beam above, and a tension beam below, crossed by radii springing from a common centre, the whole so knit together that external abutments are rendered unnecessary, added to which are cheapness and rapidity of construction, lightness and convenience of transport. The bridge across the Murray is erected on pontoons, and consists of ten arches 33 feet long, 27 feet span, and 10 feet wide. A similar bridge was then designed to cross the Campaspe river, and after being submitted to a committee of inquiry, on which were several eminent engineers, it obtained the sanction of the Colonial Legislature, who passed an Act authorizing the construction of the bridge. The quantity of timber used in this latter bridge is 1200 cubic feet, and of iron three tons. The entire length of the bridge is 121 feet; width, 11 feet clear, and 17 over all; height of sides, 10 feet; span, 107 feet. The net cost was between £700 and £800.

*On the Mechanical Effect of Combining Girders and Suspension Chains ; and a Comparison of the Weight of Metal in ordinary and Suspension Girders to produce Equal Deflections with a Given Load.** By PETER W. BARLOW, ESQ., C. E., F. R. S., F. G. S.

[Read before Section G of British Association.]

My attention has been recently directed to this subject from having been required to investigate, as engineer of the Londonderry and Enniskillen and Londonderry and Coleraine Railways, the best mode of effecting a junction between the lines at Londonderry, to be combined with an improved road communication, for which an Act has been obtained by the Corporation of the city, and the commissioners having determined to advertise for plans, leaving the decision to Sir William Cubitt—an engineer justly occupying a position so eminent, and in whose judgment I had the greatest confidence—I determined to submit the result of my investigation, although the principle which I concluded would best meet all the circumstances of the case, viz: the suspension girder, was one with reference to which considerable prejudice had existed.

Sir William Cubitt, after devoting much attention to the subject, has fully sanctioned the principle, and recommended the Bridge Commissioners to carry out my design, with some modifications suggested by him; but as some doubts have been expressed as to the accuracy of my calculations of the weight of girder to make a suspension bridge as rigid as a girder, they decided to refer the question to a second eminent engineer, and the subject is now under the consideration of Mr. Hawkshaw.

In order to verify my calculations, I have caused a series of experiments to be made, the results of which are of so much practical importance, and so fully confirm my investigations, that I determined to lay them before the British Association, in order that the simple question of the mechanical effect of combining a girder with a suspension chain—on which no difference of opinion ought to exist—should be fully decided; but before describing these experiments, I will make a few gene-

* From the London Artizan, Nov., 1857.

ral remarks upon the systems which have been adopted in bridge constructions.

General Remarks upon the Construction of Bridges of Large Span.—Bridges may be divided into three classes—

1st, The arch, a structure in which the supporting material is subjected to compression alone, but which contains no rigidity in itself.

2d, The suspension bridge, in which the supporting material is subjected to extension alone, which also contains no rigidity in itself.

3d, The girder, in which the supporting material is subjected to both extension and compression, of which there are two varieties, one which is subjected to diagonal strains, as the lattice, Warren, and tubular girders; and a second, in which all the strains are confined to the upper and lower webs, as in the bow and string, and Mr. Brunel's new girder, which is a combination of an arch and a suspension chain, each doing half the supporting duty.

This second variety is the most simple form, but has no more rigidity in itself than an ordinary arch or suspension bridge.

Of these three systems the girder necessarily requires from combining compressive and extensive resistances, a much larger amount of metal than either of the other systems, which will be rendered evident by a simple investigation, and by reference to existing structures.

In an ordinary arch the compressive force is resisted by the abutments, which in no way add weight or strain to the metal; but if the arch is converted into a girder, it can only be done by adding a tie-bar, the arch having then to support its own tie, or substitute for an abutment, in addition to its own weight.

In a suspension bridge the extensive force is resisted by back chains; and if these are taken away to make it a girder, a compression-tube or bar has to be used as a substitute for them (as in the Chepstow Bridge), which tube becomes in large spans, with its supports, by far the largest portion of the structure, and destroys the bridge by its own weight; in fact, the weight of metal is thus doubled to produce equal strength, and quadrupled to produce equal rigidity.

The great difference in weight produced by this and other causes, will be seen by comparing suspension girder bridges with ordinary girder bridges; and I will take as an example the case of the two largest railway openings yet constructed, the Niagara Suspension Girder Bridge, and compare its weight of metal with that of the Britannia tube.

The quantity of material in the Niagara Bridge, having a roadway and a single railway of three gauges in a span of 820 feet, is, in round numbers, 1000 tons; and the weight in the Britannia tube of 460 feet span, 3000 tons for a double line.

If the Britannia tube had been made on the same principle as the Niagara Bridge, the quantity of material to give the same strength and rigidity would not have exceeded $\frac{1}{3}$ th part of what has actually been employed.

So great a difference in the weight renders it obvious that the principle of an ordinary girder involves great extra material, and it became an interesting and important inquiry to ascertain the cause of this difference.

The view that has hitherto been generally adopted on the subject, is that advanced by Mr. E. Clark, in his work on the "Britannia Tube," in which he states, speaking of the proposal to use the Menai Suspension Bridge for railway purposes, "With respect to the use of the present suspension bridge for the proposed traffic, it was found difficult to devise any means of sufficiently strengthening it that did not involve an almost entire reconstruction; and great difficulty was similarly found in attempting to render any suspension bridge sufficiently rigid for railway traffic by means of ordinary trussing."

"When the passing load is small compared to the weight of the chains, and of the structure itself, there is indeed no difficulty; but the construction of a platform 450 ft. long, sufficiently rigid for railway traffic, almost amounts to the construction of the tube itself."

Although unsupported by facts or experiment, this theory has been received and acted upon, not only by a large portion of the public, whose impressions of suspension bridges are derived from what had hitherto been constructed of insufficient strength, and without being combined with a girder, but it has been received and acted upon by engineers of eminence in this country.

These experiments, however, distinctly prove that a suspended girder, as designed for the Londonderry Bridge, is rendered equally rigid with less than $\frac{1}{25}$ th of the metal required in the girder alone; so that the most important economy arises from the combination of a girder with a chain.

Experiments on Suspension Girders.—I have had the model accurately made, which is now submitted to the meeting, on a scale of $\frac{1}{33}$ d part of the actual span, the length being 13 ft. 6 ins. between the bearings, a length exceeding that of the average of the models used by the Iron Commissioners in their experiments, and is amply sufficient, due allowance being made for the scale, to determine with accuracy the deflections on the actual girder, although the deflections of the chain will be somewhat more on the model than on the girder, from the weight not being sufficient to bring the surfaces into perfect contact.

The principal object of the experiment was to ascertain the greatest deflection of the wave of a girder attached to a chain, as compared with the deflection of the same girder detached.

This being obtained, it was perfectly easy to arrive at the deflection of the wave of the Londonderry Bridge, because we have sufficient experiments on girders to enable a calculation to be made of what the Londonderry girder would deflect without the chain, which being obtained, and reduced in the ratio of the girder attached to the girder detached, gave the true deflection.

My first intention was to make the experiments with a girder which was a correct model of the actual bridge, which would have indicated $\frac{1}{33}$ d of the actual deflection, but I found the deflection of the wave to be so small that it was difficult to measure it with sufficient accuracy, and I therefore had a wooden box made of the correct depth, with the sides as thin as it would stand, viz: $\frac{1}{4}$ -inch deal plank, in order to obtain greater deflection of the wave with the correct depth of the girder, and with the chain attached to it, as in the proposed bridge.

I could no longer obtain the actual deflection of the Londonderry bridge by multiplying the experimental deflections by 33, but knowing that the deflection of a model on the correct scale would be $\frac{1}{33}$ d of the Londonderry girder, and knowing by experiment what the model did deflect when unattached, the actual deflection of the Londonderry girder is obtained by reducing the observed experimental deflection in the ratio of the rigidity of the actual model to a true model, and then multiplying by 33.

The deflections of this girder, taken without the chains attached, with a weight of 168 lbs. on the centre, was $\cdot75$ of an inch; with the chain attached, and with the weight placed $\frac{1}{4}$ from the high tower—

lbs.	Deflection at $\frac{1}{4}$ from high tower.	Deflection at centre.	Deflection at $\frac{1}{4}$ from low tower.
56	$\cdot030$	$\cdot010$	$\cdot010$
112	$\cdot060$	$\cdot040$	$\cdot010$
168	$\cdot075$	$\cdot040$	$\cdot010$

Experiment 2.

56	$\cdot030$	$\cdot020$	$\cdot000$
112	$\cdot050$	$\cdot040$	$\cdot005$
168	$\cdot075$	$\cdot050$	$\cdot005$

The ratio of the deflection of the wave at quarter the distance where the greatest amount arises when the chain is attached to that in the middle when not attached, is as 1 to 10 only; but it was evident, from the large deflection at the centre, and from no rise occurring at the opposite end, that the girder was too rigid to indicate the wave, and that the deflection observed was greatly due to the chain not coming to its bearing.

I therefore decided, in order to magnify the wave, and make its amount more distinct, to have a girder made of angle iron $\frac{1}{8}$ th of an inch thick, and a quarter the depth of the former girder, but simply suspended from, and not attached to the chain.

The deflection of this girder without the chains, with a load of 42 lbs. placed on the centre, was 1·2 ins.

The deflection of the wave with the chain attached, and 227 lbs. distributed over the girder, when the weights were placed at $\frac{1}{4}$ from the high tower—

lbs.	Deflection at $\frac{1}{4}$ from high tower.	Deflection at centre.	Deflection at $\frac{1}{4}$ from low tower.
56	$—\cdot10$	$—\cdot01$	$+\cdot05$
112	$—\cdot20$	$—\cdot04$	$+\cdot12$
168	$—\cdot28$	$—\cdot06$	$+\cdot16$

Experiment 2.—In this case the weights were placed $\frac{1}{4}$ from the low tower.

56	$+\cdot06$	$—\cdot01$	$—\cdot12$
112	$+\cdot15$	$—\cdot05$	$—\cdot25$
168	$+\cdot18$	$—\cdot07$	$—\cdot36$

giving an average of 0·32 in. with 168 lbs., equal to $\cdot08$ in. with 42 lbs., or $\frac{1}{5}$ th the deflection the girder without the chain.

The deflection of the Londonderry girder, deduced from the mean results of the deflections of the Boyne Viaduct and Newark Bridge and the Britannia Tube (see Appendix A), was 33 ins. with 100 tons in the centre, $\frac{33}{16} = 2.20$ ins., the deflection here indicated in the Londonderry Bridge, with 100 tons placed at a quarter the length of the girder.

To obtain the comparative rigidity of the experimental model with a true model of the Londonderry girder, we have 42 lbs. producing in the experimental girder 1.2 inches deflection; a true model would deflect

$\frac{33}{33}$, or 1.00 in. with $\frac{100}{33^2}$ tons, or 206 lbs. We have, therefore, as 206 :

42 :: 100 : 0.204, the deflection of a true model with 42 lbs., $\frac{1.2}{0.204}$,

or 5.88 times the rigidity of the experimental model, $\frac{0.32}{5.88} \times 33 = 1.80$

ins., the deflection indicated by a weight on the bridge of 168 lbs. $\times 33^2$, or 81.7 tons, or 2.20 ins. with 100 tons, thus confirming the previous calculation.

It was still obvious, from the deflection at the centre and little rise exhibited in the wave, that the stretching of the chains to bring the metal surfaces to bear, still sensibly influenced the result; and I had another wooden girder made, consisting of a plank $7\frac{1}{2}$ ins. in width and $\frac{3}{4}$ -inch thick, in order to still more magnify the wave, and to diminish the error from the stretching of the chain.

The deflection without the chain attached was 1.48 ins. with 10 lbs.

Experiments with the Chain attached.—With 56 lbs. placed at $\frac{1}{4}$ from the high tower on the girder, which was previously quite unloaded, the deflections were, at

1.8 from high tower.	$\frac{1}{4}$ from high tower.	3.8 from high tower.	$\frac{1}{2}$ from high tower.	5.8 from high tower.	$\frac{3}{4}$ from high tower.	7.8 from high tower.
—·31	—·48	—·32	—·02	+·22	+·29	+·15

Experiment 2.—70 lbs. equally distributed, and 56 lbs. at $\frac{1}{4}$ from high tower.

—·28	—·42	—·25	+·04	+·23	+·28	+·20
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Experiment 3.—150 lbs. all over, weight in same place.

—·20	—·35	—·20	+·02	+·20	+·23	+·14
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Experiment 4.—193 lbs. equally distributed; 56 lbs. as before.

—·18	—·31	—·17	+·05	+·18	+·20	+·14
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The deflection here indicated, with the model loaded with a weight representing 96 tons on the bridge (which experiment was several times repeated), was 0.31 with 56 lbs., = 0.55 with 10 lbs., or 1.26 of the deflection of the girder without the chain. $\frac{33}{26} = 1.27$ is, therefore, the

deflection of the wave indicated by the experiment of the Londonderry Bridge with a load of 100 tons at $\frac{1}{4}$ from the tower.

To obtain the comparative rigidity of the experimental girder, we have here as 206 lbs. : 10 lbs. :: 1·00 in. : ·0485, the deflection of a true model with 10 lbs. $\frac{1·48}{·0485}$, or $\frac{1}{30·5}$ represents the rigidity of the experi-

mental girder, $\frac{·31}{30·5} \times 33 = ·335$ the deflection by a weight on the bridge of $56 \times 33^2 = 27$ tons. 27 : 100 :: ·335 : 1·27, the deflection, as previously calculated.

This result being so much at variance with the general view of the subject, although very nearly in accordance with my calculations, I determined to verify it by a smaller girder, 6 ins. by $\frac{3}{4}$ thick, which would render the wave still more visible, the observations being made with great nicety.

The deflection at the centre when not attached to the chain was 2·375 ins. with 8 lbs.

Girder attached to the chains.

193 lbs. equally distributed.

Weights placed $\frac{1}{4}$ from high tower.

lbs.	$\frac{1}{4}$ from high tower.	Centre.	$\frac{1}{4}$ from low tower.
56	—·64	+·13	+·53

Experiment 2.—With 56 pounds at the centre of the bridge, the deflection was —·30.

The deflection of the wave here exhibited at $\frac{1}{4}$ of the length, with the bridge loaded to a weight equivalent to 100 tons on the actual bridge (which experiment was repeated several times with the same result), was 0·64 in. with 56 lbs., the deflection without the chains being 2·375 with 8 lbs., or 25 times the amount.

In determining how far this result was effected by the resistance produced by the change in the figure of the curve of the chain, I removed all the weights from the plank, and found the result as follows, with 56 lbs. at $\frac{1}{4}$ from the high tower:—

$\frac{1}{4}$ from high tower.	Centre.	$\frac{1}{4}$ from low tower.
—·85	+·20	+·75

With 56 lbs. placed $\frac{1}{4}$ from the low tower:—

+·81	+·12	—·86
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From this experiment it appears that the deflection is decreased by loading the bridge to $\frac{1}{250}$ th of that of the girder unattached, and if the chain were without weight it would be still further reduced. In practice, however, the weight on the bridge will much exceed that on a model, and $\frac{1}{25}$ th will be the least amount that will arise in practice; a result so at variance with the preconceived notions of many engineers, that it is to be expected, in some instances, it will be received with incredulity; but an investigation will show that the result is in accordance with the law

$\frac{b^3 w}{d^3 x} = \text{a constant quantity.}$

If the girder were supported only in the middle, the deflection of the

half girder would be $\frac{1}{8}$ th; but as one-half of the girder cannot deflect without the other half rising, from the action of the chain, it is reduced to $\frac{1}{16}$ th; but the girder is not supported at one point only, but at various points, which will still further reduce the deflection.

However, whether this view is precisely the correct one or not, the fact is established, that the deflection of the wave of a girder attached to the chain, and loaded as in the actual bridge, will not exceed $\frac{1}{32}$ th of the same girder without the chain, from which we may estimate the weight of a girder sufficient to produce in a suspension bridge or arch the requisite rigidity.

In order to show the importance of this result in the cost of bridges, I will compare the deflection and weight of metal in a bridge similar to the Londonderry Bridge, with a girder of equal span, in each case assuming that 3 tons per foot on the bridge will bring no strain exceeding 5 tons per inch on the metal.

	Tons.
The weight of chain, such that 3 tons per foot on the girder will not exceed 5 per inch, is (see Appendix B),	150
The weight of girder sufficient to give no wave or deflection greater than 1·32 with 100 tons (see Appendix A),	150
The weight of metal in cast iron columns, so that the greatest compression with 3 tons per foot is 4 tons per inch (see Appendix C),	60
Weight of suspension bars, so that the tensile strain does not exceed 5 tons per inch with 3 tons per foot load (see Appendix D),	15
	<hr/> 375
To this has to be added the value of the cost of the anchorage of the chains, (which in the Londonderry Bridge will be 15 per cent. of the iron work of the main girder portion of the bridge), so that I have added 57 tons to represent the value of the cost,	57
	<hr/> 432

To compare this weight with that of a girder alone of the same length and depth as that used, which would be equally rigid with the suspension girder, we have to multiply $150 \times 25 = 3750$ tons, or more than 8 times the amount of metal; but it may be correctly argued that a simple girder would be made deeper, and it is therefore fairer to make the comparison with an actual girder, of which we have an example nearly the same span in the Britannia tube.

The weight of the pair of Britannia tubes is 3100 tons, or more than seven times the amount—a difference which will be received with surprise; but it is perfectly consistent with the fact, that the Derry Bridge has nearly three times the depth, and has 2660 tons less of its own weight to support.

The weight of metal in the Londonderry Bridge does not, in fact, exceed that of the sides of one of the Britannia tubes without the top and bottom webs.

It should be observed, that the proportion of the cost of anchorage will vary under different circumstances, but in the case of the Londonderry Bridge it will be under 15 per cent.

It should also be noticed, on the other hand, as a set-off to the cost of anchorage, that the foundations will be increased in a girder bridge, from

their having to support 3110 tons, as compared with 432 tons in the suspension bridge, which will produce an amount in saving, in average cases, equal to the anchorage.

We will now compare the rigidity of the suspension bridge with that of the tube.

The deflection from 1 ton per foot all over the suspension bridge (see Appendix A) will be $1\frac{1}{2}$ ins.

The deflection of one of the Britannia tubes from 1 ton per foot all over is $3\frac{1}{4}$ ins.

The greatest wave that will be produced by a train of 200 tons, covering one-half of the Londonderry Bridge, the other portion being unloaded, will be readily found from the experiments.

The calculated deflection of the girder, with 200 tons all over, separate from the chain, is 41·25 ins. (see Appendix A) $\frac{41\cdot25}{25} = 1\cdot65$, the

greatest deflection of the wave, if the girder is simply suspended from the chain; but as the chain in the actual bridge is attached to the girder for nearly one-half the length, the rigidity will be much greater than here indicated.

It thus appears that the deflection of the Londonderry Bridge, with a suspended girder, and loaded all over, equals the wave when the Bridge is half loaded; and they are each about half the deflection of one of the Britannia tubes when loaded all over, with the same weight per foot.

It is necessary to explain that the estimate given of the deflection of the Britannia tube, assumes that they act separately; when united at the top they become suspension girders, and the deflection is reduced. On the other hand, it has to be noticed that I have not taken into account the increased rigidity from uniting the girder to the chain, instead of simply suspending it, which will have a most material influence.

I will also call attention to the fact, that, in estimating the deflection of the Londonderry Bridge, I have treated the point of support as a fixed point, which is the case if all the spans are equally loaded; but in the event of one span being loaded, and the adjoining span unloaded, the point of suspension will not be a fixed point, and the deflection will be greater than I have estimated.

Thus, with one span loaded, and the second unloaded, the girder bridge will show a comparatively better result than with the entire bridge loaded, but not to any sensible amount, as the same property which renders the suspended girder rigid, will prevent the movement of the point of suspension.

The weight on one opening will create a disposition to straighten the chain in the adjoining opening, which will be resisted by the girder so effectually, from being united with it, that little motion of the point of suspension will occur, even if no assistance were given by the tower.

We may make a similar comparison, deduced from other large girders, of which the next largest actually erected is the Boyne Viaduct; here the span is 264 feet; weight of effective metal, 300 tons.

To find a girder of equal depth and rigidity of 440 ft. span, we have

as— $264^3 : 440^3 :: 300 : 1388$ tons, the weight of a girder being continuous that would deflect 1·9 inches with 540 tons all over, or of about two-thirds of the rigidity of the Londonderry Bridge. The Boyne Viaduct thus indicates a much more favorable result than the tube, and as the system would admit of greater depth, much less metal would suffice for the span.

A similar deduction may be made from the Newark Dyke Bridge, which has: Span of opening, 240 ft.; weight of metal $244\frac{1}{2}$ tons.

Here we have, as— $240^3 : 440^3 :: 244\frac{1}{2} : 1506$ tons, the weight required to construct a girder that will deflect $2\frac{3}{4}$ ins. with 240 tons; and indicates also a more favorable result than the solid-sided girder, but not equal to the Boyne Viaduct.

I must not conclude these comparisons without referring to Mr. Brunel's new system of combining an arch and a suspension chain, giving each half the duty.

There is no doubt in the case of the proposed Londonderry Bridge, if the chain was reduced to half the section, and an arch of the depth of the chain was substituted, and the suspension rods extended to the arch, that theoretically with the same metal, there would be equal strength and rigidity; but the real difficulty is the impracticability of such a construction, the metal is an arch of 451 feet span and 80 feet rise cannot be measured by the section as in a chain, from the tendency to buckle, and from having to contend with its own weight.

Thus in the Saltash Bridge, which is now in course of construction on this principle, of 451 feet span, the depth is only 56 feet, or little more than one-third of the Londonderry Bridge, if of that construction, and thus nearly three times the metal is required to give equal strength, and nearly nine times to give equal rigidity from the deflection varying as the square of the depth.

It will be observed that there will be no difficulty in giving even a greater depth to a suspension bridge; the vertical pressure or weight of the bridge is small compared with the pressure on the arch of Mr. Brunel's girder; and, as the height is only 88 feet, no practical difficulty arises.

(To be Continued.)

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The First Locomotives in the United States

Were brought over from England by Horatio Allen, of New York, in the fall of 1829 or the spring of 1830; and one of them was set up on the Delaware and Hudson Railroad, at Carbondale, Pennsylvania, but being found too heavy for the track, its use was abandoned. The first locomotive constructed in this country, was built by the West Point Foundry, at New York, in 1830, for the South Carolina Railroad, and named the *Phoenix*—a second engine was built the same year, by the same establishment, and for the same road, and named the *West Point*. In the spring of 1831 a third engine was built by the same establishment,