(*Paper No. 3893.*)

"The Strengthening of Damodar Bridge on the Bengal-Nagpur Railway."

By Douglas Henry Remfry, Assoc. M. Inst. C.E.

(*Abstract.*)

The Damodar Bridge, situated on the Bengal-Nagpur railway about 6 miles from Asansol, carries a heavy coal-traffic from the Radhanagar coal-fields to Calcutta. It consists of ten girder spans of 200 feet and two spans of 100 feet, carrying a single line of 5 feet 6 inches gauge. The bridge was found to be weak for the newest engines and coal-trucks, which had recently been much increased in weight. All trains had therefore to be double-headed, two A class engines weighing 78 tons each being used, and the axle-loads in the coal-wagons being reduced from 16 to 14 tons each. On reaching Adra, about 25 miles from Radhanagar, one H class engine, weighing 108 tons, took on the train to Calcutta, but the loss of 4 tons of paying load in each coal-wagon continued.

As the engine-loads have recently tended to increase, it was decided to bring the whole bridge up to a standard of strength 25 per cent. above that necessary for the standard maximum loadings of 1908.

The two 100-foot spans were old wrought-iron Warren girders, weighing 66 tons per span, dating from 1885. They were extremely weak in their deck systems, the rail-bearers being stressed to about 10 tons per square inch. It was found quite impossible to strengthen these spans satisfactorily: they have accordingly been transferred to narrow gauge, and their place taken by new steel girders weighing 93·3 tons per span. A considerable amount of alteration was necessary to prepare the old girders for narrow gauge. The whole deck system had to be remodelled, the girders strengthened, new rail-bearers provided, and a wind-bracing system worked in. Nearly 10 tons of new material was used per span. The alterations were carried out in the workshop at Damodar Bridge.

The 200-foot spans were strengthened in position. The weight of a span as originally built was 214 tons. This was increased by strengthening to 275 tons, or a rise of 29 per cent. The increase in strength is considerably more than in proportion to the increase in the weight: from being 26 per cent. below the strength necessary according to the Government of India rules for the present heaviest loadings, it was raised to 25 per cent. above—a rise of over 69 per cent. The ratio of increase of strength to increase of weight was therefore 2·38, showing with what efficiency new material can be applied in strengthening old spans.

The original intention was to divert traffic from the bridge altogether while the strengthening was being carried out. For this purpose a diversion was put in with a pile-bridge 600 feet long. The work took longer than was anticipated, and it was found necessary to carry on the strengthening under traffic during the rains of 1907, after the diversion was washed away. To complete the work the diversion was again opened after the rains. Five and a half spans out of the ten were strengthened under traffic. Working under traffic was naturally slower and more expensive than when the strengthening was being carried out with a diversion. A span under traffic required about 6½ weeks to complete, while with a diversion the last two spans took 4 weeks each.

When strengthening a span it was jacked up at six points, so as to take all dead load stresses off the old material. The new material added was therefore effective in taking its share of both dead and live load stresses. The calculated deflection of the girder being 1⅜ inch under its own dead load, the span was cambered up 1½ inch at the centre, and 1⅛ inch at each quarter point, when any drilling or riveting was going on.

To support the girders, adjustable steel stagings were used, three stagings to each span (Figs. 1, Plate 6). Each staging consisted of six rolled-steel columns 6 inches by 5 inches by 25 lbs., strongly braced together, and having heavy girders at the top and bottom to distribute the load. The columns were in lengths of 12, 9, and 6 feet, and the height of a staging could be varied at pleasure, in steps of 3 feet, from 8 feet 6 inches to 41 feet 6 inches, by using suitable combinations of these lengths. All parts were supposed to be interchangeable.

The stagings were erected on the sandy river-bed, and to prevent the current from underscouring them six small steel well-cylinders were sunk under each staging. These cylinders were 3 feet 6 inches in diameter, built up of ¼-inch plate in stakes of about 4 feet, which could be bolted together. The length of the cylinders varied between

11 feet and 15 feet according to the exposure of the situation. Where heavy scour was anticipated the cylinders were pitched with sand-bags and stone. On completing the strengthening of a span, the adjustable stagings were hauled off to the next span, and the well-cylinders withdrawn and used again. For sinking the latter, small Bull dredgers were used.

Details of the Strengthening.—The top booms were strengthened by the addition of new top and side plates (Figs. 2, Plate 6). In the central bays a top plate 18 inches by $\frac{5}{8}$ inch was used, with two side plates $9\frac{3}{4}$ inches by $1\frac{1}{8}$ inch, the total additional sectional area being about 32 square inches. The new top plates gave very little trouble even under traffic, but the side plates needed careful manipulation, as in order to fix them into position a very large number of the most important rivets in the span, connecting the top gusset-plates to the top booms, had to be cut out. Under traffic conditions this could only be done by rimering the holes and using turned bolts. The bottom booms were strengthened by having heavy angle-irons riveted along their lower edges, and a new flange-plate added (Figs. 2, Plate 6). The central bays in this case were strengthened by the addition of two angles 4 inches by 4 inches by $\frac{5}{8}$ inch, and a flange-plate 2 feet 10 inches by $\frac{3}{4}$ inch, a total net section of over 31 square inches. None of the drilling for these bottom-boom plates could be done in position, as there was not sufficient clearance for the pneumatic drills to work. Very careful measurement and marking off for each span was therefore necessary.

The diagonals were strengthened by the addition of two angle-bars riveted inside them and a web-plate, making each diagonal into an H section instead of being two separate flat bars. The total additional sections needed varied between $7\frac{1}{2}$ and about 13 square inches per diagonal. A great many additional rivets were worked into the gusset-plates at the ends of the diagonals.

The vertical members only required a small additional area, and were strengthened where necessary by the addition of angles riveted along the sides of the webs.

All the counter-braces in the bridge were found to be slack and generally badly buckled. They were taken out, strengthened, shortened, re-riveted after the spans were finally lowered, and strongly laced to withstand compression as well as tension, thus relieving the central diagonals.

The cross girders were strengthened by the addition of raking struts from the bottoms of the vertical posts which supported the cross girders at their centre (Fig. 3). The struts each consisted of two angles, 6 inches by 4 inches by ½ inch, riveted back to back. The rail-bearers required a little stiffening to their webs. It was also found necessary to replace eight of the main gusset-plates on each span, as they were deficient in sectional area and could not contain sufficient rivets. To do this under traffic it was necessary to block the line for at least five hours, as the plates were large and heavy and had to be carried a considerable distance to the shops for new plates to be drilled from them. About 40,000 holes had to be drilled per span. Pneumatic drills were used and most of the drilling was done in place. It was very difficult to get enough rivets into some of the joints, especially into the ends of the central diagonals. Experiments were made with a special type of chrome vanadium steel rivet for places where the rivet area was too small. These had a shearing strength about 45 per cent. greater than an ordinary mild steel rivet, and tests seemed to indicate also that a greater bearing resistance could be relied upon in the plates, when these special rivets were used, than with mild steel rivets. The deflection of the girders after strengthening was reduced under live loads by 26 to 30 per cent. In most of the spans practically no permanent set was observable on the first passage of a train after strengthening. The camber was on the average unaltered.

The cost of strengthening ten 200-foot spans worked out to Rs.3,66,639. The total weight of new material worked into these spans was 615·8 tons, and the weight of the ten spans after strengthening, 2,756·26 tons.

The detailed cost of the strengthening was as follows:—

		Total Cost.	Cost per Ton of Added Material.	Cost per Ton of Strengthened Span.
		Rupees.	Rupees.	Rupees.
Materials		83,366	135·5	30·0
Labour		1,31,828	214·0	47·81
Establishment		27,248	44·25	9·87
Stores		80,688	131·0	29·25
Quarters		3,485	5·5	1·25
Masonry		4,529	7·37	1·62
Diversion:				
Pile Bridge	Rs.16,066			
Earth-work, etc.	Rs.10,210			
		26,276	42·5	9·5
Freight		3,017	4·87	1·06
Painting		6,202	10·06	2·25
Total		3,66,639	595	133

The cost per cwt. of material added works out as follows:—

	Rs.	An.
Material	6	12
Labour charges	10	12
Establishment	2	4
Stores	6	8
Miscellaneous charges	3	12
Total	30	0 per cwt.

The pile-bridge cost Rs.16,066, after giving return value for material used, which is Rs.26·12 per foot of waterway, being kept open for two seasons.

Work on the bridge itself was actually started in February, 1907, and completed in May, 1908, taking 15 months in all. The labour charges incurred when strengthening under traffic were about 75 per cent. greater than those when a diversion was used. About 55 per cent. of the whole work was done under traffic. Labour charges per cwt. of added material were about Rs.7·9 when work went on with a diversion, and Rs.13·3 under traffic.

If the cost of the diversion be debited to the four and a half spans strengthened with its use, the total cost of material added per cwt. amounts to about Rs.29·5, while the cost of material added under traffic, deducting the cost of the diversion, amounts to Rs.30·5. It is evident that the use of the diversion was economical in this case, it being a very large bridge. Where the diversion presents great difficulties, the case may be different. The gradients on the diversion were 1 in 50, and a banking engine had to be kept. The cost of the banking engine has not been considered, but it might very easily add as much as Rs.1·4 per cwt. of added material to the cost of the strengthening, making the cost of strengthening such a bridge without a diversion the cheaper method.

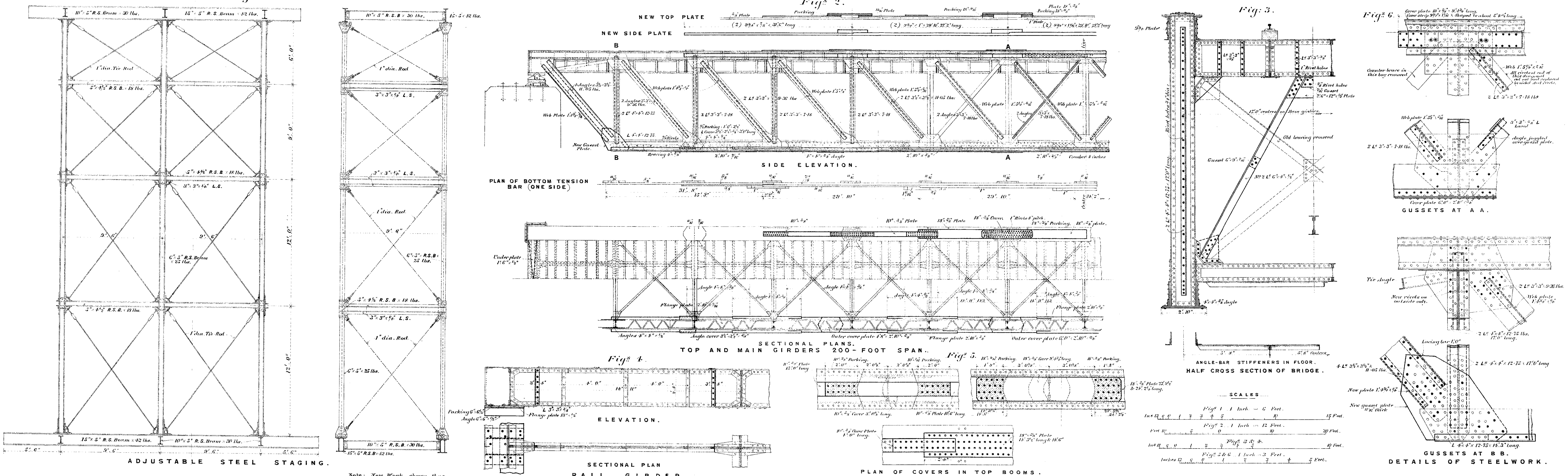
The strengthening was carried out in accordance with the Government of India Bridge Rules of 1903, Standard B + 25 per cent., which is equivalent to the Standard of 1908.

The work was carried out by the Author under the direction of Mr. C. W. Anderson, M. Inst. C.E., the Bridge Engineer of the Bengal-Nagpur Railway, to whose advice and assistance, both in the execution of the work and the preparation of the Paper, the Author is much indebted. The late Mr. E. F. Sanders was the Chief Engineer of the railway while the work was being carried out.

The Paper is accompanied by three drawings, from which Plate 6 has been prepared.

THE STRENGTHENING OF DAMODAR BRIDGE.

PLATE 6.
THE STRENGTHENING OF DAMODAR BRIDGE



THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

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D. H. REMFRY.