

Experiments on Wrought Iron Beams. By THOMAS DAVIES, F.A.I.S.*

Read at a Meeting of the Architectural Institute, held in Edinburgh on Feb. 18, 1856.

The material first used in the construction of beams was doubtless timber, and although it has many properties peculiarly fitting it for this purpose, yet, on account of its flexibility, and the difficulty of getting it of sufficient size and strength for long spans, its tendency to decay, and its destructibility by fire, it is in many cases unsuited for the purpose required.

When the manufacture of cast metal became more general, and the means were obtained of making large castings, the applicability of this material to the formation of beams could not fail to suggest itself. This material has decided advantages—in its rigidity, in its capability of being made of almost any required shape and strength, in its non-liability to decay, and in its incombustibility; and consequently, it has come to be very extensively used for the purpose referred to.

There has, however, been a general want of confidence in beams of this material, arising from different causes. One objection is, that when a beam gives way, it does so without any previous warning. Another objection is, that although we have innumerable experiments on the strength of cast metal, by which we are enabled to calculate the amount which any particular beam of this material ought to carry, it does not follow that it will bear that amount. In a large casting there may be some inequality in the metal used; again, if there is much difference in the thickness of the parts, the cooling of one part before another produces, to some extent, a tendency to fracture, especially if subjected to any sharp concussion; or the casting may be clean and apparently sound, and yet there may be a flaw, of which nothing can be known until it is revealed by a fracture. No doubt, to guard against these defects, we have the system of testing; but this is not always to be depended upon, as it has been considered, that in some cases beams have been tested so nearly to the limits of their strength, that, though passing the ordeal, they have been permanently injured thereby. This suggests another objection, that though a beam be in every way sound, yet, if it is occasionally subjected to great strains, it will ultimately be so much weakened, as to break with a load much less than the original breaking weight.

The result of the want of confidence abovementioned has been, that cast metal beams are generally made much stronger than, judging from experiment, they require to be, necessitating heavy castings and increase of cost, with the additional drawback of great weight and difficulty of handling.

Malleable iron beams unite, to some extent, the advantages of both timber and cast metal. They possess the advantage of timber, inasmuch as they are comparatively light, and therefore easily handled, and when overloaded, they show this by yielding considerably before breaking. They possess the advantage of cast metal in their incombustibility, in their being capable of being conveniently made of any required strength, and even to some considerable extent, in their rigidity; for although malleable iron is comparatively flexible, yet this quality is in a great measure counteracted by the mode of constructing the beams.

* From the Lond. Civ. Eng. and Arch's. Jour., January, 1857.

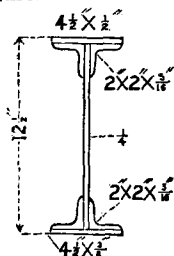
Messrs. Stephenson and Fairbairn, in their investigations and experiments relative to tubular bridges, were the first to call general attention to the use of malleable iron in the construction of beams. After many experiments on various sections of tubes, they arrived at the rectangular tube, or box beam, as the best; and it was a simple step, by dividing it in two by a vertical line, to come to the double flanch or plate beam, which is the most convenient shape for general use.

Mr. Fairbairn, in his valuable book on cast and wrought iron, shows the superiority, in many respects, of malleable over cast iron for beams. He shows, moreover, that, contrary to what takes place in cast metal, the upper flanch requires to be larger than the under one, in the proportion of 2 : 1, and gives formulæ for calculating the strength of beams. There is, however, this drawback, that while his book contains the details of many experiments on various sections of cast metal and malleable iron box beams, there is almost a complete want of experiments on malleable iron plate beams. There is given, in fact, the result of only one experiment on one kind of plate beam, and this experiment was not altogether satisfactory.

This circumstance, there is little doubt, has tended to deter many from adopting this kind of beam. Having made several experiments on the kind of beam referred to, I considered, under the circumstances, that the results of some of these might be acceptable in this Institute, and might tend to the more general use of a beam which has decided advantages for many purposes.

Having had my attention drawn to the applicability of malleable iron for beams, and having long shared in the general want of confidence in cast metal already alluded to, I determined to take the first opportunity of making a trial of them. An opportunity having afforded itself of using them, I consulted Mr. Tod, engineer, Leith Walk, and had the benefit of his experience; and I was so satisfied with the result of the trial, that since then I have not used cast metal for beams of any importance.

The beams in my first experiments, I am sorry to say, were tested by a Bramah Press which I afterwards discovered to be very inaccurate. The results of the experiments, however, which are to be laid before this meeting, are only those which have been obtained by the application of *dead weight*, so that there may be nothing to create want of confidence in the statements now laid before you. These experiments were made at various times in Mr. Tod's yard. None of the beams were tested till they broke, as all were intended for use; but, as most of them were tested to a deflection greater than that to which it would be advisable to have them permanently loaded, they give data for guidance in fixing the dimensions of other beams.



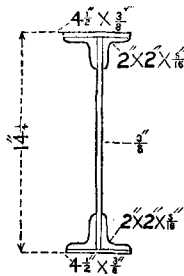
Experiment I.

Length of Beam, . . .	12 ft. 0 in.
" Bearing, . . .	11 " 8 "
Weight of Beam, . . .	4 cwt. 1 qr.

The Load rested on 20 inches in the middle of the Beam.

Divisions of Load.			Load.			Deflection Loading.		Deflection Unloading.	
Cwt.	Qrs.	lbs.	Cwt.	Qrs.	lbs.	Ins.	16ths.	Ins.	16ths.
0	0	0	0	0	0	0	0	0	0
33	0	21	33	0	21	0	2	0	3
42	2	14	75	3	7	0	3	0	4
65	2	14	141	1	21	0	4	0	5 nearly.
38	3	0	180	0	21	0	5		
27	0	7	207	1	0	0	6	0	6 full.
28	3	20	236	0	20	0	7	0	7

Load, $11\frac{3}{4}$ tons.
 Deflection, $\frac{7}{16}$ ths inch.
 There being no apparent permanent deflection.

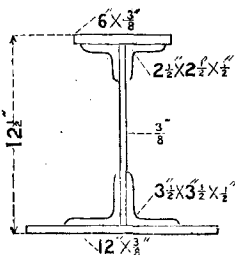
Experiment II.

Length of Beam, 17 ft. 2 ins.
 " Bearing, 16 ft. 6 "
 Weight of Beam, 6 cwt. 2 qrs.

The Load rested on 21 inches in the middle of the Beam.

Divisions of Load.			Load.			Deflection Loading.		Deflection. Unloading.	
Cwt.	Qrs.	lbs.	Cwt.	Qrs.	lbs.	Ins.	8ths.	Ins.	8ths.
0	0	0	0	0	0	0	0	0	1
37	2	0	37	2	0	0	1	0	2
33	0	24	70	2	24	0	2	0	3 nearly.
54	2	16	125	1	12	0	3	0	3 full.
52	0	0	177	1	12	0	4	0	4 full.
52	0	0	229	1	12	0	5	0	5

Load, $11\frac{1}{2}$ tons.
 Deflection, $\frac{5}{8}$ ths inch.
 Permanent deflection, $\frac{3}{8}$ th inch.

Experiment III.

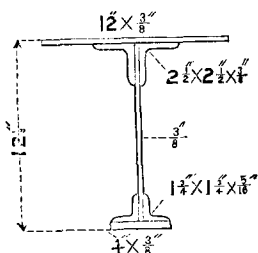
Length of Beam, 30 ft. 0 ins.
 " Bearing, 28 ft. 6 ins.
 Weight of Beam, 20cwt.2qrs

The Load rested on 27 inches in the middle of the Beam.

Divisions of Load.			Load.			Deflection Loading.		Deflection Unloading.	
Cwt.	Qrs.	lbs.	Cwt.	Qrs.	lbs.	Ins.	8ths.	Ins.	8ths.
0	0	0	0	0	0	0	0	0	3
34	1	4	34	1	4	0	2	0	5
12	3	12	47	0	16	0	3	0	6
9	2	16	56	3	4	0	4	0	7 nearly.
13	3	20	70	2	24	0	5	1	0 nearly.
12	3	12	83	2	8	0	6	1	0 full.
16	0	8	99	2	16	0	7	1	1 full.
13	0	0	112	2	16	1	0	1	2
13	0	0	125	2	16	1	1	1	3
13	0	0	138	2	16	1	2	1	4 nearly.
13	0	0	151	2	16	1	3	1	4 full.
13	0	0	164	2	16	1	4	1	5
13	0	0	177	2	16	1	5	1	6
13	0	0	190	2	16	1	6	1	7
13	0	0	203	2	16	1	7		
13	0	0	216	2	16	2	0	2	0

Load, $10\frac{3}{4}$ tons. Deflection, 2 inches. Permanent deflection, $\frac{3}{8}$ -inch.

Experiment IV.



Length of Beam, . 29 ft. 6 ins.

" Bearing, . 28 " 6 "

Weight of Beam, . 14 cwt. 3 qrs.

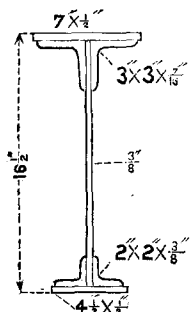
The Load rested on 22 inches in the middle of the beam.

LOADING.			UNLOADING.		
Divisions of Load.	Load.	Deflection.	Divisions of Load.	Load.	Deflection.
Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 8ths.*	Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 8ths.*
0 0 0	0 0 0	0 0	0 0 0	0 0 0	0 3 1/2
.	5 3 8	5 3 8	0 4
17 1 24	17 1 24	0 1	8 2 26	14 2 6	0 5
11 2 16	29 0 12	0 2	11 2 16	26 0 22	0 6
11 2 16	40 3 0	0 3	11 2 16	37 3 10	0 7
11 2 16	52 1 16	0 4	11 2 16	49 1 26	1 0
8 2 26	61 0 14	0 5 nearly	11 2 16	61 0 14	1 1
11 2 16	72 3 2	0 6	11 2 16	72 3 2	1 2
11 2 16	84 1 8	0 7 full.	11 2 16	84 1 18	1 3
8 2 26	93 0 16	1 0	11 2 16	96 0 6	1 4
8 2 26	101 3 14	1 1			
11 2 16	113 2 2	1 2 full. }	11 2 16	107 2 22	1 5
8 2 26	122 1 0	1 3	11 2 16	119 1 10	1 6
8 2 26	130 3 26	1 4	11 2 16	130 3 26	1 7
8 3 22	139 3 20	1 5			
9 1 14	149 1 6	1 6 full. }	15 0 22	146 0 20	2 0
6 1 0	155 2 6	1 7			
6 1 0	161 3 6	2 0 }	12 2 0	158 2 20	2 1
6 1 0	168 0 6	2 1 full.			
3 0 14	171 0 20	2 2	12 2 0	171 0 20	2 2

*The deflections were observed to 16ths of an inch, but the 8ths only are here given.

Load, $8\frac{1}{8}$ tons.
 Deflection, $2\frac{1}{4}$ inches.
 Permanent deflection, . . . $\frac{1}{8}$ -inch.

Experiment V.



Length of Beam, 23 ft. 6 ins.
 " Bearing, 22 " 6 "
 Weight of Beam, 13 cwt. $2\frac{1}{2}$ qrs.

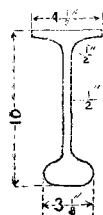
The Load rested on 21 inches in the middle of the Beam.

LOADING.			UNLOADING.		
Divisions of Load.	Load.	Deflection.	Divisions of Load.	Load.	Deflection.
Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 16ths.	Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 16ths.
0 0 0	0 0 0	0 0	0 0 0	0 0 0	0 2
34 3 20	34 3 20	0 1	17 1 24	17 1 24	0 3
20 1 14	55 1 6	0 2	20 1 14	37 3 10	0 4
26 0 22	81 2 0	0 3	23 1 4	61 0 14	0 5
23 1 4	104 3 4	0 4	23 1 4	84 1 18	0 6
20 1 14	125 0 18	0 5	23 1 4	107 2 22	0 7
18 1 8	143 1 26	0 6	25 0 0	130 3 26	0 8
18 3 0	162 0 26	0 7	25 0 0	155 3 26	0 9
18 3 0	180 3 26	0 8	25 0 0	180 3 26	0 10
15 2 14	199 2 26	0 9	25 0 0	205 3 26	0 11
15 2 14	215 1 12	0 10	25 0 0	230 3 26	0 12
12 2 0	230 3 26	0 11	21 3 14	252 3 12	0 13
12 2 0	243 1 26	0 12	16 1 26	269 1 10	0 14
12 2 0	255 3 26	0 13			
13 1 12	269 1 10	0 14			

Load, $13\frac{1}{2}$ tons.
 Deflection, $\frac{7}{8}$ ths inch.
 Permanent deflection, . . . $\frac{1}{8}$ th inch.

I have as yet had only one opportunity of testing a rolled malleable iron Beam, of which the following is the result:—

Experiment VI.



Length of Beam, 10 ft. 9 ins.
 " Bearing, 10 " 3 "
 Weight of Beam, 3 cwt. 21 lbs.

The Load rested on 8 inches in the middle of the Beam.

On account of some circumstances the testing was not quite so satis-

factory as could have been desired, so that the observed intermediate deflections are not given. The total load, however, was $(204\frac{1}{2} \text{ cwt.} =) 10\frac{1}{4}$ tons. The deflection was $\frac{3}{8}$ ths of an inch, or perhaps $\frac{7}{16}$ ths of an inch. The permanent deflection, after the removal of the load, was $\frac{1}{8}$ th of an inch.

It ought to be noticed, that the loads by which the beams in the foregoing experiments were tested, consisted for the most part of railway bars, requiring two men at each end to lift them, and that in loading there was a considerable amount of concussion and vibration, so that the test was considerably more severe than that due to the mere application of the load stated.

The foregoing are the details of all the experiments I have to bring before the meeting. I do not attempt from so few cases to generalize; but in the meantime I leave them before the Institute for their consideration. I may mention, that I am inclined to doubt the accuracy of the proportions of the upper and under flanch for plate beams, as given by Mr. Fairbairn; but I am not at present in a position to speak definitely on this subject. (See Appendix.)

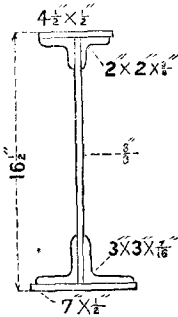
There is one remark, however, which I beg to make, before concluding this part of the paper. The flexibility of malleable iron beams, is no doubt greater than that of cast metal beams, but it is not so great as to prevent them being used for most purposes. For instance, it might be supposed that such beams were, from this cause, inapplicable to the support of walls already built, where the lower part has to be removed, as in the case of the alterations in shop fronts, which are continually being made in this city; but I may give the result of an experiment made in an alteration in Princes-street, as a case in point.

A pair of beams were used, similar to that referred to in Experiment II, except that they were 2 inches deeper, the length being 14 inches greater, and the actual bearing, when put in their place, being 16 ft. 8 ins. After the masonry above the beams had been keyed up, and the supports to the walls removed, so as to throw the whole weight of the wall above upon them, the deflection was only $\frac{1}{20}$ th of an inch. I do not mean to say, that this was all the beams had yielded; but the keying up, before the supports were removed, had taken up whatever additional yielding there had been, although this must have been very little, as there was no appearance, so far as the eye could detect, of any deflection in the beams.

APPENDIX.

As already stated in the body of the paper, I was inclined to doubt the accuracy of the proportions of the upper and under flanches, as stated by Mr. Fairbairn. Since then I have made another experiment upon the beam used in Experiment V, but reversed; that is, with the large flanch, undermost, the results of which is given in the annexed table—

Experiment VII.



(Same Beam as tested in Experiment V. the larger flanch being undermost.)

Length of Beam, . 23 ft. 6 ins.
 " Bearing, . 22 " 6 "
 Weight of Beam, . 13 cwt. 2 1/2 qrs.

The Load rested on 21 inches in the middle of the Beam.

LOADING.			UNLOADING.		
Divisions of Load.	Load.	Deflection.	Divisions of Load.	Load.	Deflection.
Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 16ths.	Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 16ths.
0 0 0	0 0 0	0 0	0 0 0	0 0 0	0 3
24 2 1	24 2 1	0 1	19 0 7	19 0 7	0 4
17 1 3	41 3 4	0 2	19 2 21	38 3 0	0 5
18 0 24	60 0 0	0 3	21 1 0	60 0 0	0 6
18 0 24	78 0 24	0 4	27 1 8	87 1 8	0 7
14 3 16	93 0 12	0 5 bare }			
17 1 12	110 1 24	0 6 }	34 2 24	122 0 4	0 8
20 1 0	130 2 24	0 7 }	34 2 24	156 3 0	0 9
20 1 0	150 3 24	0 8 }	31 3 8	188 2 8	0 10
23 0 16	174 0 12	0 9 }	23 0 23	211 3 3	0 11
20 1 1	194 1 13	0 10 }	15 0 20	226 3 23	0 12
27 1 18	211 3 3	0 11	15 0 20	242 0 15	0 13
15 0 20	226 3 23	0 12	15 3 6	257 3 21	0 14
15 0 20	242 0 15	0 13	12 0 16	270 0 9	0 15
15 3 6	257 3 21	0 14			
12 0 16	270 0 9	0 15			

Load, . 13 1/2 tons.
 Deflection, . 1 5/8ths inch.
 Permanent deflection, 3/8ths inch.

The circumstance of this being the same beam which was tested in Experiment V. and which received a set of 1/8th of an inch in the opposite direction from that in which it was strained in the present instance, accounts for the apparent anomalies in the above experiment, as compared with the results of the former. Thus, at the commencement of the second testing, the beam falls more quickly than on the former occasion, while as the experiment proceeds, it seems to recover strength, and there is little difference in the ultimate strength in both cases. Again, in unloading, the beam in the second testing springs up more quickly than in the first, which is inconsistent with the idea of its being weaker, as the observed deflections imply.

An allowance ought therefore to be made for the previous set of 1/8th of an inch, and the following table is probably near what ought to be substituted for that just given.

Experiment VII.—(as corrected.)

LOADING.			UNLOADING.		
Divisions of Load.	Load.	Deflection.	Divisions of Load.	Load.	Deflection.
Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 16ths.	Cwt. Qrs. lbs.	Cwt. Qrs. lbs.	Ins. 16ths.
0 0 0	0 0 0	0 0	0 0 0	0 0 0	0 1
35 0 0	35 0 0	0 1	19 0 7	19 0 7	0 2
23 0 0	58 0 0	0 2	19 2 21	38 3 0	0 3
27 0 0	85 0 0	0 3	21 1 0	60 0 0	0 4
25 1 24	110 1 24	0 4	27 1 8	87 1 8	0 5
20 1 0	130 2 24	0 5	34 2 24	122 0 4	0 6
20 1 0	150 3 24	0 6	34 2 24	156 3 0	0 7
23 0 16	174 0 12	0 7	31 3 8	188 2 8	0 8
20 1 1	194 1 13	0 8	23 0 23	211 3 3	0 9
17 1 18	211 3 3	0 9	15 0 20	226 3 23	0 10
15 0 20	226 3 23	0 10	15 0 20	242 0 15	0 11
15 0 20	242 0 15	0 11	15 3 6	257 3 21	0 12
15 3 6	257 3 21	0 12	12 0 16	270 0 9	0 13
12 0 16	270 0 9	0 13			

Load, 13 $\frac{1}{2}$ tons.
 Deflection, $\frac{1}{16}$ ths inch.
 Permanent deflection, $\frac{1}{16}$ th inch.

It would have been desirable, in order to have obtained the strength of the beam, as above, without requiring to have recourse to allowances, to have used a beam which had not been previously strained by testing. This was intended in making the above experiment; but through a mistake, the same beam was used over again, and there was not an opportunity of making another experiment before the beams were sent away.

It would be very unadvisable to attempt to draw particular conclusions as to the exact proportions of the upper and under flanches, from these two experiments merely, but the results seem to warrant us in coming to the general conclusion, that for this kind of beam the flanches ought to be nearly equal, the under flanch being rather larger than the upper.

Since making this last experiment and coming to the above general conclusion, and while preparing this paper for the press, I have seen a new work by Mr. Fairbairn, entitled, "Useful Information for Engineers." In it he inserts some of the mathematical investigations of Mr. Tate on the subject, which quite agree with the statements here made. Mr. Tate concludes his remarks by saying—"The difference in the value of these constants is so small, as to lead us to infer, that the beam in Experiment 12 approaches to that of maximum strength with a given quantity of material. The sectional area of the top and bottom flanches are to each other as 14 : 15, which is very nearly a ratio of equality.