XIII.—*On the Security and Limit of Strength of Tubular Girder Bridges constructed of Wrought Iron.* *By* WILLIAM FAIRBAIRN, ESQ., V.P.

Read April 2, 1850.

BRIDGES have been in use from remote antiquity, and have received in all ages that consideration which the importance of the structure, and their great public utility, so justly entitle them to. They form the connecting link between one part of the earth's surface and another; allow of a continuous communication, by connecting the opposite banks of rivers and deep ravines, and overcome various obstacles which might otherwise be considered impassable. They, in fact, form a very important element in that system of communication by which the civilized nations of the world hold intercourse with each other, and which constitutes the medium of commercial interchange between the different districts of a country. They add facilities for the enjoyment of social life—for the easy direction of the necessary political supervision—and for that invaluable interchange of intellectual and physical relations, which contributes so largely to the wealth and intelligence of a nation. They, moreover, in modern times (associated with that wonderful development of iron "highways," which now traverse in every direction the surface of the country) constitute a medium of concentration in that union of distant objects, which is productive of so much benefit, and by which—through the aid of the locomotive engine—the remotest districts of the empire are now united.

These advantages are common to all countries; and now that rapidity of transit has become an essential part of our existence, it naturally follows that every discovery and every improvement which tends to the extension and enlargement of these facilities, must prove beneficial to the public, as well as interesting to the philosopher and the engineer. Impressed with these views, I have endeavoured to collect the results of a long series of experiments, and to narrow within the compass of a few pages those labours which have occupied no small share of my time and thought, whilst devising means for the construction and proportioning of the parts of a new system of bridge-building. I now propose to submit these results for the consideration of the Society, prefacing them by a few remarks relative to the construction and other matters connected with the security and permanency of this description of bridge.

In a paper given to the Institution of Civil Engineers I have stated, that "every erection of this kind, having for its objects public convenience and a public thoroughfare, should have within itself the elements of undeniable security. Bridges above all other structures should contain those elements: they are the most liable to accident; and, from whatever cause such accident may arise, the community are equally interested in the strength and durability of the structure. In attempting the introduction of a new system of construction, comprising the use of a new and untried material, it behoves the projector, therefore, on public grounds, to be careful and attentive to all the minutiæ directly or indirectly affecting its security. In bridges of the tubular construction, considerations of this kind are of primary importance, as much depends not only upon a correct application of the principle, but upon the quality of the material and the workmanship introduced, which, in every case, should be of the very best description. In the construction of Tubular Girder Bridges, I have endeavoured, as correctly as possible, to apply those principles; and having a strong conviction of the great superiority of strength, durability, and cheapness which the system offers in compassing large spans, I have not hesitated to advocate its extension. It, however, becomes necessary, from time to time, to submit the bridges to a rigid examination; and, before opening any one of them as a public thoroughfare, it is essential to submit them to severe and satisfactory tests. These tests and examinations have been various and frequent; and I believe we may venture to affirm, that in no case where the Tubular Girder Bridge has been duly proportioned and well executed, has there been the least reason to doubt its security.

"The first idea of a Tubular Girder Bridge originated in the long preliminary experimental research which I conducted, in connection with the great bridges on the line of the Chester and Holyhead Railway; and, during its first application to railway constructions, the utmost precaution was observed in the due and perfect proportion of the parts. These proportions were deduced from the experiments made upon the model of the Britannia Tubular Bridge at Millwall, London; and after repeated tests upon a large scale (full size), the resisting powers, and other properties of the bridge, were fully established. From these experiments, a formula was deduced for calculating the ultimate strength of this tubular description of bridge, having spans of from 30 up to 300, or even 1000 feet; and, as that formula is now before the public, I believe it may be relied upon as practically correct. To relieve it, however, from any thing like ambiguity, I shall endeavour to state as briefly as possible, certain points which, in my opinion, should be taken into consideration in its application."

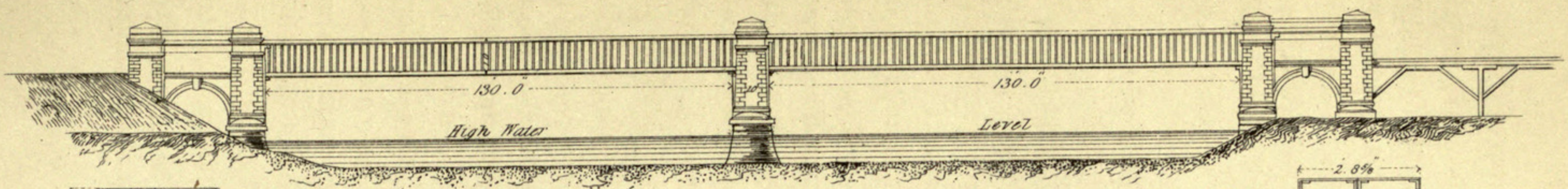
Experiments were made on a large scale to determine the accuracy of my views, and to ascertain the best and strongest form of tube as a means of supporting the Chester and Holyhead Railway, across the wide spans of the estuary of the Conway and the Menai Straits. The original conception of a huge wrought-iron tube, of a circular or elliptical sectional form, suspended in mid-air, and of dimensions calculated to allow of the passage of the locomotive and its accompanying train through its interior, yielded before the facts which these experiments brought to light, to the still more extraordinary and daring project of a colossal hollow beam, having within itself not only self-supporting powers, but a sufficient excess of strength to carry the weight of nearly a dozen railway trains. Beyond this, the experiments gave the rough outline to the system now under consideration, and which has already received, in an extended application, the sanction and approval of practically scientific men, and the confidence of the public.

The Millwall experiments not only successfully realized those objects, but they made us acquainted with other constructions of equal if not even greater importance, in the development of the tubular girder system, which is admirably adapted for almost every description of bridge; and, beyond comparison, infinitely more extended and more general in its application, than the form of tube which now spans the depths of the Menai Straits. It is this girder construction which I am anxious to bring before the meeting, in order to explain its peculiar adaptations, and to receive those suggestions for its improvement, which, I am satisfied, will be freely given by the members of this Society.

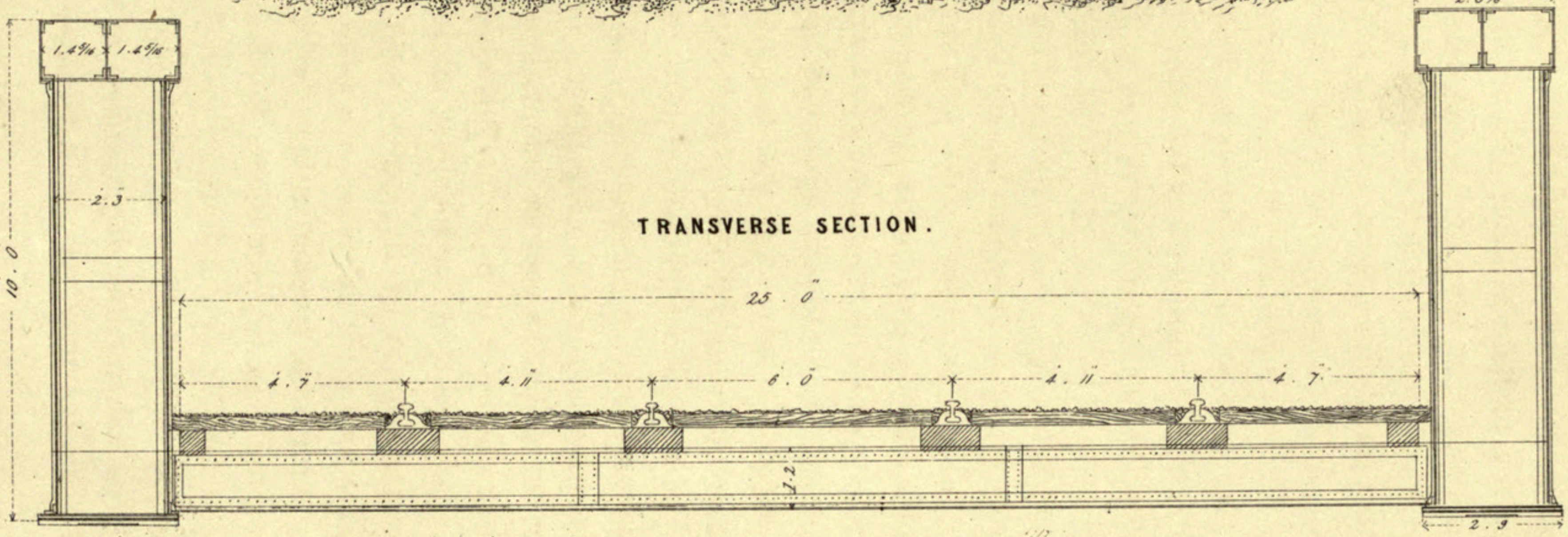
It was determined by the experiments, that, in order to balance the two resisting forces of tension and compression in a wrought-iron tubular girder having a cellular top (as shown in the plate), that the sectional area of the bottom should be to the sectional area of the top, as 11 : 12; and the proportional of these parts being thus established, it therefore follows, that any increase to one or other of them will not materially affect the strength of the bridge.

TORKSEY TUBULAR GIRDER BRIDGE OVER THE RIVER TRENT.

GENERAL ELEVATION.



TRANSVERSE SECTION.



Sectional Area in Top

Plates	2.8 5/8 x 2 x 3/8 =	24.47
Vertical do	1.1 3/4 x 3 x 5/16 =	12.42
Angle Iron	4.75	13.35
Total Area in Top		50.24

Sectional Area in Bottom

2 Plates	2.9 x 2 x 5/8 =	41.25
Centre Strip	1.0 x x 3/4 =	9.0
Packing Strip	3 3/4 x 2 x 5/8 =	4.68
		54.93
Deduct Rivets		5.25
Total Area in Bottom		49.68

On the contrary, if additions be made to the one (assuming the ratio to be correct) without a proportional addition to the other, if the girder does not become absolutely weaker, it is evidently not increased in strength; inasmuch as increased dead-weight is given to the girder by the introduction of a quantity of material which is totally inoperative.* This being the case, it is of importance to preserve as nearly as possible the correct proportion of the parts, in order to ensure the maximum of strength in the two resisting forces of tension and compression, an arrangement essentially important in those structures; and also in the application of the formula to determine the utmost strength of the girder.† If, for example, an excess of material were given to the bottom of the girder shown in the plate, the formula ($W = \frac{a\ d\ c}{l}$) would not apply, inasmuch as the top and bottom areas would be disproportionate to each other, and the girder would fail from the yielding of the top before the stronger bottom

* It may be said that an increase of material to either top or bottom will increase its stiffness, and—*a fortiori*—its strength. I do not, however, admit this doctrine, as there is no telling to what extent these discrepancies may be carried, and the consequence of a disproportion of the parts, if once allowed, might lead to dangerous error. Besides, these proportions must either be correct or incorrect—if the former, any deviation from them is inadmissible.

† It is important to bear in mind, that in devising the formula for calculating the utmost strength of a tubular girder—which formula is, that the breaking weight is equal to the sectional area of the bottom multiplied by the depth, and by a constant derived from experiment for the particular form of girder under consideration, and the whole divided by the length—I have invariably assumed that the proportions which I have announced, and which were arrived at by frequent and direct experiment, are maintained; and further, that the constant which I have given is for a tubular girder constructed after these proportions, and with a cellular top. Other constructions would require other constants to be derived from experiment.

exerted its full resistance to the tensile strain. In estimating the dimensions for the application of the formula, the excess therefore would have to be reduced to the due proportion of 11 : 12 ; or, in other words, the additional strength must be left out of the calculation in computing the strength of the bridge. The same reasoning will apply when the excess of area happens to be in the cellular top, although in this case the formula $(W = \frac{a\ d\ c}{l})$ does apply, as the excess (in my opinion) goes for nothing in the calculation of the strength of the girder.

In every case, however, where these proportions are maintained, we have, in the above formula, a nearly correct principle on which to estimate the strength of similar wrought-iron tubular girders, whatever may be their relative dimensions.*

It must further be noticed, that in calculating the strength of bridges of this description, it is always assumed, that in addition to the proportions of the top and bottom of the girder being maintained, the vertical sides are sufficiently rigid to retain the girders in shape; and it is further assumed, that the whole of the plates, angle iron, &c., are in the line of the forces, and that the workmanship as well as the riveting is well executed.

* Mr. Tate, an eminent mathematician, remarks upon the formula—

1st. With respect to $(W = \frac{a\ d\ c}{l})$, where A is the area of the section of the bottom, and C = 80, the constant deduced on this supposition will apply to all depths of the tube within short limits of error where such depths, or A, are large in proportion to the depths of the cells and the thickness of the plates.

2nd. With respect to the formula $(W = \frac{a\ d\ c}{l})$, when A is the area of the whole section, and C = 26·7, then the tubes should be similar in all respects; but a slight variation in depth from that of similar form will not produce much error, especially where the depth is considerable. At the same time, it must be observed that both formulæ apply with great exactness where the tubes are similar.

At a recent discussion on this subject, which occupied two successive meetings of the Institution of Civil Engineers, Westminster, it was maintained that my formula was not correctly applicable in cases of girders of more than one span, and that I had neglected in the calculations the great increase of strength which was derived from the girders being continuous.

This continuity of the girder was estimated by some to add not less than one-third, and by others one-fourth, to the ultimate strength of that part of it which formed a single span, when viewed simply as a beam supported at the ends, as exhibited in the model now before you. On this question, I observe in a note appended to my paper read at the Institution of Civil Engineers, "that the doctrine of continuity is doubtless true to a certain extent; and, although I admit the fact, I have purposely neglected in the calculation any auxiliary support of that kind as a counterpoise," &c.—I think it safer to do so, as any admission of increased strength in that direction, might lead to serious practical inconvenience, if not dangerous results. I have therefore freely given, as additional security, those advantages of strength, whatever they may be, rather than adopt refinements in the calculation, which, if exercised by the general practitioner, might lead to serious error in reducing the ultimate strength of the bridge. To give to a tubular girder bridge, of more than one span, the full benefit of the extra strength derived from the counterpoise of the girders on the opposite side, the girders would require to be differently constructed; and, in place of the joinings of the plates being prepared to resist compression throughout the whole length of the girders, the cellular top would require to be constructed for about two-thirds of the span in the middle of each girder on the principle of compression—and for a distance of one-sixth on each side of the pier on the principle of tension. In fact, it would require a complex series of constructive operations, in order to meet all the requirements of varied strain to which horizontal girders of this kind are exposed.

Viewing the question in this light, it appears preferable to adhere to a general formula, and to give to the artificer a simple rule of extensive application, such as he may safely use without entering upon theoretical investigation, which more properly belongs to the mathematician than the man of practical science.

In offering these remarks, I am far from underrating the manifold advantages which we derive from the theoretical disquisitions of the mathematician. Every investigation for the elucidation or correction of existing formulæ by the test of the exact sciences must be highly valuable; but having corroborated certain facts by repeated trials and experiments on a large scale, and having found the formula from which the calculations were made, apply with remarkable precision to almost every extent of span, I am strongly inclined to adhere to its truth, and to place implicit confidence in the construction obtained from such a source. I hope, however, that the time is not far distant when we may receive from some able mathematician a preferable and more accurate formula, if such can be obtained.

It may, however, prove instructive if we examine this question more closely, and endeavour to ascertain the real value of the additional strength thus imparted to each successive span by the continuous girder, and, for the sake of illustration, let us take the design of the bridge before us,* which has three spans, the middle being double the width of the two end ones, and consequently required to support double the weight. Now, it is evident that any considerable weight laid upon the centre of the large span of 250 feet, will cause a deflection; and, supposing the depth of the girder at the pier to be 14 feet, we then have 125 feet, or half the span, as the distance of the point of greatest de-

* The design for a Tubular Girder Bridge for supporting the Dublin and Belfast Junction Railway across the Boyne at Drogheda.

flection on one side of the pier, which, acting as the fulcrum, or support of the beam, has a tendency to raise, or tilt up the end of the land girder to the same height exactly from the abutment pier. Assuming this to be the fact, and the girder to be perfectly rigid, we should then have a tensile strain along the top side of the girder over the pier in the ratio of 125 : 14, nearly as 9 : 1. This is one of the advantages peculiar to the wrought-iron tubular girder, as, in every bridge having more than one span, the girders have always been made continuous; but as repeated changes are continually going forward from the passing trains, and as these changes, producing a severe strain, have a tendency to destroy the elasticity of the material, and the soundness of the workmanship at that part, I have considered it essential for the public safety to neglect it in the calculation, and to give in any additional strength which may arise from that source. Should it, however, be determined to take these advantages into account, a new formula must be deduced, and a new system of construction must be adopted over the piers, in order to attain the full benefit of this new element of strength.

The excess of strength that should be given to Girder Bridges, has received considerable attention not only from the profession, but also from the general public. The various accidents which have occurred in the failure of bridges of different constructions, have created of late years considerable alarm as to the stability of those important structures; and when the enormous weight of a railway train, and the momentum of that train moving at fifty miles an hour, are taken into consideration, it requires the utmost foresight, and the greatest possible care, to have the bridge sufficiently strong. These are considerations of deep importance to the engineer as well as the public; and although great difference of opinion exists as to the exact multiplier that should be given to the maximum load, to obtain the load which would produce rupture, I am of opinion that it should never be less than four times the greatest load that can be brought upon the bridge. In the wrought-iron Tubular Girder Bridge, I have computed the breaking weight at twelve tons to the lineal foot, inclusive of the weight of the Bridge, which is equivalent to about six times the maximum load than can practically be brought upon it.

On this calculation, the following Table exhibits the strengths and proportions of Girder Bridges, from 30 up to 300 feet span. It has been computed from experiments on previously constructed Tubular Girder Bridges.

The first column gives the length of the span clear from pier to pier.

The second, the breaking weight of the bridge in the middle.

The third, the area of the plates and angle iron of the bottom of the girder.

The fourth, the area of the cellular top.

And the last, the depth of the girder in the middle.

TABLE

SHEWING THE PROPORTIONS OF TUBULAR GIRDER BRIDGES, FROM 30 TO 150 FEET SPAN.

SPAN.		Centre Breaking Weight of Bridge.	Sec. Area of bottom of one Girder.	Sec. Area of top of one Girder.	Depth at the Girder in the middle.	
Feet.	In.	Tons.	Inches.	Inches.	Feet.	In.
30	0	180	14·63	17·06	2	4
35	0	210	17·06	19·91	2	8
40	0	240	19·50	22·75	3	1
45	0	270	21·94	25·59	3	6
50	0	300	24·38	28·44	3	10
55	0	330	26·81	31·28	4	3
60	0	360	29·25	34·13	4	7
65	0	390	31·69	36·97	5	0
70	0	420	34·13	39·81	5	5
75	0	450	36·56	42·67	5	9
80	0	480	39·00	45·50	6	2
85	0	510	41·44	48·34	6	7
90	0	540	43·88	51·19	6	11
95	0	570	46·31	54·03	7	4
100	0	600	48·75	56·88	7	8
110	0	660	53·63	62·56	8	6
120	0	720	58·50	68·25	9	3
130	0	780	63·38	73·94	10	0
140	0	840	68·25	79·63	10	9
150	0	900	73·13	85·31	11	6

TABLE

SHEWING THE PROPORTIONS OF TUBULAR GIRDER BRIDGES, FROM 160 TO 300 FEET SPAN.*

SPAN.		Centre Breaking Weight of Bridge.	Sec. Area of bottom of one Girder.	Sec. Area of top of one Girder.	Depth at the Girder in the middle.	
Feet.	In.	Tons.	Inches.	Inches.	Feet.	In.
160	0	960	90·00	105·00	10	8
170	0	1020	95·63	111·56	11	4
180	0	1080	101·25	118·13	12	0
190	0	1140	106·88	124·69	12	8
200	0	1200	112·50	131·25	13	4
210	0	1260	118·13	137·81	14	0
220	0	1320	123·75	144·38	14	8
230	0	1380	129·38	150·94	15	4
240	0	1440	135·00	157·50	16	0
250	0	1500	140·63	164·06	16	8
260	0	1560	146·25	170·63	17	4
270	0	1620	151·88	177·19	18	0
280	0	1680	157·50	183·75	18	8
290	0	1740	163·13	190·31	19	4
300	0	1800	168·75	196·88	20	0

In the above Table it will be seen that I have adopted a large multiplier for the excess of strength which I conceive necessary to be observed in the construction of a railway bridge. Twelve tons per lineal foot, equally distributed over the surface of the bridge, is a heavy load as a measure of strength; and although I differ with some of my professional brethren in this question, I am nevertheless of opinion, that the difference of cost in effecting this object is inconsiderable when weighed against the additional security obtained.

In the wrought-iron tubular girder, the difference in the weight of the bridge itself is proportionally less than in any

* I have generally taken the depth of the girders at $\frac{1}{15}$ of the span; but in cases where the span does not exceed 150 feet, I have found it more economical to adopt $\frac{1}{13}$ of the span. With upwards of 150 feet span it is, however, more convenient, on account of the great height of the girder, to adhere to the original proportion of $\frac{1}{15}$, in order to keep the centre of gravity of the girder low, and in order to prevent oscillation to the passing load. In situations where it is objectionable to increase the depth of the girders, it then becomes essential to increase the sectional areas of the bottom and the cellular top in the ratio of the depths.

other construction; and, considering the risk of oxidation arising from neglect in attending periodically to the cleaning and painting of the girders, I am satisfied I am not wrong in making such a provision, and in substituting this large power of resistance for the strength of the principal parts of the structure. It is for these reasons that I have assumed for a double line of rails 12 tons per lineal foot as the ultimate strength of a Tubular Girder Bridge, calculated to ensure permanency, and to meet all the requirements of railway traffic. I have done so in order to meet the various contingent forces of the weight of the bridge itself, the maximum rolling load, and the various other conditions to which railway bridges are subjected, such as vibration or the force of impact acting injuriously upon the bridge.

Amongst other considerations which have engaged the attention of the commissioners on railway structures, is that of impact, and the effect of vibration upon bridges composed of cast-iron, either in the shape of the single or the compound trussed girder. The elaborate investigations on this subject, recently published, are exceedingly valuable; and, although they indicate several new and important properties in the strength of materials, they do not, so far as my own investigations extend, give the correct law as respects the effect of the impinging forces by which these structures are assailed. I believe Professor Willis (whose high standing as an acute mathematician is a sufficient guarantee for the accuracy of the experiments) is perfectly aware of this fact, and has qualified the experiments made at Portsmouth on cast-iron beams, nine feet long, by others upon existing bridges of not less than 50 feet span. These latter experiments are more satisfactory than those at Portsmouth, and approximate much nearer to those made by myself, and other experiments of a similar character.

The effects produced upon a girder bridge by a heavy body, such as a locomotive engine rolling over its surface at a high velocity, is a subject of such vital importance to the permanency and stability of the structure, as to require the most careful investigation. It cannot therefore be surprising that it should have occupied a considerable portion of the time of the commissioners, and that it should have found a prominent position in their report.

It must, however, be observed, that the deflection of a girder bridge arises from one of two causes, or from both. First, from the weight of the bridge itself, which is a constant producing a permanent deflection; and, secondly, from the passing load, whether viewed as a dead or a rolling weight, acting as an antagonistic force to the resisting power of the bridge.

In some parts of the commissioners' report, the experiments do not appear to me to bear out the facts of increased deflection produced by a body, such as a railway train moving at great velocity, and the same body remaining stationary, upon the bridge. In several carefully conducted experiments on tubular girder bridges of different spans, some of them upwards of 150 feet, I found the deflection as nearly as possible the same at all velocities; and, although the experiments recorded by the commissioners are highly valuable, they do not afford to the general practitioner those conclusive results which seem to be essential for the attainment of sound principles of construction. It is true, the commissioners in their report have qualified the results obtained from these experiments by others upon existing cast-iron railway girder bridges, where the deflection was reduced from an increase of the statical deflection, amounting to $\frac{9}{10}$ths of an inch, as produced upon the nine feet bars, at 30 miles an hour, to $\frac{1}{7}$ upon a bridge of 48 feet span, at 50 miles an hour, clearly showing that the larger the bridge, and the greater the rigidity and inertia of the girders, the greater will be the reduction of deflection to the passing load. In the tubular girder bridges composed of riveted plates, it must be observed that the commissioners had no experience, nor were they acquainted with the strength, rigidity, and other properties of girders composed of wrought-iron riveted plates. In these, the deflection due to the passing load is nearly the same at all velocities; and unless there exist irregularities and inequalities on the rails, so as to cause a series of impacts, we may reasonably conclude that the deflections are not seriously, if at all, increased at high velocities.

The questionable security of a great number of horizontal bridges which, of late years, have been introduced for the support of railways, or common roads, has not only called for legislative interference, but the appointment of a commission to watch over the public interests and public safety in railway constructions. This commission, or the inspectors under their direction, I believe, have instructions to pass no bridge or other structure upon any line of railway, until carefully tested as to its security, and other conditions calculated to meet all the requirements of general traffic. These inspectors are employed for the exclusive purpose of examining every new line of railway, and reporting upon its efficiency before it is opened to the public; and, in order to assure themselves of the security of the bridges, cuttings, tunnels, embankments, &c., upon the line, these are generally submitted to severe tests, in order to ascertain their condition and fitness for securing to the public a safe and agreeable transit from one end to the other. Bridges, above all other structures, are regarded with suspicion, and, in order that the lives and limbs of the public should be duly protected, are submitted to a certain proof, which generally consists of a double train of locomotive engines and tenders being run over the bridge at different velocities. A train of locomotive engines is considered the greatest load that can be placed upon a bridge; and, having ascertained the deflection of the girders from their own weight, and that of the roadway, the experiment generally proceeds as follows:—

First—To ascertain the increased deflection due to the heaviest load, as a dead weight placed upon the bridge.

Secondly—The amount of vibration produced by the passage of the same load at different velocities.

Thirdly—The amount of deflection due to the rolling load, and the variations, if any, when the trains are retarded or accelerated; and,

Lastly—The principle of construction is taken into consideration, and the excess of strength which a bridge should have over the greatest load, in order to declare it safe for general traffic.

On the first, second, and third, there appears to be little, if any, difference of opinion; but on the latter, the greatest and most opposite views are entertained. Some contending for three, and others for four, five, and six times the greatest load; whilst others again, more timid than the rest, insist upon eight or ten times the greatest load in order to be safe. Such appear to be the present views entertained by the profession, and such they will continue to be, unless decided by some high authority, from which there is no appeal, as to what should be the resisting powers of a bridge.

I make no doubt we have now in existence several bridges which, to all appearance, are duly performing the important functions of supporting heavily loaded trains within the narrow limits of probably half the weight that would lead to destruction; and others again are of such enormous strength as to bid defiance, for ages to come, to the heaviest load that can by possibility assail them.

Such I believe to be the present state of a considerable number of our railway structures, and such are the widely spread notions which have taken possession of some of our railway engineers. Under these discrepancies, it becomes a question of deep importance as to what should be the exact measure of strength, and what excess should be given to a bridge beyond the load it is called upon to support.

It appears to be the opinion of the railway commissioners, that the flexure of girders should never exceed one-third of the ultimate deflection; and, although I concur in that opinion, I would venture to affirm that in wrought-iron tubular girders, such as are now in use, the effects of reiterated flexure is only one-sixth, and consequently they present a larger margin of security than girders composed of any other material.

On the effects of impact I entertain the same views as the commissioners, that the deflection produced by the striking body on wrought-iron is nearly as the velocity of impact, and those on cast-iron greater in proportion to the velocity. These facts have, however, been strikingly exemplified by experiments made on the first tubular girder bridges constructed for the support of a railway. Two bridges of this kind were erected near Blackburn, over the canal and turnpike road. Both bridges were 60 feet span, and before they were opened to the public they were subjected to the following tests:—

A train of three locomotive engines, weighing 60 tons, occupied the entire span of the bridge, and, having ascertained the deflection in their quiescent state, they were started at different rates of velocity, varying from 5 to 20 miles an hour, which produced a deflection of $\frac{3}{10}$ths of an inch. Two long wedges of the height of one inch were then placed upon the rails in the middle of the span, and the fall of the engines from this, when moving at a speed of 8 to 10 miles an hour, caused a deflection of only ·42 inch, which was increased to ·54 inch, or about half an inch, when wedges $1\frac{1}{2}$ inch in thickness were substituted.

These were severe tests, such as should not again be recommended, as the enormous strength of these girders is now well understood, and they may safely be considered fit for service after being submitted to the heaviest rolling load, or one-sixth of the breaking weight.

In closing these remarks, I would observe that, after these experiments, I came to the conclusion that the tests for bridges of this kind should not exceed the greatest rolling load, and that load to be one-sixth of the breaking weight of the bridge. I may be wrong in this conclusion, which, with great deference, I submit for correction; but in this I am fully persuaded, that in order to give the necessary security, and to provide for all the contingencies consequent upon railway traffic, it will not injure the interests of a railway proprietary to have the bridges of sufficient strength to resist six times the greatest load.

TORKSEY BRIDGE OVER THE RIVER TRENT.

The two main girders extend over the middle pier, on which they rest, with expansion rollers on each abutment.

	Feet.	Inches.
Total length of each girder	282	0
Clear span of each opening	130	0
Depth of main girder	10	0
Breadth	2	9
Depth of cross girders	1	2
Span of „	25	0
Distance of „ from centre to centre	2	0
Total length of bridge, including masonry	342	0

	Tons.	cwt.
Total weight of iron in main and cross girders	252	14

PERMANENT LOAD FOR ONE OPENING.

	Tons.	cwt.
Weight of main girders	91	12
Weight of cross girders	27	1
Timber	18	5
Ballast (2 inches thick)	19	10
Rails, chairs, and fastenings	7	18
	164	6

	Inches.
Sectional area of top, in inches	50·24
„ „ bottom „	49·68

The bridge has been tested with six locomotive engines in steam, equally distributed over one opening, of the aggregate weight of 222 tons, when the deflection was found to be 1·26 inch in the middle. On the removal of the load the bridge returned to its original level.