a certain distance, and finally about midway of its length opens into the sea, after passing over a distance of about 12400 metres, (13561 yards,) (7·70 miles.) This portion of the canal, consisting entirely of excavations, even where it enters the bay, which must be deepened, offers no difficulty of execution; the cutting necessary for the passage through the ridge will have a maximum depth of 20 metres (65·02 feet) to the surface of the water; and for a length of 3000 metres (3281 yards) its depth will not exceed 10 metres, (32·81 feet.)

The distance from Dos Hermanos to the mouth of the Gatine along the actual course of the Chagres, is 11800 metres, (12904·86 yards,) (7·33 miles;) by the cuttings necessary to render the river easily navigable, this distance will be reduced to 9310 metres, (10181·71 yards,) (5·785 miles.) The total length of the line of navigation between the two oceans, will then be 76450 metres, (83608·24 yards,) (47·50 miles,) to wit:—

		Met.	Miles.
		54740	(34·01)
Artificial Navigation.	{ Between the Pacific and the Chagres,	12400	(7·70)
	{ Chagres and Bay of Limon,		
Natural Navigation.—The River Chagres,	Together,	67140	(41·71)
		9310	(5·79)
Total,		76450	(47·50)

(To be continued.)

Summary of Results offered, in conjunction with one by WILLIAM FAIRBAIRN, Esq., M. Inst. C. E., to ROBERT STEPHENSON, Esq., M. Inst. C. E., &c., &c., for the Directors of the Chester and Holyhead Railway, on the subject of a proposed Bridge across the Menai, near to Bangor. By EATON HODGKINSON, F.R.S.

(Continued from page 28.)

Having in the month of August last year been requested to render assistance, principally in a scientific point of view, with respect to the experiments to ascertain the practicability of erecting a Tubular Bridge across the Menai Straits, of sufficient strength for railway trains to pass through it with safety, I attended twice in London for that purpose: and as the experiments made there were on tubes of various forms of section, including several elliptical and circular ones, I investigated formulæ for reducing the strength of the leading ones. It appeared evident to me, however, that any conclusions deduced from received principles, with respect to the strength of thin tubes, could only be approximations; for these tubes usually give way by the top or compressed side becoming wrinkled, and unable to offer resistance, long before the parts subjected to tension are strained to the utmost they would bear. To ascertain how far this defect, which had not been contemplated in the theory, would affect the truth of computations on the strength of the tubes proposed to be used in the bridge,—and also to show whether the principles generally received could be applied with certainty in reasoning as to the strength of the

bridge from that of models comparatively very small,—for these two purposes I urged the necessity of a number of fundamental experiments, which, besides supplying the wants above mentioned, might enable me to obtain additional information to that from Mr. Fairbairn's experiments, with respect to the proportions that the different parts of the section of such a bridge ought to have, as well as what form it should be of, in order to bear the most.

Feeling that there might be objections against allowing me to follow the courses I proposed, however necessary it might appear to myself, I suggested a much more limited series of experiments than now appear to me to be necessary; and, as the time consumed in getting the plates rolled and the tubes prepared, caused the experiments to be delayed till the beginning of the year, the time given me has been too limited to obtain all the facts which the few experiments proposed would have afforded.

I will now give the results, so far as they have been obtained and seem worthy of reliance, subject to correction from future experiments; beginning with the reduction of Mr. Fairbairn's experiments on the strength of tubes of wrought iron made of plates riveted together.

Cylindrical Tubes.—The strength of a cylindrical tube, supported at the ends, and loaded in the middle, is expressed by the formula

$$w = \frac{\pi f}{a l} (a^4 - a'^4).$$

Where l is the distance between the supports; a, a' the external and internal radii; w the breaking weight; f the strain upon a unity of section, as a square inch, at the top and bottom of the tube, in consequence of the weight w ; $\pi = 3.14159$.

From this formula we obtain

$$f = \frac{w l a}{\pi (a^4 - a'^4)}.$$

As it will be convenient to know the strain f per square inch, which the metal at the top and bottom of the tube is bearing when rupture takes place, this value will be obtained from each of Mr. Fairbairn's experiments: the value w being made to include, besides the weight laid on at the time of fracture, the pressure from the weight of the tube between the supports, this last being equal to half that weight. Computing the results we have, from

Experiment 1,	$f = 33456$	} Mean 29887 lbs. = 13.34 tons.
" 2,	$f = 33426$	
" 3,	$f = 35462$	
" 4,	$f = 32415$	
" 5,	$f = 30078$	
" 6,	$f = 33869$	
" 7,	$f = 22528$	
" 8,	$f = 22655$	
" 9,	$f = 25095$	

Fracture in all cases took place either by the tube failing at the top, or tearing across at the rivet holes; this happened on the average, as appears from above, when the metal was strained $13\frac{1}{2}$ tons per square inch, or little more than half its full tensile strength.

Elliptical Tubes.—The value of f in an elliptical tube broken as before, (the transverse axis being vertical,) is expressed by the formula

$$f = \frac{w l a}{\pi (b a^3 - b' a'^3)}.$$

Where a, a' are the semitransverse external and internal diameters; b, b' the semi-conjugate external and internal diameters; and the rest as before, w including in all cases the pressure from the weight of the beam.

Computing the results from Mr. Fairbairn's experiments we have from

$$\begin{array}{lcl} \text{Experiment 20, } f = 36938 \text{ lbs.} \\ \text{" } 21, f = 29144 \\ \text{" } 24, f = 45185 \end{array} \left. \vphantom{\begin{array}{l} \\ \\ \end{array}} \right\} \text{Mean } 37089 \text{ lbs.} = 16.55 \text{ tons.}$$

Rectangular Tubes.—If in a rectangular tube, employed as a beam, the thickness of the top and bottom be equal, and the sides are of any thickness at pleasure, then we have

$$f = \frac{3 w l d}{2 (b d^3 - b' d'^3)}$$

in which d, d' are the external and internal depths respectively; b, b' the external and internal breadths; and the rest as before.

Mr. Fairbairn's experiment No. 14 gives by reduction

$$f = 18495 \text{ lbs.} = 8.2566 \text{ tons.}$$

This is, however, much below the value which some of my own experiments give, as will be seen further on.

The value of f , which represents the strain upon the top or bottom of the tube when it gives way, is the quantity per square inch which the material will bear either before it becomes crushed at the top side or torn asunder at the bottom. But it has been mentioned before, that thin sheets of iron take a corrugated form with a much less pressure than would be required to tear them asunder; and therefore the value of f , as obtained from the preceding experiments, is generally the resistance of the material to crushing, and would have been so in every instance if the plates on the bottom side (subjected to tension) had not been rendered weaker by riveting.

The experiments made by myself were directed principally to two objects:—

I.—To ascertain how far this value of f would be affected by changing the thickness of the metal, the other dimensions of the tube being the same.

II.—To obtain the strength of tubes, precisely similar to other tubes fixed on,—but proportionately less than the former in all their dimensions, as length, breadth, depth, and thickness,—in order to enable us

to reason as to strength from one size to another, with more certainty than hitherto, as mentioned before. Another object not far pursued, was to seek for the proper proportion of metal in the top and bottom of the tube. Much more is required in this direction.

In the three series of experiments made, the tubes were *rectangular*, and the dimensions and other values are given below :—

Length.		Depth.	Breadth.	Distance between supports		Weight.	Thick-ness of Plates.	Last ob-served Deflec-tion.	Corres-ponding Weight	Break-ing Weight	Value of f , for crush-ing Strain.
ft.	in.	in.	in.	ft.	in.	cwt. gr.	inch.	inch.	Tons.	Tons.	Tons.
31	6	24	16	30	0	44 3	.525	3.03	56.30	57.50	19.17
31	6	24	16	30	0	24 1	.272	1.53	20.30	22.75	14.47
31	6	24	16	30	0	19 1	.124	1.20	5.04	5.53	7.74
						lb. oz.			lb.	lb.	
8	2	6	4	7	6	78 13	.132	.66	9.416	9.976	23.17
8	2	6	4	7	6	38 11	.065	.32	2.696	2.315	15.31
8	2	6	4	7	6	..	..	..	..	..	..
4	2½	3	2	3	9	10 12	.061	.435	2.464	2.464	24.56
4	3½	3	2	3	9	4 15	.03	.13	560	672	13.42

The tube placed first in each series, is intended to be proportional in every leading dimension, as distance between supports, breadth, depth, and thickness of metal,—and any variations are allowed for in the computation. Thus the three first tubes of each series are intended to be similar; and in the same manner of the other tubes, &c.

Looking at the breaking weights of the tubes varying only in thickness, we find a great falling off in the strength of the thinner ones; and the values of f show that in these—the thickness of the plates being .525, .272, .124 inch—the resistance, per square inch, will be 19.17, 14.47, and 7.74 tons respectively. The breaking weights here employed, do not include the pressure from the weight of the beam.

The value of f is usually constant in questions on the strength of bodies of the same nature, and represents the tensile strength of the material, but it appears from these experiments that it is variable in tubes, and represents their power to resist crippling. It depends upon the thickness of the matter in the tubes, when the depth or diameter is the same; or upon the thickness divided by the depth when that varies. The determination of the value of f , which can only be obtained by experiment, forms the chief obstacle to obtaining a formula for the strength of tubes of every form. When f is known the rest appears to depend upon received principles, and the computation of the strength may be made as in the *Application de la Mécanique* of Navier, Part 1st, Article IV; or as in *Papers* of my own in the *Memoirs of the Literary and Philosophical Society of Manchester*, vols. iv and v, second series. I have, however, made for the present purpose, further investigations on this subject, but defer giving them till additional information is obtained on the different points alluded to in this report; and this may account for other omissions.

In the last table of experiments the tubes were devised to lessen or to avoid the anomalies which riveting introduces, in order to render the properties sought for more obvious. Hence, the results are somewhat higher than those which would be obtained by riveting as generally applied.

The tube 31 feet 6 inches long, 24 cwt. 1 qr. weight, and .272 inch in thickness of plates, was broken by crushing at the top with 22.75 tons. This tube was afterwards rendered straight, and had its weak top replaced by one of a given thickness, which I had obtained from computation; and the result was, that by a small addition of metal, applied in its proper proportion to the weakest part, the tube was increased in strength from 22.75 tons to 32.53 tons; and the top and the bottom gave way together.

If it be determined to erect a bridge of tubes, I would beg to recommend that suspension chains be employed as an auxiliary, otherwise great thickness of metal would be required to produce adequate stiffness and strength.

EATON HODGKINSON.

Steam Navigation.

At the request of W. C. REDFIELD, Esq., we insert the following communication from him on the subject of Steam Navigation, being an appendix to what has already appeared in the Journal from the United States Navy Department.

COM. PUB.

APPENDIX.

Comparative weights of Shot thrown at a round, by different vessels, reckoned according to the calibre of the guns.

	Line Ship Ohio.	Frigate Brandywine.	Steam Fri- gate Mis- sour.	Light 6 gun Steamer.
Weight thrown at broadside, . . .	lbs. 1600	lbs. 864	lbs. 386*	lbs. 388
Do. in chase, bow on, . . .	128	128	260	258
Do. " " stern on, . . .	256	192	128	258
Do. by the whole armament, . . .			768	512

* The above is computed from the present armament of the Missouri, counting but one of her two traversing guns to act in broadside. The broadside of this vessel may, however, in favorable circumstances, be increased by shifting the guns. In the like circumstances, the whole armament of the *six-gun* steamer might be brought to bear in broadside.