *b b* the tube, and C, the chimney. The tube projects, from the end of the boiler,

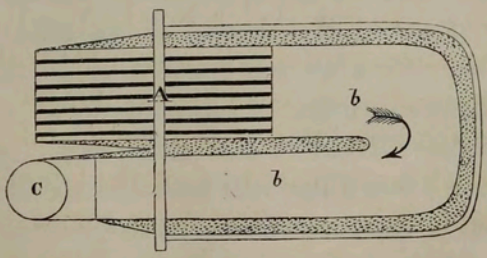
about 3 feet; and at the fire end a semi-circular casing surrounds the top of the tube, as shewn in the drawing; and the whole 3 feet, but at the chimney and the casing, extends only 2 feet. This was for the double purpose of obtaining an area of heating surface, and sufficient air to pass through the fire-grate, which tubes, entirely within the backs, do not possess. At the fire end the tube was 2 feet diameter, tapering away to 15 inches, the diameter at the chimney; the length of grate-bars being 5 feet. The area of surface of water exposed to the direct action of the fire or *radiant heat*, is therefore 15.7 square feet; and to the *communicative* power of the heated air and flame, 74.6 square feet, the area of fire-grate being 10 square feet.

In Messrs. BRAITHWAITE and ERICSSON'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. 1, 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, passes through the upright generator from top to bottom; near the bottom it

N°1.



No. 2.



To face page 384.

is, as shewn in No. 2, increased in diameter, for the purpose of receiving the fire-grate F; the fuel being supplied from the top, 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 a diminished scale in No. 2,) within the horizontal generator, and to 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.

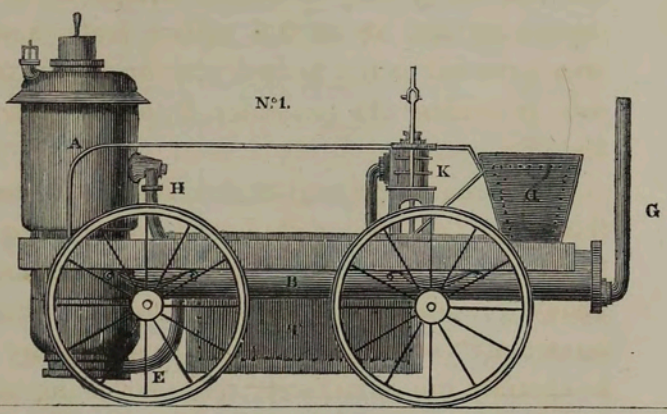
No. 2, will shew the mode of generating the steam more particularly. A is the upright generator; C, the inner tube; F, the fire-grate; B, the horizontal generator; H, a pipe through which the steam from B, passes into the steam chamber A. From C, the inner tube or pipe, *e e e* (on a diminished scale) 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: that 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

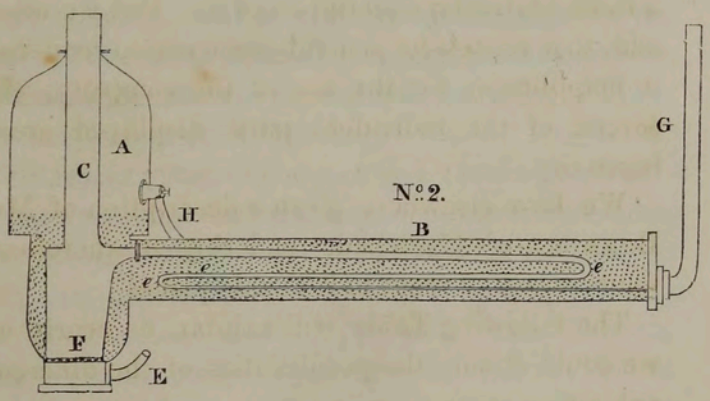
the winding tube *e e e*, into the atmosphere, through the pipe G. The area of grate-bars, in this engine, is only about 1.8 square feet. The *radiant surface*, about 9.5 square feet; and the area exposed to the heated air, by means of the tube traversing the generator B, about 33 square feet.

Mr. BURSTALL's engine, not being adapted for the present celerity of Rail-road conveyance; the boiler, consisting 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,—not 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. 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.

We have elsewhere given a description of Mr. BRANDRETH's Cycloped, rendering it, therefore, unnecessary to recur to it in this place.

The following Table will exhibit, as nearly as we could obtain, the peculiarities of the different exhibiting engines.





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TABLE IV.

Names of engines.	Area of fire-grate in feet.	Area of *radiant* 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.
Rocket . .	6.	20.	117.8	18.24	11.7
Sans Pareil	10.	15.7	74.6	24.	28.8
Novelty . .	1.8	9.5	33.		
Old Engines	7.	11.5	29.75	15.92	18.34

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 attributable to the use of the tubes of small diameter, presenting such an area of surface to the water in the boiler. 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.

With a less area of fire-grate, than the old engines, the surface exposed to the radiant 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 22 inches 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 25 tubes, 3 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 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 radiant heat of the fire, compared with the area of fire-grate is as $3\frac{1}{3} : 1$, while, in the Sans Pareil, it is only $1\frac{1}{2} : 1$; 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 fire-grating, is as $19\frac{2}{3} : 1$; while, in the Sans Pareil, the proportion is only $7\frac{1}{2} : 1$. The bulk of air passing through the tube of the latter, will, at its exit into the chimney, be 176.7 square inches, the exposed surface being 47.12, or, 25 : 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 $1\frac{1}{3}:1$. These will sufficiently account for the great difference in the economy of fuel between the two engines; 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 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 issuing 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, 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 12 or 15 miles an hour, the draught was so great, that it actually threw the cinders 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 10 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 us to an enquiry 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 become 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 passing into the chimney, will be greater than that of the water in the boiler. This heat will, however, be insufficient in engines of this kind, to cause a sufficient quantity of air to pass through the fire for the purpose of combustion; and it 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 Rail-ways, especially for quick travelling. The performance of those engines depends entirely upon the quantity of steam they can raise in a given time; and when travelling at the rate of fifteen 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 its passage 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, therefore, 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 lately made.

The "Novelty" engine is 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" is 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 radiant 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 36 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, 36 feet long, or 6 tubes, each 6 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 25 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 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 enquiry was of the utmost importance. Theoretically considered, we are of opinion, that this mode of generating steam, is 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 exhaustion of the chimney. If the same quantity of air pass through the grate-bars in each, 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; for we suppose the temperature reduced to the same, in both cases, in the exit pipe. For if the heated air, in both cases, pass into a chimney of the same area, and equal to that of the exit-pipe from the generator, on the exhaustion principle; the temperature of the heated air being supposed to be the same, in both cases, in the exit pipe: the heated air from the generator with the bellows will, therefore, have to expand itself in the chimney, into twice its volume, which will, of course, reduce its temperature below that of the other; thus proving a more complete abstraction of the heat. 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 greater 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 enquiry, 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 disquisition, to explain, so far as we are able, the cause of the failure of the Novelty engine at the Liverpool experiments; to shew that it arose from no defect in the principle, but only in the construction of that engine. It will be seen by the sketches of this engine, that the flame and heated air, after leaving the fire, passed through the winding pipe of the horizontal generator. The generator was only 12 inches diameter, and there were three folds of the flue-tube within it, in diameter from 4 inches at one end, to 3 inches at the other; very little space was, therefore, left between the flue-tube and the top of the generator. The temperature of the flame, within this tube, when the engine was running at a quick rate, would be very great, especially where it left the upright generator; and

the evolution of heat would, therefore, be so rapid, that the passage of the steam out, would prevent the water from flowing along this 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, arises from no defect of principle, and was easily remedied.

We shall now give some account of the proceedings, subsequent to, and 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 expence 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, bear so great a proportion to the weight or powers of the engine; subsequently, these engines have been made more powerful, and their effective performance has consequently been 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 XII.

28.5 tons conveyed 30.813 miles = 878.07 tons.
7.5 tons..... 3.224 .... = 24.28 ..
17.5 tons..... 33.205 .... = 58.11 ..
67242
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 the Experiment..... 526 ..
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 .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 .918 lbs. of coke per ton per mile.

The time occupied in performing the whole distance, was 6.26 hours. The average rate

588) 67242 (588 / 536 / 520) 8.5 lbs per mile

between the posts, while at full speed, is said to have been 8.05 miles per hour, the rate in the above time, would be about 6 miles per hour. The bellows was blown by a separate cylinder, and was said to be at work during the whole time, or 6.26 hours; the quantity of steam expended, was, therefore, that which required 6.26 hours to generate, 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 7 miles per hour.

Mr. STEPHENSON had 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 XIII.

			H.	M.	S.
37¼ tons conveyed	9	miles in	0	41	18
41¾ tons	3	....	0	13	15
46¼ tons	3	....	0	13	8
	15	miles in	1	7	41

equal to 13⅓ miles per hour, nearly, with an average load of above 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 XIV.

"Meteor" engine, having 90 tubes, each 2 inches diameter; area of grate-bars, 6 square feet; extent of radiant surface, 20 square feet; and of surface 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 10 to 12 miles per hour. This is equal to 1500 tons, conveyed 1 mile. Consumption of fuel, including the engine and tender, (7 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 XV.

"Arrow" engine, of similar construction to the last, with 92 tubes, each 2 inches diameter, passing through the boiler; area of fire-grate, 6 square feet; extent of radiant surface, 20 square feet; and extent of communicative surface, 144.81 square feet.

28 Tons conveyed over a space of 36¼ miles, and 32¼ tons conveyed 6 miles, equal to 1208 tons conveyed 1 mile; consumption of coke, 1008 lbs. The average speed being 12 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.

TABLE VII.

Engines.	Average rate of speed in miles per hour.	Consumption of coke in lbs. per ton per mile.
No.		
1 Rocket	14	2.41
2 Sans Pareil	15	2.47
3 Novelty	8	0.918
4 Phœnix	12	1.42
5 Arrow	12	1.25

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 18.34lbs.; 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 expence of fuel, per ton per mile, is greater than in the old ones.

The engines lately made on the Liverpool Railway, are more powerful, and not only render the cost of fuel, per ton per mile, (as shewn in the Table,) less, from the greater quantity of goods compared with the weight of the engine, which they are enabled to convey; but we think the arrangement of these engines more likely to produce a greater economy of fuel, whilst at the same time their evaporating powers are considerably increased.

The following Table will shew the arrangement of the boilers of the different engines, noticed in the work.

TABLE VIII.

Names of Engines.	Area of fire-grate, in square feet.	Area of surface exposed to radiant heat, in square feet.	Area of surface of communicative heat, in square feet.	Area of volume of heated air passing thro' tubes in inches.
Rocket ...	6.	20	117.8	176.7
Arrow	6.	20.	282.7	282.
Planet....	7⅓	29.	225.	144.8

Comparing the "Rocket" and "Arrow" together, we find the area of surface exposed to the heated air increased, in the latter, from 117.8 to 282.7 square feet; which causes a more perfect abstraction of heat, as we find from the experiment previously given with this engine. But we must

remark that another effect arises from the construction of this engine. The volume of heated air passing through the tubes, is increased from 176 to 282 square inches; this has the effect of allowing a greater quantity of heated air to pass off, creating a greater force of blast to the fire, and thus increasing the evaporating powers; hence we find that the quantity of water evaporated per hour, as per experiment afterwards detailed, is increased from 185 to 275 gallons per hour. If, therefore, the surface of heated air had not been correspondingly increased, we should not have had the economy of fuel so great in this engine as in the "Rocket." As it is, the relative economy bears no proportion to the increase of surface, arising from the cause above mentioned. For if we compare the volume of heated air in the tubes, with the area of the chimney, we find that it is nearly double; and hence the heated air is in a considerably more compressed state in the chimney, than in the tubes; the reverse of what should produce the greatest economy in the consumption of the fuel.

Mr. Robert STEPHENSON has favored us with a very interesting experiment on this subject.

EXPERIMENT XVI.

A box 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, 5½ feet long by 16 inches wide,

which was traversed by 9 tubes, each 3 inches 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, 6 square feet, and the tubes $24\frac{1}{2}$ 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. 32 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 6 gallons, and the tubular vessel 8 gallons of water. The time of evaporating the above quantities was therefore 38 minutes; this would make the fire-box evaporate 10 gallons, and the tubular vessel 12.75 gallons *per hour*. Hence, 1 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 1 foot, exposed to the heated air in passing through the tubes, evaporated $\frac{1}{2}$ 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 by 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 the "Planet" engine.

Under these circumstances, and contemplating what appears certain to be the result, that the consumption of fuel in these engines will be still further reduced; it is scarcely, perhaps, consistent to assign any fixed quantity at the present moment. As it may, however, be necessary, for the purposes of calculation, to fix upon some standard for practice, we shall take No. 4, which, though not giving the most economical result, yet considering that it is the result of careful experiment, and that considerable waste often occurs in practice, it may be advisable to adopt for practical purposes. This is 1.42, or say 1.5 lbs., per ton per mile, for goods, or 1 lb. gross. This will be the greatest consumption of those engines of the construction mentioned. But Mr. STEPHENSON informs me that, from some recent experiments, he finds the economy of the "Planet" engine much greater; and that .666 lbs. per ton gross, or 1 lb. per ton of goods, will cover all waste with that engine; which arises mostly from the economy of construction previously noticed, and partly from the load capable of being conveyed, bearing so great a proportion to the weight of the engine.

Adopting the formula previously used, and supposing P the friction of the engine, with 5-feet wheels, = 340 lbs., R the friction of the load, with the above consumption = 305 lbs., we have $\frac{45 \times \overline{R + P}}{645}$, the quantity of coke in lbs. required to convey any quantity of goods, the friction

of which is equal to R, one mile, by the older engines; and $\frac{30 \times \overline{R + P}}{645}$, the quantity of coke, in lbs., as consumed by the "Planet" engine, going at the rate of 15 miles an hour.

On attempting to compare the relative consumption of one engine, however, with another, we must pay some attention to the rate of travelling. The "Novelty" engine appears the most economical; but it must not be overlooked, that the rate of travelling was only two-thirds. that of Nos. 4 and 5.; and that, consequently, the engine was enabled to take a correspondingly greater quantity of goods, compared with the weight of the engine, than when travelling at a quicker rate of speed.

We come now to the performance, or quantity of work, which these engines are capable of doing; and here we shall find the tubular boilers, or the modern and improved modes of generating steam, of the most importance; considerably greater than any saving in the economy of fuel.

In the former edition of this work, we stated the performance of the best locomotive engine as equal to 40 tons, conveyed at the rate of 6 miles an hour: four years after this, or in 1829, according to the Table given by Messrs. WALKER and RASTRICK, they fixed 48½ tons, conveyed 5 miles an hour, or 19½ tons, conveyed 10 miles an hour, as the greatest performance the Directors of the Liverpool Rail-way could expect from them.

We cannot subscribe to the conclusion of Messrs.

WALKER and RASTRICK, that the *same engine*, capable only of moving 60 tons, including itself, at the rate of 5 miles an hour, will propel 30 *tons* at the rate of 10 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 engine, 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 9 tons. This is, therefore, the least friction we can calculate upon; indeed, we have previously stated, in respect to the consumption of fuel, that the whole resistance 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 $700 \times 5 = 3500$, the effect at 5 miles an hour. Then $3500 \div 10 = 350$, the resistance which the same power is capable of moving, at the rate of 10 miles an hour; whence $350 - 200 = 150$ lbs., the useful effect which the engine is capable of producing, or 15 *tons* gross, equal to 10 tons of goods. Our estimate of 40 tons, at 6 miles an hour, would, according to the above calculation, give 16 tons gross, conveyed at the rate of 10 miles an hour.

Supposing, however, Messrs. WALKER and RASTRICK's *standard* to have been at 10 miles an hour, and that the proposed engine would take 19½ tons gross, or 13 tons of goods, at that rate of speed, this would give only 6¾ tons gross, or 4 tons of goods at the rate of 15 miles an hour, or the average rate of travelling upon the Liverpool and Manchester Rail-ways at present.

We see, therefore, that in 1825, and for four years afterwards, there *did exist* some grounds for arriving at the conclusions which have, subsequent 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 anticipation 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 those 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 twelve months 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 Rail-ways on which they had been introduced; and now we find their regular day's work, averaging more than 15 miles, and, in one instance, a distance of above 30 miles traversed within an hour. 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 inclined, however, notwithstanding the error into which we are accused of having previously fallen, to fix our data, rather upon their present powers, than upon any speculative capabilities which we do not doubt they may hereafter attain.

We shall, in doing so, be obliged to confine our-

selves to the engines of Messrs. STEPHENSON and Co. ; for although we do not doubt, that Messrs. BRAITHWAITE and ERICSSON, and others, may produce engines capable of competing with those in performance, at some time or other; yet we have, at present, no other data than those on which we can assign any tangible performance. We understand, that in the engines lately made by BRAITHWAITE and ERICSSON, for the Liverpool Rail-way, those gentlemen have abandoned the principle of *forcing* the air through the fire, by means of the bellows, and have 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 ERICSSON's principle, having shewn a surprising result, as to the economy of fuel, may have induced the adoption of the latter principle. The length of flues, in this Experiment, (see Note C., Appendix,) was, however, 45 feet, a length, we should imagine, rather difficult to obtain in a locomotive engine; and on which, we suspect, the economy of fuel resulted.

Both the engines of Messrs. STEPHENSON and Co. and of Messrs. BRAITHWAITE and ERICSSON,

may now, 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 in which, is kept up by the rarefaction in the chimney; and, therefore, we should expect in time, a considerable effect produced both in the economy of fuel, and also of performance.

Experiment XIV. gives the performance of the "Meteor" engine, 34½ tons, conveyed at the rate of from 10 to 12 miles an hour, in traversing a short stage. Subsequent experiments and observation shew, that some of the engines, lately made for the Liverpool Rail-way, are capable of a much greater performance, especially in travelling right forward upon long stages, and not subjected to

the tedious and disadvantageous operation of traversing back and forward upon short stages, thus alternately dragging and pushing the carriages.

An experiment with the "Rocket" engine, cited by Messrs. R. Stephenson and Locke, p. 26*, gives the average rate of performance 37¼ tons gross, or 25 tons of goods, at 13 miles an hour; this engine, however, is of much smaller powers than those subsequently made.

The power being in strict proportion to the quantity of water which the engine is capable of evaporating in a given time; the following Table of experiments, on the actual quantity of water evaporated in a journey between Liverpool and Manchester, will shew that the powers of those engines are much increased: distance, 32 miles; the whole time occupied 2 hours, including stoppages.

TABLE IX.

Engines.	Quantity of coke consumed in lbs.	Quantity of water evaporated in gallons.	Gallons of water evaporated per hour.
Rocket.....	650	370	185
Arrow.....	900	550	275
Phœnix.....	850	430	215

* On the comparative merits of locomotive and fixed engines.

These experiments shew the great increase of effect between those engines and the old ones, with a single tube; in the latter we have the quantity of water evaporated per hour, equal to about 94 gallons; whereas the above is double, and, in the "Arrow" engine, nearly treble. We find also the evaporating powers of the "Rocket" engine considerably increased by the application of the steam, as a blast into the chimney, in the proportion of 114 : 185.

The power being, as before stated, in strict proportion to the quantity of water evaporated, or steam generated per hour, we have, in the "Arrow" engine, 275 gallons, equal to 501,328 cubic inches of steam, at 50 lbs. pressure per square inch, evaporated per hour. This will give 2,088,866 lbs. pressure per foot per minute; and if we take 30 per cent. as the effective power, we have 626,659 lbs. moved one foot per minute. If we suppose 15 miles per hour, or 1320 feet per minute, the average rate of travelling, this quantity of steam would give 474 lbs. moved at that rate; we may, therefore, safely estimate the powers of those engines at 30 tons gross, conveyed at the rate of 15 miles per hour, including any casual stops; which would leave 174 lbs. for that resistance which is peculiar to those engines; or the power expended in effecting their locomotion, which is considerably greater than required; being only the resistance

of the axles and the wheels upon the rails, more than that of ordinary engines.

In assigning this performance, we trust we have kept quite within the capabilities of these engines, even in their present state of improvement. We cannot, however, suppose that they will remain in this state; the powerful direction of public attention to them, and the very important consequences likely to result from their economy and despatch in interior communication, will doubtless ensure their further improvement: and, therefore, in assigning a performance equal only to their present capabilities, we are liable to fall into the same error as in the former edition of this work. Still we prefer this mode, rather than to affix a performance, which depends upon adventitious circumstances, and which, if not realised in practice, might be attended with injurious consequences.

The "Rocket," and light engines of similar power, are not capable of effecting this performance; and we have previously shewn the loss consequent upon the employment of engines with such powers: we are, therefore, of opinion, *that it will not be advisable, in order to effect the greatest economy in the application of this mode of conveyance, to use engines of less power than what are capable of effecting the performance we have assigned.*

One of the most powerful reasons for adopting this conclusion is, that we presume, in the majority of cases where these engines are used, and especially on public rail-ways, they will be employed in the conveyance of passengers on the same line of rail-way, upon which heavy goods and merchandize are to be conveyed. We have before shewn, that the greatest economy is effected, when the quantity of goods conveyed, bears the largest proportion to the weight of the engine; and, for the conveyance of passengers, the greatest effect is produced, when the rate of speed (consistent with safety) is the greatest. It follows, therefore, *that a maximum effect is produced, when the greatest load is conveyed at that velocity, which is deemed necessary for the conveyance of passengers;* presuming, which will not be questioned, that, if possible, without a sacrifice of economy, all the traffic upon any rail-way should be carried on at the same rate of travelling.

We are of course confined to the load that can be taken, by the weight of the engine, and the adhesion of the wheels upon the rails. We have given Tables, shewing the load which an engine of a certain weight can overcome upon different acclivities; and the weight of the engine will depend upon the strength of the rails used. In a general way, perhaps, the undulations will allow of the transit of a load, equal to 30 tons, being effected; and, therefore, we have fixed

upon that load as a standard, only for the purpose of enabling us to enter into a comparison with other modes of conveyance; as the Tables given will shew the effect with other loads. The only question now is, whether engines can be made with that power, of a weight below that which will injure the rails: reviewing the improvements that have recently been effected, and contemplating those likely to occur, we think there cannot exist any doubt that an engine, capable of effecting the performance we have assigned, may be constructed of such a weight, as will not be productive of such injury. The "Planet" engine, which we deem of the requisite power, is between 5 and 6 tons weight, and no doubt this weight will be reduced as improvements go on; but when we consider the trifling proportion which the additional weight of a few pounds per yard, of iron, applied to increase the strength of the rails, bears to the whole cost of the rail-way, we cannot suppose that the addition of 20 or 30 cwt., in the weight of an engine above that of the ordinary carriages, will be put in competition with the permanent economy in the means of transit, by such a trifling increase of expenditure. At the same time we beg to be understood, that we are not an advocate for the use of heavy engines, but only for the application of engines of such powers, as are capable of effecting a maximum result—if such can be applied without more injury to the rails than what arises

from the common carriages; or if such application can be effected, with a like result, by the addition of a few pounds weight of iron per yard.

On the Liverpool and Manchester line, the entire cost of the rails constitutes less than 6 per cent. of the whole expence of the Rail-way; and that weight, per yard, which would increase their strength more than one half, would not be equal to 2 per cent. of the whole expenditure, or 2*s*. 6*d*. per lineal yard, of single Rail-way.

We shall, therefore, estimate the performance of locomotive engines, upon a level Rail-way, at 30 and 40 tons gross, according to the weight and power of engines which the strength of the rails will admit of being used; which will give 20 and 38 tons of goods respectively, conveyed at the rate of 15 miles an hour: and the following Tables will shew the quantity, at different inclination of planes.

TABLE X.

Gross load in tons, which a Locomotive Engine, capable of taking 30 tons, at 15 miles an hour, will drag at the undermentioned velocities, in miles an hour.

Inclination of Plane.	10	11	12	13	14	15	16	17	18	19
Level . .	53.4	51.81	45.	39.23	34.28	30.	26.25	22.94	20.	17.36
1 in 4480	50.85	49.35	42.57	37.35	32.62	28.57	24.97	21.82	18.97	16.5
— 2240	48.51	47.1	40.87	35.62	31.12	27.22	23.85	20.85	18.15	15.9
— 1120	46.5	45.03	39.07	34.05	29.77	26.02	22.8	19.95	17.32	15.07
— 1000	43.56	42.3	36.75	32.02	27.97	24.45	21.45	18.7	16.27	14.17
— 900	42.9	41.7	36.3	31.57	27.6	24.15	21.15	18.45	16.12	13.95
— 800	41.7	39.9	35.15	30.6	26.77	23.4	20.47	17.85	15.6	13.5
— 700	41.25	39.	34.05	29.7	25.95	22.73	19.87	17.32	15.07	13.12
— 600	39.	37.8	32.85	28.57	24.97	21.9	19.05	16.72	14.55	12.67
— 500	37.05	36.	31.2	27.22	23.77	20.85	18.22	15.9	13.87	12.
— 448	35.61	34.5	30.	26.1	22.87	19.7	17.47	15.25	13.27	11.55
— 400	33.75	33.15	28.8	24.37	21.97	19.2	16.8	14.7	12.75	11.1
— 350	32.7	31.56	27.37	23.92	20.85	18.25	15.97	13.95	12.15	10.5
— 300	31.44	29.76	25.8	22.53	19.65	17.17	15.07	13.12	11.47	9.97
— 250	28.2	27.36	23.77	20.7	18.57	15.82	13.87	12.07	10.57	9.15
— 200	25.11	24.36	21.22	18.45	16.12	14.1	12.37	11.05	9.37	8.17
— 150	21.36	20.7	18.	15.6	13.65	12.	10.5	9.15	7.95	6.93
— 100	17.55	17.02	14.77	12.9	11.25	9.82	8.62	7.5	6.58	5.71

TABLE XI.

Gross load in tons, which a Locomotive Engine, capable of taking 40 tons, at 15 miles an hour, will drag at the undermentioned velocities, in miles an hour.

Inclination of Plane	11	12	13	14	15	16	17	18	19	20
Level . . .	69.08	60.	52.30	45.70	40.	35.	30.58	26.66	23.14	20.
1 in 4480	65.8	57.1	49.8	43.5	38.1	33.3	29.1	25.3	22.	19.
— 2240	62.8	54.5	47.5	41.5	36.3	31.8	27.8	24.2	20.9	18.1
— 1120	60.07	52.1	45.4	39.7	34.7	30.4	26.6	23.1	20.1	17.3
— 1000	56.4	49.	42.7	37.3	32.6	28.6	25.	21.7	18.9	16.3
— 900	55.7	48.4	42.1	36.8	32.2	28.2	24.6	21.5	18.6	16.1
— 800	53.2	46.9	40.8	35.7	31.2	27.3	23.8	20.8	18.	15.6
— 700	52.3	45.4	39.6	34.6	30.3	26.5	23.1	20.1	17.5	15.1
— 600	50.4	43.8	38.1	33.3	29.2	25.4	22.3	19.4	16.9	14.6
— 500	48.	41.6	36.3	31.7	27.8	24.3	21.2	18.5	16.	13.9
— 448	46.	40.	34.8	30.5	26.6	23.3	20.3	17.7	15.4	13.3
— 400	44.2	38.4	32.5	29.3	25.6	22.4	19.6	17.	14.8	12.8
— 350	42.1	36.5	31.9	27.8	24.3	21.3	18.6	16.2	14.1	12.1
— 300	39.7	34.4	30.05	26.2	22.9	20.1	17.5	15.3	13.3	11.4
— 250	36.5	31.7	27.6	24.1	21.1	18.5	16.1	14.1	12.2	10.6
— 200	32.5	28.3	24.6	21.5	18.8	16.5	14.4	12.5	10.9	9.46
— 150		24.	20.8	18.2	16.	14.	12.2	10.6	9.25	8.
— 100		19.7	17.2	15.	13.1	11.5	10.	8.78	7.62	6.58

We have given two Tables, one Table X., on the supposition that 30 tons moved at 15 miles an hour is the load, and the other one-third more, or 40 tons moved at the same rate.

On long lines of road, we may calculate upon a load, equal to the resistance of 30 tons upon a level being taken, calculated upon the *average inclination* of the whole line; provided that any short undulations which may occur, do not present a resistance greater than the power of adhesion of the wheels, or greater than given in Table XI.

The latter Table will, therefore, shew the load which may be overcome upon any short undulations, and the velocity which the engine can move with such loads; and we have not carried the calculations of those Tables farther, than the load, which the adhesion of the wheels can overcome.

That the engines are capable of effecting such a performance, as that shewn in Table XI., will appear from a calculation of the powers of the "Planet" engine. The cylinders are 11 inches diameter, length of stroke 16 inches, area of cylinders = 190 inches, which, moved through 32 inches in each revolution of the wheels = 6080. The diameter of the wheels is 5 feet, circumference 188.4, the resistance of 40 tons is 400 lbs. whence $188.4 \times 400 = 79360$; therefore, $\frac{79310}{6080} = 13$ lbs. per square inch, upon the piston effective pressure; to overcome a resistance, equal to 40 tons moved at the rate of 15 miles an hour; which, with steam

of the elasticity of 50 lbs. per square inch, is an effective pressure of 26 per cent. The number of strokes per minute being 84, velocity of piston, 224 feet per minute. We shall now ascertain, if the boiler is capable of generating a sufficient quantity of steam, to keep up an adequate supply, at 50 lbs. pressure per square inch. The area of the two cylinders is 6080 × 84 strokes per minute = 510,720 cubic inches of steam, expended every minute. We find, from Table IX., that the "Arrow," whose powers of generating steam is not equal to the "Planet," evaporated 275 gallons per hour, or 458 gallons per minute; which will give about 501,328 cubic inches of steam, at 50lbs., or 510,720 cubic inches, at 49lbs., increasing the effective pressure from 26 to 26.5 per cent. We have previously found, that these engines are capable of yielding an effective power of upwards of 30 per cent. of the pressure on the piston.

We thus see that, those engines are not only capable of effecting a performance equal to that in Table XI., for short distances, or over casual undulations; but that, with a power of evaporation equal to 275 gallons per hour, they will be capable of constantly keeping up that performance.

In the construction of these Tables we have supposed the power of the engine to be constantly the same, or the production of steam in the boiler to be constant and regular, or equal quantities in

equal times; but a little consideration of the mode by which the steam is generated, will shew this is not the case.

The supply of air for the support of combustion, is almost entirely produced by the exit of the steam into the chimney; if this is capable of producing a certain effect at 12 miles per hour, when the engine is moving at 24 miles per hour, *double* the same number of cylinders full of steam pass into the chimney *in the same time*, and therefore the draught will be greater, and the generation of steam more rapid; and hence we should have, at greater velocities, an increase of effect with the same engine. But as in this case, the piston moves at a correspondingly increased velocity, thereby producing a diminution of effect; and there being also an increase of resistance from the air at great velocities, perhaps in the absence of experiment to prove the amount of all these different forces, we ought in practice to suppose the power of the engine constant, and capable of producing, at the higher velocities, an effect equal to that shewn in Table XI.

These Tables are formed on the supposition that the load is equal in both directions, as they shew the load which the engines are capable of dragging *up* planes of the inclination given; the load *down* the respective planes will be as much greater, as the assistance which gravitation affords.

It would be extremely difficult to give Tables for all the different cases which may occur in practice, and we shall, therefore, give a Formula from the "Rev. James ADAMSON's sketches, of our information on Rail-roads."

Let E represent the weight of the engine, and a be that fractional part of its weight representing the available friction or adhesion, which produces the progressive motion of the engine wheels upon the rails; then E a will represent the engine's force of traction upon a level.

Let i be the angle of inclination;

W the weight of the carriages and load;

f the friction at the axle of the carriages, when the pressure is 1;

n the diameter of the wheel, when that of the axle is 1;

Then we have the general equation, to express the relations of those quantities.

$$\mathrm{E}\,(a \mp \sin i) = \mathrm{W}\left(\frac{f}{n} \pm \sin i.\right)$$

$$\text{Whence } \mathrm{W} = \frac{\mathrm{E}\,(a \mp \sin i.)}{\frac{f}{n}\left(\pm \sin i.\right)}$$

The upper signs give the equations for ascending slopes, and the lower for descending slopes.

If we express W as a multiple of E, then we shall be able to find the inclination at which any required proportion of the work, done on a level, may be performed.

$$\text{If } \sin i = o; \text{ then } \mathrm{E}a = \mathrm{W}\frac{f}{n}$$

And, as we have previously found $a = \frac{1}{23}$, ($= \frac{1}{15}$ of $\frac{3}{5}$ths of the weight of the engine and $\frac{1}{20}$ respectively; and $\frac{f}{n} = \frac{1}{224}$ (or 10 lbs. per ton.)

Then W = 9E, or 11 E, respectively; and hence we find, that the proper load for an engine upon a level, is 9 or 11 times its weight, as the case may be.

This formula, will afford us the means of discovering what ought to be the inclination of a Rail-road, when the traffic, in one direction, bears a known proportion to that returning in the opposite direction. If we make the ratio of these loads, expressed as multiples of the engine, to be $q : 1$, then taking the values of sin i from the equations, with the upper and lower signs separately, we have the resulting equation.

$$\text{Sin } i = \tfrac{1}{2} + \frac{q+1}{q-1} \times \left(a + \frac{f}{n}\right) \pm \sqrt{\tfrac{1}{4} \times \left(\frac{q+1}{q-1} \times a + \frac{f}{n}\right)^2 - \frac{af}{n}}$$

As an example, if we make $q = 3$, which is the proportion of loaded to empty carriages; $\frac{f}{n} = \frac{1}{200}$, and $a = \frac{1}{25}$. Then we have sin i = ,002389, whence $\text{W} = \dfrac{\text{E}\,(a - \sin i)}{\frac{f}{n}\,(+ \sin i)} = 5.$

Therefore q W = 15. From which we find, that an engine, which on a level Rail-road takes 8 times its own weight, will, on that inclination (viz. $\frac{1}{418}$), where its performance is a maximum, with loaded carriages 3 times the weight of the empty ones, drag up 5 times its weight, and take down the inclination 15 times its weight.

If E, or the weight of the engine, be 6 tons, then the weight of the empty carriages will be 30 tons, and that of the loaded carriages, down the plane, 90 tons.

HORSES AND LOCOMOTIVE ENGINES.

We shall now endeavour to shew the relative performance of horses, and locomotive engines; we have, previously, given Tables of the respective performances of the two modes; but it will, perhaps, place their relative values in a clearer point of view, to contrast them according to one standard.

We shall place them in contrast, at two rates of speed, viz. that when, with regard to horses, their performance with the load taken is a maximum; and that when travelling at the greatest rate of speed, horses are capable of yielding any available power to the load.

The standard which we have assigned to horse power, in the first of those cases, is 12 tons, conveyed 20 miles; or 240 tons, conveyed 1 mile each day.

From the document of the Liverpool coach proprietors previously alluded to, (see Note D, Appendix,) we find, that the average distance for each horse, per day, is 13 miles; and that four horses take a common stage coach at the rate of about 9 miles an hour, that distance. Suppose that the coaches, on an average, weigh 36 cwt., and that the difference of resistance between carriages on the common, and on Rail-roads, is as

7.5 : 1, then 4 horses will, upon a Rail-road, accomplish a performance of 13.5 tons, 13 miles a day, or 175.5 tons, 1 mile; being for each horse, 43.8 tons, 1 mile. Mr. WALKER, in his report on the Liverpool Rail-way, according to this proportion of the resistance, gives 37.5 tons, 1 mile, and Mr. RASTRICK, 60 tons, 1 mile; but the former gentleman takes 10, and the latter 20 miles a day, as the day's work: 13 miles we have, as the actual performance from practice; and therefore Mr. RASTRICK's data will be $60 \times \frac{13}{20} = 39$ tons, 1 mile. Mr. TREDGOLD gives, in his work on Rail-roads, 48 tons, drawn one mile on the turnpike-road; making $4.8 \times 7.5 = 36$ tons, 1 mile. In assigning, therefore, 43.8 tons, conveyed 1 mile, at the rate of 10 miles an hour, we shall, in practice, be quite as high as the powers of the horse will justify.

Table X. gives the performance of a locomotive engine, at the rate of 10 miles an hour, 53.4 tons; and we are convinced, from experiments made since the calculation of that Table, that we are quite within their powers. An experiment with the "Planet" engine gives 75 tons gross, conveyed from Liverpool to Manchester (30 miles), in 2 hours and 54 minutes (see Appendix, note E).

We shall, however, take the performance in the Table at 12 miles an hour, equal to 45 tons, and continue the comparison for 8 hours; which will

make, at 2½ miles an hour, the horses accomplish their day's work of 20 miles, and the engine 96 miles in that time.

The following Table will then shew the respective performances.

TABLE XII.

	Velocity in miles per hour.	Load taken in tons.	Distance travelled per day.	Effective performance in tons conveyed one mile.	Number of horses equal to one locomotive engine.
Locomotive engine . .	12	45	96	4320	—
Horses	2½	12	20	240	18
	10	3⅜	13	43.8	98

The above Table will shew, in a very striking point of view, the rapid increase in the ratio of performance of locomotive engines, the power of which, at all rates of speed (within that attainable by horses), is always the same ; over horses, the energy of whose power diminishes very rapidly at increased rates of speed. And this result is not confined to this particular case alone, but applies equally to every other species of art, where animal and mechanical action are brought into competition. The energy of horses being limited, must ever curb and check the advance of any art, where, from necessity, they are obliged to be employed : but, in the application of me-

chanical power, we have scarcely any limit, our numerous manufactories affording abundant proofs of the extent to which it may be carried.

At that rate of speed, where a maximum effect is produced by horses, we find one engine in 8 hours perform the work of 18 horses. In the calculations on the power of those engines, we trust we have given sufficient explanation, to shew that the assigned performance is quite within their powers. Except the instance cited, which gives in 3 hours nearly the same performance, as one standard of 8 hours, we cannot at present appeal to practice, to corroborate our opinions. Those engines, as stated before, have scarcely yet reached a settled standard; every one made since the Liverpool experiments, has possessed some improvements over the preceding ones: and, therefore, in fixing upon the above performance, we have taken rather what their existing powers are capable of effecting, than what, perhaps, the improvements in progress would justify us in assuming.

We have, in this comparison, taken the rate of travelling with engines at 12 miles an hour, from which, independent of the fact of one engine doing the work of 18 horses, we have the goods conveyed in nearly one-fifth of the time. In most cases, we presume that passengers will be conveyed along the same line of road; and, therefore, though the most economical load will

be the greatest which the engine can take, with the power of adhesion of the wheels, yet where passengers are to be conveyed also, it is indispensible that both must travel at the same rate of speed. The question then assumes this shape: *that the load to be taken must be the greatest which the engine is capable of dragging at that rate of speed, which it is advisable to convey passengers.*

In most cases, probably, 12 miles an hour, exclusive of stops, will be sufficient; but if we take 15 miles an hour, the load will then be 30 tons, and supposing that conveyed the same distance, will be 2880 tons 1 mile, which is equal to the performance of 12 horses in 6½ hours. But we must observe, that this contrast between the two modes is scarcely fair, as we are taking the performance of the engines at a diminished value, for the double purpose of conveying goods and passengers at a rate of speed incapable of being effected by horses; while we are taking the maximum effect of horses at a low rate of speed, precluding the conveyance of passengers.

We come now to the comparison with horses, travelling at quick rates of speed, and here we find the disproportion enormously great. With horses, certainly not effecting a rate of transit equal to 10 miles an hour, exclusive of stops; we find the engine, at 12 miles an hour, in 8 hours performing the work of 98 horses. And if we take the performance of the engine at 15 miles

an hour for 6½ hours, the number of horses required to perform the same work, will be 165 horses; from which we see the impossibility of any competition between the two modes, at high rates of speed.

These facts lead to this conclusion: *that where passengers are to be conveyed upon the same Rail-way as goods, and that the rate of travelling with passengers shall not average less than* 10 *miles an hour, the power of horses is quite inapplicable.*

The performance of horses has been taken in the most favourable point of view; and we shall appeal to the *practice* of the Liverpool and Manchester Rail-way, in corroboration of this. We find, there were 26 coaches upon the turnpike-road between those two places, previous to the Rail-way being formed. Supposing these fully loaded in every trip, with 14 passengers in each direction, this would make 728 passengers daily. Reckoning the distance between the two places 37 miles, we have $26 \times 74 = 1924$ miles per day, traversed with 4 horses; and supposing each horse to perform 13 miles, would require 591 horses. Each engine upon the Rail-way takes 120 passengers in one direction, which they perform in 2 hours; if they make only 3 trips each day, = 90 miles, each engine will convey 360 passengers; and therefore 2 *engines upon the Rail-way performs the work of* 591 *horses upon the turnpike road.* The distance, by the turnpike, is

37 miles; by the Rail-way, 30 miles: taking this into the account, we have $591 \times \frac{30}{37} = 480$ horses. From which we find, *that one engine on a Rail-way, will perform the work of* 240 *horses on a turnpike road, travelling at the respective rates of* 15 *and* 10 *miles an hour*. This result must, however, undergo some qualification in its general application: it can only exist in degree, and where the intercourse is equal to that of the case cited. Few places can, perhaps, furnish a supply of 120 passengers at a time, to constitute a load for an engine; and, therefore, if that engine has to travel with *passengers alone*, and with only half the number, the effect will be, in some proportion, diminished.

We however find, that an engine can travel at a rate of speed quite sufficient for the purposes of common intercourse, and certainly quite equal to that which is at present effected by other modes, with almost the most economical load; and, therefore, if there are not a sufficient number of passengers, the load of the engine can be completed with goods.

If the contrast between the two modes is not, therefore, made out with passengers alone, in cases where the intercourse is less than between Liverpool and Manchester, the quantity of goods which the engine is capable of conveying, in addi-

tion to, and without any inconvenience to the passengers, will fully bear out the comparison.

This brings us to the conclusion, that in most, if not in every case, when the conveyance of passengers is to constitute part of the traffic, they must, in order to effect the most economical result, form part of the general load of an engine, in common with the goods or merchandize; and, *therefore, that every species of transit must be effected at the same rate of speed.*

This is a very important change in the features of Rail-road conveyance,—the result of the late improvements in locomotive engines, whereby they are capable, not only of taking a useful load, but, perhaps, *the most economical load* of which their nature is susceptible, at that rate of speed, which enables them to embrace the conveyance of passengers at a rate of speed greater than has ever yet been attained by any other practicable mode of conveyance.

Adverting again to the comparison of horses and locomotive engines, at greater rates of speed, we found that, with a load of 120 passengers, one engine was doing the work of 240 horses, upon a turnpike road. We have before said, the relative resistance upon the common and Rail-roads, was as 1 : 75; and, therefore, 32 horses would, on a Rail-way, do the work of 240 horses on a turnpike, reducing the relative performance of locomotive

engines and horses to 32 : 1. But we must observe, that 120 passengers, with the carriages, will not be equal to 12 tons, or about one-third of the load of an engine travelling at that rate; and, therefore, $32 \times 3 = 96$ horses, which is nearly the former result, shewn in Table XII.

The least performance of a locomotive engine, will be equal to that of 18 horses, supposing that an average velocity of 12 miles, for 8 hours a day, be attained. Much of this will depend upon the length of the Rail-way, and the nature of the traffic in which they are employed; in short lines of road, where the delays in changing, &c., produce considerable stops, this performance will be diminished: but still their performance will equal that of a considerable number of horses. The relative cost will, of course, depend much upon the situation of the district in which they are used, with respect to the price of fuel, and other circumstances; and their performance, upon the length and features of the Rail-road on which they are made to travel. In a general way, perhaps, at the rate of speed above assigned, we may state the cost of one locomotive engine, equal to that of four horses and their attendants. So long, therefore, as the performance of a locomotive engine exceeds that of four horses, the economy of transit will be in favour of engines; and when the length of the Rail-way, and the nature of the traffic, will allow of a maximum

performance, then their relative utility, compared with horses, will be as $4\frac{1}{2}$: 1.

FIXED AND LOCOMOTIVE ENGINES.

The enquiry, instituted by the Directors of the Liverpool and Manchester Rail-way, 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 Rail-ways, where any information on the subject was likely to be obtained, and having published their report, have afforded us some very valuable information of the relative economy of the different modes of transit on Rail-ways, at that time; and, more particularly, on the two, the subject of our present attention. And as these reports, together with some observations upon them, furnish the *latest* information we have 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 Rail-ways, to give the substance of these reports, for which we are indebted to the liberality of the Directors of the Liverpool Rail-way.

In doing so, it is necessary to observe, that the estimates of Messrs. Walker and Rastrick

were made *previous* to the recent improvements in the locomotive engines; 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.

The Reports of Messrs. WALKER and RASTRICK*, arose from a request of the Directors of the Liverpool and Manchester Rail-way, that those gentlemen should undertake "a journey to Darlington, and the neighbourhood of Newcastle; to inspect the different Rail-ways 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 Rail-way?"

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 Rail-way, 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 Rail-way from Liverpool to Manchester being as follows:—

	Distance. Miles.	Yards.	Inclination.
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
— 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 F).

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

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 F) . .				107	8	0
Coal for fuel, 382 tons, at 5*s.* 10*d.* (*c* note F)				111	8	4
Wages, grease, hemp, &c. (*d* note F) .				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 4,000 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 F), and therefore calculated upon those planes being worked by stationary engines with ropes, the expence of which (*f* note F) is equal to				5,013	6	0
Crossing upon level of way, 120*l.*, of which the interest is				6	0	0
Annual expence of water stations (*g* note F) .				922	10	0
Duplicates of engines	£400	0	0			
Ditto of ropes, 18 tons 17 cwt. 16lbs., 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 F)	9,190	0	0
Duplicates for same, and machinery (as above)	400	0	0
Ropes for Rainhill, deducting old, (*f* note F) .	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 F) .	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 6 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 19 miles from the foot of the plane to Manchester, into twelve stages of 1½ mile each, and one stage of 1 mile, nearest to Manchester." The speed, when in motion, to be 12 miles an hour, which, including stoppages, will be reduced to an average rate of 9 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 G)	120
1— 40 ditto, at the foot of the plane . .	40
2—120 ditto, to work the Rainhill and Sutton planes, (*b* note G)	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 EXPENCE OF STATIONARY ENGINES.

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 G) . .	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 G) .	8,130	0	0
15 stations, with two 30 horse engines, each, cost 3,500*l*. (*d* note G)	52,500	0	0
Two 12 horse engines, at the Manchester end, (*e* note G)	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

Interest of capital 5*l.* per cent., and depreciation $1\frac{1}{2}$ per cent. = $6\frac{1}{2}$ per cent., on 87,172*l.* 10*s.* is . . .	5,666	4	3
Repairs, coals, and working expences (*f* note G)	11,257	15	8
Ropes, at $\frac{8}{1000}$ of a penny per ton per mile, upon 4000 tons, conveyed 27 miles per day, for 312 days (*g* note G) . .	11,232	0	0
Ropes upon Rainhill and Sutton planes (detailed in *e* note F) . . .	3,315	12	0
Rope for tail-rope on Rainhill and Sutton planes, at $\frac{2}{1000}$ of a penny per ton per mile, upon 4000 tons, conveyed 3 miles per day, for 312 days (*g* note G) . .	312	0	0
Spare rope, interest upon value (*h* note G) .	219	15	0
Sundry expences (*i* note G) . .	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.

Engines as above	87,172	10	0
Duplicates of same (*i* Note G)	1,354	0	0
Ropes 4395*l.* (*h* Note G) and 792*l.* (*e* Note F)	5,187	0	0
Cast-iron crossings	300	0	0
Store-ropes 5336*l.* 16*s.* 8*d.* (*h* Note G) 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 expence.	Expence of taking a ton of goods one mile.
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.

The publication of the Reports, containing these calculations and conclusions, brought forth an examination of their correctness from Mr. R. STEPHENSON, son of Mr. Stephenson, engineer to the Rail-way, and Mr. LOCKE, one of the sub-engineers*. Disclaiming 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

* Observations on the Comparative Merits of Locomotive and Fixed Engines, by Robert Stephenson and Joseph Locke, Civil Engineers.

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 enquiry, 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 H.)

Cost of one engine and tender . .	600
One-fifth for spare engines and tender	120
Total cost	£720

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 H)	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 H)	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 ⅓ths 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 H)	3,246	8	4
Annual cost of five water stations, at 104*l* each (*e* Note H)	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.

93 engines and tenders, at 600*l.* . .	55,800	0	0
4 water stations, at 500*l.* (*e* note H) . .	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 I) .	40
3—80	ditto on the 1½ stages, to the foot of the Rainhill plane (*a* note I) . . .	240
2—50	ditto at the foot of the two planes (*d* note I)	100
1—48	ditto on the level between the planes (*b* note I)	48
2—80	ditto to work the two planes (*c* note I)	160
12—80	ditto between the foot of the Sutton plane and Manchester (*a* note I) . .	960
1—24	ditto at Manchester	24
	Total horses power	1572

ESTIMATE OF THE EXPENCE OF STATIONARY ENGINES.

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 I) at 4,200*l.* .	71,400	0	0
2 stations at the bottom of the two planes, with two 25 horse power each (*f* note I) at 2,880*l.*	5,760	0	0
Carried forward,	£78,960	0	0

Brought forward,	£78,960	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 I)	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 $6\frac{1}{2}$ per cent.	6,238	19	2
Coals for engines, repairs, and working expences (*h* note I)	18,917	5	0
Ropes (*i* note I)	16,136	7	10
Duplicate ropes, interest of value upon (*k* note I)	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.

Estimated capital as before	95,984	0	0
Ropes, &c. in use (*i* note I)	10,727	18	0
Duplicate ropes and machinery (*k* note I) .	14,784	9	0
Capital requisite for stationary engines	£121,496	7	0

COMPARISON OF THE TWO SYSTEMS.

	Capital.	Annual expence.	Expence of taking a ton of goods one mile.
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 Rail-way, 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 Rail-way.

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 Rail-ways, and to lines of road nearly level: on private Rail-ways, 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 expences attendant upon each

particular case. 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 K) a Table of the wear of ropes upon several planes, which will still further assist the reader in making the necessary calculations.

CHAPTER IX.

COMPARATIVE PERFORMANCES OF MOTIVE POWER ON CANALS AND RAIL-ROADS.

THE existing agitation of the public mind, respecting the relative utility of Rail-roads and Canals, in the transit of goods from one place to another, renders it a subject of proper enquiry, to ascertain the relative performances of the different kinds of motive power upon those two species of internal communication.

I shall, therefore, give a brief comparison founded on the foregoing deductions of the different kinds of motive power upon Rail-roads, with the performance of horses by the present mode of Canal navigation.

Not having had an opportunity, from my own personal observation, of ascertaining, with sufficient accuracy, the weights which a horse will drag in a boat upon a Canal, I 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.

Mr. R. Stevenson, of Edinburgh, in his report on the Edinburgh Rail-way, in 1818, states, "Upon the Canals in England, a boat of 30 tons burden is generally tracked by one horse, and navigated by two men and a boy; on a level Rail-way it may be concluded that a good horse, managed by a man or lad, will work with 8 tons; at this rate, the work performed on a Rail-way, 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 Rail-way, equal to 10 tons.

Mr. Sylvester, in his report on the Liverpool and Manchester Rail-way, gives 20 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.

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 19 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.

With this load, Mr. BEVAN remarks, one horse generally travelled 26½ miles a 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

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 21 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 98 feet, and the mean

distance of the boat from the towing-path, 20 feet. From this experiment, considering that the Canal, in that part, was of greater area then it is upon an average, it may be inferred, that to maintain a velocity of 4 miles an hour, with a loaded boat, it would require the aid of 4 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, 8 feet width of floor, 10 feet width of water line, 50 feet extreme length, loaded with 14 tons, and drawing 2.25 feet water, dragged against a stream, the velocity of which was $5\frac{1}{2}$ miles an hour, with 28 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, 22 tons burden, from 2 to $2\frac{1}{2}$ miles an hour, with one horse.

Mr. James WALKER, of London, made some experiments in the London Docks, on the relative resistances, at different velocities, the result of which he communicated to the Royal Society, (May 31, 1827,) which, being very conclusive, and conducted with great care, we give an abstract of them. (Note L. Appendix.)

The result of these experiments was, that the resistance increased in a greater proportion than the duplicate ratio of the velocities. The respective resistances being as follows :—

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

Some experiments, subsequently made, on the Forth and Clyde Canal, are said to have produced a contrary result at high velocities. We have not seen any official account of these experiments, but it is said, that at low velocities, the resistance was found to correspond with that previously known; but on pushing the horses at a greater rate of speed, the force of traction diminished, the wave at the bow of the boat disappeared, and the agitation of the water, in the Canal, became comparatively trifling.

We confess we are somewhat sceptical as to the *practical* result of these experiments, and at the present eventful period in the *life* of Canal conveyance, should think, that such an important fact ought not to lie dormant. The welfare, and indeed, almost the existence of so many millions of property, depending upon the enquiry, calls loudly for the substantiation, or disproval, of such important results, by a series of incontrovertible experiments.

Whatever may have been the *experimental result*, we had an opportunity, lately, on a visit to Edinburgh, of observing the *practical result*, arising out of these experiments.

A boat, constructed of that form which was found to produce the least agitation of the water in the Canal, has been applied to convey passengers from Edinburgh, by the Union, and then the Forth and Clyde Canal, to Glasgow.

The boat is of great length, and narrow; and in passing at the rate of $6\frac{1}{3}$ miles an hour, or 1120 yards in 366 seconds, the wave, following the boat, was very considerable, so great, that we observed, at one of the bridges, the water washing over a height of masonry, $19\frac{1}{2}$ inches above the ordinary level of the water in the Canal. The boat was dragged by three horses, attached to the towing line, with a boy riding a poney, to drive them. The distance, travelled upon the Union Canal, is $31\frac{1}{2}$ miles, and, in that distance, there are six sets, or changes of horses; the same horses returning the same distance back. This will give the power required, equal to that of three horses travelling 10.5 miles, per day; the boat carrying about 60 passengers. The horses seemed much distressed by the draught, the action being that of a continual dead and unrelaxing effort. Since this, at the commencement of the frost, in December, the boats have been laid aside, and are not, it is said, to be resumed, until an iron boat, of a better form, be built.

Suppose the useful load of this boat equal to 5 tons, then $\frac{5 \times 10}{3} = 16\frac{2}{3}$ tons, conveyed one

mile, will be the daily performance of a horse, on a Canal, at seven miles an hour. And if we take 24 tons of goods, conveyed 20 miles, at $2\frac{1}{2}$ miles an hour, we have the relative performance at $2\frac{1}{2}$, and 7 miles, as $16\frac{2}{3} : 480$. But we have the relative effort of horses at $2\frac{1}{2}$ and 7 miles an hour, as $102 : 384$, whence $\frac{16\frac{2}{3} \times 384}{102} = 62.5$; and, therefore, the relative performance of horses dragging boats on Canals, at $2\frac{1}{2}$ and 7 miles, is as $62.5 : 480$; the resistance, being equal to the duplicate ratio of the velocity, would give $62.5 : 490$.

According to the experiments of Messrs. BEVAN and WALKER, the resistance should have afforded results, greater than the duplicate ratio of the velocities; but we must observe that those experiments were made with the *same* boat; whereas the result above is from *another* boat than that which was used for slow rates of speed, and of a construction more adapted for diminishing the resistance.

We are, therefore, we trust, justified in concluding, that when the most suitable form of boat is adopted, for the particular load it has to carry, the resistance of boats on Canals, is at least equal to the duplicate ratio, or square of the velocity. The diagram III, page 195, will, therefore, represent the resistance, at the different velocities; and the following Table will shew the relative quantity of work which a horse is capa-

ble of performing, by dragging boats on Canals, and carriages upon Rail-ways; assuming, that the maximum of useful performance, daily, on the former, is equal to 480 tons of goods, conveyed one mile; and upon the latter, 160 tons, conveyed one mile; making the relative performances as 3 : 1.

TABLE XIII.

Velocity in miles an hour.	Useful weight conveyed, in tons.	Distance, in miles.	Useful effect, in tons conveyed one mile.	Number of horses required on Canal.	Number of horses required on Rail-way.	Ratio of performances of horses on Canals and Rail-ways.
Maximum rate . .	24	20	480	1	3.	1 : 0.33
3	24	20	480	3.4	4.5	1 : 0.75
4	24	20	480	8.2	6.3	1 : 1.3
5	24	20	480	18.	8.7	1 : 2.7
6	24	20	480	31.8	10.6	1 : 3.
7	24	20	480	53.6	13.	1 : 4.1
8	24	20	480	85.6	16.	1 : 5.3

From this we find, that, when the rate of speed is about two miles an hour, the quantity of goods which a horse can convey upon a Canal, is three times that which the same horse can convey upon a Rail-road. And that, when the velocity on each, is about $3\frac{1}{2}$ miles an hour,—the resistance of the Canal increasing as the square of the velocity, while that of a Rail-road remains the same,—the two become equal; and a horse is then enabled to drag as much weight upon a

carriage on a Rail-road, as in a boat on a Canal. When the velocity is further augmented, then the disproportion becomes greater, and a much heavier load can be conveyed on a Rail-road, with the same quantity of motive power, than can be done on a Canal.

If, therefore, the rate of tonnage on a Canal, arising from the cost of forming and keeping it in a state of active use, together with the cost of boats, be not greater than the tonnage required to form and keep a Rail-road in repair, and also the carriages by which the goods are conveyed; then the relative economy, at different rates of speed, in the transit of goods upon Canals and Rail-roads, will be represented by column 7 of the preceding Table. But as, in general, the formation of a Canal costs much more than the formation of a Rail-way, and the annual charges of keeping the boats, towing-paths and bridges, &c., in repair, is also considerable, if those expences be as much greater on a Canal than upon a Rail-road, so as to compensate for the extra advantage of the Canal in the greater quantity of goods conveyed at a slow rate; then their relative utility will assume a different value, and the Rail-way, requiring a less investment of capital, and less annual charges, may be superior and more economical, even at the lowest and most advantageous rate of motion upon Canals: and, where facility or expedition of transit is an ob-

ject, then, at the more rapid rates of speed, the Rail-way will be proportionably superior.

These elemental considerations, being, however, matters of calculation, where every instance may present a different conclusion, and being dependent upon all the various concomitant circumstances incident to each particular case, cannot, in a work like this, be made the subject of even conjecture. We have endeavoured to furnish all those data which appeared general, and which applied to the two modes in conjunction with each other, in a practical and general point of view; and it must be left to those pursuing the enquiry into all the circumstances of each particular case, when they come into competition with each other, to judge from the individual characteristics of each mode, which of the two is preferable.

When it becomes a subject of discussion which of the two modes is to be adopted, it assumes rather a different shape than when a Rail-road, the transit on which is performed by horses, is to enter into competition with a Canal already formed. In the latter case, the Canal proprietor commences with considerable advantage, by the additional quantity of goods which a horse can drag at a slow pace upon a Canal, where, perhaps, a little loss of time may be no object; and the Canal proprietor may, even with his great investment of capital, by reducing his rates of tonnage extremely low, be enabled to compete successfully with a Rail-way.

For although a horse may, when travelling at the rate of four or six miles an hour, convey a greater quantity of goods upon a Rail-way than when employed in dragging goods at the same velocity upon a Canal; yet still a horse cannot drag more goods at the rate of four miles an hour upon a Rail-way, than he can at two miles an hour upon a Canal; for in no case does the greatest quantity of work, that a horse can do, at the most beneficial pace on a Canal, reach below three times that which a horse can do at any pace upon a Rail-road.

For the conveyance of passengers, or where the transit of any species of goods may require a celerity of four miles an hour, then Rail-ways become, unquestionably, more economical than Canals; but if the question be the abstract performance, or quantity of goods to be transported from one place to another, without reference to speed; then the *quantity of work* done by a horse, on a Canal, will always be three times that which he is capable of doing on a Rail-way. The comparative expence, arising from the extra interest of capital, and the annual charges and maintenance of a Canal, may reduce this proportionate performance near to an equality; or, if the one compensate for the other, then, perhaps, the less investment of capital in a Rail-road, and the greater certainty of transit, may make it superior to a Canal. But, unless the disparity of cost is

great between a Rail-road entering into competition with an existing Canal; or unless some extraordinary circumstances in the nature of the traffic occur, it may be difficult to say, when *horses* are the motive power on each, which is superior.

There is one very important property in a Rail-way, which gives it a great advantage over a Canal, viz. the range of undulation which its nature permits; a straighter and shorter line can mostly be made between one place and another, which, from the necessity of having Canals always perfectly level, or, at least, that level only broken at certain intervals, by the occurrence of locks, occasions, frequently, a difference in distance of considerable magnitude; and this, in many instances, may diminish the comparative cost of transporting goods, and give a superiority to Rail-roads.

And again, in many cases, where the principal part of the goods are to be conveyed in one direction; by a proper inclination of the Rail-way, the weight of goods conveyed, or quantity of work done, may, in some instances, be considerably augmented, without presenting a greater average resistance than previously stated, when the relative performance upon Rail-roads will be proportionably increased. We have a very striking proof of this in Table V., of the weight which a horse can drag, upon certain inclinations of road, when the train is descending. On 1 in 250, the gross

weight is 28.44 tons, an increase of performance in the ratio of 28.44 : 12, which cannot be taken advantage of by a Canal; as in that case, locks would be required, which would diminish, rather than increase the performance.

Having thus given a few hasty remarks on the comparison of Rail-roads with Canals, in the use of animal power, we shall now give a brief comparison between the use of mechanical power on Rail-roads, and animal power on Canals; and here, as in every other case, where the two species of action come in competition, we shall find the mechanical power outstrip the animal, in general economy.

Table of the relative performances of horses dragging boats on Canals; and locomotive engines dragging carriages upon Rail-roads. The former supposed to be without locks, and the latter horizontal.

TABLE XIV.

Velocity, in miles per hour	Useful weight conveyed, in tons.	Distance, in miles, being that which a horse travels in a day.	Time, in hours, occupied by horses in travelling 20 miles, at the respective velocities of column 1.	Number of horses required to perform the work on a Canal, from Table XIII.	Distance, in miles, which a locomotive engine, on a Rail-road, would travel in the time of column 4.	Ratio of distance traversed in the same time by locomotive engines on a Rail-road, and horses dragging boats on a Canal.	Ratio of performance of horses on Canals, and locomotive engines on Railroads, in the time of column 4.
Max. rate.	24	20	8	1	120	6 : 1	1 : 6
3	24	20	$6\frac{2}{3}$	3.4	100	5 : 1	1 : 17
4	24	20	5	8.2	75	$3\frac{3}{4}$: 1	1 : 30
5	24	20	4	18.	60	3 : 1	1 : 54
6	24	20	$3\frac{1}{3}$	31.8	50	$2\frac{1}{2}$: 1	1 : 80
7	24	20	$2\frac{6}{7}$	53.6	$42\frac{6}{7}$	$2\frac{1}{4}$: 1	1 : 120
8	24	20	$2\frac{1}{2}$	85.6	$37\frac{1}{2}$	$1\frac{3}{9}$: 1	1 : 175

From this Table, we find, that a locomotive engine, effecting a constant average velocity of fifteen miles an hour, will, in ten hours, on a Rail-road, perform the work of six horses, employed in dragging goods at the rate of two miles an hour upon a Canal; and, as this rate of speed on a Canal, is that when the performance of a horse is a maximum, we derive the conclusion—*That so long as the expence of one locomotive engine does not exceed that of six horses, and their attendants; then goods can be conveyed with the same expenditure of motive power at fifteen miles an hour upon a Rail-road,*

that they can be conveyed at two miles an hour, upon a Canal.

We have elsewhere stated that, in general, one locomotive engine may be estimated to cost as much as four horses; but the comparison was made with horses upon Rail-roads, where one attendant to each horse is sufficient. On Canals it will be different, as the attendants upon each horse and boat are generally three;—the relative cost of locomotive engines will, therefore, be diminished, and their utility, in comparison with horses on canals, proportionably increased.

But this is not the only benefit resulting from the application of steam power to Rail-ways, viz. that goods are conveyed with the same expenditure of motive power on a Rail-road, at the rate of fifteen miles an hour, that goods can be conveyed at the rate of two miles an hour upon a Canal. If it be attempted to augment the velocity on a Canal, to three miles an hour, then one locomotive engine on a Rail-road will, in six hours and two thirds, perform the work of seventeen horses on a Canal;—and if the velocity be further increased to four miles an hour, then, in five hours, the locomotive engine will perform the work of thirty horses; and as often as these *times* are repeated, a similar ratio of performance will be accomplished.

We have a very conclusive illustration of this, in the instance of the *fly-boat* on the Union Canal;

supposing it loaded with sixty passengers back and forwards, the $31\frac{1}{2}$ miles requires eighteen horses. Upon the Liverpool and Manchester Rail-way, nearly the same distance, an engine traverses twice a day, with 120 passengers at a time = 120 miles. Therefore, $\frac{120 \times 2}{60} \times 18 = 72$ horses. From which we find, that an engine half loaded, performs the work of 72 horses, conveying passengers on a Canal, at a rate of transit more than double that on the Canal.

This is sufficient to shew the utter impracticability of attempting a competition between Canals with horses, and Rail-roads with locomotive engines, in the conveyance of passengers.

It follows, from this, that the only superiority existing in any part of the economy of Canals, and that wherein a transient advantage over Rail-roads occurs, when animal power is employed, and which consists in the less resistance opposed to the motive power in transporting heavy goods at a slow pace; is superseded by the application of machinery to Rail-ways. And this result may be expected whenever, as previously stated, the nature of the work permits the application of mechanical power in the one case, and it is brought into competition with animal labour in the other.

These observations of the relative performances, with respect to work on Rail-roads and Canals,

apply to the motive power only. If the formation and annual charge of a Canal exceed that of a Rail-road, then a further increase of advantage is produced in favour of Rail-roads;—on the contrary, if the balance is in favour of a Canal, then it will become a question, whether the additional celerity in the transit of goods by a Rail-road, will compensate for any additional cost of the Rail-way. In general, the difference of cost, both in the formation and annual charges, is presumed to be in favour of Rail-roads, (see note M) and, if any judgment can be formed from a comparison of the tonnage upon the various Canals, in the different districts of England, and that on Rail-roads, the presumption appears nearly indisputable. (See note N.)

The trifling injury done to the road by the action of the locomotive engine, considerably enhances its value, by diminishing the charges of tonnage for annual repairs, which, added to the less investment of capital required in the formation of a Rail-road, excites reasonable expectations of a very important change in the economy, and also celerity, of internal communication.

In the above disquisitions, Canals have been compared with Rail-ways, in their most favourable state, as being without locks; any variation from this, will throw the balance more in favour of the latter; any deviation in the line of a Canal

from the horizontal, must be overcome by locks, which are productive of delay; whereas, in a descending line, especially when the trade is in that direction, an increase of effect takes place.

In these disquisitions, we have a decided superiority of Rail-roads, both in point of economy and dispatch, in the conveyance of heavy goods, over Canals. In the conveyance of light goods, or passengers, no practical comparison can be made. Canals, after between 70 and 80 years' experience, seem incapable of being applied to those purposes. Rail-ways, on the contrary, seem indisputably the best and most economical, for all the purposes of internal communication and traffic, for light or for heavy and bulky goods, as well as for celerity of intercourse, the most rapid ever yet effected.

Taking all these circumstances into consideration, it can no longer be questioned which of the two modes is superior; the example of the Liverpool and Manchester Rail-way, where it has been proved that, with an expenditure of capital of the greatest magnitude in overcoming difficulties which, perhaps, will never again present themselves, the conveyance of passengers alone was sufficient to realise a remunerating price to the Company. Canals being incapable of adaptation to the celerity of transport requisite for such purposes, are, therefore, deprived of a source of revenue the most lucrative; in a few,

and, perhaps, only in a very few instances, can therefore Canals be brought into a comparison with Rail-ways. And when we look at the rapid improvement which the latter have undergone within so short a period, the improvements which are still in progress, and which the ingenuity of that combination of talent, now so powerfully directed towards them, cannot fail of bringing to the highest state of perfection, we are led to expect the most important results, in the economy and celerity of commercial intercourse.

It will not, perhaps, be necessary, in a work like this, to explain at greater length the relative merits of Canals and Rail-roads; local circumstances may effect general results, but unless other causes transpire than the simple abstract question of the two modes in comparison with each other; we have, by the application of mechanical power to Rail-roads, the advantage of a less investment of capital, and also a saving by the motive power; which, combined with the celerity of dispatch, must prove of infinite importance to commerce.

APPENDIX.

NOTE A.

In a review of the former edition of this work in the Repertory of Arts (Sept. 1825), the Editor, in speaking of Mr. Tredgold's work on the same subject, says, "Indeed, his work is of that masterly nature, that Mr. Wood might be thought somewhat indiscreet in publishing on the same subjects, *so soon after him;* but of this he has altogether, and well, freed himself, having given valuable information on some points that had escaped the former Author; corrected one of his very few errors, though a material one; added considerably to the number of facts, and experiments on the same subject, and increased the number of useful tables respecting them. His treatise may, therefore, be considered as a valuable *appendix* to that of Mr. Tredgold."

After offering, as an excuse for the imperfection of the work, the *originality* of the matter, we feel it incumbent upon us to negative the above assertion of the Editor of the Repertory, and therefore trust we shall be excused, in giving an extract from a letter to us from Mr. Tredgold himself, dated Durham, January 2, 1825.

Sir,—In travelling from London to this place, I had the pleasure to read your work on Rail-roads, which issued from the press *on the same day* as my own little treatise on the same subject. If I had been guided by interested motives alone, I should have regretted the appearance of a work which must affect the sale of my own; but I trust I shall never be so guided, but

will always regard with pleasure every effort to advance science—and particularly when that effort produces an *original* and valuable accession to an important subject, &c. &c." And further on Mr. Tredgold says, "There are some *very singular coincidences* in the two works."

NOTE B.

DURATION OF WROUGHT AND CAST-IRON RAILS ON THE STOCKTON AND DARLINGTON RAIL-WAY.

Malleable Iron Rails, 15 feet long, over which Locomotive engines pass, weighing from 8 to 11 tons. Waggons and their loads, 4 tons each.

86,000 tons passed over in a year, exclusive of engine and waggons.

Weight of rail, 1 cwt. 24½ lbs.
Loss of weight in 12 months, 8 oz.

Cast-iron Rails, 4 feet long, over which waggons only pass, weighing 4 tons each, when loaded.

86,000 tons passed over in a year, exclusive of waggons.

Weight of rail, 63 lbs.
Loss of weight in 12 months, 8 oz.

The loss of weight in Malleable Iron Rails, when waggons ONLY passed over, was, in the same period, 8 ounces for 15 feet length—the same quantity of goods, 86,000 tons.

NOTE C.

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.	Diam. 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, 3rd, 4th, and 5th turns, 3 in. wide,

2 ft. deep. ..... $\frac{1}{4}$ 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 5 inches, being 19 square inches area, which was loaded for a pressure of 4 lbs. on the square inch. Giving 76 for the load. Of this, 66 lbs. of iron was 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 77 feet per second, or upwards of 52 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 45 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 27 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. Helen's coal (that principally used in steam-boats), measured 63 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 $3\frac{1}{2}$ cubic feet weighs 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-guage attached to the boiler, standing at $7\frac{1}{2}$ 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—41$\frac{1}{2}$	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 was 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 $2\frac{1}{2}$ cwt. per hour, the expense of which is $12\frac{3}{4}$*d.*, and as the consumption diminishes after the first hour, the expence 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,
May 29th, 1830.

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 33 coaches travel between the points before stated, and the cost of working them for the year last past. Presented 3rd May, 1830."

Duty for 33 coaches for one year .		£8455 16 8	
Assessed taxes for coach servants .		261 0 0	
Mileage for 26 coaches to Manchester, at £13 4 0 per day .	£4818 0 0		
Ditto for 4 coaches to Bolton, at £1 15 0 per day .	638 15 0		
Ditto for 2 coaches to Wigan, at £0 14 8 per day .	267 13 4		
Ditto for 1 coach to St. Helens, at £0 3 0 per day .	54 15 0		
		£5779 3 4	
			£14496 0 0
Tolls for 33 coaches, at £18 10 8 per day, . . .			8005 13 4
Duty and tolls, .			£22,501 13 4
Carried forward,			

				Brought forward,	£22,501	13 4
EXPENSES.						
Harness for 709 horses, at £4 per year each	£2836	0	0			
Iron and labour to blacksmiths for 709 horses, at £3 per year each	2127	0	0			
Eighty-seven men as ostlers, &c. at £1 per week each	4524	0	0			
Rent of stables and coach-offices	1418	0	0			
Consumption of horses, say 709 horses, at £15 each, *to be renewed every three years,*	3545	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	4615	0	0			
	£46,716	0	0			
Deduct value of manure, which is calculated at the price of straw,	4615	0	0			
					42,101	0 0
					£64,602	13 4

NOTE E.

" On Saturday last (4th Dec. 1830) the 'Planet' engine, Mr. Stephenson's, took the first load of merchandise which has passed along the Rail-way from Liverpool to Manchester. The team consisted of 18 carriages, containing 135 bags and bales of American cotton, 200 barrels of flour, 63 sacks of oatmeal, and 34 sacks of malt, weighing altogether, 51 tons, 11 cwt., 1 quarter. To this must be added the weight of the waggons and oil-cloths, viz. 23 tons, 8 cwt., 3 quarters. Tender, water and fuel, 4 tons, and 15 persons on the team, 1 ton, making a total weight of exactly *eighty tons*, exclusive of the engine, about 6 tons. The journey was performed in 2 hours and 54 minutes, including three stoppages of five minutes each (one only being necessary under ordinary circumstances) for oiling, watering, and taking in fuel: under the disadvantages also of an adverse wind, and of a great additional friction in the wheels and axles, owing to their being entirely new. The team was assisted up the Rainhill inclined plane by other engines, at the rate of 9 miles an hour,

and descended the Sutton incline at the rate of 16½ miles an hour. The average rate on the other parts of the road was 12½ miles an hour, the greatest speed on the level, being 15½ miles an hour, which was maintained for a mile or two, at different periods of the journey."—*Liverpool Paper.*

"The journey between the two places was, on the 23rd November, performed by the 'Planet' engine in 60 minutes, including 2 minutes, the time employed in taking in water on the road, as usual.

"The motive for performing the journey, was, that the engine had been engaged to bring up from Manchester to Liverpool some voters for the election, and by some cause or other, the time of setting out was delayed, rendering it necessary to use *extraordinary* dispatch, in order to convey the voters to Liverpool in time."—*Liverpool Paper.*

"The engines have conveyed about 50,000 passengers, and have traversed a distance of 28,620 miles, or 954 trips from Liverpool to Manchester and back, from the 16th September to the 7th December, inclusive. During which period there have only been eleven instances of the journey exceeding by half an hour the time fixed for its performance."—*Liverpool Paper.*

NOTE F.

(*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 $\frac{150}{4}$ = 37.5 lbs. = horses' power, at 10 miles per hour, or 375lbs for 10 horses, equal to friction of 30 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 RAIL-WAY, 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 = 894,96 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 $15\frac{1}{3}$ tons.

HETTON ENGINES, BY MR. WOOD'S REPORT.

In 30.00 chains falls .. 14 ft. 0 in. which is equal to .. 1 in 141
72.45 —— .. 9 $3\frac{1}{2}$ —— .. 1 in 514

102.45 —— .. 23 $3\frac{1}{2}$ —— .. 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 $4\frac{1}{2}$ 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.

Resistance descending ... 365 lbs. ÷ $12\frac{1}{2}$ = ... Tons 29 down.

512 + 210 = 722 cwt. = 80,864 lbs. ÷ 180 = 449 lbs. = friction.
80,864 lbs. ÷ 287 = 282 lbs. = gravity.

Resistance ascending ..... 731 lbs. ÷ $12\frac{1}{2}$ = Tons $58\frac{1}{2}$ up.

$87\frac{1}{2}$

Divide by 2 for averaging, or on level .... $43\frac{3}{4}$ tons.

But as the rise on part of the road is not favourable, say the work, on a level, is $50\frac{1}{2}$ tons, at 5 miles per hour.

Upon this basis, the work, at different speeds, is as follows :—

	5 miles.	8 miles.	10 miles.
Goods	$23\frac{1}{3}$	14	$9\frac{9}{10}$
Waggons	$16\frac{2}{3}$	7	$4\frac{9}{10}$
Engine	$10\frac{1}{2}$	$10\frac{1}{2}$	$10\frac{1}{2}$
	$50\frac{1}{2}$	$31\frac{1}{2}$	$25\frac{1}{4}$

Now $50\frac{1}{2}$ tons, at 5 miles = 101 tons, at $2\frac{1}{2}$ miles, and $101 \div 12 = 8\frac{5}{12}$ horses' power.

(*b.*) REPAIRS, &c. OF LOCOMOTIVE ENGINE.

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 10 horse engine will take 13 tons of goods 10 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 $2\frac{1}{2}$ lbs.* of coals per ton per mile = 2929 lbs. of coal per day, and 2925 × 912,600 lbs. per year = $380\frac{1}{4}$ tons, or say 382 tons of coal for each Locomotive Engine per year.

(*d.*) ACCOUNT OF WORKING EXPENCES.

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 ÷ 180 = 12.44 lbs. friction,
2240 ÷ 96 = 23.33 lbs. gravity,

35.77 lbs. per ton, and the engine, &c., being $10\frac{1}{2}$ tons, is $375\frac{1}{60}$ lbs. resistance. Now as (by *a*, note F) the power of the engine, at 10 miles, is 375 lbs, it is

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* The consumption of $2\frac{1}{2}$ 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 $4\frac{1}{2}$ 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 was principally relied on, was the *actual* consumption on the Darlington Rail-road, 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.

evident that an engine will just move its own weight up the hill at 10 miles per hour.

If the same rate of speed and tonnage is to be kept up, the following calculation is given:—

10 horse engine upon these planes = 10½ tons at 10 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 5 miles per hour:—

Horses' power at 5 miles = 150 ÷ 2 = 75lbs., or for 10 horses	750 lbs.
Deduct gravity and friction of carriage	375
Leaves applicable to load	375 lbs.

375lbs. ÷ 35.77lbs. (resistance of one ton, text) gives gross 10¾ tons, or goods only, 7⅓ tons.

Or, if 8 miles be the rate of travelling on a level, the engine would take 27 tons of goods and waggons up the plane, and,

Horse power at 8 miles = 150 ÷ 2½ ÷ 8 = 47lbs., or for 10 horses, 470 lbs.

Then 470 ÷ 12½ (resistance of one ton) gives .	37.6 tons.
Deduct Engine, &c.	10.5
Leaves goods and waggons	27.1 tons.

Or goods 18 tons, and waggons 9 tons.

And with the assistance of another engine, of similar power, would ascend at the rate of $4\frac{1}{2}$ miles an hour, as follows:—

TIME OF LOCOMOTIVE ENGINE ON INCLINED PLANES.

$27 + 10\frac{1}{2} + 8\frac{1}{2} = 46$ tons = weight of load, and two 10-horse engines.

$35.77 \times 46 = 1645$ lbs. = total resistance to 20 horses.

$1645 \div 46 = 82$ lbs. = exertion for each horse.

82 lbs. : 150 lbs. :: $2\frac{1}{2}$ miles :: $4\frac{1}{2}$ miles per hour.

They therefore had recourse to the stationary system to work the two planes; and supposing to give 9 miles clear an hour, the rate in motion should be 12 miles; and for 3000 tons to be passed in each direction daily, the load for each journey will be 50 tons, and the power required.

FIXED ENGINES FOR RAINHILL.

52 tons, or 116,480 lbs. ÷ 96, the rise of the plane, give for gravity	1213 lbs.
Add 116,480 lbs. ÷ 180 for friction . .	647
Together	1860
Friction of rope = $\frac{1}{2\frac{1}{2}}$ of its weight, or of 10,560 lbs. .	480
Gravity of rope = $\frac{1}{96}$ of its weight . . .	110
	2450 lbs.

2450 lbs. ÷ 31 lbs. (power of horse at 12 miles) = 80 horses, or allowing for surplus power, say 2 engines, each 50-horse power.

(*f.*) EXPENCE OF ENGINES UPON RAINHILL.

Two 50-horse engines, at 1500*l.* each	3000
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
	£4595

Interest on 4595*l.* at 5 per cent.				229	13	6
General depreciation at $1\frac{1}{2}$ per cent.				69	0	0
Boilers, say three, to last 12 years, difference of value 24*l.* per ton = 480*l.* to be expended at the end of 12 years, equal to an annual expence 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 80 horses, working 12 hours per day, allow 15 lb. 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
Wages as follow:						
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 expences for the other plane				848	17	0
Carried forward				£1697	14	0

Ropes; 4 ropes for these two inclines, each 2640 yards long, $5\frac{1}{2}$ inches circumference = 4 lb. to one yard, each rope, therefore, 94 cwt. 1 quar. 4 lb., and the 4 ropes, 18 tons, 17 cwt. 16 lb., which at 42*l.* per ton, (being 51*l.* less 9*l.* for old ropes,) gives 792*l.*

		Brought forward	£1697	14	0
Interest upon 792*l.* capital, at 5 per cent	39	12 0			
Annual expence of ropes, being for 4000 tons, passed 3 miles daily for 312 days, at $\frac{7}{100}$ 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	3276	0 0			
			3315	12	0
		Making total,	£5013	6	0

(*g.*) WATER STATIONS.

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 $6\frac{1}{2}$ per cent..	42	0	0
Wear of boiler and bars, grease, &c.....	5	0	0
Coal for engine, kettle, &c. 50 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 G.

(*a.*) POWER OF STATIONARY ENGINE.

Friction of 52 tons = 52 ÷ 180	647 lbs.
Friction of ropes, sheeves, and drums = $\frac{1}{20}$ of weight,* say of 3400 (being weight of $1\frac{1}{2}$ mile of $3\frac{1}{2}$ inch rope) equal to	155 lbs.
Friction of rope upon barrel	13
	815 lbs.

Power of horse at 12 miles = 150 × $2\frac{1}{2}$ ÷ 12 = 31 lbs., then 815 ÷ 31 = 26 horses, or say, allowing for spare strength, 30 horses, required in one direction, making two 30-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 50-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

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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 = (10½ miles per hour) which gives friction	82
Average friction	$85\frac{1}{2}$

Weight of rope = 1861 lb. ÷ 85 ½ = 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 4 minutes, with $4\frac{1}{2}$ inch rope after them, of which the weight was 3096 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.

level, an increase of 10-horse power has been made to each engine, making two 60-horse engines to each station.

Two 60-horse engines, each 1800*l.*	3600
Machinery drums	500
Engine-house and chimney	700
Dwelling-house	100
Well and pond	100
	£5000

Two Engines at 5000*l.* = 10,000*l.*

(*c.*) ENGINES FOR MIDDLE OF THE 2 MILES LEVEL, AND AT THE FOOT OF EACH PLANE.

Two 20-horse engines, each 900*l.*	1800
Machinery and drums	300
Engine-house and chimney	450
Dwelling-house	75
Well or pond	85
	£2710

Three Engines at 2710*l.* = 8130*l.*

(*d.*) ENGINES UPON $1\frac{1}{2}$ MILE STAGES.

Two 30-horse engines, each 1200*l.*	2400
Machinery, drum, &c.	400
Engine-house and chimney	500
Dwelling-house	100
Well or pool for water	100
	£3500

Fifteen Engines at 3500*l.* = 52,500*l.*

(*e.*) ENGINES AT MANCHESTER END.

Two 12-horse engines, each 500*l.*	1000
Machinery and drums	200
Engine-house and chimney	400
Dwelling-house	75
Well and pump, or pool for water	50
	£1725

(*f.*) REPAIRS AND WORKING OF STATIONARY ENGINES.

Repairs to boilers of engines, for the power of 1354 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 one 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.* . . .	3168	7	2
			4159 9 8

Men required as follows :—

	Manchester Engine.	Fifteen one and half mile Engines.	Three 30-horse Engines.	Two 60-horse Engines.	Liverpool Tunnel, extra.				
Engine-men	2	30	6	4	1 = 43	at £51	12	£2347	16
Bank-men	2	30	6	4	2 = 44	—	39	0	1716	0
Brake-men	1	30	6	4	1 = 42	—	39	0	1638	0
Assistants	0	15	3	2	1 = 21	—	39	0	819	0
Ten men to oil pullies, at £39.									390	0
									6910	16	0
Oil, 30 miles at 50 gallons per mile = 1500 gallons, at 2*s.* 6*d.*									187	10	0
									£11,257	15	8

(*g.*) EXPENCE OF ROPES.

"From an account kept by Mr. Thompson of the wear of ropes on the Shields and Brunton Rail-way, 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, 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 upon all the coal conveyed over them, as follows :—

Rope on Brusselton Plane.

1851 yards, inclination 1 in $33\frac{1}{2}$ ascended with load.
825 ditto 1 in $30\frac{1}{2}$ descended with load.

Average taken at 1 in 33 which gives 69lbs. gravity of 1 ton.

Tons.

$1851 \times (69 + 12\frac{1}{2}) \times 1.5 = 226{,}284$ } loaded.
$825 \times (69 - 12\frac{1}{2}) \times 1.5 = 69{,}919$ }

$825 \times (69 + 12\frac{1}{2}) \times .5 = 33{,}618$ } empty.
$1851 \times (69 - 12\frac{1}{2}) \times .5 = 52{,}292$ }

$382{,}113 \div 12\frac{1}{2} = 30{,}569$

$30{,}569 \div 1760 = 17.37$
Deduct $\frac{1}{3} = 5.79$

11.58 say $11\frac{1}{2}$

$11\frac{1}{2}$ 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 $2\frac{1}{2}$ miles for an expence of 780*l.* in ropes. By reducing this to a level, and to suit our

case, we find the cost to be $\frac{13}{100}$ 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.

114 miles of $3\frac{1}{2}$ inch rope at $1\frac{2}{3}$ lb. per yard, is 104 tons 12 cwt. 3 qrs. 14 lbs. at 51*l.* for new	5336	16	8
Less 9*l.* for old	941	16	8
	£4395	0	0

Interest on 4395*l.* at 5 per cent. . . 219*l.* 15*s.*

(*i.*) SUNDRY EXPENCES AND CHARGES.

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 1354 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 1354 horses at 1*l.* = 1354*l.*				67	14	0
Ropes, capital as above note	5336	16	8			
For planes per locomotive estimate	961	14	3			
	£6298	10	11 at 5 per cent.	314	18	0
Interest upon signals, 550*l.* at 5 per cent.				27	10	0
				£1291	4	6

NOTE H.

(*a.*) The data for assuming this power of the engine, are as follow:—

Darlington Rail-way.—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 20 loaded waggons on the level, and 20 empty waggons on 1 in 100 at the rate of four miles in an hour.

Weight of 20 loaded waggons . .	80 tons
Engine and tender	12
	92 tons

92 tons ÷ 200 = 1030 lbs. the maximum resistance at 4 miles an hour; and $\frac{1030 \times 4}{10}$ = 412 lbs. at 10 miles an hour.

And with 20 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 4 miles an hour;

and $\frac{1242 \times 4}{10}$ = 497 lbs. at 10 miles an hour.

Springwell Rail-way.—The inclination varies from $\frac{1}{280}$ to $\frac{1}{80}$ the average being $\frac{1}{222}$, one engine travels with 18 waggons weighing $22\frac{1}{2}$ tons, or with engine 33 tons at an average speed of 6 miles an hour.

Average resistance. Gravity 606 lbs.
Friction 370

976 lbs. × 6 ÷ 10 = $585\frac{1}{2}$ lbs, the effect at 10 miles an hour.

Occasional resistance at $\frac{1}{80}$. Gravity 924
Friction 370

$1294 \times 6 \div 10 = 776$ lbs.

Bolton and Leigh Rail-way.—From an experiment with the Lancashire Witch, 58 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 10 miles an hour.

Liverpool Rail-way.—Rocket engine traversed back and forwards with a gross load of $37\frac{1}{4}$ tons *at the rate of* 13 *miles an hour.*

Another engine employed in leading marle, generally conveyed 70 tons (exclusive of its own weight) *at the rate of 5 miles an hour.*

From these experiments it was concluded, that a locomotive engine would convey 20 tons of goods, exclusive of carriages, at the rate of 12 miles an hour, which would require a force of 497 lbs.

(*b.*) This is derived from the actual expence of the Springwell and Darlington engines. *Springwell* furnished by Mr. John Wood of the cost in the years 1827—1828.

1827.	Wrightwork . . .	10	15	5
	Smithwork . . .	40	17	3
	Sundry tradesmen's accounts .	50	2	0
		101	14	8
	Deduct old materials	9	19	$3\frac{1}{2}$
	Cost of two Engines	£91	15	$4\frac{1}{2}$
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	$6\frac{1}{2}$
	Cost of two engines	£86	3	$11\frac{1}{2}$

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 50*l.*			

(*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 12 hours 1031 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 1800 tons per day, which is 3150 lbs. per day, and 312 days is 439 tons, at 5*s.* 4*d.*, equal to 128*l.* 10*s.* 0*d.*

(*d.*)—Messrs. Stephenson and Locke propose, that the locomotive engines should, upon the other parts of the line, take 20 tons of goods 12 miles an hour, and that the same engines would take 8 tons of goods up the plane at 10 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 16 miles an hour. Another experiment with the same engine, mounted the plane at the rate of 12½ miles an hour, with 20½% tons, including engine.

And, calculating the effect of an engine having two 10-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 10 miles an hour) = 803lbs., which exceeds the resistance of 8 tons of goods on a plane ascending 1 in 96, by 147 lbs.

(*e.*) ANNUAL COST OF WATER STATIONS.

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 I.

(*a.*)—The power of the engines on the 1½ mile stages will be thus:—

Friction of 52 tons, at $\frac{1}{200}$	582 lbs
Friction of 1½ mile of 4½ inch rope, weighing 6888 lbs. at $\frac{1}{12}$*	574
	1156 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

Power of a horse at 12 miles an hour = 150 × 2½ ÷ 12 = 31 lbs., then 1156 ÷ 31 = 37-horse power, or, allowing for spare power, say 40-horse power for one line, or 80 horses for two lines.

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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 3397lbs., on a plane ascending 1 in 33.

Experiment II.—Four waggons, weighing 96 cwt., maintained the same speed with 1370 yards of rope, weighing 5004 lbs.

Experiment III.—Five waggons, weighing 6 tons, maintained a speed of 1⅝ mile an hour, with 1810 yards of rope, weighing 6600 lbs.

To reduce these to fractional parts of the rope's weight:—

1st.	Gravity of waggons.....	244½lbs.
	Gravity of rope	103
		347½
	Deduct friction of waggons	39
	Leaves	308½lbs., or $\frac{1}{12}$th of the weight of the rope for its friction.
2d.	Gravity of waggons.....	326lbs.
	Gravity of rope	152
		478
	Deduct friction of waggons	52
	Leaves	426lbs., or nearly $\frac{1}{12}$th.
3d.	Gravity of waggons.....	407½lbs.
	Gravity of rope	200
		607½
	Deduct friction of waggons	65
	Leaves	542½lbs., or nearly $\frac{1}{12}$th.

(*b.*) POWER OF ENGINES FOR ONE MILE STAGES.

Friction of 52 tons, as above	582 lbs.
Friction of one mile of rope, being $\frac{2}{3}$ of the above .	382
	964 lbs.

But since these engines need not be made to propel the goods at more than 8 miles per hour, because the space of 1 mile can only be travelled over in the same time, that the others are moving $1\frac{1}{2}$ mile (on account of the necessary dependence of these engines upon the others); therefore, the power of a horse, at 8 miles an hour, will be $150 \times 2\frac{1}{2} \div 8 = 47$ lbs., which divided into 964, gives the power of these engines $= 20\frac{1}{2}$ 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 gives for gravity . . .		1213 lbs.
52 — ÷ 200 gives for friction . . .		582
Friction of rope ($5\frac{1}{2}$ inches circumference)		
	10,700 lbs. ÷ 12	891
Gravity of rope . .	10,700 lbs. ÷ 96	111
		2797 lbs.

2797 lbs. ÷ 31 (power of a horse at 12 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 80 horses.

(*d.*)—The power of the engine, at the foot of the inclined planes, will, by allowing 10 horses to assist in overcoming the friction of the rope, be 50 horses, and the extra power at the tunnel, 40 horses.

(*e.*) ESTIMATE OF CAPITAL REQUIRED FOR ENGINES AND MACHINERY ON THE $1\frac{1}{2}$ MILE STAGES.

One engine of 80-horse power . . .	2800	0	0
Four rope rolls and machinery . . .	550	0	0
Engine-house and chimney . . .	650	0	0
Dwelling-house reservoirs	200	0	0
	£4200	0	0

Seventeen stations, at 4,200*l*... £71,400.

(*f.*) EXPENCE OF ENGINES AT THE BOTTOM OF THE TWO PLANES.

One engine, of 48-horse power . . .	1600	0	0
Rope rolls	500	0	0
Engine-house and chimney . . .	600	0	0
Dwelling-house and reservoir . . .	180	0	0
	£2880	0	0

Two engines at bottom of planes.. £5760.

(*g.*) One engine at Manchester, 24-horse power	960	0	0
Rope rolls	250	0	0
Engine-house, &c.	500	0	0
Dwelling-house, reservoir, &c. . . .	180	0	0
	£1890	0	0

(*h.*) ANNUAL EXPENCE OF STATIONARY ENGINES.

Coals for engines, being altogether 1572-horse power, working 10 hours per day, for 312 days, at 17 lbs. per horse power per hour = 37,222 tons, at 4*s.* 6*d.*	8374	19	0
Repairs of engines and machinery, including fire-bars, boilers, hemp, oil, &c. at 1*l.* per horse power, per annum	1572	0	0
Carried forward,	£9946	19	0

Brought forward,	9946	19	0
43 Engine-men, at 54*l.* 12*s.*	2347	16	0
21 Assistants, at 40*l.*	840	0	0
42 Brake-men, at 40*l.* per annum . . .	1680	0	0
84 Men to ride the trains, being one man to each rope, 40*l.* per annum	3360	0	0
Wear and tear of rope sheaves, at 8*l.* per mile of double way	240	0	0
Oil for sheaves, 2100 gallons, at 2*s.* 6*d.* . .	262	10	0
8 men to oil sheaves, at 30*l.* per annum . .	240	0	0
Annual cost of keeping the machinery in working order.	£18,917	5	0

(*i.*) ROPES.

108 miles of $4\frac{1}{2}$ * inch rope on the level stages = $221\frac{1}{3}$ tons, (after deducting value of old material) at 42*l.* per ton . . .	9296	0	0
6 miles of $5\frac{1}{2}$ inch head rope for inclined planes, $19\frac{1}{10}$ tons, at 42*l.*	802	4	0
6 miles of $3\frac{1}{2}$ 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

* The load which Mr. Walker has assigned to be conveyed by each engine is 52 tons, to be dragged by a rope $3\frac{1}{2}$ 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 Rail-ways where similarity of circumstances will warrant a comparison. The resistance of 52 tons will be $582\frac{1}{2}$lb.

On the Hetton Rail-way, a 5-inch rope is used to drag 24 empty waggons, each weighing 28 cwt., up an ascent of 1 in 250. On this plane a $3\frac{1}{2}$ inch rope was originally used, but it was so frequently broken that it was removed in four months.

Then $3136 \times 24 \div 250 = 301$lbs. gravity.
$3136 \times 24 \div 200 = 376$ friction.

Resistance requiring a 5-inch rope 677lbs.

WEAR OF ROPES.

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 $\frac{1}{10}$th 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

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 = 376lbs., 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 are nearly alike.

It is clear, therefore, that for such a line of Rail-way 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 Rail-way, on which the cost of ropes is said not to exceed the $\frac{1}{25}$th of a penny per ton of goods per mile, is extremely favourable; but the 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 Rail-way, 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 important point, is on a part of the Hetton Rail-way, which is nearly level, where 301,800 tons are conveyed over 2½ miles for an expence 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.

(*k.*) DUPLICATE ROPES.

108 miles of spare $4\frac{1}{2}$ inch rope, $221\frac{1}{3}$ tons, at 51*l.*	11,288	0	0
6 miles of $5\frac{1}{2}$ inch head-rope for inclined planes, $19\frac{3}{16}$ tons, at 51*l.* . . .	974	2	0
6 miles of $3\frac{1}{2}$ inch tail-rope for inclined planes, 7 tons, 7 cwt., at 51*l.* . . .	400	7	0
Duplicates for engines, at the 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

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 is 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.

NOTE K.

Statement of the expence 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	$7\frac{1}{4}$	119.944
2	— Do. . . S.	775	30	..	810	$5\frac{3}{4}$	205.621
3	— Do. . . S.	775	115	..	820	$7\frac{1}{4}$	154.214
4	— Do. . . C.	2530	..	$63\frac{1}{2}$	2600	$4\frac{1}{2}$	171.349
5	— Do. . . C.	1820	nearly	level	1900	$4\frac{1}{2}$	136.928
	— Do. tail-rope of No. 5.		..	..	1620	$4\frac{1}{4}$	171.349
		..	..	..	..	..	..
6	— Do. . . S.	1864	68	..	1910	$5\frac{3}{4}$	108.146
		836	..	33			
7	— Do. . . S.	1104	42	..	1200	5	168.805
8	— Do. . . S.	1905	..	89	2000	$4\frac{1}{2}$	218.625
9	— Do. . . C.	964	$57\frac{1}{2}$	..	1100	5	102.050
		1012	..	33			
10	— Do. . . S.	1263	..	82	1500	5	134.000
11	Self-acting plane . . C.	1302	..	$130\frac{1}{2}$	1356	$5\frac{3}{4}$	342.648
12	— Do. . . C.	1224	..	$129\frac{1}{2}$	1256	$5\frac{3}{4}$	342.648
13	— Do. . . C.	716	..	$54\frac{1}{2}$	720	$4\frac{3}{4}$	303.393
14	— Do. . . S.	902	..	$76\frac{1}{2}$	950	$5\frac{1}{2}$	325.565
15	— Do. . . C.	325	..	$67\frac{3}{4}$	370	$6\frac{1}{2}$	193.071
16	— Do. . . S.	715	..	57	800	5	183.456
17	— Do. . . C.	631	..	$77\frac{1}{2}$	750	$5\frac{1}{2}$	168.340
18	— Do. . . S.	704	..	89	780	$4\frac{1}{2}$	126.200
19	— Do. . . S.	942	..	$101\frac{1}{2}$	1000	$4\frac{1}{2}$	169.000

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 L.

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.

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 resistances 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 4 of these experiments, was 106 yards per minute, or 3.60 miles per hour, resistance, 10.4 lbs.; and of 4 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 4 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 M.

The great expence per mile of the Liverpool and Manchester Rail-way, has been often referred to, in contradiction to this assumption:—but any one having seen the works on that Rail-way, will at once see, that on this line there have been more than ordinary difficulties to contend with, and that it cannot be taken as a standard for general reference.

We have, through the kindness of Mr. Booth, Treasurer to the Liverpool and Manchester Rail-way Company, been allowed to give the following extracts of the expences of the different works on that Rail-way; from his very concise and useful pamphlet on the progressive operations of that undertaking, and of Rail-ways in general, which is well worthy of perusal, by those desirous of possessing information on the subject.

General Abstract of Expenditure, to 31st May, 1830.

Advertising account				322	1	4
Brick-making account				9724	4	4
Bridge account				99065	11	9
Charge for direction				1911	0	0
Charge for fencing				10202	16	5
Cart establishment				461	6	3
Chat Moss account				27719	11	10
Cuttings and embankments				199763	8	0
Carrying department, comprising—						
Amount expended in lands and buildings, for stations and depots, warehouses, offices, &c., at the Liverpool end	35538	0	0			
Expended at the Manchester Station	6159	0	0			
Side Tunnel, being the approach to the Crown-street Station	2485	0	0			
Gas-light account, including cost of pipes, gasometer, &c.	1046	0	0			
Engines, coaches, machines, &c.	10991	11	4	56219	11	4
Formation of road				20568	15	5
Iron-rail account				67912	0	2
Interest account (balance)				3629	16	7
Land account				95305	8	8
Office establishment				4929	8	5
Parliamentary and Law expenditure				28,465	6	11
Stone blocks and sleepers				20520	14	5
Surveying account				19829	8	7
Travelling expences				1423	1	5
Tunnel account				34791	4	9
Tunnel compensation account				9977	5	7
Waggon account				24185	5	7
Sundry payments for timber, iron, petty disbursements, &c., not included in the foregoing accounts				2227	17	3
			Total	£739,165	5	0

The Directors, in their Report, dated 25th of March last, estimated the total expenditure, including warehouse, machinery, and carriages, at 20,000*l.*, which may be apportioned as follows:—

Expenditure, as above, in actual payments, to 31st May	739165	5	0
For walling the slopes in sundry places, and completing permanent road . .	6750	0	0
For completing the bridges, including the Irwell 6,000*l.*, and parapets of the Sankey Viaduct, 1,400*l.*, and compensation in lieu of bridges	9500	0	0
Additional engines, waggons, and machinery, part under contract for delivery . .	17000	0	0
Completing stations, wharfs, warehouses, Offices, &c., ...	25000	0	0
Fencing at sundry places	3000	0	0
Contingencies	12084	15	0
Outstanding engagements to the same date.	7500	0	0
Total,	£820,000	0	0

The following are some particulars of the foregoing sums, extracted from the work of Mr. Booth:—

Brick-making accounts.—The greater part of the bricks are fast using in the building of the Manchester warehouses, offices, &c., and some in completing the bridges at each end of the line.

Bridges.—The following description of the several bridges, in a tabular form, I have thought would not be uninteresting, as affording a popular view of the kind of structures that may be expected to occur in similar undertakings. It will be seen, that several of the bridges are still unfinished, though fast approaching their completion; for this purpose a fund is reserved, as per estimate preceding. In almost all the bridges, the foundations are good, except in that across the Sanky Brook, and some of smaller magnitude, in the vicinity of the Moss. The Sanky

bridge required piling, which were put in 2 feet distant, being about 200 under each of the piers—20 to 30 feet in length, and double planked with 4 and 6 inch plank; the great height of the embankment on each side (nearly 60 feet) required the wing walls very strong—the base being about 12 feet broad.

Chat Moss. Under this head is comprised the earth work from Bury-lane Bridge to Legh's Occupation Bridge, on the east border of the Moss, a distance of $4\frac{3}{4}$ miles. The embankments in this space consist of about 277,000 cubic yards of moss-earth, in the formation of which, about 677,000 cubic yards of raw moss have been used. The difference in measurement being occasioned by the squeezing out of the superabundant water, and consequent consolidation of the moss. The expenditure in this district has been less than the average expenditure of the rest of the line.

As this "far-famed Chat Moss," as Mr. Booth expressly designates it, forms a very prominent feature in this Rail-way, we shall, perhaps, be excused in offering a few additional remarks on the execution of the road across it.

This moss is of considerable extent, comprehending an area of about 12 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 10 to 35 feet, resting on clay and sand. The distance which the Rail-way was to be carried over it, was upwards of $4\frac{1}{2}$ miles, an undertaking which required some degree of nerve to contemplate. It is necessary to premise, that in carrying the Rail-way across, the level required, that it should, in some places, be 12 feet above, in others 9 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 Rail-way above; forming a cut below; and forming the road level with*, the moss.

Embanking the Rail-way above the moss. There is another moss of considerably less extent than this, over which the Rail-way passed, and which, at one end, was terminated by extensive cutting: as an embankment, of 4 feet in height, had to be formed over this moss, the materials from the excavation were used for this purpose. The moss was about 20

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 height of the Rail-way is only 4 or 5 feet above the original surface of the moss, the quantity of metal deposited would have formed, on ordinary ground, an embankment 24 or 25 feet high; with such materials (clay and gravel) it would have been impossible to form an embankment over Chat Moss. The quantity required, and the consequent expence 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 in the same way as gravel and clay. In its natural state, the moss was unfit for this purpose, but drains were cut 5 yards apart, which laid dry the part between them, and rendered it excellent material for the purpose. With this material, embankments have been formed upon part of the moss, which required 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 Rail-way, 18 inches to 2 feet deep, which laid dry that portion of the moss between them. About 12 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, carry off the water; by this means the top was partially consolidated, forming a layer or surface of dry moss; upon this hurdles, 9 feet long and 4 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 this stratum of 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 Rail-way, 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.

Cuttings and Embankments.—Under this head is comprised the earth work on the whole line, exclusive of the Chat Moss district. The cuttings somewhat exceed the embankments; the surplus is principally deposited along the border of the great Kenyon cutting. The excavations consist of about 722,000 cubic yards of rock and shale, (including some side cuttings, at Eccles, to expedite and improve the consistency of the Barton embankment), and about 2,006,000 cubic yards of marle, earth, and sand. This aggregate mass has been removed to various distances, from a few furlongs, to between three and four miles; and no inconsiderable portion of it has been hoisted up by machinery from a depth of 30 to 50 feet, to be deposited on the surface above, either to remain in permanent spoil-banks, as at Kenyon, or to be afterwards carried to the next embankment, as at the deep rock cutting through Olive Mount; the process, in this latter case, being rendered expedient from considerations of increased expedition. Where land, for the deposit of spoil-banks has been purchased, the cost of the land forms part of the expenditure under this head, and a good deal of substantial and lofty walling, in the deep cuttings, is also included.

The greatest extent of cutting, is at the following places:—

The area of Edge Hill, at the top of the tunnel, 21 yards wide, 40 to 50 feet deep, at the mouth of the tunnel, running out level with the surface to each. The general price per cubic yard, was 1*s.* 6*d.* Red sandstone.

Olive Mount excavation, is through red marl, or sandstone, about two miles in length ; deepest part, 70 feet ; 1*s.* to 2*s.* per cubic yard.

Rainhill and Sutton. Clay, marl, and sandstone ; from 8*d.* to 1*s.* 1*d.* per cubic yard.

Kenyon cutting.—42 feet the deepest part, and containing above 800,000 cubic yards of excavation, in marl, gravel, and sand. Cost from 8*d.* to 1*s.* per cubic yard. 115,529 cubic yards employed in forming embankments eastward, and 152,874 cubic yards on the west ; leaving 258,122 cubic yards to be deposited as spoil-banks.

Eccles cutting, near Manchester, containing, of marl and sandstone, 332,767 cubic yards ; 10*d.* to 1*s.* 4*d.* per yard.

The embankments are—

The Broad Green, two miles long, greatest height, 45 feet, containing 488,000 cubic yards of materials obtained from the Olive Mount cutting.

Embankment joining the Sanky Viaduct, near 60 feet at the end of the bridge.

Newton Valley, 42 feet deep, adjoining the bridge.

Barton embankment, containing 332,373 cubic yards, formed from the Eccles cutting.

Formation of the permanent road.—"This consists of what is termed *ballasting* the road ; that is, depositing a layer of broken rock, and sand, about two feet thick, viz. one foot *below* the blocks, and one foot *between* them, serving to keep them firm in their places ; spiking down the iron chairs to the blocks or sleepers ; fastening the rails to the chairs with iron keys, and adjusting the Rail-way to the exact width, curve, or level, come under this head of expenditure."

Iron rail account.—This expenditure comprises the following items :—

Rails for a double way from Liverpool to Manchester, with occasional lines of communication, and additional side lines at

the different depots, being about 35 miles of double way, 35lbs. per lineal yard = 3847 tons, at prices averaging something less than 12*l.* 10*s.* per ton, ...	48,000	0	0
Cast-iron chairs, 1428 tons, at an average of 10*l.* 10*s.*	15,000	0	0
Cost of spikes and keys to fasten the chairs to the blocks, and the rails to the chairs .	3,830	0	0
Cost of oak plugs for the blocks . .	615	0	0
Sundry freights, cartages, &c. &c. . .	467	0	2
Total,	£67,932	0	2

Land.—"This is a heavy item of expenditure; the price of land in the vicinity of large towns is usually high; and the outlay was further enhanced, by numerous claims for compensation, owing to the prejudice which, a few years ago, existed against Rail-ways, and especially against what now appears their peculiar recommendation—the locomotive engine. A great change has taken place, in this respect. At the close of 1828, the charge, under this head, was nearly 102,000*l.*; but a portion of this amount being for the depots, has been transferred to the carrying department."

Office establishment.—"This comprises the salaries of treasurer and clerks, office rent, stationery, printing, &c. since October, 1824."

Stone blocks, and sleepers.—"Out of the 31 miles, about 18 are laid with stone blocks (2 feet square), and 13 with wood sleepers, oak or larch; these latter being laid principally across the embankments, and across the two districts of moss. A considerable quantity of wood sleepers have been destroyed, unavoidably, in the progress of the work."

Surveying account.—"This comprises the cost of surveys, plans, &c. for the two applications to Parliament in 1825 and 1826; also the salaries of the engineer, and principal assistants, stationery, &c. from the commencement of the undertaking."

Travelling expenses.—"This includes the cost of sundry journeys and deputations to London, Darlington, Newcastle, &c.

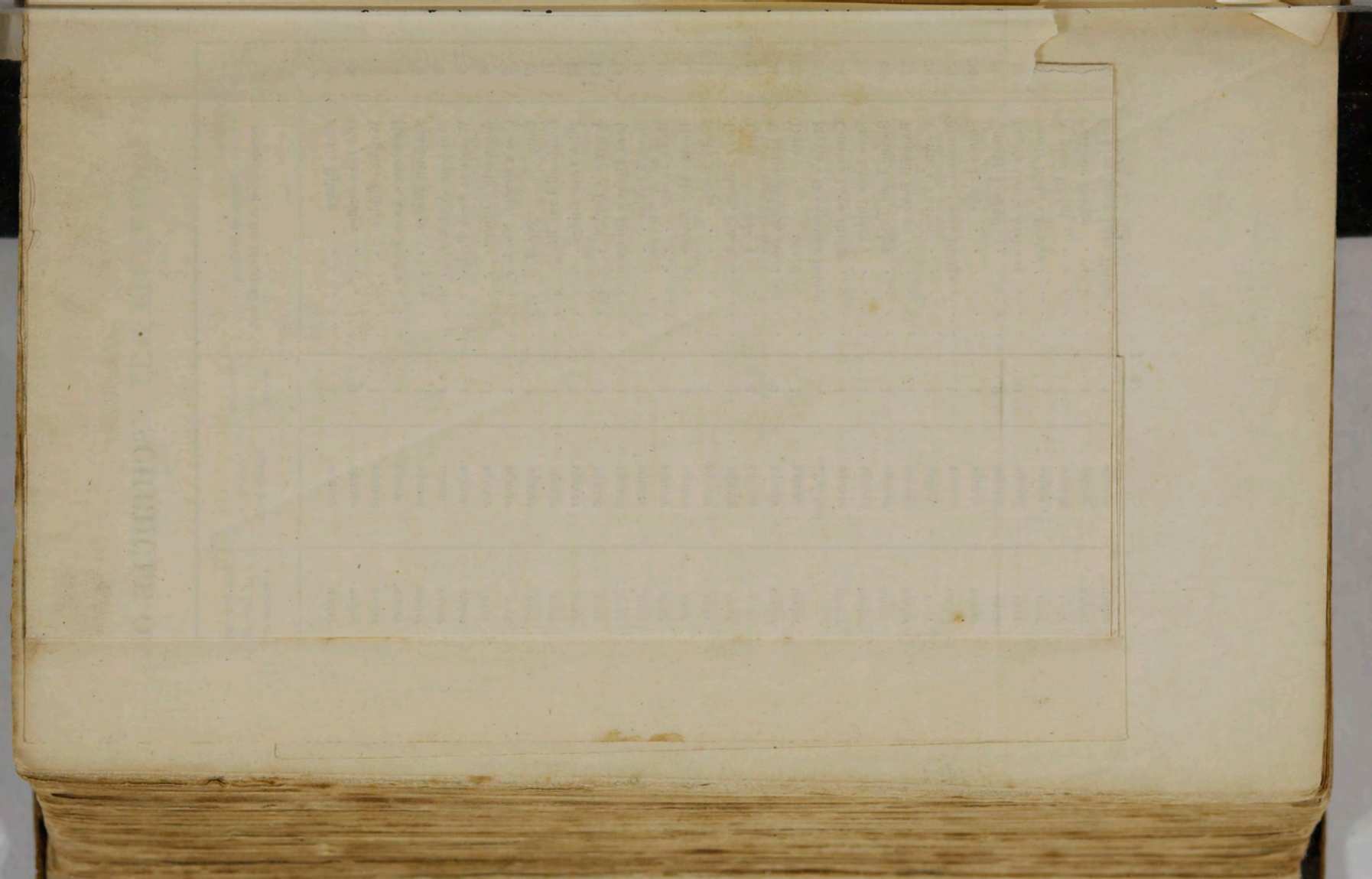
since 1824; also the cost of journeys of inspection, on the line of Railway, during the progress of the works."

Tunnel compensation account.—"This consists of compensation paid to parties, under whose premises the Liverpool tunnel is excavated, for damage, either real or supposed; and further, of loss sustained on the re-sale of sundry houses and land, which the Company were required to purchase. There will be a credit to this account, for premises re-sold, to the extent of about 2500*l.* The previous item constitutes the expence of excavating or forming the tunnels. The length of the main tunnel is 2250 yards, 16 feet in height, and 22 feet wide; the sides being perpendicular, 5 feet in height, and arched semi-circular at the top, 11 feet radius. It is cut through, as Mr. Booth very clearly states (p. 49), various strata of red rock (new red sandstone), blue strata and clay, but principally through rock, of every degree of hardness, from the softest sandstone, to the most compact freestone, which the axe or chisel will, with difficulty, penetrate. Where the natural rock could not be trusted to support the superincumbent strata, the roof is arched with brick work; the height, from the roof of the tunnel, is from 5 to 70 feet; the whole length is white-washed, and lighted with gas. This tunnel terminates in an area of excavation, 40 feet deep at the mouth; and from this area, a return tunnel proceeds to the surface, at the upper part of the town, nearly parallel with the other, but with a contrary inclination, 290 yards in length, 15 feet wide, and 12 feet high. This tunnel is for the passengers and traffic from the high parts of the town, to the area previously named, from whence the locomotive engines start.

Waggon account.—"This expenditure is principally for waggons used in the progress of the work. There will be a credit to this account, for the re-sale of such waggons as cannot conveniently be adapted to the future purposes of the Rail-way, and, by a transfer of the remainder, to the carrying department at their estimated value."

SCHEDULE OF BRIDGES ON THE LIVERPOOL AND MANCHESTER RAIL-WAY.

	Names of Bridges, commencing at the Liverpool end.	Number of arches.	Askew or Square built.	Rail-way *under* or *over* the common road.	Span of the Arch, in Feet, on the askew face.	Whether Ashler, Rubble, or Brickwork.	Description of String, Course, and Coping.	Abutments, whether Rock, Masonry, or Brickwork.	Width of way, in feet, between Parapets *over* arch.	Width of way, in feet, between Side walls *under* arch.	Height under the centre of the Arch, from Rail-way or common road, in feet.	Slope of common road *over* the Rail-way.	Slope of common road *under* the Rail-way.	Number of feet common road is *raised*.	Number of feet common road is *sunk*.	Cost.
					Ft. In.				Ft. In.	Ft. In.	Ft. In.			Ft. In.	Ft. In.	£ s. d.
1	Park's Bridge	1	square	under	—	Ashler, with brick arch faced with stone	stone	masonry	28 ..	30 ..	26 9	level	—	—	—	741 5 9
2	Old Lane Bridge	1	square	under	—	Brickwork	do	brick	12 ..	30 ..	18 ..	do	—	—	unfinished	156 10 0
3	Wright's Bridge	1	square	under	—	Brickwork	do	do	15 ..	30 ..	18 ..	do	—	—	—	184 5 6
4	Rathbone's Lane Bridge	1	askew	under	38 ..	Ashler, with brick arch faced with stone	do	masonry	23 6	30 ..	24 3	do	—	—	unfinished	973 14 2
5	Sandown Bridge	1	square	under	—	Ashler	do	do	15 8	40 ..	40 6	do	—	—	—	765 13 1
6	Mill Lane Archway	1	askew	under	25 6	Brickwork	none	rock	60 ..	25 ..	35 ..	do	—	—	—	91 3 11
7	Wavertree Nook Bridge	1	askew	under	38 ..	Ashler	stone	do	20 ..	37 6	18 ..	1 in 20	—	3 ..	—	274 9 4
8	Ainsworth's Bridge	1	square	over	—	Ashler	do	masonry	34 6	12 ..	13 6	—	level	—	—	418 5 10
9	Case's Bridge, No. 1	1	square	over	—	Ashler	do	do	34 6	12 ..	16 ..	—	do	—	—	418 0 2
10	Ditto No. 2	1	square	over	—	Ashler	do	do	34 6	12 ..	16 ..	—	do	—	—	493 0 3
11	Childwall Lane Bridge	1	square	over	—	Brick arch with ashler quoins	do	do	66 6	14 ..	16 ..	—	do	—	—	346 12 1
12	Pilch Lane Bridge	1	square	over	—	Ditto	do	do	34 6	16 ..	16 ..	—	1 in 30	—	5 6	270 1 0
13	Jameson's Bridge	1	square	over	—	Ditto	do	do	34 6	12 ..	18 ..	—	level	—	—	202 7 0
14	Lord Derby's Bridge	1	square	over	—	Ditto	do	do	34 6	12 ..	20 ..	—	do	—	—	241 16 1
15	Baron's Bridge	1	square	over	—	Ditto	do	do	34 6	12 ..	16 ..	—	do	—	—	240 9 11
16	Ball's Bridge	1	square	over	—	Ditto	do	do	34 6	12 ..	19 ..	—	do	—	—	204 5 5
17	Huyton Hey Bridge	1	square	over	—	Ditto	do	do	34 6	12 ..	12 4	—	do	—	—	302 3 2
18	Seel's Bridge	1	square	over	—	Rubble with ashler quoins	do	do	34 6	12 ..	14 ..	—	1 in 30	—	1 6	215 0 3
19	Lee's Bridge, No. 2	1	square	over	—	Brich arch and ashler quoins	do	do	34 6	12 ..	14 10	—	level	—	—	215 8 10
20	Ditto No. 1	1	square	over	—	Ditto	do	do	34 6	12 ..	21 10	—	do	—	—	282 0 9
21	Whiston Bridge, No. 1	1	square	under	—	Ditto	do	do	47 6	22 ..	18 ..	1 in 13	—	14 ..	—	960 5 0
22	Ditto No. 2	1	askew	under	47 ..	Ashler with brick arch faced with stone	do	do	24 ..	30 ..	18 ..	1 in 20	—	15 ..	—	1174 0 1
23	Makin's Occupation Bridge	—	unfinished	—	—	Timber on stone piers	—	—	—	30 ..	—	—	—	—	—	74 15 2
24	Cumber Lane Bridge	1	square	under	—	Ashler	do	do	16 ..	30 ..	18 ..	1 in 20	—	12 ..	—	536 13 0
25	Store Lane Bridge	1	square	under	—	Wood with stone piers	do	do	9 ..	45 ..	18 ..	level	—	—	—	193 15 3
26	Spring Lane Bridge	1	square	under	—	Ashler with brick arch faced with stone	do	do	16 ..	30 ..	18 ..	1 in 30	—	8 ..	—	418 19 8
27	Rainhill Bridge	1	askew	under	54 ..	Ashler	do	do	30 ..	30 ..	18 ..	1 in 26	—	12 ..	—	3735 6 7
28	Bourne's Tunnel	1	askew	over	14 ..	Ashler and rubble	do	do	104 ..	7 ..	7 ..	—	—	—	—	165 5 9
29	Marshall's Cross Bridge	1	square	under	—	Ashler	do	do	24 ..	30 ..	18 ..	1 in 20	—	5 ..	—	864 13 10
30	Sutton Bridge	1	square	under	—	Ditto	do	do	26 6	30 ..	23 ..	level	—	—	—	470 8 9
31	Sankey Viaduct	9	square	over	—	Brick with stone face, quoins, and parapets	do	brickwork	25 ..	50 ..	60 to canal	—	—	—	—	45,208 18 6
32	Legh's Cattle Archway	1	square	over	—	Brickwork	none	brick	none	12 ..	6 ..	—	—	—	—	275 18 5
	Sandy Main's Bridge	1	askew	over	15 6	Ditto	stone	do	35 ..	12 ..	15 ..	—	—	—	—	429 0 1
	Newton Bridge	4	square	over	—	Brickwork with stone facing	do	do	25 ..	30 ..	27 ..	—	—	—	—	5340 12 5
	Parkside Bridge	1	askew	under	32 6	Brickwork	do	rock	20 ..	30 ..	18 6	1 in 18	—	6 ..	—	316 19 6
	Lockingstump Lane Bridge	1	square	under	—	Ditto	do	brick	20 ..	30 ..	18 ..	level	—	—	—	491 14 9
	Kenyon Tunnel	1	square	under	—	Ditto	do	do	—	30 ..	19 ..	do	—	—	—	1703 19 1
	Hardman's Bridge	1	square	under	—	Ditto	do	do	12 ..	30 ..	20 ..	1 in 9	—	—	3 6	434 7 9
	Newton's Bridge	1	square	under	—	Ditto	do	do	12 ..	30 ..	18 ..	1 in 12	—	7 ..	—	369 12 2
	Brosely Bridge	1	square	under	—	Ditto	do	do	20 ..	30 ..	18 ..	1 in 18	—	7 ..	—	663 4 10
	Withington's Bridge	1	square	over	—	Ditto	do	do	35 ..	12 ..	14 ..	—	level	—	—	419 15 4
	Duckingfield's Bridge	1	square	over	—	Ditto	do	do	35 ..	12 ..	14 ..	—	do	—	—	323 10 3
	Bury Lane Bridge	1	square	over	—	Brickwork with stone quoins	do	do	35 ..	16 ..	16 ..	—	1 in 20	—	3 ..	621 1 7
	Glazebrook Bridge	1	square	over brook	—	Brick with stone quoins and stone pilasters	do	do	35 ..	30 ..	30 ab. river	—	—	—	—	1758 8 6
	Hodgkinson's Cattle Bridge	1	square	over	—	Brick	do	do	35 ..	9 ..	10 ..	—	—	—	unfinished	13 9 0
	Chat-Moss (Frame) Bridge	1	square	over	—	Brick and timber	do	do	25 ..	12 ..	13 ..	—	—	—	—	466 19 6
	Legh's Brick Arch	1	square	over	—	Brick	do	do	25 ..	16 ..	16 ..	—	level	—	—	513 9 6
	Worsley Brook Great Culvert	1	square	over brook	—	Ditto	do	do	125 ..	13 ..	13 to water	—	—	—	—	1598 5 8
	Trafford's Bridge	1	square	over	—	Ditto	do	do	69 ..	12 ..	13 ..	—	level	—	—	589 6 0
	Sandy Lane Bridge	1	square	over	—	Brick and stone quoins	do	do	25 ..	16 ..	21 ..	—	do	—	—	1098 18 4
	Winton Skew Bridge	1	askew	over	31 ..	Brick and stone pilasters	do	masonry	25 ..	22 ..	20 ..	—	do	—	—	1725 10 5
	Canal (Duke's) Bridge	2	square	over	—	Dressed ashler	do	do	25 ..	25 ..	12 to water	—	do	—	—	1158 8 11
	Monk's Hall Bridge	1	square	under	—	Brick	do	red rock	36 ..	30 ..	18 ..	1 in 18	—	6 ..	—	453 19 11
	Eccles Bridge	1	square & askew	under	34 ..	Brick and stone quoins	do	do	48 ..	30 ..	18 ..	1 in 24	—	6 ..	—	954 0 1
	Whitaker's Mill Dam	1	—	—	—	Brickwork and masonry	—	—	—	—	—	—	—	—	—	631 10 2
	Stothard's Occupation Bridge	1	square	under	—	Brick	do	brick	12 ..	30 ..	16 ..	1 in 14	—	5 ..	unfinished	31 19 0
	Gore Booth's Bridge	1	square	under	—	Ditto	do	do	18 8	30 ..	18 ..	1 in 18	—	5 ..	—	417 13 7
	Cross Lane Bridge	1	askew	under	30 3	Brick and stone quoins to arch	do	do	48 ..	30 ..	18 ..	1 in 30	—	6 ..	unfinished	801 12 3
	Jones's Bridge, No. 1	1	askew	under	30 4	Brick	do	do	42 ..	30 ..	18 ..	1 in 20	—	6 ..	do	
	Ditto No. 2	1	askew	under	30 3	Ditto	do	do	42 ..	30 ..	18 ..	—	—	6 ..	do	559 14 5
	Ditto No. 3	1	askew	under	30 3	Brick and stone quoins	do	do	48 ..	30 ..	18 ..	1 in 20	—	6 ..	do	
	Oldfield Lane Bridge	1	askew	under	33 ..	Ditto	do	do	48 ..	30 ..	18 ..	1 in 30	—	7 ..	do	988 15 11
	Irwell Bridge	2	askew	over river	65 ..	Ashler	do	masonry	53 ..	63 ..	30 to river	—	—	—	do	8795 4 4
	Sundry Culverts, Foot Bridges, and Compensation in lieu of Occupation Bridges	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4296 16 0
																£99,965 11 9



NOTE N.—RATES OF TONNAGE UPON THE STOCKTON AND DARLINGTON RAIL-WAY,

COMMENCING ON THE 1st OF AUGUST, 1830.

No.		d.	
1	For all coals and cinders, for home consumption, carried on the main line or any of the branches	2¼	Per ton per mile.
2	For all coals put on board any vessel in the port of Stockton-upon-Tees, to be delivered at Hartlepool or Saltburn	1½	Per ton per mile.
3	For all lime or stone, put on board any vessel in the port of Stockton-upon-Tees, to be delivered at Hartlepool or Saltburn	1	Per ton per mile.
4	For all stones and gravel, to be used for the making or repairing of public or private roads, which may be carried on the main line or branches	½	Per ton per mile.
5	For all marl, sand, clay, and manure, carried on ditto	1	Per ton per mile.
6	For all lime, carried on ditto	1¾	Per ton per mile.
7	For all rough rubble-stone for building, ashlar and hewn stone, bricks and tiles, carried on ditto	1½	Per ton per mile.
8	For all slate, lead in pigs or sheets, bark and timber; also all meal, flour, grain, straw and hay, bar and pig iron, staves and deals, carried on the main line and branches	1½	Per ton per mile.
9	or all goods, commodities and merchandize not before specified, carried on ditto	2½	Per ton per mile.
10	For all coals put on board any ship or vessel, lime, stone, goods, wares and merchandize, or other articles deposited in or upon, or loaded or unloaded at any depot, shoot, staith, wharf, warehouse or landing-place belonging to the company	1	Per ton.
11	For all coals or cinders which shall be shipped on board any vessel at or near Stockton, for the purpose of exportation, or for the purposes of navigation	½	Per ton per mile.
12	For all lime and stone which shall be shipped on board any vessel in the port of Stockton-upon-Tees, for the purpose of exportation	1	Per ton per mile.
13	For all coals and cinders which shall be put on board any vessel at or near Middlesbrough, for the purpose of exportation	½	Per ton per mile.
14	For ditto ditto, so far as the same shall pass on the Middlesbrough branch Rail-way, the additional sum of	1	Per ton per mile.
15	For all coals, lime, stone and cinders which shall be carried or conveyed upon or over the bridge of suspension erected across the river Tees	2	Per ton.
16	For all articles, matters, and things, for which a tonnage is hereinbefore directed to be paid, which shall pass the inclined planes, worked by the permanent engines	6	Per ton.
17	For all the articles, matters, and things, for which a tonnage is hereinbefore directed to be paid, descending any one inclined plane worked by the permanent engines, and which shall not have ascended any such plane	2	Per ton.
18	For every chariot, coach, or other carriage which shall be used for the conveyance of passengers on the main line, or any of the branches	3	Per mile.
19	For ditto ditto on Sundays	6	Per mile.

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