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ROBERTSON AND STONEY

ON

INDIAN BRIDGES.

INDIAN BRIDGES:

COMPRISING THE FOLLOWING PAPERS:—

I.

THE LANSDOWNE BRIDGE OVER THE INDUS AT SUKKUR.

By FREDERICK EWART ROBERTSON, M. INST. C.E.

II.

THE NEW CHITTRAVATI BRIDGE.

By EDWARD WALLER STONEY, M.E., M. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPERS.

EDITED BY
JAMES FORREST, ASSOC. INST. C.E.
SECRETARY.

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THE INSTITUTION OF CIVIL ENGINEERS.

Sect. I.—MINUTES OF PROCEEDINGS.

2 December, 1890.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

- Marcelin John Chabrel, B.E.
- Frank Gotto.
- Edward Hopkinson, M.A., D.Sc.
- Hugh Lewin Monk.
- John Hemphill Morant.
- George Moyle.
- Matthew James Joseph Patrick Norman.
- Henry Oliver.
- Ernest Ifill Shadbolt.
- Ernest Alfred Sibold.
- Alexander Siemens.
- John Simmons.
- William Harry Stanger.
- Charles Froggatt Wike.

The following Candidates have been admitted as

Students.

- Alfred Seabold Eli Ackermann.
- Edward Hazledine Barber.
- Ernest Albert Seymour Bell, F.C.H.
- Edward Charles Bickersteth.
- Arthur George Bristow.
- Henry Charles Brabazon Campbell.
- John Francis Carr.
- Harry George Christ, Wh.Sc.
- Frank Clayton, F.C.H.
- Frederick Charles Colyer.
- Jules Ferdinand Conradi.
- Osmond Dawnay.
- Stephen Mitchell Dixon, B.A.
- Richard Frederick Drury.
- Nicholas Dunscombe.
- Bertram Wyburne Ellis.
- Somers Howe Ellis.
- Paul Traugott Julius Estler.
- Francis Douglas Fox, B.A.
- George William Gait.
- William Gilbert, Wh.Sc.
- William John Griffiths.
- Isidore Hoffmann.
- Henry William Maclean Ives.
- William Eric Leigh Jenkinson.
- Percy Johns.
- Christopher Watkins King.
- William Arthur Baird Laing.
- Ralph Morgan Lewis.
- Harry Calder Löbnitz.
- Dugald McLellan.
- Arthur Woodroffe Manton.
- William Gosling Moore.
- Ernest Charles Adams Mumme.
- George Edward Luther Poulden.
- Edward Hulme Rigby, B.Sc.
- Gervase Henry Roberts.
- Keith Robinson, A.K.C.
- Leonard Cowley Seavill.
- John Miles Simson.
- Eric Arnold Slater.
- William Grimshaw Stones.

Students—continued.

Hugh Stowell.
Frank William Swift.
Lucas Thomasson.
John Edward Thornycroft.
Richard Fenwick Thorp.
John Henry Tonge.
Stanley Tooth, B.A.
Robert Ponsonby Loftus Townshend, B.A.
Bertram Vallance.
Eric Hamilton Whiteford.
Arthur John Williams.
Benjamin Leonard Wilson.
Norman Forster Wilson.

The following Candidates were balloted for and duly elected as

Members.

Frederick Robert Bagley.
William Evans.
Herbert Septimus Harrington.
Clemens Herschel.
William Rich Hutton.
John James Jones.
William Redfern Kelly.
Morice Leslie.
Hyalmar Frederick Stavelius.
William Thow.

Associate Members.

Joshua Thomas Noble Anderson, B.A., B.E.
Frank James Appleby.
Thomas Arnold.
Samuel Athim.
John Edmund Bach.
George Herbert Bayley.
Raymond John Birt, Stud. Inst. C.E.
Arthur Sackville Boucher.
Thomas Allen Bullough.
Edward Burton, B.A., Stud. Inst. C.E.
Evaristo de Chirico.
Thomas Clarkson, Wh.Sc., Stud. Inst. C.E.
David Decimus Coath.
William Bartholomew Cole, Stud. Inst. C.E.
Henry Paul Ramsay Copeland.
William Wallace Copland.
Arthur Cecil Crampton.
George Blythe Cuthbert.
Peter Dodd.
Heber Duckham.
Alfred John Duncan.
Frederic MacDonnell Evanson.
Robert David Fitz-Gerald, Stud. Inst. C.E.
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Frank Foster.
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John Maxwell Sullivan Green, Stud. Inst. C.E.
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Francis William Hardwick, M.A.
Charles Chetwode Hardy, Stud. Inst. C.E.
George William Hick.
Frederick William Hudson.
Albert Francis Jacob.
William Thomas Jones.
Charles Aldwin Kempson, Stud. Inst. C.E.
Robert Kendall.
Hugh Torrance Ker, Stud. Inst. C.E.
Charles Edward Knowles.
David Laidlaw.
Frederic Nix Latham, Stud. Inst. C.E.
Frederick Lowry.
Patrick Blackstock McGlashan.
James Mackenzie.
John Smith McNeill.
Howard Martineau, Stud. Inst. C.E.
George Henry Mee.

Associate Members—continued.

Johan Viggo Sigvald Muller.
Robert Andrew Munn.
Ernest Anthony Nardin.
Albert Edward Nichols, Stud. Inst. C.E.
James Palmer Norrington.
John Seabury O'Dwyer, B.A.Sc. (Montreal.)
Ashby Frederick Osborn, Stud. Inst. C.E.
Arthur Oughterson, Stud. Inst. C.E.
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James Robertson Porter.
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John Arthur Saner, Stud. Inst. C.E.
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Edward Marsh Simpson.
Robert William Smith-Saville, Stud. Inst. C.E.
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Robert Warrack, Stud. Inst. C.E.
William Watson, B.A., B.E.
James Philip Webster.
Herbert Nicol Weldon, Stud. Inst. C.E.
William Hugh Williams.
Robert Anderson Wyse.
Cesare Zanetti.

Associates.

William Edwin Archdeacon, Staff Comm., R.N.
John McCormick.

(*Paper No. 2475.*)

"The Lansdowne Bridge over the Indus at Sukkur."

By Frederick Ewart Robertson, M. Inst. C.E.

Between Peshawur and Kurrachee, the North-Western State Railway crosses the Indus twice—once at Attock, near its exit from the hills, where the river is bridged by two spans of 308 feet and three of 257 feet; and again at Sukkur, where the Indus passes through an isolated ridge of nummulitic limestone, and is divided into two channels by the island of Bukkur. The rise of the river in time of floods is 17 feet, and the velocity 9 miles an hour.

The Sukkur Pass is bridged by three spans, of 278 feet, 238 feet, and 94½ feet respectively, which call for no special remark.[1]

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[1] The timber staging used in the erection of these spans was described in the Roorkee Professional Papers, No. 10, vol. iii., July 1885.

The Rori channel is about 70 feet deep at low water, sloping down pretty steeply from the two sides, and is crossed by a single span, whose width at the site selected for the bridge could not be reduced below 820 feet. At the upper part of Bukkur island the channel could have been crossed by a span of 650 feet; but as the approach would then have cut right through the town of Rori, its increased cost, together with the heavy compensation for land, would have annulled the advantage of this route.

The steel superstructure for this span of 820 feet was designed by Sir A. M. Rendel, K.C.I.E., but its details, which would require a Paper to themselves, will not be alluded to further than is necessary to describe the erection. It consists of two single cantilevers, each having a projection of 310 feet, and carrying between them a central girder 200 feet in length. The entire steel-work of each cantilever was made in England, and was put together upon a timber scaffold in the maker's yard before shipment. The floor is of corrugated deck-plating, filled with wood, so as to give a cartway on the same level as the (single) railway, and there is a footway for men and for beasts of burden, corbelled out on both sides.

Plate 4 gives a general view of the span, and indicates the names by which the different members were distinguished. The foundation work consisted simply in clearing away the material down to the rock. The abutments are of Portland cement concrete, which was considered a better material than that furnished by any of the layers of Sukkur stone that would yield blocks of sufficient size for such work. The anchorages for the back-stays, or guys, are cellular structures, 32 feet by 12 feet by 6 feet, and are bedded in or behind the rock in cement concrete. The bedplates for the support of the cantilevers are also cellular, 20 feet by 10 feet by 8 feet, secured to the abutment by fourteen holding-down bolts, 9 feet long and 3 inches diameter; and for further security against horizontal thrust, they are concreted up solid to the rock behind.

The large vertical member called the "pillar" has a height of 170 feet, and comes almost to a point at the bottom. In the final erection of the bridge it had to be built with a backward rake of 6 inches, to give the requisite camber to the nose of the cantilever, and it was therefore necessary first to erect a staging to support it during construction.[1] This was built to the profile of

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[1] Described in Indian Engineering of Nov. 5, 1887.

the back guys, and also served to erect them. The pillar was built up from the bed-plates, and the guy from the anchor, until they met at the top. The cover-plates in the last length of guy were left blank at one side of the joint, and the guy-plates were cut shorter to allow of making the joint at the actual temperature required to give the pillar 6 inches of backward rake at 100°, that being fixed upon as the normal temperature. The temperature in the sun runs up to 180°, and even at night often exceeds 90°. As the guy of the second cantilever was closed in much colder weather than that of the first, an allowance had to be made in the backward rake of the pillar, so as to keep the noses of the two cantilevers at the same level. After joining the pillar and guy, the next member to be built out was No. III strut. This is 230 feet long, and weighs 240 tons, and, being riveted to the bed-plate, it required some care to erect it without injury. The setting out, to keep it in line in both directions, was arranged as follows:—A sight-block with cross-wires was placed on each horizontal girder of the pillar against the front and the back leg; and when the cantilever was erected in England, a bull's-eye was painted and punch-marked on the spot where this sight cut No. III strut, and the exact position of sight-blocks was also marked. Re-aligning this sight gave the true position, both for line and for level. Measurements were also taken from certain places on the pillar to others on the strut, with a common tape and pocket spring-balance, a combination which will read to $\frac{1}{8}$ inch in 100 feet. For longer lengths than 100 feet a wire was used.

Fig. 9, Plate 6, shows the position of the ties used to support the strut during erection. The arrangements for the temporary ties will first be described. All these were of steel-wire rope, with a breaking-strain of 60 tons, the wire of which they were made having a strength of 135 tons per square inch; and as they were to be afterwards used in the suspension staging for erecting the "horizontal tie," they were all made of one length, with a strong thimble at each end.

Figs. 1 to 4, Plate 6, show the details of the attachment to the pillar and strut. Two 8-inch by $2\frac{1}{2}$-inch steel channel-bars, rather longer than the width of the pillar, were drilled with holes of uniform pitch, so that the bearing-plate and the bearings of the screws could be shifted to suit the taper of the pillar. The two screws were pitched such a distance apart as just to clear the pillar-leg; and the eye of the rope being shackled to one screw, it was taken round a stirrup of small channel-bar on the leg of the strut, and secured to a loose tail of rope shackled to the other screw, by three cast-iron clamps, of which the detail is given in Fig. 4. All the ropes that were tested to destruction in England were held by this arrangement, and it never failed, nor could the slightest injury to the rope be detected. A ply of canvas was generally wrapped around them, and the precaution was taken to tighten up the bolts as the strain came on. The screws were made with a taper thread, and the nuts had a spherical seat to prevent any tendency to bend the screws. In putting on a new tie, the rope was first pulled as tight as convenient with a block and tackle; then the tail was clamped on, the slack coiled away in a convenient place, and the screws tightened until the new tie took all the weight, when the old one was removed. The working-strain adopted for the ropes was in all cases fixed at less than one-sixth of the breaking-strain, in order to avoid trouble from stretching. As the temporary ties had to be removed for use in building the "horizontal tie," and as it was also necessary to have the strut under control at the moment of junction, a special support, called the main tie, was employed for this purpose. The position and attachments of the main tie are shown in Plate 6, Fig. 9, and in Figs. 2 and 3; it consisted of four ropes doubled to each pillar, and coming to a bearing on the head of the pillar. For this bearing two 12-inch by 6-inch steel joists, a little longer than the outside width over the pillars, were laid across the heads, and were so arranged that they could be lifted by a hydraulic jack placed within, being guided by a couple of brackets bolted to the head of the pillar, as shown in Figs. 2, 3. Bars of iron, 4 inches square, were laid across the joists just clear of the pillar-head, the projecting ends being rounded to fit into an ordinary railway-coupling, of which three were strung together to assist in drawing up the ties. One end of the ties was shackled direct to the couplings, and the other end, after passing round a thimble 2 feet 6 inches in diameter, was clamped to itself by two of the cast-iron clamps before described. The main tie was attached to No. III strut by passing it round a couple of steel joists, laid against the upper legs, and packed up with wood to such a diameter as not to injure the ropes. To distribute the pressure, a chain, set up by couplings, was also taken from the joists to the lower legs of No. III strut.

The arrangements for erecting No. III strut are illustrated in Figs. 1 and 2, Plate 5. A staging to support the crane, and to guide the strut laterally, was built on the trimmer or girder of the roadway; but as this member was not nearly strong enough as a cantilever to carry such a load, it had to be supported from below. A small temporary pier was therefore built in the river, and on this were placed iron cylinders, 3 feet in diameter, carried up to the level of the trimmers. The staging was then built on the trimmer, and on the staging was placed a double derrick crane, with sufficient sweep to build from the bottom up to the main tie. The wire-ropes of this crane were led away below to special winches, which also served other purposes, so that there was no gear on the crane itself. A piece of the strut, generally about 30 feet long, and weighing 5 tons, was lifted into its place, and held up by a 1½-inch wire rope (7 tons breaking-strain), which was fitted with an eyebolt to put into a rivet-hole at the top until all the four were placed. Four distance-girders were next sent up, and the corners being thus connected a temporary tie was placed, after which the cross-braces were put on, and also the internal cross diaphragms, to keep the work square. Adjustment for line and level was next attended to, and then the riveting was put in hand. Most of the time was consumed in rigging up the small stages for the men to work on, as, owing to the shape and rake of the members, it was not found possible to arrange any form of staging to travel right up. After the strut had been built up beyond the reach of the double derrick, a pine derrick, 75 feet long, was erected on one of the main distance-girders between the legs. This was worked by three wire-ropes, one guy directly behind, and two side guys, passing through pulleys at the end of beams outrigged from the strut itself, all being attached to the special winches. The hoisting was done with an ordinary block and tackle from a steam-hoist; but owing to the great height, special coils of rope of double length had to be used. On the temporary pier, and bolted up against the cylinders on each side, were placed two Howe-truss cantilevers, to carry the inclined boom, which could not be conveniently supported from above, because it was outside the reach of the other members, as shown in the general plan. Thus the first and second lengths were supported, and the third length completed the junction with No. IV raker. On the completion of No. III strut, the span for the "horizontal tie" proved to be ⅝ inch too much on one side, and 1¼ inch on the other.

The next operation was the erection of the "horizontal tie." This member is 123 feet span, and weighs 86 tons, and as lifting it in one piece was out of the question, it was decided to erect it on a temporary suspension-bridge or staging; but the suspension-cables being attached to the strut at one end, the bridge presented the difficulty of having a flexible abutment, for the horizontal pull of the ropes when loaded was more than sufficient to counterbalance the weight of the strut by about 20 tons. As already mentioned, the ropes that first served as temporary ties for the erection of the strut were made of a suitable length for use in the suspension-bridge, and were provided with a thimble at each end and a screw-coupling to shackle thereto.

Figs. 6 and 7, Plate 5, illustrate the temporary suspension-bridge. There were on each side four ropes, each forming a complete loop, laid on cast-iron saddles on the head of the large pillar and No. III strut, so that each side of the bridge had eight supports. To ensure perfect uniformity of strain the ropes were first strung on the saddles placed upon the ground at approximately the correct span, and were adjusted by means of the couplings, until they all lay perfectly level at the lowest part. A mark was then scribed down the back of the saddle and the ropes, so that replacing them in the same position ensured the correctness of the dip, the couplings having been secured by a wooden chock, and the ropes marked for their respective positions. Planks suspended by an iron loop were next slid down the ropes, and these afforded a convenient platform for the men to work upon, and to arrange the trestles, which were simply pushed down to their proper places, and then held upright by the bracing. After this was completed, the planks which formed the temporary platform were removed. This suspension-bridge proved remarkably stiff, although during the erection the wind blew so strongly that the work was sometimes stopped by the camber-blocks being blown over. The tie was carried on sand-boxes, and all the pieces were laid in their places before the connections were made, so as to avoid any alteration in the figure, and consequent strain, by unequal loading of the bridge. The nose of No. III strut was loaded to the required extent to counterbalance the increasing horizontal pull of the bridge, by first slacking off the main tie, and then by adding load at the head.

For the erection of the horizontal tie, this temporary bridge carried two travellers of the form shown in Plate 5, Fig. 6, the lifting gear being simply a 5-ton differential block hung from a 3-inch round bar rolling on the two scantlings which formed the nose of the traveller. The pieces were raised by a derrick on the large staging behind, and passed under the noses of the two travellers, where they were laid hold of. As soon as the first triangle was completed on each side of the river, by joining the pillar and No. III strut, a system of overhead suspenders or carrying-ropes was at once fitted between the tops of the two triangles, spanning the intervening gap, and serving for the erection of a great part of the main superstructure. This apparatus is shown in Figs. 5 to 8, Plate 6, and is the only special plant used on the work. The winches were placed upon the permanent steelwork of the horizontal tie, and were worked by a running rope, driven by a portable engine placed at the foot of the main guy. The drums were 5 feet 2 inches in diameter, and 2 feet 6 inches wide, and were driven by worm-gearing. There were three speeds, and the driving-shaft, which was fitted with one fast and two loose pulleys driven by a belt and crossed belt, could be also worked by hand. The wire-rope was attached to the drum, in the manner shown in Figs. 5, 6, being passed through a slit in the barrel, and held by clamps passing through the drum-head, so that the rope could be fastened at any point by over-running it, and coiling away the slack inside the drum like a tape.

The arrangement of ropes, &c., was as follows:—A gallows was erected on the head of No. III strut, carrying two pulleys, 4 feet 6 inches in diameter, in the line of each tie, and a saddle on the top for the fixed end of one rope to pass over, and furnished with a projecting arm which on one side of the river carried a pulley, and on the other side a saddle. Referring to Fig. 7, Plate 6, which shows the arrangement on one side of the river only, it will be seen that No. 2 rope is a carrying-rope leading from a winch on this side of the river, and fixed at the other side, while the corresponding rope from the winch on the other side is No. 4, passing over the saddle and fixed. Both sides have No. 1, which has a loose end, and is the guiding-rope passing over the second pulley. No. 3 is the outside rope leading from a winch at one side, and fast at the other, its particular duty being to suspend the bottom of the raking-pieces. A piece to be erected was suspended from runners on two ropes, and raised as a whole, the level of the piece being adjusted by winding on both ropes, or on one more than another; and it was guided by the third rope, which was hooked directly to it. Thus a tie-piece would hang from the two winches in line, but a raking member such as No. I strut would hang by the head from the pulley in line, and by the foot from the projecting pulley. The ropes used were of 36 tons breaking-strain. Underneath each pair of winches ran a countershaft across the horizontal tie, and these were actuated by the running rope driven by the portable engine, so that to start, stop, or reverse a winch, all that had to be done was to pull the striking-gear at a given signal. This running rope-gear, when once rigged up, did the whole of the work with the greatest convenience, the pieces being drawn up by it until the rivet-holes met, and the finishing touches were then put in by hand. The largest piece lifted was the first joint of the inclined tie, 80 feet long, and 14 tons weight.

While the erecting-gear was in progress, No. IV vertical and raker were dropped down, and the trimmers (as the girders of the internal viaduct are called) were connected with the vertical; and from these again the inclined boom was reached, and built up piece by piece till connected with the raker, thus completing the first quadrangle.

The next step was to build No. II strut by a derrick from No. IV vertical, and then to connect it by erecting the inclined tie in the manner described above. The joint of the tie was first made good at the top, and then the head of the strut set to meet it exactly by the screws of the suspending-ropes already used as temporary ties for No. III strut. No. III vertical was next joined with the trimmer, and the boom carried forward to meet the raker as before; this series of operations being repeated for the remaining bays, except that the members had now become light enough to be picked up whole, as was done with No. I strut.

Two large barges of 400 tons burden, formerly belonging to the Indus flotilla, were of great service for these operations when the current permitted them to work. It should be explained that the difficulty in making use of such floating craft lies not so much in the mere force of the current (for a wire cable can be got of almost any strength), as in the quantity of debris that the river brings down from the caving in of the banks at certain seasons. Whole islands of timber-trees sometimes come down, and if they foul a mooring it can never be freed. In fact, any mooring in the stream is certain to be lost, the pressure being sufficient to completely flatten a 4½-inch rope in the hawse-pipe. These barges were fitted with a trestle, as shown in Figs. 3, 4, Plate 5, and with a large lifting-platform, which was so arranged that it could be adjusted at any height, to suit the different levels of the river, or of the work to be done. The barge was brought up in front of the bridge, and the piece to be lifted was pushed on board on rollers assisted by the crane. This crane was a 6-ton hand derrick-crane mounted on a high trestle, which ran on ways, so that if it was required to get the working platform under the bridge, the crane and trestle could be pushed back as far as required to clear the splayed-out booms.

On the completion of the cantilevers, their noses were exactly level. The line, or rather the middle position of the diurnal variation, was also correct. As the bridge lies north and south, the effect of the sun on alternate sides used to make the nose vary nearly 1 inch either way. The Author has not been able to obtain a record of this variation since the bridge was completed. The width of the central gap was also correct at mean temperature.

It only remained now to erect the central girder. In designing the bridge in England, this was treated as a simple girder resting on rollers on the cantilever noses, and was arranged in such a way that it was impossible to build it out, as it had been taken for granted that it would be floated into position. This, however, was impracticable during six months in the year, owing to the violence of the floods, while the selection of a site on which to erect the girder so as to be accessible during the low season was also a very doubtful matter. It was therefore concluded that the span must be built on the cantilevers; and after studying various projects for transporting the completed girders—a method of erection which was rendered difficult by their height being more than that of the first overhead bracings of the cantilever, and also by the confined space at the nose—it was finally determined to use a staging built out and hanging from the cantilever noses, as shown in Figs. 7 to 11, Plate 5. This temporary stage is a deck bowstring-bridge 196 feet 8 inches in span, and weighing 56 tons complete, excluding floor planking. It comprises a full system of adjustable diagonal bracing under the floor, which is not shown in the drawing.

The end length of the top chord, with one post and bottom chord bars hanging, was first got up and hung from the cantilever by the links. Then the bottom chord was drawn across by the overhead gear and fitted; and the horizontal reaction necessary to convert it into a suspension bridge was obtained by means of a wire-rope and screws, from the back link shown in the drawings. On the pins were strung the stumps of the posts and of the diagonals. Next, a length of top chord, with the posts and long lengths of diagonals hanging, was sent out by the overhead gear and placed in position, each post being dropped over the stump belonging to it; and this operation was repeated until the bridge was completed, each bay being secured by the bracing as fast as it arrived. On the completion of the top chord, the back chains were slacked off, and the structure became a girder. This operation took seven days, and in carrying it out some little trouble was experienced in getting the diagonals into their couplings. As they were too stiff to spring, each diagonal had to be brought to meet the coupling, and then screwed up as the piece was lowered. This trouble might probably have been avoided by the adoption of a different form of connection for the diagonals.

The joints in the top chord, and in the foot of each post, and other places which would generally be filled by rivets in a permanent structure, were made by cottered pins, shown in Fig. 8, Plate 5. These were found easy to handle, and were apparently as tight as a riveted joint. The wind-pressure was taken by a bracket bolted to the cantilevers, and bearing against check-plates on the last cross-girder.

The main girders were erected on sand-boxes, sufficient extra camber being given in laying out the bottom chord to allow for the deflection of the staging. On closing the main girders, the cross-girders and flooring were immediately proceeded with, the weight upon the staging being kept constant by slacking off the sand-boxes so as to keep the same deflection. The pieces were all run out by the overhead gear, and the main girder was erected, and the bottom chord riveted, in four and a half days.

The cost of the whole bridge was as follows:—

Items.	Sukkur Channel.	Rori Channel.	Total.
	Rs.	Rs.	Rs.
Approaches and stations	..	..	4,30,000
Foundations	1,60,000	2,76,000	4,36,000
Ironwork	1,99,000	17,01,000	19,00,000
Erection and painting	1,13,000	5,70,000	6,83,000
Flooring and railing	20,000	32,000	52,000
Staff quarters, workshops, sidings	..	..	27,000
Plant from England	..	..	91,000
,, from other works[1]	..	..	2,21,000
Boat service	..	..	10,000
Contingencies	25,000	37,000	62,000
Grand total			39,12,000
Deduct value of plant in hand			1,70,000
Net total Rs.			37,42,000

The English charges amounted to Rs.21,42,000.

The details of the charge for erection are as follows:—

		Rupees.
Labour		2,40,830
,, in Painting		5,140
Cordage, fuel, special plant		1,22,733
Carriage and repairs of plant		12,612
Large staging for pillar and guy—		
Labour	46,331	
Timber	1,52,783	
Stores	15,743	
Foundations	2,573	
	2,17,430	
Less credits for timber transferred	66,487	
		1,50,943
Staging for tie and on barges, and other false works		34,105
Photographs, &c.		3,792
Total Rs.		5,70,155

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[1] Of this Rs. 67,300 was for carriage and new bottoms to the two big barges.

The present value of the rupee is about 1*s.* 5*d.* In addition to the above works, others to the amount of Rs.90,000 were executed for the Military Department.

The plant from England consisted of the following:—Four 6-ton derrick cranes, two portable 5-ton yard-cranes, two steam hoists, one set of riveting plant, wire-rope with specially large and strong pulleys, differential blocks, ordinary rope-blocks. The following items of plant were also supplied, but not being useful for transfer to other works were debited to the erection:—special winches and running-rope gear, ironwork for the gallows, screws and clamps for the attachments of the ties, bracing-bars for sundry trestles, special double crane for No. III strut.

Work was begun, with a few men only, on the anchors of the Bukkur cantilever in April 1887, and proceeded very slowly until September for want of ironwork. The bed-plates for the Rori cantilever arrived in November 1887, and from that date the work of erection was pushed forward until its completion. The staging for the central span was begun January 18th, 1889, and the girder closed February 9th. The bridge was tested March 19th, 1889, and formally opened March 27th.

The Paper is accompanied by five sheets of tracings, from which Plates 4, 5 and 6 have been prepared.

[APPENDIX.

APPENDIX.

Weight of the Principal Members.

	Tons.
Large bed-plates	55
Small ,,	4
Large pillars	183
Small ,,	7
Anchor	35
Guys	233
No. I. Guy supports	7
,, II. ,, ,,	9
,, III. ,, ,,	15
No. I. Struts	18
,, II. ,,	36
,, III. ,,	240
,, IV. ,,	8
Booms	157
Horizontal tie	86
Inclined tie	80
Secondary tie	6
No. I. Vertical and raker	4
,, II. ,, ,,	4
,, III. ,, ,,	14
,, IV. ,, ,,	62
Trimmers	90
Distance-girders and wind-ties	39
Cross girders	32
Roadway and railing	96
Total weight of the Bukkur cantilever	1,520
Add the Rori cantilever, of which the guy was 22 feet 8 inches longer	1,540
	3,060
Central span	256
Total	3,316

9 December, 1890.
SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2483.*)

"The New Chittravati Bridge."

By EDWARD WALLER STONEY, M.E., M. INST. C.E.

AT a distance of 212¾ miles from Madras, the main line of the Madras Railway crosses the Chittravati River, and has for some years been carried upon a bridge of forty 70-foot openings spanned by plate girders. In this bridge, the abutments and ten of the piers on each side of the river had originally been built of masonry upon brick well foundations, while the remaining nineteen piers consisted of screw piles. The bridge was opened for traffic in 1868, and was partially destroyed by a great flood in October 1874, when nine of the masonry piers were undermined and overthrown. These were replaced by screw piles, and the structure has hitherto served to carry the traffic, but has now been superseded by the new bridge which forms the subject of this Paper.

The new Chittravati bridge has a total length of 2,680 feet, consisting of nineteen spans of 140 feet, from centre to centre of the piers. Its position, in relation to the old bridge, and also the diversion that was necessitated in the line of the Madras Railway, for a length of 1¾ mile, in forming the approaches, is shown in Fig. 16, Plate 7.

Fig. 1, Plate 7, is a geological section of the bed of the river. At the south abutment rock lies at a depth of 18 feet below the present bed, and dips gradually to a maximum depth of 80 feet at pier No. 17. Above the rock the deposits consist of varied and irregular strata of sand, gravel, clay, and large trap boulders, while mixed with the sand were found water-worn pebbles, and large fragments of rock, some sharp and others rounded.

The Chittravati River rises 80 miles above the bridge, and in this distance drains an area of 2,400 square miles. Its fall, at the bridge, is at the rate of 8 feet per mile; and its mean velocity and discharge during the flood of 1874 were calculated to have been

8·46 feet per second, and 114,625 cubic feet per second respectively, and it is believed that the sandy bed of the river was then scoured to a depth of 15 or 20 feet. As a rule, the river remains practically dry for about nine months in the year, although the water-level never falls lower than about 3 feet below the surface of the sand. This favourable circumstance was taken advantage of in the erection of the bridge; and the dry bed of the stream was made use of, not only for the transport of materials, but also for the erection of the iron-work, and for the operations connected with the sinking of the pier foundations.

PRELIMINARY WORKS.

To facilitate the delivery of materials, a through siding was made alongside the main line at A C in Plate 7, Fig. 16; with branches to the stores and workshops, and also to the south end of the bridge, from which point three lines were laid across the whole width of the river-bed. Two of the lines through the river I Q, K O were kept parallel to the outside of the cylinder piers, 8 feet away, and on these ran and worked the cranes, dredgers, hoists, and other machinery, while a third I P was used for bringing up materials. These parallel lines were connected by cross-over roads L M, N O, and by traverser roads between the piers where required. They were protected from the action of floods by stones and boulders, from 6 inches to 12 inches in diameter, laid between the rails, and for a width of about 2 feet outside them; and with the exception of the rails sinking a little, and getting crooked, no material damage has been done to them.

SOUTH ABUTMENT.

The abutments were built of coursed hammer-dressed masonry, of blue limestone, brought by rail from quarries 24 miles distant. Their construction is shown in Figs. 2, 3, 4, 5, and 15, Plate 7.

The south abutment, Fig. 15, was founded directly upon the rock by means of a cofferdam, which was designed to meet the existing practical conditions. The main piles, which were 20 feet long, were driven at a distance of 6 feet apart, and each pile consisted of a pair of double-headed 75-lb. rails, hooped together by wrought-iron bands. Behind these, planks 6 feet by 1 foot by 3 inches, with planed edges, were pushed and driven down from the top as the excavation proceeded; and when the rock was reached, a wall of bags filled with clay was made upon it against the planks to exclude the outside sand. A water channel to the sumps was also formed with these bags, and two No. 8 pulsometers placed one at each end, beyond the newels, kept the dam dry. The rail piles were strutted transversely by old rails forced down between them to follow the excavation.

The rock, which dipped rapidly, was cut into rough steps, all loose parts removed, and the foundation levelled up with concrete, composed of 1 part of Portland cement, 2 parts of sand, and 4 parts of broken stone, by measure. The maximum head of water against the dam was 13 feet and the rock was covered by 11 feet of sand.

The cost of the cofferdam, including labour and materials, was Rs.1,736; and the entire cost of the excavation, including cofferdam, pumping and all charges, amounted to Rs.3 2a. per cubic yard of the net contents.

North Abutment.

As originally designed the foundations for this abutment consisted of seven brick wells on iron curbs, having an outside diameter of 12 feet; but as there was material to spare for cylinders, this design was altered, and three 12-foot cast-iron cylinders were used in the centre under the body of the abutment, with four brick wells, two under each wing wall, arranged as in Figs. 4 and 5, Plate 4.

In order to avoid the trouble, delay, and expense of loading these cylinders on the top with rails, they were sunk by weighting them with an internal lining of masonry set in cement mortar. The ring of masonry was carried upon an annular plate of cast iron, designed for this purpose (Figs. 12, 13, and 14, Plate 7), and fixed between two lengths of cylinder. By this means the permanent filling of the cylinders was made to do the useful work of sinking them. The weight of the masonry ring, before immersion, was about 4 tons per lineal foot of the cylinder.

Priestman's grabs were used for dredging out the material, the sinking being continued until the cylinders reached the bed of boulders at a depth of 60 feet below the surface. The excavation was then carried on by divers, until the cylinders were sunk to a bed levelled in the rock at a depth of 66 to 68 feet.

The brick wells were built on wrought-iron curbs, as shown in Figs. 7 to 11, and were sunk by means of Wild's and Priestman's dredgers, and loaded with 75-lb. rails, 20 feet long. The load required consisted of 300 to 1,300 rails, in addition to the weight of the well itself, which varied from 150 to 288 tons.

The wells were carried down to the boulders and were bedded by divers at a depth of 60 to 63 feet below the surface. Considerable trouble was experienced in sinking them, as they were firmly held by the top stratum of stiff clay, which was 27 feet thick. It sometimes happened that a hole had to be dredged in the centre 14 to 20 feet below the cutting edge before the well could be made to sink, and in such cases the outside sand would often rush in, forming a crater all round. In consequence of these slips, some of the wells were drawn out of plumb, and one under the west newel canted outwards, so that when sunk to the proper depth it came in the way of the next well, which struck upon its curb during the process of sinking and could not be got any deeper. This incident illustrates the necessity of leaving ample room between any contiguous cylinders which have to be sunk to considerable depths, so as to prevent their coming in contact if they get slightly out of plumb. The tops of the wells and cylinders are adjusted at a level 6 feet below the river-bed, and are united by arches on which the superstructure of the abutment is carried up.

Instead of providing large stones for the girders, a box 4½ feet by 4 feet by 2 feet was left in the masonry, and was filled with Portland cement mortar of 1 part of cement to 2 parts of sand, on which the bearings were fixed. These cement bed-blocks have answered very well, and are cheaply and easily made.

CYLINDER-PIERS.

Each of the eighteen river-piers consists of a pair of cast-iron cylinders, placed 18 feet apart, from centre to centre, and braced together at the top by a deep and massive box of plate and angle-iron. Their construction is illustrated in Fig. 2 and in Figs. 11 to 21, Plate 8.

The cylinders have a diameter of 12 feet throughout the lower portion, to within 9 feet of the river-bed, at which point a conical tapering length is inserted, reducing the diameter to 9 feet. The 12-foot portion was made in lengths of 6 feet, each length being cast in six segments with 1¼ inch thickness of metal, strengthened with internal flanges and feathers, and united by 1¼-inch bolts. The joints were caulked with iron-rust cement to within ¾ inch of the inner edge, this space being filled with a mixture of 1 part of sand to 1 of Portland cement to make the joints air-tight and fit for pneumatic work.

Each cylinder was furnished with a special bottom length of wrought-iron, forming a cutting-ring 3 feet in height built of $\frac{5}{8}$-inch plates. The cutting-rings, after being riveted together, were placed accurately in position on the dry river-bed, and were sunk 2 feet 6 inches by men digging inside them. Two lengths of cast-iron cylinder were then erected upon each cutting-ring, and when they had been bolted and caulked, a Priestman's crane and dredger, standing on the working lines of railway in the river-bed, continued excavating until the top had been sunk to the level of the ground. Two additional rings were then built up, forming a second length of 12 feet, and provision was now made for weighting the cylinders by placing across the top two pairs of hardwood beams 18 feet by 18 inches by 18 inches, on which the 75-lb. rails were stacked. The load varied from 200 to 1,120 rails, according to the depth of the cylinder and the nature of the strata it passed through. With large loads the height of the stack above the river-bed was often as much as 27 feet, so that the Priestman's dredger could not be used, and Wild's, Bell's, or Bull's dredgers were employed, being worked by steam-hoists by means of derrick poles.

All these dredgers answered well in sand, but the progress was slow when there were many pebbles or boulders, as these frequently came between the teeth of the dredger, a small stone being sufficient to allow all the sand to escape. Several boulders of 3 to 5 cubic feet were brought up; the largest measured 9 feet in length by 5 feet in girth, and was caught and hauled up by a Priestman's dredger. None of these dredgers were of the slightest use in clay, even of moderate stiffness. In a few instances some sinking was done by pumping out the cylinders with pulsometers and digging out the clay; but as the material was often more or less sandy, the outside sand sometimes rushed in, and in one case filled the cylinder for a height of 27 feet. The greatest height from water-level to the discharge-pipe of the pulsometer was 64 feet. All the cylinders, with the exception of pier No. 11, were bedded on the solid rock, the bottom being dressed level by divers or with the aid of pneumatic apparatus, except in the case of piers Nos. 7 and 8, which were kept nearly dry by pulsometers, and in which the rock was dressed level by stone-cutters.

As far as pier No. 9 the sinking and bedding of the cylinders was comparatively easy, but beyond this point all the piers gave considerable trouble, especially Nos. 10, 11, 12, 13, and 14, as the bed-rock was here covered by a depth of from 7 to 22 feet of boulders, the largest taken out unbroken being 5 feet long by 11 feet in girth, and containing about 45 cubic feet. When large boulders were met with under the cutting-edge it was a difficult matter to remove them safely. If they were pulled into the cylinders it generally happened that a blow of sand would follow; and when the projections were cut off by blasting, the cylinders were sometimes cracked by the dynamite, although the charges used were small; while the drilling of the holes by divers was always a tedious operation.

An average of 6 feet a day in sand could be excavated by dredgers, while from ½ to 1 inch a day was about the rate of sinking through boulders by divers. The use of small charges of from 1 to 2 ozs. of dynamite fired on the bottom of the holes dredged or excavated by divers was found to facilitate the work, as the tremor and vibration set up by firing them enabled the load to overcome the friction, so that the cylinders sank with a smaller load of rails than would otherwise have been required, starting in most cases directly after the explosion, but occasionally from two to five minutes later.

When a 12-foot cylinder was sunk to within about 8 feet of the anticipated rock-level, as shown by the borings, the taper-piece was put on with a 9-foot diameter ring on the top of it, as the design provided that 9-foot rings should be used from just below the river-bed to the pier-tops. The borings unfortunately proved incorrect, rock being met in places at a higher level than was expected, and in such cases the taper-pieces, and perhaps one or two rings below them, had to be dug out and readjusted to allow of the former being got low enough to put the bracing-box in place.[1] This trouble would have been saved if the 12-foot cylinders had been carried right up to the top, which would also have allowed more room for adjusting the girder-bearings when the cylinders happened to cant or draw away from their true position. This frequently occurred when the cylinder struck a boulder or some hard material on one side, and in pulling it upright it was more or less displaced. It is practically impossible to sink cylinders to depths of 60 or 80 feet in the exact position they should occupy, and for this reason ample diameter should be given to allow room for setting the bearings true to centres.

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[1] In one case, at pier No. 3, the cylinders were pulled bodily up 12 feet from a depth of 25 feet, by six 60-ton hydraulic jacks.

Piers Nos. 12, 13, and 14, were bedded by the aid of pneumatic apparatus, but the operation was slow and expensive, owing to the repeated failure of the air-pumps, which were of an old pattern and much worn. The difficulties experienced at pier No. 11 were more serious than at any other part of the work, in consequence of the great depth (22 feet) of the bed of large boulders here met with. In sinking the cylinders through these boulders divers were employed at first, but they only succeeded in sinking the left cylinder 10 feet in six months, working 603 shifts, and the right cylinder 7 feet 4 inches in five months, working 429 shifts, or at an average rate of 1 foot in 60 shifts of four hours each. In consequence of this slow rate of progress pneumatic apparatus was substituted, and when the cylinders were laid dry it was found that some of the segments of the lowest ring had been cracked by the dynamite charges before alluded to, and permitted a leakage of air, which gave some trouble. A luting of stiff clay was used to stop the cracks.

When working in the left cylinder by the pneumatic process at a depth of 60 feet a loud report occurred, and it was found that two segments had cracked in a line with the cracks in the lower ring, originally caused by the dynamite, thus making a continuous fracture 18 feet high. Pneumatic work was then stopped, as it seemed unsafe to continue the air-pressure; and a hole 10 feet in diameter was sunk by divers to get down to the rock bed. But when the bed which had been touched by the borings was reached, it proved to be only a superficial layer 9 inches thick, and under this large boulders were again found. In getting out one of these from under the cutting-edge an inrush of sand occurred, which filled up the cylinder for 15 feet. It was then decided to stop further sinking, clear out the sand and put in the concrete, which was done successfully.

The right cylinder took eight and a half months, and the left eleven and a half months, to sink through 22 feet of these boulders. These particulars show how difficult it is to forecast the time required for such foundations, as the mishaps experienced at one pier may upset all calculations derived from the progress on the others.

The recorded details of the loading of the cylinders, and of the average resistance in sinking, are given in the Appendix.

DIVERS' WORK.

In all 168 lineal feet of cylinders were sunk, chiefly through boulders, by native divers in 4,274 shifts; this gives an average of 25·4 shifts per foot. Similarly 35 feet of 12-foot wells were sunk by divers in 1,068 shifts, or an average of 30 shifts per foot. The rock at the bottom of thirty-two cylinders was dressed level by divers in 1,621 shifts, or an average of fifty shifts a cylinder; as the rock dipped rapidly, this bedding generally involved cutting away at least a depth of 2 to 3 feet of rock, or about 8 to 12 cubic yards. The rock was an indurated clay slate.

An account was kept of the quantity of material excavated during each shift, and the general results obtained from a total of 27,988 hours' work, in 6,997 shifts, is given in the Appendix. The average number of cubic feet excavated in a shift by a single man working by contract, or by day labour, was as follows:—

Soil.	Contract.	Day Labour.
Sand	7·13	10·65
Clay	5·89	..
Boulders	5·91	7·68
Rock	7·88	5·36
Sand	7·32	8·83
Clay, Sand, and Pebbles	7·12	2·44

DREDGING CYLINDERS.

The greater part of the work was done by two of Priestman's double-chain dredgers of 15 cubic feet capacity, weighing when full about 2·2 tons each. The greatest depth of 12-foot cylinder ever sunk by one of these dredgers in a day was 12 feet 6 inches in sand, the average being 5 feet 6 inches. Besides these, Wild's single-chain dredger of 10 cubic feet capacity, and Bell's and Bull's dredgers of the same size were used. All these worked well. In one month 300 lineal feet of cylinder were sunk, and this was the maximum attained.

Cost of Cylinder-Sinking.—The total amount of cylinder sinking executed by each of the methods above described, and the average cost of sinking per lineal foot, including fuel and supervision, were as follows:—

	Lineal Feet of Sinking.	Cost per Lineal Foot.
By dredging	1,323	9 rupees.
By pulsometers	112	85 „
By pneumatic apparatus	46	443 „
By divers	168	162 „
Sinking cutting-rings by hand-labour	124	5 „
Total	Rs. 1,773	

The total cost of erecting and sinking 1,773 feet of cylinders, including all charges except the original value of machinery, amounted to Rs.56 8a. per lineal foot.

CONCRETING CYLINDERS.

For the first 4 feet in depth the concrete was composed of 1 part of Portland cement, 2½ parts of sand, and 4 parts of stones broken to 1½ inch cube, the concrete for the remainder of the cylinders to within about 6 feet of the river-bed being composed of 1 part of cement, 2½ parts of sand, and 6 parts of stone measured dry; the cement and sand were first mixed dry, then made into mortar, after which the stone was added. The material was lowered through the water in skips until a sufficient quantity had been deposited to make the cylinder almost watertight. This was allowed to set for a week, and the cylinder was then pumped dry, the concrete for the remainder being put in by hand and rammed in thin layers. Taking the average of all the cylinders, a depth of 18 feet of concrete at the bottom was required to staunch them, and the top of this was at an average depth of 30 feet below water-level in the river; but these dimensions varied greatly in the different piers, the maximum depth being 50 feet below water with 3 feet of sealing.

Although the concrete set quite hard, and was very dense, the river-water percolated through it as well as alongside the cylinder ribs. The Portland cement was supplied by several English makers, and there was a considerable difference in the behaviour of the various samples; one in particular left after each days' work a quantity of slime or slurry over the concrete, and when the cylinder was baled out, after a thickness of 30 feet had been deposited under water, it was found that the slurry extended to a depth of 8 feet. Below this the Author expected to find stone and sand instead of concrete, but on being cleared, washed and examined, it was found to be set quite hard. The other cements used never left more than 6 inches to a foot of such slime on the top.

The concrete cost in place Rs.14 5a., or about £1 per cubic yard, the materials costing Rs.13, and the labour Rs.1 5a.

Above the concrete the cylinders were filled to within 3 feet of the summit with hammer-dressed masonry of fine flat-bedded limestone, set in mortar composed of 1 part of lime, 1 part of sand, and 1 part of surki, the masonry costing about one half the price of the Portland cement concrete. The last 3 feet of filling was formed of 1 part of Portland cement to 2 parts of sand, and on this the cast-steel roller bearings were bedded and fixed by lewis-bolts.

BRACING-BOXES.

Each of these was sent out in two pieces of the form and dimensions shown in Plate 8.

In order to fix them in position, the 9-foot cylinder-rings were put in place and fixed together with a few bolts in each segment; the halves of the bracing-box were then lifted by a derrick-pole and crab-winch, and held accurately in place, while the two top bolt-holes were drilled on each side. In these holes short bolts were fixed, and the remaining bolt-holes were then drilled in the cylinder segment. The two halves having thus been fixed, the cover-plates were bolted on by holes on one side of them, those on the other side being drilled in place. All cover-plates, etc., were then service-bolted and riveted up, after which the four outside segments of each 9-foot cylinder were taken down, in order to provide room for the erection of the girders. For the fixing of each bracing-box two hundred and sixty-four holes had to be drilled, and three hundred and seventy-two rivets put in. After the cylinders were finished and concreted, each bracing-box was filled with concrete.

GIRDERS.

The superstructure is designed for a single line, the girders being of the Murphy-Whipple type. Each span has a length of 139 feet

8 inches over all, or 136 feet from centre to centre of the bearings, with a working depth of 16 feet, and a width of 16 feet 7 inches in the clear, or 20 feet 3 inches over all. The weight of a span is 146 tons 12 cwt., or a little more than 1 ton per foot. The booms came from England in five pieces, while the lattice-bars, cross-girders, rail-runners, struts and pillars were each sent separately. Taking advantage of the fact that the river-bed was safe to work in for about nine months in the year, the Author was enabled to get the spans erected upon the ground, each in its proper position, and afterwards lifted into place. For this purpose camber-blocks were placed at the ends and under the shipment-joints of the girders, and were supported on sleepers laid directly upon the river-bed, their level being so adjusted as to keep the underside of the bottom boom 2 feet 6 inches to 3 feet over the river-bed, so that a great portion of the riveting could be done at the most convenient height for working.

The bottom booms were first placed, and the cross-girders bolted up, after which the end-pillars and vertical struts were put in and joined by their respective diagonal tension-bars; then followed the top boom and overhead struts, and when the whole had been secured in place and the joints screwed up by service-bolts, the riveting was commenced. This was all done by native workmen, and in each span there were 10,216 rivets of $\frac{7}{8}$ inch diameter, besides 1,120 rivets of $\frac{3}{4}$ inch diameter.

The blocks were set to have a camber of 0·23 foot at the centre; after erection levels taken on the girders showed the average actual camber to be 0·157 foot, the maximum being 0·17 foot and the minimum 0·13 foot. The rails were laid without camber, the longitudinal teak timbers on which they rest having been dressed level *in sitû*, their thickness increasing gradually from the centre to the ends of each girder. The girders are supported at one end by a fixed cast-steel rocker and at the other end by a combined rocker and roller, so as to allow of expansion. Details of these bearings are shown in Figs. 4 to 10, Plate 8.

As soon as the riveting was finished, a 60-ton hydraulic jack was placed under each end pillar, and the entire span was lifted from the river-bed to a height of 9 inches above its final level, the lifting being done at the rate of 4 to 5 feet a day. During this operation the ends of the main girders were, of course, occupying a position in the centre of the 9-foot cylinders, from which the outer segments had been removed as before mentioned and as indicated in Fig. 20, Plate 8; and as soon as the girder was raised high enough the cylinder segments were successively replaced;

and by the insertion of packing, the ironwork was kept always supported on the cylinders, safe from risk of floods or freshes. This method of erecting the girders proved very convenient, expeditious and economical, as no false staging was required, and the bulk of the work was done and inspected from the dry river-bed. It also allowed as many spans to be worked at as there were piers finished to support their ends.

An abstract of the principal items of work done in the bridge is given in the Appendix. The first cylinder was pitched on the 23rd of April, 1888, and the bridge was fully finished and opened for traffic on the 6th of March, 1890; so that the time occupied in actual construction was a little over twenty-two months. The entire cost amounted to Rs.480 per lineal foot of bridge, or £38 at current rate of exchange; the cost of supervision, including engineers' salaries, office establishment, &c., was 2·71 per cent. on the outlay. The total cost of the bridge was Rs.12,81,200 = £101,428, and of the approaches Rs.54,341 = £4,302.

The girders were tested with two of the heaviest engines and tenders in use on the Madras Railway, weighing together 177 tons 13 cwt. 3 qrs., the dead-load being 159 tons 8 cwt. 2 qrs. The test-

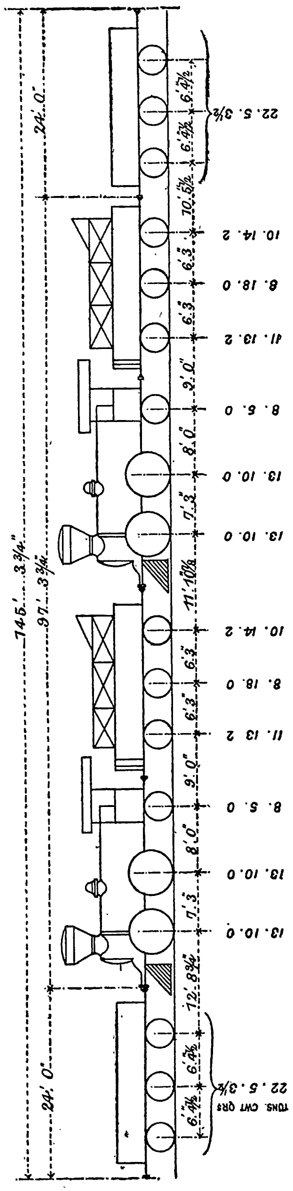

Fig. 1.

DIAGRAM OF TESTING ENGINES.

load was therefore equal to a live-load of 1 ton 6 cwt. 1 qr. per foot, and a dead-load of 1 ton 3 cwt. 2 qrs. per foot, or a total of 2 tons 9 cwt. 3 qrs. per foot. The deflections of the several spans were singularly uniform, the average under a standing-load being 0·43 inch, and when running 20 miles an hour 0·49 inch.

The bridge was designed by Messrs. Hawkshaw, Son, and Hayter, by whom the ironwork was sent from England. The laying out of the work, and its entire management and supervision were entrusted to the Author, by Messrs. W. R. Robinson and H. R. P. Carter, MM. Inst. C.E., Engineers-in-chief of the Madras Railway.

The Paper is accompanied by numerous drawings, from which Plates 7 and 8 and *Fig. 1* have been prepared.

APPENDIXES.

APPENDIX A.—SUMMARY OF THE MAIN ITEMS OF WORK DONE AT CHITTRAVATI BRIDGE.

Description of Work.	Unit.	Quantity.	Total.
Cast-iron work in cylinders	Tons	2895	6211
Wrought-iron work in girders	„	3316	
Cylinder sinking below river-bed	Lineal feet	1772	
Lineal feet erected above river-bed	„	541	
Lineal feet of wells below river-bed	„	446	
Cylinders bedded	No.	36	
Brick- and cylinder-wells, bedded	„	7	
Concrete in cylinders	Cubic yards	5359	6179
„ in north abutment	„	582	
„ in south abutment	„	40	
„ in bracing boxes	„	198	
Masonry in cylinders	„	2391	4497
„ in three wells, north abutment	„	442	
„ in abutments	„	972	
Brickwork, four wells, north abutment	„	692	
Timber work for rail-runners fixed in place	Cubic feet	2302	4888
Joists	„	2586	
Teak-wood planking	Square feet	23940	

APPENDIX B.—LOADING CYLINDERS. FRICTIONAL RESISTANCE, &c.

An account was kept of the loads put on each cylinder and well, and from these a number of calculations as to the surface frictional resistance have been made.

The data obtained in sinking cylinders by the pneumatic apparatus ought to give very accurate results, as the interior of the cylinder was cleared and undercut to a depth of 3 feet below the cutting edge; the air was then allowed to leak off, and the pressure at which the cylinder sank was noted. Therefore at the moment when the cylinder began to move the external load just overcame the cylinder surface friction, plus residual air-pressure.

The results of nine experiments, made in this way, are given in Table I.

TABLE I.—LOADING OF CYLINDERS SUNK BY THE PNEUMATIC PROCESS, AND FRICTIONAL RESISTANCE IN SINKING, AS FOUND BY NINE EXPERIMENTS IN THE CYLINDERS OF PIERS 11 AND 13.

—	Pier 11. Left Cylinder.			Pier 11. Right Cylinder.					Pier 13.
	A.	B.	C.	A.	B.	C.	D.	E.	
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft In.	Ft. In.
Imbedded depth of cylinders: sand	33 2	33 2	33 2	33 2	33 2	33 2	33 2	33 2	33 8
" " " clay	10 2	10 2	10 2	10 2	10 2	10 2	10 2	10 2	10 0
" " " sand and clay . .	7 3	7 3	7 3	0 8	4 6	7 3	7 3	7 3	1 0
" " " clay and boulders.	5 8	7 5	9 1	..	..	7 11	7 11	12 5	2 4
Total	56 3	58 0	59 8	44 0	47 10	58 6	58 6	63 0	52 0
Area of imbedded cylinder surface, square feet .	2,165	2,232	2,296	1,693	1,841	2,251	2,251	2,426	1,960
Load employed, weight of cylinders, in tons .	78·28	..	..	70·23	70·23	85·12	78·27	78·27	70·83
" " " rails "	222·22	..	..	173·33	248·88	222·22	222·22	222·22	229·70
" " other extraneous load "	10·30	..	..	4·74	4·74	4·74	4·74	10·30	10·30
Total load "	310·80	310·80	310·80	248·30	323·85	312·08	305·23	310·79	310·83
Lifting force, due to air-pressure observed "	40·32	44·64	44·64	..	..	..	..	..	49·10
Net sinking force "	270·48	266·16	266·16	248·30	323·85	312·08	305·23	310·80	261·73
Frictional resistance per square feet of imbedded cylinder surface . . . } in cwt.	2·50	2·38	2·32	2·93	3·52	2·77	2·71	2·56	2·67

The average surface-friction, as deduced from the load actually used in sinking the cylinders, whether by pneumatic or other process, is given in Table II in cwts. per square foot of imbedded cylindrical surface.

TABLE II.—SURFACE FRICTION OF CYLINDERS AS DEDUCED FROM THE LOADS ACTUALLY USED IN SINKING.

——	Cwts. per Square Foot.		
	Mean.	Maximum.	Minimum.
Average of thirty-six cylinders sunk to depths varying from 10 feet to 27 feet and averaging 19 feet, under their own weight only, which varied from 25½ to 33 tons, and averaged 31 tons	0·85	1·33	0·63
Average of one hundred observations in sinking thirty-six cylinders, at depths varying from 17 to 64 feet, under a load of rails varying from 31 to 249 tons and averaging 132 tons besides the weight of the cylinder	2·13	4·08	1·29
Average of nine observations in sinking three cylinders by pneumatic process, at depths varying from 44 to 63 feet, as shown in detail in Table I	2·71	3·52	2·32

TABLE III.—WORK DONE BY DIVERS PER SHIFT AT CHITTRAVATI BRIDGE, TAKING THE AVERAGE OF THEIR ENTIRE WORK IN SINKING AND BEDDING CAST-IRON CYLINDERS 12 FEET IN DIAMETER.

——	Sand.	Clay.	Rock.	Boulders.	Pebbles.	Sand and Pebbles.	Sand, Clay, and Pebbles.	Clay and Pebbles.	Sand and Rock.	Sand and Stone.	Clay, Sand, and Stone.
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
Maximum . . .	57	18	13½	9	2	40½	18	3	6¾	27	23
Minimum . . .	2	1	1	½	1	1	1	2	2¼	2½	2¼
Average . . .	29½	9½	7¼	4¾	1½	20¾	9½	2½	4½	14¾	12½

Discussion.

Sir John Coode, President, thought it would be admitted that clearer descriptions of executed works, of the difficulties encountered, and of the mode in which those difficulties had been overcome had rarely been put before the Institution. Their thanks were eminently due to the Authors for their most interesting and instructive Papers. Sir John Coode.

Mr. Harrison Hayter, Vice-President, said that he was responsible for the design of the new Chittravati bridge on the Madras Railway; but before noticing a few features to which he would presently draw attention, he would briefly allude to circumstances connected with the Madras Railway, bearing upon some of the bridges. That line, which was between 800 miles and 900 miles long, crossed in its course several valleys, many of which were of the nature of the Chittravati Valley—that was to say, they were wide, with little or no water in the channels during a period of about nine months, but for the rest of the year they were more or less flooded. The porous material of the beds of the rivers, however, was at all times charged with water below the level of some 3 feet from the surface. The Madras Railway Company was incorporated in 1853, and at the outset the line was laid with rails weighing 65 pounds per lineal yard, and worked by locomotive engines with 10 tons only on the driving axle. Other works were to a great extent in proportion. It was, in fact, what would now be looked upon as somewhat of a light railway, although not regarded as such at the time when the works were designed. He did not wish to imply that the pioneers of the line were not justified in thus fixing upon the type of its construction, especially as at this early stage of railways in India their success was by some considered problematical. Owing, however, to the great extension of the system and of the increase of traffic, the Madras Railway had become one of the most important lines in India, and had now a heavy permanent way, and was worked with locomotive engines as powerful as any in that country. Some of the bridges, however, were not in so satisfactory a state as could be desired. Most of them had spans of 70 feet, measured from centre to centre of the piers. Some had been strengthened or reconstructed, and a few still remained to be dealt with. In some cases the 70 feet spans had been retained, but in the Chittravati bridge and others, Mr. Hayter.

Mr. Hayter. where the piers had to be sunk to considerable depths, it was less costly to double the spans, making them 140 feet from centre to centre of the piers; and this was a type that suited the conditions. There were one or two matters of detail in the design of the Chittravati bridge to which Mr. Hayter would allude. It would be noticed that the cylinders of the piers were of cast-iron, excepting the bottom length, which was of wrought-iron (Plate 8, Figs. 15–19). This had resulted from experience gained during the construction of the Charing Cross bridge, designed in 1860, carrying the Charing Cross branch of the South Eastern Railway across the River Thames. The cylinder-piers of that structure were of cast-iron from top to bottom, sunk in the London Clay; and, notwithstanding that the bottom length was made thicker, when a bed of septaria was met with in sinking, this bottom length cracked in places, giving trouble, and involving some additional cost. Since then—excepting only in the case of the Cannon Street bridge, where the bottom length was much thickened—his firm had always made at least the bottom length of the pier cylinders of bridges of wrought-iron. In the Chittravati bridge this bottom length was 3 feet deep, and made sufficiently strong to absorb any strain that would come upon the cylinders during the process of sinking. It would also be noticed that the top length of the cylinders was an adjusting piece or cap of cast-iron 2 feet 2 inches deep (Plate 8, Figs. 14 and 15). Every one in the habit of sinking cylinders knew the importance of such a provision. Being of a larger diameter than the cylinder, it could be moved up or down, and bolted through to the cylinder exactly where required, forming at the same time a suitable projecting terminal cap to the column. This adjusting cap was filled with strong Portland cement concrete, carried up a little above the casting, and splayed all round, so that the longitudinal girders would nowhere touch the casting, but would bear entirely on the concrete. The north abutment of the Chittravati bridge was designed to be founded on brick wells; but these were only partially used, because there were some spare cast-iron cylinders at hand. The brick wells were built upon a strong wrought-iron curb (Plate 7, Figs. 7–10), sent from England; and there were through bolts extending from the bottom to the top, with wrought-iron continuous bond-rings, or circular washers, at vertical intervals of 15 feet passing round the central circumferential line of the brick well. In this way the curb could not separate from the brickwork, nor could the brickwork break away, both forming, as it were, one solid piece. The outside diameter of the curb was

Mr. Hayter.

12 feet 3 inches, and it was 3 feet deep. The outside diameter of the brick well was 12 feet, and the circular bond-ring 4 inches wide by $\frac{3}{8}$ inch thick. The Author clearly described the process of sinking the wells. All who designed bridges to be erected in India knew the importance of duplicating parts as much as possible. All corresponding pieces of the Chittravati bridge, and of other bridges, were therefore made so that they might be interchangeable. That was essential in places away from any manufacturing centre, and where the failure of an important part might cause a delay of weeks, or even months; but by sending out a few extra pieces, the contingency could be effectually met. He had nothing to do with the erection of the Chittravati bridge beyond arranging as to the plant to be sent from England, and seeing that it was properly manufactured. The credit of the erection was due to Mr. Stoney, who carried out the work in a satisfactory and workmanlike manner. Mr. Hayter had received an official document, issued by the Public Works Department of the Government of Madras, containing a report by the Government Consulting Engineer for Railways on the inspection of the Chittravati bridge, in which, after praising the quality of the work, he said, "As regards cost and time occupied in completion, it beats any record, at least in Southern India." This was somewhat remarkable, because the bed of the river was full of boulders, no less than 1,800 cubic yards having been removed from the inside of the cylinders, some of them weighing as much as two tons, a circumstance which would add much to the difficulty and to the cost of erection. The Governor of Madras also issued the following order:—"His Excellency, the Governor, in Council records with great pleasure his high appreciation of the professional skill exhibited by Mr. E. W. Stoney on the construction of the new Chittravati Bridge." Mr. Hayter would give a few figures which would be found generally useful. The cylinders, excluding the concrete filling, cost to sink Rs. 56½ (about £4 10*s.*) a ton—the tonnage included the weight of all the ironwork from the bottom of the wrought-iron bottom length to the top of the adjusting cap, with all the bolts and fastenings, and the money included all charges except carriage from Madras and plant. The girders cost to erect Rs. 3,487 a span, or Rs. 22½ (about £1 16*s.*) a ton, which included also all charges except carriage from Madras and plant. The cost per lineal foot of the bridge, including the provision of the material in England, transport and erection in India, supervision, and depreciation of plant, taking the rupee at the current rate of one shilling and sevenpence, was a little over £38.

Mr. Hayter. The average depth of cylinder sunk per working day was about 9 feet. He gave these figures because they were just those required to assist in framing an estimate of like structures in like situations. It was worth while also to record that a little more than one half of the total cost was due to the provision of the ironwork, metalwork, and Portland cement sent from England and delivered in Madras, the remainder to the work transported from Madras to the spot of erection, and erecting it in place complete in every respect. The prevailing rates of manufactured ironwork were low at the time the Chittravati bridge was let in England. The cast-iron work in the sub-structure was procured at £4 12*s.* a ton, and the wrought-iron bottom length and the bolts and nuts at £12 18*s.* 10*d.* a ton. The wrought-iron work in the superstructure cost £9 5*s.* per ton, and the steel bearings £23 17*s.* 6*d.* a ton, all delivered in London. The superstructure was let to Messrs. Head, Wrightson & Co., of Stockton-on-Tees; and it was in a measure owing to the good workmanship that the tests to which the bridge was subjected after erection, and which were singularly uniform, proved so satisfactory. The testing load consisted of two locomotive engines with tenders, each locomotive engine with tender weighing 66 tons 11 cwts., and of two loaded rail-wagons, each weighing 22 tons 5 cwts. 3 qrs. The testing load applied, together with the dead load of the bridge, did not produce a strain in any part of the material beyond the stresses specified by the Government of India. The Author, in Table II of the Appendix, gave some information as to the surface friction of cylinders in sinking. Mr. Hayter directed attention to this, as it was instructive and likely to be useful. Mr. Stoney had remarked on the inability of the ordinary grab to remove any but very soft material from the inside of cylinders; and this coincided with Mr. Hayter's experience. The implement had, however, been improved by Mr. William Matthews, M. Inst. C.E., who added an upper weight and side tines; and this tool would excavate stiff clay from the inside of cylinders. The capability of grabs was referred to by him (Mr. Hayter) and by others in the discussion on the paper of "Dredging Operations and Appliances,"[1] and he only now briefly alluded thereto as bearing upon, and in confirmation of the remarks made by Mr. Stoney in his Paper on the Chittravati bridge.

Mr. Robinson. Mr. W. R. Robinson said that, having been chief engineer of the line during a portion of the time that the Chittravati bridge was is in construction, he might say a word upon one or two points

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[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 43.

Mr. Robinson.

mentioned by the Author. With reference to the contiguity of the wells, the Author recommended that they should not be placed too closely together. He could thoroughly endorse that. There was really no necessity for it. As in the case mentioned, a slight cant brought one well foul of the other, and if two outer wells were sunk first, then there was always a difficulty in getting in another one between them. With regard to the Portland cement, it was tested as it came out, in the chief engineer's workshop. It was also tested before it went up country, and again when it arrived. The proper proportions to be used in making concrete with it were carefully ascertained. They had always found a difficulty in dredging silt. Mr. Walton in his Paper on the Benares bridge, remarked that he used a chisel made of two rails bolted together, which he dropped into the silt so as to break it up, and then removed it by dredging. Unless this was done, the dredger merely scraped the surface and came up empty; it would not bite into it. They also found that if a small boulder or pebble got between the jaws of the dredger, it let all the silt go out, and he had seen dredger after dredger come out without there being half a cubic foot of material removed. The Author had spoken of continuing cylinders to their full height with a diameter of 12 feet, which he said was an advantage. Of course an engineer always liked a margin; but large wells reduced the waterway, and that was the reason, he believed, for the design. Speaking of dynamite, he thought it was a very dangerous experiment, and one which he never would have approved, to attempt to blow up a boulder under the cutting-edge with dynamite, and he was not at all surprised to hear that the cylinder was blown out. Dynamite had been successfully used in that and other bridges by putting a charge below the bottom of the cylinder into the pit excavated by the grab or dredger and exploding it there. In that case it did not do the slightest harm, but caused a trembling motion of the earth all round, and the cylinder generally went down at once. Removing boulders was always a very slow operation, but in dealing with Indian rivers, they could never feel safe until the cylinder rested on the rock. The Author had stated that the bed of boulders was 14 to 22 feet thick under the piers, but 50 or 100 feet further up the river it might be only 2 feet deep. It was frequently found that they were thrown up in big shoals in the bed of the river, and a change in the position of the bridge might alter the circumstances considerably. The Chittravati bridge had been constructed

Mr. Robinson. very cheaply, as Mr. Hayter had explained, and he did not think they could have chosen a better man than the Author.

Sir John Coode. Sir JOHN COODE, President, asked whether any conclusion had been drawn as to what would be the proper distance between the cylinders; of course it would vary in different soils.

Mr. Robinson. Mr. ROBINSON said he should not hesitate to place them 3 feet apart; 3 feet between two cylinders was not much.

Sir Bradford Leslie. Sir BRADFORD LESLIE said that the observations he had to make about the Chittravati bridge, were chiefly with reference to the points in which the design differed from that of similar work carried out in the Bengal Presidency. The Paper was very interesting, as affording details of the difficulties met with in cylinder-sinking through varying strata, especially through the beds of large boulders, overlying the rock. The trouble occasioned by boulders under the cutting-edge was very clearly explained; either they had to be dragged into the cylinders, which generally resulted in an inrush of sand, or the projecting portion of the boulder had to be removed by blasting at the risk of damaging the cylinders. This indicated one great advantage of the adoption of single-well piers. A well or cylinder of 17 feet diameter, with the same area as two cylinders of 12-foot diameter, would have a perimeter of 54 feet only against 75 feet for the two 12-foot cylinders, thus reducing the length of cutting-edge liable to come in contact with the boulders by 40 per cent. The frictional resistance to sinking would also be lessened in the same ratio. The weight of the single 17-foot well would be equal to that of the two 12-foot wells, while the area of skin-surface exposed to frictional resistance in sinking would be diminished by 40 per cent. In deep sinking, moreover, a well of large diameter was much more easily kept upright than a small one. Where they could be pitched in the dry bed of the river, a wrought-iron curb at the bottom connected with the well by vertical ties and diaphragms built into the brickwork, as was done in the north abutment of the Chittravati bridge, was generally found to be sufficient for wells of large diameter. For wells of small diameter in proportion to the depth to be sunk, and especially in cases where it might be necessary to have recourse to the pneumatic process, a complete iron cylinder extending the full height of the pier was generally adopted, as in the Chittravati bridge. The bridge carrying the Bengal Nagpur Railway over the Damvodah river, consisted of ten spans of 200 feet each, and the piers were built on single 20-foot brick wells, without any external iron

Sir Bradford Leslie.

cylinders. These wells had been sunk to a depth of 70 or 80 feet into the bed of the river, generally on to the rock. It would be very interesting to have an account of the construction of this bridge, with particulars of the well-sinking for comparison with the new Chittravati bridge. It was probable, however, that the cheapest mode of bridging some of these wide Indian rivers that were dry or nearly so for more than half the year, and where there was no navigation, was by short spans carried above the flood-level by piers sunk a comparatively short distance into the river-bed, which should be protected from scour by a sunken causeway or weir between and around the piers. Everything would depend upon the stability of this sunken causeway, but engineers had now no difficulty in making weirs for irrigation purposes across the largest rivers, and the experience of properly floored flood-openings subject to the full strength of the flood-spill of the Ganges in Eastern Bengal, showed that such bridges would be perfectly reliable. It was a question whether the old Chittravati bridge might not have been protected by a causeway of rubble-stone deposited at a depth of say 10 feet below flood-level, and if the plate-girders were too weak for the modern locomotives, being plate-girders, intermediate piers might have been placed. The greatest credit was due to the engineer for the execution of an immense amount of difficult foundation-work, and girder-erection in a very short space of time, and their best thanks were due to the Author for the record he had given them of the difficulties experienced in sinking through boulders, and the valuable data as to side-friction at various depths below the surface.

Sir Douglas Fox.

Sir DOUGLAS FOX said they were much indebted to the Author for the account which he had given them of the difficulties he met with in sinking these cylinder piers. Engineers who had had to deal with a foundation of that kind could sympathise with those difficulties, and there was one point particularly in the Paper to which too much importance could not be attached in practice, namely the statement as to the great uncertainty of borings. They were tempted to rely a great deal too much upon borings, and certainly his experience was that they were the most deceptive things that they could possibly attempt to trust to. An instance of this kind was recorded in the Minutes of Proceedings.[1] Careful borings were taken across the River Esk, near Whitby, and showed soft silt right down to the bed rock. When they came to sink the

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 304.

Sir Douglas Fox. cylinders it was found that they could not get them below even half the depth; they all refused to move any further. On examination it was discovered that there was about halfway down a submerged forest of trees lying horizontally interlaced one with the other, and that the borings had in every case gone between the trees down to the bed rock. They had just the same trouble with the cylinders as had been referred to by Mr. Hayter, the timbers having to be dragged out from beneath the cutting edge. Dynamite was employed to some extent, and altogether it was a very expensive and troublesome process. In another case, where the borings showed good stiff clay, the actual material proved to be such soft silt that cylinders were sunk to a depth of 50 feet with little more than their own weight. He wished to bear testimony to the excellent effect of using foundations consisting of brick wells, in which plan they were following the ancient practice of the natives of India who had been accustomed for many years to sink these brick wells by divers. By using the wrought-iron cutting-edge and a brick well on the top of that, a most substantial pier could be carried to a considerable depth. In South India it was found important, as had been mentioned by Sir Bradford Leslie, to floor the bridges. A great deal was sometimes learnt by misfortune, and they had an example in South India which showed what a thoroughly efficient foundation such wells, carrying masonry piers combined with a floor would make. They had there a bridge rather larger than the one in question, with seven spans of 150 feet, which was suddenly assailed by an unprecedented flood, caused by the bursting of a large irrigation dam just above, bringing down on it a forest of trees. The bridge was constructed with lattice-girders, and if it had not been for the trees nothing would have happened. The flood rose much above its normal height, and reached a level never known before. It came up practically to the top of the girders, and gradually the trees piled themselves in a dam against the sides. What he wished to point out was this, that though the whole of those seven spans of 150 feet were swept away into the bed of the river, the piers stood perfectly sound and good, so that in order to repair the bridge they simply raised the height of the piers sufficiently to meet such an abnormal flood, and replaced the girders upon them. It was not only an economical mode of construction, but was thoroughly efficient. He agreed with what had been said as to the importance of leaving plenty of room between the cylinders for canting. He hoped that a Paper would be brought before the Institution, referring to the very large cylinder sunk by his brother, Mr. Francis Fox,

M. Inst. C.E., in connection with the River Dee, in which case it was found very important to provide against canting, because they had a difficulty with the sand. There was no reason why the space referred to by Mr. Robinson of 3 feet between the cylinders should in an ordinary case cause any special difficulty, and he thought it would be unwise to attempt to place cylinders in a river of that kind, as closely as they could place them in the River Thames. In the case of the Victoria (Pimlico) and other bridges the cylinders were placed close to one another, but in the London Clay they could be controlled very much better than they could in an Indian river. Sir Douglas Fox.

Mr. Barry. Mr. J. Wolfe Barry asked if the Author could supplement his Paper by some further particulars as to the circumstance he mentioned of there being 8 feet of slurry found after a thickness of 30 feet of concrete had been deposited under water. That seemed very extraordinary, and if the Author made any analysis of the slurry to determine its composition, so as to see whether it was cement which was not set and had been washed out—or partly cement and partly dirt—it would be instructive to engineers who had to deposit concrete under water, and were never absolutely certain what happened with it, to have that information. With regard to what had been said by Sir Bradford Leslie as to the desirability of affording some surface protection to the piers, he would draw attention to the fact that one of them, No. 11, appeared to be resting upon a foundation which was not thought good enough for the rest of the bridge. It would seem prudent, therefore, to take some precaution for shielding that pier from the action of the river if any erosion of the bed should take place.

Mr. Robinson. Mr. W. R. Robinson said it had always been the intention as far as he knew to throw stone round all those piers, but he had not heard if it was yet done. In the original plan there was a flooring, and he thought it had been put in.

Mr. Deacon. Mr. G. F. Deacon said it would be useful to hear the opinion of others as to the employment of dynamite for the purpose of causing vibration of the ground, and thus increasing the tendency of large cylinders to sink. His own experience had not been very satisfactory. When a cylinder was forced down by simple loading, the strata were disturbed to the slightest possible extent; but the explosion of the dynamite shook the ground, and thus, while causing the cylinders to descend with a smaller load, increased the tendency of the soil to run in below the cutting-edge. The resistance to vertical motion of the cylinders was generally different at different parts of the cutting-edge, and this, when the run of the ground

Mr. Deacon. and sinking of the cylinders took place simultaneously, often caused serious canting. The use of dynamite fired well below the cylinders was an expedient which might succeed when loading and excavating failed, but was only to be applied with great caution. Like Mr. Barry, he had been much struck by the statement concerning the quantity of slurry found upon the concrete in one of the piers. More information respecting this was desirable. It seemed incredible that the whole of that 8 feet of slurry should have been the product of the 30 feet of concrete beneath it.

Sir John Coode. Sir John Coode, President, said he agreed with Mr. Barry and Mr. Deacon that the existence of the 8 feet of slurry was very extraordinary, and more so when taken in connection with the fact that the concrete below it was set quite hard. The Author would, no doubt, be able to give them further explanation on the subject.

Mr. Shelford. Mr. W. Shelford said that in his own experience some of the hardest concrete he had ever seen had been so honeycombed that it would admit of the passage of the silt from the bed of the river right through it, and he thought that the extraordinary thickness of the slurry found on the top of the concrete in the cylinder might be accounted for in that way. With regard to the observations which had been made about the sinking of cylinders by means of grabs, a great deal depended upon the form of the grab-scoop. He had himself found that where grabs would not penetrate the bottom at all, when a tooth was added on the outside of the scoop it enabled it to enter and do its work. Very much depended certainly upon the material to be encountered in sinking the cylinders. The cutting-edge of the grab must be of a form suited to the material intended to be removed. Although for the purposes of sinking it might be cheaper to have the lower part of the cylinder smaller in diameter than the upper part, it caused great inconvenience when grabs were used, but, on the other hand, if the cylinder was of the same diameter all the way up, it interfered with the waterway of the river. He entirely agreed with what had been said by Sir Bradford Leslie as to the practicability, in such a river as the Chittravati, of protecting the piers from scour by the construction of a weir. He had lately seen in the Argentine Republic a bridge about a quarter of a mile long, with spans of 10 or 11 metres, carrying a railway across a river of a very similar description, the piers being screw-piles. The bed of the river was sand, which was usually dry, so that it was the easiest thing possible to erect the bridge; and no doubt if at any time it gave trouble the simplest way to keep it in position would be to protect the sand from being scoured away by the floods. He had himself proved the practicability of that plan, having made a weir across a river with a silty bed in the Fen district, at a very small cost, which effectually prevented any scour. Mr. Hayter had not said anything about the design of the girders, and Mr. Shelford would like to ask why the depth had been fixed in such a way that it was necessary to raise the transverse girders overhead 10 inches above the main girders in order to give headway to the train underneath. He did not see why the girders should not have been made of a greater depth, and, in fact, they would have been cheaper if they had been deeper. The American practice, as they were aware, was to make the girders of much greater depth proportionately than these, and they had found out by experience that that was the most economical system; and he had proved it to be so in a Paper read before the British Association in 1886. He would also like to ask why the cross-girders were attached to the side of the bottom boom, and not suspended underneath in the way which was now usual. The common practice was to carry the web-plate of the vertical members through the bottom boom, and to attach the girders to it in such a manner that they formed part of it, so that there should be no undue strain on the rivets, but only a sheering stress. He would also ask why the girders were made of iron and not steel, which he thought a more reliable material. Mr. Shelford.

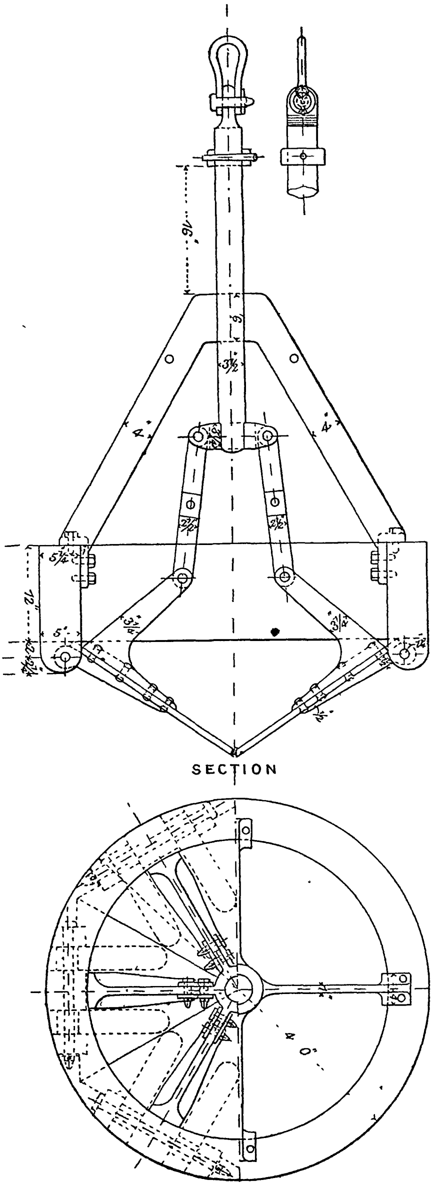
Mr. GEORGE BERKLEY, Vice-President, said that some of the cylinders, 11 feet in diameter, of the Bookree bridge, on the Great Indian Peninsula Railway, had cracked in or near the bottom, although there was no apparent fault in the metal. When a cylinder was sunk through material containing boulders, or rocks, one part of the cutting-edge might rest upon them, whilst the other had no such support, and when a weight of some 300 to 400 tons was put on the top of a cylinder, sunk 50 or 60 feet into the soil, and arrested in that manner by the obstructive material, there was very great risk that the cast-iron would crack. It did crack in the case referred to. He thought it would be desirable to pull the cylinder down as well as push it, so as to relieve the compressive strain. Mr. Berkley.

Mr. ROBERT RIDDELL said, in 1884 he was engaged as resident engineer in the erection of a girder-bridge with cylinder-piers across the Bookree River on the Great Indian Peninsula Railway from the designs of Mr. Berkley. The conditions were somewhat similar to those of the Chittravati bridge. The river was subject to floods rising as much as 20 feet in a few hours during the Mr. Riddell.

Mr. Riddell. monsoon. The strata through which the cylinders were sunk consisted of moorum with large stones, conglomerate of kunkur, moorum, and gravel, and impacted sand and moorum. (Moorum was supposed to be decayed trap-rock; it was like a hard clay or marl.) On the last of these the cylinders were founded at a depth of about 36 feet below the bed of the river. Each pier consisted of two cast-iron cylinders 11 feet in diameter below the bed of the river, and reduced by a tapering ring to a diameter of 9 feet above that level. The superstructure was for two lines of railway, and the spans were 109 feet from centre to centre of the piers. The method of sinking was similar to that described in the case of the Chittravati bridge, namely, by placing a stack of rails on the top of the cylinders. From the results, he thought there was no doubt it would have been better to have put some of the weight inside the cylinder by building up a ring of brickwork, or concrete, resting on a ledge. That would have reduced the chance of fracture, which did happen in a slight degree, and also the cost of sinking, and of removing and re-stacking the rails every time a new ring had to be added, which was very considerable. In excavating hard stuff in the cylinders below water it was often found that the Bull dredgers, which were used, would not sink through it. He therefore employed a long vertical iron rake, the shaft of which was made of old rails bolted together, pointed at the end, which sunk into the ground in the centre of the cylinder. About 3 feet above the bottom a cross-piece armed with strong steel prongs was bolted on, and the rake was revolved by capstan-bars from the top of the stack of rails. That loosened the hard clay, impacted gravel, and conglomerate of moorum, kunkur and gravel, and enabled the dredger to bring up the stuff. They met with a good many large stones and boulders, which had to be broken by the divers with hammer and bar, and then sent up in buckets to the top. There was no difficulty after the boulders, debris, and conglomerate had been broken and removed, in bringing up the rest. The excavation was always kept down below the level of the cutting-edge, except where a run took place, when the cutting-edge sank deeply in the ground: the maximum run was about 5 feet. The average final weight placed on the cylinders was 335 tons, the minimum being 333 tons, and the maximum 375 tons. When the cylinders reached the required depth a plug of cement-concrete about 8 feet thick was let down in hopper-boxes through the water. That was allowed sufficient time to set—sometimes four days, sometimes a week, and the cylinder was then pumped dry. On the top of the concrete about 3 or 4 inches of white sludge was found, which he believed to be composed of fine particles of the lime from the cement; it had no setting property whatever. The cylinder being dry, the cement was let down in hopper-boxes, disturbed as little as possible, and never rammed. Experience taught him that cement-concrete of good material in proper proportions, and mixed with the right quantity of water, did not require ramming, and indeed he thought ramming was injurious. Possibly the large quantity of sludge of which the Author had spoken—8 feet of sludge to 30 feet of concrete—was due to the concrete being unduly agitated in the water. Mr. Riddell.

Mr. J. R. Mosse said, with reference to the remarks of Sir Douglas Fox, that he knew of two instances in which foundations had not proved to be what was anticipated, without any blame at all being attributable to the engineers. The first of these occurred on the Inter-Colonial Railway of Canada, of which Mr. Sandford Fleming was engineer, about the year 1870. That railway, in going through New Brunswick, crossed a large tidal river at Miramichi by several spans of 220 feet each; the depth from high-water to the sand being 30 feet. There was 10 feet of sand, then a bed of gravel 7 feet thick, and below the gravel 50 feet of silt. There was great discussion as to whether the foundations should be laid upon the 7 feet of gravel, or whether they should go down to the rock through the silt, which would have made the depth of the foundation from high-water level 97 feet. After a good deal of consideration, Mr. Sandford Fleming determined to found upon the bed of gravel. The piers were of heavy ashlar work, with large cut-waters to resist the pressure of the ice. They were put down in timber caissons 60 feet by 30 feet, and so much difficulty was experienced in getting the foundations down to that bed of gravel, that 1,416 cubic yards of material were removed from Pier No. 10, and 356 cubic yards of water were pumped up for every cubic yard of excavation. He did not know whether other engineers had had similar experience, but he thought that 356 cubic yards of water for 1 cubic yard of material constituted an enormous difficulty in getting in foundations. The piers were of solid masonry founded upon this bed of gravel over 50 feet of silt. They were loaded for six months with from 500 to 600 tons of rails. They all sank somewhat, the minimum being about 6 inches, and the maximum 13 inches, but without cracks and with only a gradual settlement of the masonry. It proved very successful, and to the best of his knowledge no flaw had ever occurred. A similar Mr. Mosse.

Fig. 2.



Ceylon Government Railway Excavator.
Scale ½ inch = 1 foot.

Mr. Mosse.

case occurred in Ceylon, where a large river at Kalutara was crossed by a bridge built in 1876 with twelve spans of 100 feet. There was rock on the ledge of the bank, and every indication that there would be rock in the bed of the river. The depth of the water was 35 feet, but the bottom proved to be only a layer of gravel 2 or 3 feet thick, and afterwards came some 30 feet of sand. They had to get down to the rock from 60 to 70 feet below the water. The cylinders were small, 6 feet in diameter, so that no elaborate plant was needed. They had to use the best native labour they could get, and therefore something very simple had to be adopted. All kinds of machines already mentioned for getting out foundations in cylinders were tried, including the ordinary jham and sand-pump, Bull's dredger, Molesworth's dredger, Ives' excavator; they all worked well in the sand, but when they came to clay great difficulty was found. The best implement for the clay was what was called the Helical excavator, invented by Mr. E. W. Stoney, the Author of the Paper. That was found effectual, but at great depths it gave a good deal of trouble in working the vertical rods. Boulders were removed, and rock excavation done by divers wearing Heinke's dresses. In 1880 a large bridge was built over the Kelimi River, and the dredger used was invented by the resident engineer of the railway, Mr. Edward Strong, who had been in Ceylon for many years. It consisted of a cylinder, *Fig. 2*, 4 feet in diameter, the vertical part of which was about 2 feet in depth; the bottom was nearly semicircular, divided into six parts, and made almost to fit as a hemisphere. The triangular pieces were pointed and sharp. It was weighted heavily, and went down so that the sharp points penetrated the clay, and when it was drawn up it raised the material with considerable effect. As far as his experience went, it was the best dredger he had seen. **Mr. Mosse.**

Mr. Wrightson. Mr. T. Wrightson said he had never known a bridge go through any works so rapidly as the New Chittravati bridge had done. The reason was that the details were so thoroughly well worked out beforehand, in Westminster. That was not always the case, and therefore the manufacturers did not wish to take any credit to themselves for that particular part of the work. With reference to what had been said by Mr. Shelford with regard to increasing the depth of the girder, possibly some saving might have been effected by doing so, but he did not think it would have been very great. But if Mr. Hayter had designed the girder of a greater depth, he would have been able to get the top boom so much deeper that he would have had rivet surface enough for the attachment of the diagonals direct to the top boom, and that would have been a considerable saving in the weight, as the separate joint-plates would have been saved. With regard to the conclusion come to by the Author upon the question of cylinder-sinking, he had done good service in recording his experience. He had tabulated about one hundred and forty-five extremely interesting observations, evidently made with considerable care. And the average of these gave a skin-friction equivalent to just under 2 cwt. per square foot, the maximum running up to 3·52, and the minimum being 0·63. In designing cylinders for supporting a bridge it was often difficult to get the necessary information by which to decide the depth. They might trust largely to the skin-friction; they might trust entirely to support at the base of the cylinder, or the bridge might be designed taking both into account. Any information upon the question of skin-friction must be exceedingly useful to those who had

Mr. Wrightson. to design bridges, and therefore this was perhaps the most valuable part of the Paper. With regard to skin-friction, it would not do to depend upon too low a coefficient. He had under observation some two or three years ago the case of two bridges in Devonshire, one across the Tavy and the other across the Laira, and in those bridges the cylinders went down into the mud 70 or 80 feet in the deepest part. It might be within the knowledge of the older members of the Institution that one of the first works which the elder Rendel carried out, and one of the things that brought him prominently before the public, was the building of the bridge across the Laira, and when his firm took the contract for a modern bridge within a few feet of that structure, he consulted Mr. Rendel's Paper[1] with great interest to see what kind of foundation they would have to deal with. The design of the later work was made by Messrs. Galbraith and Church. When the cylinders were sunk into the river they had to weight them down, and a very curious thing happened. In many cases the weight had been on, sometimes for a considerable time, when the cylinders suddenly sank, for 10, 20, 30, and even as much as 40 feet. In the case of the Laira there was one that went as far as 42 feet in a few seconds, and in the Tavy there was one within a foot of that figure. It might be easily imagined that this caused some alarm to the men; in fact, in the case of the first cylinder which sank, the men had just gone to their breakfast, and they had not been out more than two or three minutes when it shot away in that extraordinary manner. After a time, however, they became quite accustomed to the phenomenon, and prepared themselves for it. The majority of the cylinders in both bridges sank in this way. He had made an estimate of the amount of skin-friction which was overcome at the time when these runs occurred. In one case in the Laira bridge, taking the weight of cylinder plus the weight of rail with which it was loaded, and assuming it to act over the whole of the subterranean part, the resistance amounted to 2·1 cwt.; in another case to 2·5 cwt.; and in another to 2·8. In the Tavy bridge cylinders, most of which ran away, the skin-friction was from 2·3 cwt. to 2 cwt., so that these figures approximately corresponded with those given by the Author. Of course the value of the skin-friction varied in different circumstances; but it would be an interesting contribution to their

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[1] Transactions Inst. C.E., vol. i. p. 99.

knowledge if some one could ascertain what it was in the many cases of cylinder-sinking which had been recorded. Mr. Wrightson.

Mr. E. W. Young said that the most important point for consideration in the discussion on the erection of the Sukkur bridge was the comparative merit of the two systems of erection. In the large bridges which were now made the parts were very often built up in pieces, and it was necessary to adopt that system of erection in many cases, but it was not so satisfactory in some respects as building up each member complete, adjusting it to its exact length, and so getting it into position. The system of building-up, especially where temperature came into play very much, was productive of error. One could understand that the difficulty of putting up a strut, raking in two directions like No. III, from such a small base, and getting it to the right position at the top must be very great. In confirmation of this view he observed that the Author spoke of an error on the completion of No. III strut, where "the span for the horizontal tie proved to be $\frac{5}{8}$ of an inch too much on one side, and $1\frac{1}{4}$ inch too much on the other." That was comparatively a small error, but it must be very objectionable to have those differences of length. He should have preferred to build the strut in one piece, haul it up, and drop the end of a temporary tie into a V-shaped jaw at the upper end of the strut, getting it into position in that way. He hoped to hear from members who were qualified to speak on the matter their experience as to which was the best method of erecting structures of that kind, whether by building them up piecemeal and riveting them together, or taking each member as a single piece and hauling it into position. The Author had stated that "a piece of the strut, generally about 30 feet long and weighing 5 tons, was lifted into its place, and held up by a $1\frac{1}{2}$-inch wire-rope (7 tons breaking strain)." That was in his judgment working rather too close to the limit of the strength of the rope. He should be very sorry to put 5 tons on a rope with a breaking strain of only 7 tons. The method of hauling by means of winches worked by an endless rope from below was very ingenious and useful for that mode of erection, and the Author deserved great praise for the ability he had shown. Mr. Young.

Mr. Ewing Matheson said the description of the Sukkur bridge, as he gathered from the Paper, was confined entirely to its erection. That was a little to be regretted, as there might be something to say with regard to the design of the bridge. In describing the erection of it the Author gave some figures which Mr. Matheson.

Mr. Matheson. really involved the question of design. It would be interesting if a comparison could be made between the superstructure of that bridge and that of the Forth bridge, inasmuch as both had large cantilever spans. They could hardly think that the Sukkur bridge was more difficult to erect than the Forth bridge, but it appeared to have cost more per ton. Taking the figures given by the Author he thought it was not quite right to put down the cost of the erection merely as 570,000 rupees. Of the incidental expenses which appertained to erection, such as workshops, sidings, plant, boat-service, and so on, ironwork ought to bear its share, and if that were the case it seemed to produce a very high price per ton for the erection. It would be interesting if the Author could ascertain if the price of the ironwork delivered at the site, which seemed to be rather extraordinary, was due to the peculiar manner of dealing with it at the beginning. It was all put together in London, and it was a question how much was saved thereby in the erection of the bridge at the site.[1] When they came to set it up, probably they found considerable advantage from the fact that the bridge had been already once erected. Such a proceeding was, however, he thought, unprecedented.

Sir Bradford Leslie. Sir BRADFORD LESLIE said that the mode of erection of the Sukkur bridge appeared to be admirable, and to have been well carried out, so that there was very little to be said on that subject. As to the design of the bridge he wished to make a few observations, seeing that the difficulty of erection had been affected by it. The cantilevers seemed to have been arranged almost without reference to this question. He did not know whether the engineer by whom the bridge was to be erected was consulted, but if that course had been adopted he should have expected that the design would have been much improved. The main strut No. III, weighing 240 tons, was a most difficult member to erect, being inclined not only longitudinally in the direction of the bridge but transversely. No doubt there were good reasons for the adoption of a strut in that case, one probably being that it would impart stiffness to resist wind-pressure, but the same object could have been attained if the vertical end-pillar A had been strengthened; in fact it might have taken the form of a cast-iron standard, and being erected on shore would have been straightforward work. A tie from point A to the foot of No. IV

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[1] An account of the temporary erection of the Sukkur Cantilever Bridge at the Works of Messrs. Westwood, Baillie and Co., Poplar, appeared in "Engineering," March 9th, 1888.

Sir Bradford Leslie.

vertical might then have been substituted for strut No. III, and such a tie would have been much lighter and easier of erection. That again would have reduced the strain on the top horizontal tie AB, which might then have been less heavy, and therefore more readily put in place. The erection of the top tie was a very difficult matter, as would be seen by reference to the diagrams, a special kind of suspension bridge having been constructed for the purpose. It was true that the weight of No. IV vertical member would have been increased by such a modification of the design, but being vertical in the transverse plane, the difficulty of erection would not have been greatly affected by a little increase of weight. The end pillars on the abutments, the main strut No. III, and the other minor struts and pillars, being reduced almost to a point at the ends, it appeared that the superior strength of pillars fixed at the ends was practically sacrificed. At the point B the pillars appeared to shrink specially to avoid contact one with another instead of becoming united as soon as possible, and the material in those struts and pillars was used to little better advantage than it would have been in pin-connected columns. If pin-connections had been adopted much of the difficulty and extreme care necessary to avoid straining the joints would have been obviated, and a considerable saving of time would have been effected. Riveted connections having been decided upon it would have simplified both the construction and the erection to have made the struts and pillars with parallel sides, instead of spindle-shaped. This would have obviated the delay experienced in rigging stages for the men to work on, and would have greatly stiffened the structure, as it would have enabled the struts and pillars to be more rigidly connected by the increased area at their ends. The system adopted by Mr. Robertson, especially the precautions taken for the accurate building up of the main raking-strut No. III, and the suspended staging for the erection of the main horizontal tie at an elevation of 170 feet, depending at the outer end on the unstable head of the main strut, was a skilful and ingenious manner of accomplishing a difficult task. The accuracy with which the calculations had been made of the allowances for the extension of the back guys due to the weight of the cantilevers, and complicated by variations of temperature, was very remarkable, and the use of the adjustable steel-wire spans for carrying the lighter members of the cantilevers into position, and also the temporary bow-string bridge for the erection of the central girders were equally admirable. It appeared to him difficult to suggest any improvement on the mode of erection adopted. Its safety and

Sir Bradford Leslie. simplicity, and the small amount of special plant required, were some of its best features. Before deciding on the general design of a bridge, it was to be supposed that a comparison was made with other designs which were feasible. Where the entire length of a cantilever on both sides of the fulcrum or central support could be turned to account for bridging a large span, it was beyond all question the best type of construction, but in a single-span bridge the proper application of the cantilever principle would seem to be that it should be used as a temporary means of erecting some more appropriate type of bridge. The anchoring of the cantilevers of the Lansdowne bridge required a large amount of steel-work behind the abutments—some 600 tons—which would have been saved by the adoption of a trussed bridge, like Brunel's Saltash bridge over the Tamar. A structure of this type, including special wind-bracing, would have weighed roughly 2,600 tons and could have been conveniently erected by using half the chains temporarily as back guys for the standards on each side of the river, and the other half to provide a temporary inverted bow-string girder (similar to that used by Mr. Robertson for the centre girders) for the erection of the permanent structure. When that was complete, the links temporarily used as back guys, would have been removed, and fixed in their proper positions in the bridge. They might first have been suspended independently, and their share of the weight brought on to them by hydraulic pressure. In that way a bridge of the Saltash type might have been very easily erected. It was, however, impossible to look at the section of the river, with the limestone rock rising on both sides available to resist horizontal thrust as well as vertical pressure, without feeling that the site was favourable for the consideration of some form of arched bridge. By an arched bridge, he understood one in which the material of the longitudinal ribs was subject to compression only, varying within certain limits according to the position of the moving load. In such a structure there would be a rise and fall at the centre, owing to differences of temperature; but otherwise any required degree of stiffness could be given with a weight of metal not exceeding half of that of the cantilever-bridge. If properly designed to facilitate erection, it could hardly be doubted that such a bridge could have been successfully placed in position, especially by an engineer like Mr. Robertson. A skeleton arch to serve as a staying for the complete structures of which its material would ultimately form an integral part, might have been built on the side of the river, floated down and erected, or it might have been built in the

Sir Bradford Leslie.

centre line of the railway, and launched forward somewhat in the manner done with the girders of the Jubilee bridge. Whatever method of erection was adopted, no doubt an arched bridge, including wind-stays and bracing, could have been built for half the cost of the cantilever-bridge, by taking advantage of the rock abutments. He was aware that this form was out of fashion just now; but for large spans, where the abutments were not too expensive, it would be found to be more economical than any other type, provided that the system of erection was considered in making the design.

Mr. Parsey.

Mr. WILLIAM PARSEY wished to offer some remarks with regard to the method of constructing the Sukkur bridge. He was engaged by Messrs. Westwood, Baillie and Co., and had the entire charge of the erection of the work in their yard. The temporary erection was carried out on quite a different system to the final, because in the first case, the whole structure had to be supported upon scaffolding, whereas in the final erection, having been already put together once, it all came easily into place. The scaffolding employed in the yard had to carry the entire weight of the bridge, and it was necessary that it should be perfectly rigid. There was no movement at all except in strut No. III, which lent over at the top end ½ or ¾ inch. The mode adopted for the final erection by Mr. Robertson appeared to have been as perfect and as good as skill could contrive. There was only one other way in which it might have been done, and that was to have carried wire-ropes across, so as to form a wire-tramway, and to have used a travelling carriage, dropping the weight down from that, which would have amounted to much the same thing. It had been asked whether it was advisable under such circumstances to erect a bridge of that class in England. Upon that subject his impression was that it was perfectly necessary that the work should have been put together in this country. It was the universal practice with bridges of 100 or 200 or 300-foot spans to put them together in the contractor's yard before sending them out, and this bridge being of a novel construction and very complicated, it was all the more necessary that it should be treated in the same way. Reference had been made to the testing of the lengths of the different members. All the pieces were laid down in the contractor's yard and very carefully tested before they were erected on the temporary scaffold. They went together perfectly, and in no instance did they have to shift or alter a single piece, and he thought that the contractors were entitled to considerable credit for the care and skill exercised on that part of the work. The

Mr. Parsey. cost of erection in this country was between £3 or £4 a ton. He estimated it at £5 a ton before starting with the work. The total cost at the finish was between £12,000 and £15,000 for the 3,000 tons, including scaffolding, or nearly £5 a ton, and when the scaffolding was taken down, the timber, which cost over £7000 was sold, and the contractors got £2000 or £3000 back, so that altogether the actual cost of erection could not be put at more than about £3 10*s*. a ton. As to the mode of keeping the centre-lines and the direction of the members, it was all set out in the yard to centre lines, arranged with the theodolite from one end to the other, and everything worked from the centres. At the final erection that mode could not be very well carried out; and therefore, in dealing with the principal members, marks were made, and lines drawn so that the levels and widths could be checked. These lines and marks were put on the steel and iron-work in the yard by erecting temporary stages at various points. He first of all got the widths from the centre-line on each side, put the theodolite down, then ranged the line up to cut the different parts of the structure, which were marked with paint lines and centre-punch holes, and these were the marks by which Mr. Robertson finally erected it. With regard to the lifting-gear, that was all designed in England by Mr. Robertson. It seemed to have answered very well indeed.

Mr. Read. Mr. R. JOHN G. READ said he had been very much interested in reading the account of the erection of these bridges. There were some points in the design he should like to speak upon. He would ask what was the idea of putting the last strut in the reverse direction on the nose of the cantilever. He thought the strut put in its normal position following the previous ones would have been at too flat an angle, and therefore it had been superseded by a tie in the opposite direction. He should be glad of some information as to the proportion of the length of the central girder to that of the arms of the cantilever. Perhaps the engineer of the Forth bridge might be able to tell them how that was arrived at. He thought it was found by trial in this way:—given a certain length of span, calculating what would be the weight of the whole bridge with the centre span of an assumed length, and the cantilever arms following it. In a shorter span cantilever-bridge due regard must be taken to the moving load, because if the cantilever arms were made long in proportion to the centre span the deflection from the moving load would be greater in comparison to the weight of the structure in the small than in the large spans, and therefore the nose of the

Mr. Read.

cantilever would be deflected more. That was experienced in the Niagara River bridge where they found great deflection with trains running at high speeds, whereas if the centre girder was made longer in those small spans it would tend to reduce the deflection. He asked what was the deflection of the bridge with the ordinary traffic. It was, he believed, stated in some of the Indian papers that, although trains had been running over it at high speeds and it appeared to be rigid, or nearly so, after Lord Reay had declared it open, a crowd of natives rushed to go across it and set up such a vibration that they had to be ordered off, and the bridge was practically stopped for foot-traffic until it had been stiffened by some cross-bracing. He would be glad to know if that was true, and, if so, what bracing had been put in, and whether it had acted successfully under a similar strain. Looking at the general design he could not help being struck with the great difference between it and all existing cantilevers with which he was acquainted. Most of the bridges now built were made with two piers at least so as to give the cantilever a balancing arm on each side towards the shore end. In the case of the Sukkur bridge it seemed impossible to have built a pier in the river, and therefore there was a wide span to be got over with practically a flat bank on each side, and supposing a cantilever to be adopted he did not see what else could be done than to anchor back the projecting arms in the way that had been done. That was not altogether satisfactory. It seemed that the centre of gravity of the arm of the cantilever was hanging over the water, instead of, as in most bridges—in fact in all that were now built, coming either over the pier or at the back. In the Forth bridge, in which the arms were equal, it would go over the piers. In the Hooghly bridge, support was afforded by two piers at wide distances apart, and therefore the centre of gravity of the whole came well within the middle of the piers. In the Niagara River bridge, the shore-arms were made heavier than the river-arms, and the centre of gravity was thrown back behind the supports, which helped it to sustain the extra weight of the centre girder on the nose of the cantilevers. In the Forth bridge the extra weight of the centre girder was counterbalanced by the heavy load put on at the end of the shore-arm to keep it down, and probably in that way it had been found by experience to be more economical to add that extra dead weight than to extend the length of the arm; the cost of building out a long cantilever-arm was more than that of putting on the dead weight and erecting the extra pier on the shore. It

Mr. Read. seemed that in the double-armed cantilevers there must be great deflection. The vibrations in cantilever-bridges were of two kinds, varying above and below the normal line, the amplitude of vibration being much greater than in an ordinary girder-bridge. The weight in an ordinary girder-bridge and the deflection were greatest in the middle, and the weight tended to rectify the bridge to its normal condition after the moving load had passed; but in cantilevers the lightest part of the bridge was at the nose of the cantilever where the greatest deflection would take place. When a train was entering on a double-armed cantilever the tendency was to lift the nose of the cantilever in front, and when it came on to the bridge it was tilted the other way, so that there was a vibration up and down at the centre. In the bridge under discussion there could only be a deflection one way, because the load as it came on to the bridge was simply bearing on the abutment—and as it reached the cantilever arm the only tendency was to deflect it downwards. He should be glad of information as to how the bridge behaved under deflection.

Mr. Hayter. Mr. Harrison Hayter, Vice-President, said that, in the absence in India of Mr. Stoney, the Author of the Paper on the Chittravati bridge, he would reply to the various points raised in the discussion in connection with that structure. Allusion had been made to the question of protecting the bed of the river and the piers of the Chittravati bridge with stone. If stone-pitching had been introduced under the bridge as well as above and below it, which would have been necessary, and if it could have been kept in place, there might have been no occasion to have sunk the cylinders until they reached solid material. He had gone into the question of the comparative cost of going down to the full depth, and of finishing at a lesser depth and pitching the bed of the river, and he found it unfavourable to the latter plan. During floods the sandy material of the river-bed was subject to the action of scour to a depth of 15 or 20 feet below the surface, and it would have been impossible to have kept stone-pitching in place without pile-work or works of protection both on the up-stream and down-stream side of the bridge, and the cost would have been altogether prohibitory. The same remarks would apply as to the construction of weirs, which had been referred to. As to throwing loose stone around the cylinders, he remarked that the bottom of each of them had a good hold on solid material, and at the top, each pair was well braced together by rigid wrought-iron plating (Plate 5, Figs. 11 to 13). No scour that could take

Mr. Hayter. place could, he believed, affect the stability of the piers; hence it would have been useless to have incurred the great cost of throwing in loose stone around them. It was evident that should any one of them at any time be unduly scoured, loose stone could be placed round that particular pier, but it was not probable that the necessity for it would arise, considering the depth to which the cylinders were sunk and the solid material reached, and there was no reason to provide by anticipation against such an occurrence. He quite concurred in the remarks made by Sir Douglas Fox as to the uncertainty of borings. He had some borings made in connection with an important work, and they indicated that rock would be met with at a certain depth, whilst actual excavation revealed the fact that it was some 20 feet deeper, and he could cite other similar cases. Attention had been drawn by Mr. Barry to the slime or slurry referred to by the Author, which was left over the concrete in the cylinders, and the circumstance had also been noticed by the President and Mr. Deacon. This slurry was formed to a remarkable extent in the case of concrete made with Portland cement obtained from one particular manufacturer, the cement having been supplied by several. Mr. Hayter believed that the occurrence was due to the fact that there was an excess of lime in it, which was not taken up by the silica and alumina, and which being set free, floated to the surface. The material in other respects seemed to have been good, for the Author said it set quite hard. There was great variation in the quantity of lime contained in different Portland cements, the limits ranging perhaps from 55 to 65 per cent. He believed that generally speaking the lime was in excess, and this was to some extent necessary to enable the material to stand the often severe tests to which it was subjected at an early stage after manufacture. He had reduced these tests with advantage, and he got a cement that was stronger after the lapse of time. But lime was not so injurious as magnesia, which also created a slime. It was well known that when concrete was subjected to the action of sea-water entering and leaving it, a deposit of magnesia was formed with most disastrous results, of which he had had considerable experience. Hence the necessity for a chemical as well as a mechanical test. Unfortunately it was not known at present what should be the constituent parts of good Portland cement, but he understood that the subject was being investigated by a competent chemist. When in the possession of reliable data he for one hoped to institute a chemical test as well as a mechanical one in the case of Portland cement. Mr. Shelford asked why

Mr. Hayter. Mr. Hayter had not, in designing the Chittravati bridge, placed the cross-girders underneath the main girders, and this opened up the subject as to the best method of supporting cross-girders. The plan he believed most usually adopted for some years after the introduction of wrought-iron for the purpose, was to rivet the cross-girders underneath the bottom boom or flange of the main girders, so that they depended for their support upon the rivet-heads. But whenever the cross-girders were deflected by a load, it was evident that the effect would first of all be to bring a strain on the row of rivets nearest the centre of the cross-girders, and this row would have to be brought into a considerable state of tension before the next row came into action. In this way the row of rivets nearest the centre line of the cross-girder fastening it to the bottom boom would be strained more than the second row, and so on in succession until the last row furthest removed from the centre line of the girder was reached, which would have little or no strain upon it. This plan, therefore, was not mechanically correct. Further, it was objectionable to depend upon the heads of rivets for support. The same remarks would apply if bolts were used instead of rivets. In the Charing Cross Railway bridge over the River Thames, which he had described in a Paper read at the Institution in 1863,[1] the cross-girders were suspended to the underside of the bottom boom of the main girders by two vertical angle-irons on each side of the bottom boom, riveted to it and continued down so as to embrace the cross-girder on either side, and to which the cross-girders were riveted. In this way the support did not depend upon the heads of the rivets but upon their resistance to shearing, and the rivets on each side of the bottom boom would act together, as they would be over one another, or in the same plane of resistance. An objection to the plan was that the outside faces of the vertical plates of the bottom boom had to be kept flush, so that the suspending angle-irons might be riveted to them, and thus the angle-irons securing the vertical plates of the boom to the bottom horizontal plates could be placed on the inside only. The plan referred to by Mr. Shelford of attaching cross-girders to the underside of the bottom boom of main girders was in every way satisfactory, and no better could be devised, as it effectually united the latter together transversely. In the Chittravati bridge, however, head-way was a consideration. If he had fastened the cross-girders underneath the main girders, the whole of the cylinders and the abutments would have

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[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 512.

had to be raised an additional height nearly equal in extent Mr. Hayter. to the depth of the cross-girders, which would have increased the cost of the structure. The plan he had adopted was the not unusual one of resting each cross-girder on the bottom horizontal plate of the bottom boom. It took its bearing on the inside bottom angle-iron, was riveted through it and through the bottom horizontal plate and to an angle-iron on the upper edge of the inside vertical plate of the boom (Plate 8, Fig. 2). A diaphragm or filling-piece was inserted at each cross-girder in the trough of the bottom boom, which was strongly attached to it and to the cross-girder. In this way the cross-girder was practically carried through the bottom boom and would bear over its width. This mode of attachment was mechanically correct, and was free from objection, and in fact was the only proper plan to follow in cases where a fixed headway underneath the bridge had to be maintained at a minimum cost. He would give reasons for preferring iron to steel in the case of the Chittravati bridge, as that subject had been raised. He had from to time considered the question, and the conclusion he had arrived at was that in cases where the spans were not great, steel was not desirable. This was specially so if the girders were deep, and the sides of lattice or bar construction, because the sectional area of the parts, which were made of the same form whether in steel or iron, was so reduced that the girders became deficient in rigidity. In 1877 his firm designed a bridge nearly a mile long, which was erected over the River Nerbudda on the Bombay, Baroda and Central India Railway. The spans were 180 feet, and the depth of the girder about one-tenth the span. Wrought-iron was used, and very properly so, as at that time there was a greater difference in cost between steel and wrought-iron than at present. It was possible that if that bridge had to be constructed now, when the relative prices more nearly approximated, that steel might be adopted, but of this he was not sure without again studying the question with the particular end in view. It would depend in a great measure upon whether it would be more economical to do so. Another matter also had to be considered, and that was the question of oxidation. Assuming that the two materials were alike in this respect—and it was probable that there was not much difference—the smaller the parts, the greater relatively would be the mischief by deterioration from oxidation, and the shorter would be the life of the bridge. If the Chittravati girders of 140 feet span had been made of steel they would have cost more than if made of iron, and would not have had the same rigidity. The question was asked whether it would

Mr. Hayter. not have been better to have made the girders of the Chittravati bridge deeper, and to answer this he would briefly summarize the past history of wrought-iron girders. It was only about forty years since they were introduced, and before that time nothing but cast-iron girders were used. Engineers at the outset were guided by experimental investigations made by Mr. Fairbairn and others. The rule recommended and generally adopted, was to make the depth of wrought-iron girders one-fifteenth of the span. After a time, however, and when the subject became better known, this proportion was gradually made greater. From one-fifteenth of the span there was a successive but very cautious increase to one-tenth, a not uncommon limit at the present time, but he had made the Chittravati girders about one-eighth of the span. He thought this was a reasonable limit to adopt, but in his own practice he did not prescribe any invariable rule, for the exact ratio was not a matter materially influencing efficiency or cost. He knew that some American engineers were in the habit of making girders very deep, even to the extent of one-fifth of the span, but he for one would not venture upon excessive depths. The parts were so much attenuated that, notwithstanding there was no greater strain anywhere than the conventional 5 tons per square inch on iron, or 6½ tons per square inch on steel, the superstructure rattled and vibrated when trains passed over at speed. In this country girders having excessive depths had not been adopted, and would not, he believed, be regarded favourably by the Government inspecting officers, and in India there was, in the interests of the public, a like strict supervision. There was not so much saving in weight as some had supposed in adopting girders so proportioned. Additional braces and ties were needed, and he had found besides that they were relatively at a disadvantage in the matter of wind-pressure, for which provision had to be made. These circumstances went towards neutralizing even the saving in weight that would otherwise result from deepening girders, and to this again must be added the greater mischief from oxidation by reason of the reduced size of the parts, as in the case of steel girders just referred to by him. It had been assumed, owing, he supposed, to the circumstance that the conical part of the cylinders was sunk almost or altogether into the bed of the river —the top of the cone being generally at about the level of the ground (Plate 7, Fig. 1)—that therefore there was necessarily a contraction from 12 feet to 9 feet in the working diameter during the sinking, which would add to the difficulty of the operation. But the cylinders of the larger diameter would be sunk to the ground-line or thereabouts; and when that was reached a length of the same diameter could be added temporarily until the full depth was attained. The ground outside could then be sloped away as far as necessary, the temporary length withdrawn, and the conical piece with the upper portion of the smaller diameter could be permanently fixed. If this plan had not been followed, as he had supposed it would have been, it was evident that the cylinders need only be contracted when sinking the last few feet, which would not be a matter of much moment. At all events he should have been sorry not to have reduced the diameter of the upper portion. To have omitted to do so would have added to the cost of the work unnecessarily. Besides, if the larger diameter of 12 feet had been continued to the underside of the girders, which was at most only about 20 feet above the bed of the river, the piers would have been unsightly, as their size would have been out of all proportion to their visible height and to the span of the openings. Mr. Berkley had alluded to cast-iron cylinders cracking during sinking. Mr. Hayter had referred to such occurrences in his opening remarks, stating that he had provided against the contingency by making the bottom length of wrought-iron strong enough to take up any strain that might be superinduced during the process of sinking. In conclusion he would remark that the Chittravati bridge was one of the least costly of the kind ever erected under like conditions, and at the same time the official and other tests proved that it was a structure of proper rigidity. He would only add that he was sure Mr. Stoney would be well satisfied with the favourable reception accorded to his Paper. Mr. Hayter.

Correspondence.

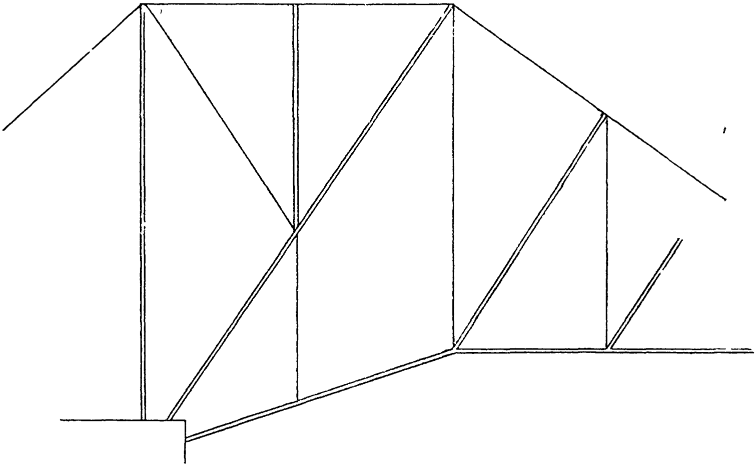
Mr. G. BOUSCAREN said that with regard to the cantilever span of the Sukkur bridge over the Indus, Mr. Robertson's Paper was specially interesting to American Engineers, as illustrating some points of difference between the methods of bridge-building in vogue in England and America. The first question which the designer of a bridge must answer before the general features and details of his plan could be determined was, "How was the structure to be erected?" In the case of an 820-foot cantilever span, as at Sukkur, this question would very probably have been answered in America "by building out with a traveller;" and one of the principal reasons for this was, that large structures were now Mr. Bouscaren.

Mr. Bouscaren. rarely erected by the contracting bridge companies, who preferred to confine themselves to the shop work, and sublet the erection to other parties who made a special business of that class of work, and were well equipped and trained to do it in that particular way. The result would probably have been a very different structure, especially as to details, from that designed by Sir A. M. Rendel. The commercial necessity of bending to the consideration of cheapness, arising from a keen competition, did not, perhaps, obtain in England to the same extent as in America, and left more latitude to the originality of the designer. The use of wire-rope carriers, although not a new feature in bridge erection, had been very ingeniously applied in this case, and seemed to have answered the purpose admirably, as no accident or mishap was recorded in Mr. Robertson's account of the work; but the time actually consumed in the erection of the span, from November 1887 to February 1889, seemed long, as compared with American practice, even after making all due allowance for the importance of the structure. Mention was made incidentally in Mr. Robertson's Paper of the large amount of drift carried by the river at certain seasons of the year, and this naturally called attention to the inclined booms at the abutment ends of the cantilevers, and the close proximity of the lower ends to the water suggested a liability to injury from drift, as well as danger to the crafts coming under the bridge at high water. It was a matter of regret to him that with all the valuable information given in Mr. Robertson's Paper, a little more had not been added with reference to the general specifications for the superstructure, as for instance, the live load designed to be carried by the bridge, the grade of steel used, and the limiting stresses per square inch allowed for the different members of the span. Such data would have been of great interest and value in comparing English and American practice at the present time.

The local conditions at the Chittravati bridge seemed to have been all that could be desired, and full advantage appeared to have been taken of them in the execution of the work. It was not clear, however, from Mr. Stoney's interesting account of the foundation work, why the inside curbing of masonry, which was found so useful in assisting by its weight in the sinking of the three cylinders under the north abutment, was not used as well for the cylinder-piers. The comparatively great cost of the pneumatic process as applied to some of the cylinder-piers for the removal of the large boulders appeared to have been due chiefly to the insufficiency of the plant; and with adequate machinery it seemed probable that time and expense could have been saved by a more liberal application of this process in lieu of divers. In cylinder-foundations, where rock and boulders were liable to be encountered, he would give preference to wrought-iron over cast-iron for the cylinder-shells. With an inside curbing of masonry, no danger of deformation in the process of sinking from lack of rigidity need be apprehended, and the wrought-iron was better adapted to resist the air-pressure and the vibrations from the small blasts used in removing large boulders and levelling the bed-rock. **Mr. Bouscaren.**

Mr. Cooper. Mr. THEODORE COOPER remarked that the span of the Lansdowne bridge alone would make it a notable structure. The peculiar skeleton of its trusses, the extraordinary act of putting up each of its large cantilevers at the makers' yard before shipment, the difficulty of erecting the structure, and the statement of its cost, rendered it especially interesting to American bridge engineers. Facility and cost of erection did not seem to have received any consideration in the selection of the proportions of the skeleton. Without endorsing the general form of truss adopted for this bridge, he thought that a very slight change in the triangulation would have been a great improvement, especially when the erection was considered. Mr. Robertson's description of the steps necessary in order to connect together the first panel of the cantilever, emphasized very strongly the faulty division of the truss at this point. Had it been subdivided by a vertical line,

Fig. 3.



Mr. Cooper. making two panels of 61 feet 6 inches, and a diagonal tension-member extending from the top of the pillars to the centre of strut No. III, as in *Fig. 3*, it could all have been erected and made self-sustaining by means of a crane or derrick of only moderate reach. The reduction in weight by thus sub-dividing the present long members, and therefore lessening the bending strains, would have exceeded the additional material needed for the new members. Other modifications could have been made, having in view the same object. The absence in this design of features considered so essential for economy and facility of manufacture and erection by the American bridge-builder, rendered an examination of the statement of cost very instructive. The total weight of iron in the trusses was given as 3,316 tons, and the cost of the ironwork was Rs.17,01,000, or £120,487, taking the Author's rate for a rupee. The cost of the erection was Rs.5,61,223, or £39,753, omitting photographs and labour for painting. These figures made the cost of ironwork £36 6*s.* 8*d.* per ton; cost of erection £11 19*s.* 9*d.* per ton, giving a total for ironwork erected of £48 6*s.* 5*d.* In addition, it was difficult to exactly apportion the other items, such as charges for quarters, workshops, boats, plant, and contingencies, which would probably bring up the above amount to £50 per ton in the finished bridge. Presumably the cost of the ironwork alone, as above given, included that of the preliminary erection at the makers' works. Assuming that this, together with the taking down again, would amount to as much as the second erection, nearly half the money was expended in this way. As the cost of erecting such a bridge should not have exceeded £6 per ton, and as, according to the American practice, accuracy of length of the parts and correctness of fitting of the connections would have been attained without the preliminary erection, American bridge-builders would gladly have discounted the actual cost of the ironwork erected to the extent of £18 per ton at least.

Mr. Fidler. Mr. T. CLAXTON FIDLER said the two bridges described in these Papers could hardly be compared. They presented a wide contrast in the lines of their design, and if possible a still wider one in the means adopted for their erection. At Chittravati the engineer boldly ventured down upon the bed of the stream, and making the best use of the dry season, succeeded in erecting his long line of girders by a method of the greatest simplicity, and at the lowest possible cost. But at Sukkur the erection of the cantilevers over the rapids in that confined gorge of the Indus presented difficulties of a very different order, which were surmounted by the employment of the

Mr. Fidler

ingenious system of wire-rope transport described in Mr. Robertson's Paper. Of course the Sukkur bridge was not the first that had been erected by a method of overhead suspension; but in this example the appliances seemed to have been worked out, in all their details, with great ingenuity, and being admirably adapted for the difficulties of the situation, they appeared to have been employed with perfect success. In connection with this wire-rope rigging, there were one or two points on which some further information would perhaps be desirable. Whenever a member of the web-bracing was sent out for erection, it had to be suspended in a transversely battering direction, and the head of the piece was held in its true position by a rope or pair of ropes, hanging in the vertical plane of the top member; but to give it the requisite lateral spread at the foot the heel-rope must apparently have been worked from some sort of yard-arm, or spinnaker-boom, rigged out laterally from the gallows-frame. Something of this kind was incidentally referred to in the Paper, but the drawings did not show this spinnaker-boom, and it would be interesting to know its length, and how it was rigged and worked. It appeared also that, in a general way, the pieces were picked up from barges moored out in the river, but sometimes the barges could not be used, and on such occasions the Author did not explain by what course the pieces were taken out into position, and how they were steered up aloft so as to avoid fouling with the existing work. Another remarkable feature was the preliminary erection of the cantilevers on staging in the makers' yard. It would probably occur to most engineers that the construction of this great timber scaffold must have been attended with an expense which seemed disproportioned to the object in view, if that object was nothing more than to present the parts together so as to secure their accurate fitting; although the adjustment of such members, meeting at varying angles of transverse inclination, might very likely have been a complex matter. It was obvious, however, that such a proceeding would greatly facilitate the erection in mid-air by this wire-rope system of suspension; and perhaps the timber stage at Millwall, and the wire-rope rigging at Sukkur ought to be considered as complementary parts of the same scheme. It would be interesting to know how far they were so regarded by the engineers engaged in the work. Apart from the method of its erection, the Sukkur bridge presented some remarkable features in its design, which might be an interesting subject for discussion if the materials were at hand. But the Paper was concerned with the erection rather than with the

Mr. Fidler. bridge itself. The drawings showed the anchorage only in diagrammatic outline, and did not give the sectional area of any of the steel members; while no information was afforded as to the live load or the contemplated wind-pressure, nor as to the deflection of the bridge under these forces. It was evident, however, that the structure differed from the ordinary form of cantilever-bridges. It was not a balanced cantilever anchored vertically downwards at the tail end, but might perhaps be described as a single-armed cantilever, strutted against the abutment at the foot, while the head was held back by an inclined back-stay and anchorage, like those of a suspension bridge. The adoption of this form was evidently attended with certain consequences. The contraction and expansion of the backstay must cause the pillar to rock upon its bearings, and the cantilevers to rise and fall at the outer end. These movements would be produced by change of temperature, and also by the imposition and removal of the live load. So far as they were due to change of temperature they would be entirely avoided in the ordinary form of balanced cantilever; but, on the other hand, the horizontal movement at the top of the pillar, and the consequent drooping of the outer end, due to the imposition of the live load, would be less in this tied cantilever than in the ordinary balanced form. The maximum movement, from a condition of no load and cold temperature to a condition of full load and hot temperature, would of course be the sum of the two separate effects; but unfortunately the movement due to load could not be calculated in the absence of the necessary data as to the weight and as to the sectional area of the members; though it appeared probable that the maximum movement in this design was on the whole greater than it would be in a balanced cantilever. It was, no doubt, provided for in the calculated fibre-stress arising in the slender ankles of the pillar and main strut. The comparative anatomy of bridges suggested also the question of the cost of this inclined anchorage, as compared with that of a vertical anchorage and a steel strut, by which it might conceivably have been replaced. The question, however, would be governed by local considerations, and the presence in this case of the natural rock at a level considerably higher than the abutment, might have suggested the method here adopted for counterbalancing the cantilever.

Mr. Gaudard. Mr. Jules Gaudard recalled the fact that the Fribourg suspension-bridge had been erected in 1832–34 by the French engineer Chaley, across a span which was equal to that at Rori, and which was at the time the widest that had ever been bridged in any country.

Mr. Gaudard.

At Niagara and at Brooklyn, Roebling appeared to confirm the idea that suspension-cables alone offered such a combination of lightness and tenacity as could be trusted for spans of such size; but a method of constructing rigid arched-ribs was making its way, in which wire cables or back-stays were used only as a temporary support for the permanent structure during the successive phases of its erection. In this way the cast-iron arch of 230 feet span, over El Cinca in Spain, was built in 1866 by Messrs. Schneider and Co. of Creusot without any scaffolding; and by the same means, in 1873, Eads erected the three great steel arches at St. Louis, which were again surpassed in width by the Garabit arch of 541 feet, and by the arches of Maria Pia and of Dom Luis at Oporto, which were executed by Messrs. Eiffel and Seyrig, and all of which were erected without any staging, by the aid of wire-rope stays. At St. Louis the temporary suspenders were accompanied by trestles of timber which abutted upon the piers, and flanked them on either side in the manner of cantilevers. But if the cantilevers were capable of sustaining the weight of the permanent bridge, why could they not take its place in sustaining the weight of the train? Such was the consideration which had guided Messrs. Fowler and Baker in spanning the Firth of Forth. Like the shooting stem of a plant, the cantilever sustained by its own strength the successive elements which it assimilated in its progressive growth; so that the temporary supports, instead of having to carry ultimately the whole weight of a semi-arch, had only to carry the fractional members of the structure, which themselves were gradually built out by the aid of movable platforms. From the day when this method of building not only chimney-shafts and light-house towers but also inclined members, was learnt, the art of erecting colossal structures made a new and rapid advance. The Rori girder was a modern witness of this fact, and it remained only to record in fitting language the consummate ability of the engineers, and the coolness and bravery of the workmen of all ranks who had co-operated in its erection. Some slight criticism might, however, be offered on æsthetic grounds. The Forth bridge had been objected to on account of its inelegant appearance, which was like that of a huge mass of scaffolding; although nothing could be more rational than its general outline, which recalled the figure of a diagram of bending moments in a continuous girder, with its parts grouped symmetrically about the supports. But it must be avowed that the appearance presented by the Sukkur bridge seemed far from being an artistic improvement. The logic of it, certainly, was conspicuous enough. Every stage

Mr. Gaudard. in the execution had been wisely calculated. The abutment offering a point of support for the thrust of the lower boom, the latter had been made use of to sustain the foot of the vertical member IV (Fig. 1, Plate 4), just as a pier would support it; hence this vertical might be treated as forming a counterpart to the pillar A, with which it was connected by the horizontal member AB; while from the summits A and B reached in each direction the back-stay or "guy," and the tie BE, sloping with symmetrical inclinations. But it was precisely this false symmetry about a wrong axis that had something hipped and limping about it. The jump or sudden change of height which occurred at the end of the central span, separating it from the pointed nose of the cantilever, expressed the articulation of the system; but the defect of level was not without an injurious effect upon the appearance. It was not clearly apparent why the struts of the web-bracing should change the direction of their inclination on each side of the vertical II; and moreover, the swelled form of the great struts was perhaps a little exaggerated. It would be interesting to discuss the comparative merits of this connecting-rod form, and of the tubular form adopted at the Forth bridge, which was more consolidated, well able to resist compressive stress, and lent itself easily to the progressive shifting of the movable platforms, but presented on the other hand the inconvenience of a complicated intersection at the joints of the framework. If, then, cantilever bridges aspired to better æsthetic conditions, it appeared that for them, beauty could hardly consist simply in "the splendour of truth;" but that, as architects confessed when they built false windows, art sometimes demanded a little dissimulation.

Mr. Gaudard then referred to a preliminary design prepared by Messrs. Bartissol and Seyrig for a bridge at Lisbon.[1] Proposing a system of cantilevers, the Authors disguised the break at the articulations under the elegant appearance of arches with a continuous elliptical curvature, sacrificing the logical form of the central girder, which was made to decrease in height towards the centre instead of giving it the rational bowstring form. In structures placed above the bridge-platform, it was at least possible, in default of the arch, to imitate the curvature of a suspension-bridge. The girder at Rori, for example, might be modified as in *Fig. 4*. Referring to the Chittravati bridge, Mr. Gaudard remarked that it was a very substantial work, the features of which

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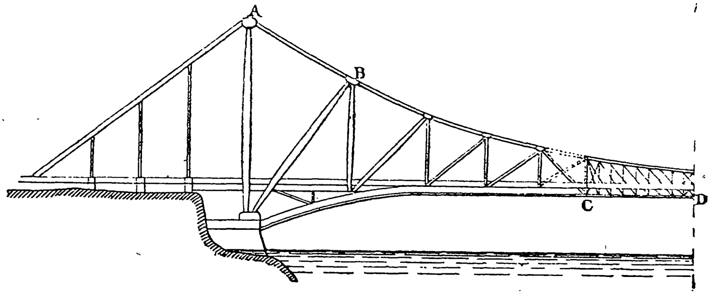
[1] Paris. imp. Barré, 1889.

Mr. Gaudard.

had doubtless been dictated by local conditions connected with the transport of materials and the employment of native labour. The old bridge having been undermined, the constructors of the new one had desired, at any cost, to sink the foundations down to the solid rock. With the object of employing, as far as possible, an economical construction in concrete, they had recourse to cast-iron cylinders, which were mostly sunk with open tops to facilitate the dredging, although they had not neglected to avail themselves of subsidiary appliances, such as pulsometer pumps, diving operations, and the use of compressed air. But although piers founded upon the rock might well justify the adoption of continuous girders, they had employed independent girders throughout, and this form had probably been selected in consequence of the separate erection of each span upon the bed of the river. Subject to these considerations, Mr. Gaudard went on to indicate the points in which this work seemed to differ from the prevailing tendencies of continental practice. Since the execution, in 1859, of the foundations of the bridge at Kehl, by Vuignier and Fleur-Saint-Denis, masonry piers in single blocks had generally been preferred to multiple columns with cast-iron casing—a preference which was even more strongly grounded in the case of a narrow single-line bridge. The pier could be kept plumb in the process of sinking with great certainty; and if any deviation took place, it was of less importance when the constructor was relieved of the necessity of fitting bracings, or connections between the columns; the progressive building of the masonry, *pari passu* with the sinking, dispensed with the employment of auxiliary loads—at least in the case of pneumatic sinking, which required only small shafts; and lastly, there was the endeavour to reduce the employment of metal in the piers, even though it might be attended with certain risks of settlement or cracking when the upper part of the

Fig. 4.



Mr. Gaudard. masonry was hung up in some tenacious bed of material while the lower part descended. It might be presumed that the piers of the old bridge rested in the sand, without reaching either the clay or the boulders; at the depth where the boulders were buried, they would seem to be safe from undermining, and to constitute a sort of coarse concrete nearly as good as that concrete by which they were replaced. If, when the cylinders had been sunk more than 50 feet below the river-bed, a material was met with that was difficult to excavate, the fact was an indication that the sinking might be stopped with perfect safety. Probably the screw-piles which had held good in the old work, had reached the point of refusal at the first large stones that were met with; and the conclusion that it would have sufficed to stop sinking on meeting the boulders, seemed to be again confirmed by the weight of rails employed to force the descent of the cylinders. For example, pier No. 11, when empty and undermined at the base, carried 444 tons of rails (222 on each cylinder), while the pier when completed and properly bedded, would only have to carry 160 tons of dead load, and 177 tons of test-load, or 337 tons altogether. The frictional resistance varied with the depth and with the lateral pressure exerted by the soil. If the soil was supposed to be without cohesion at all depths, so that the total pressure increased as the square of the height, the idea of a pressure per square foot, the variations of which were shown in Table II, might be replaced by an abstract number or a coefficient of friction, constant for any given material. As it was difficult to estimate correctly the pressure of earth, it had been proposed to take as a basis of comparison the simple pressure of water. Applying this idea to the friction of 2·13 cwts. per square foot, given in Table II, and referring to the depths, of which the mean was 41 feet, the following results were obtained:—Friction for this depth $= 2 \cdot 13 \times 41$; corresponding imaginary pressure of water $= 0 \cdot 2787 \times 41^2$; ratio $= 0 \cdot 19$. Table I, with a mean friction of 2·71 cwts. for a mean depth of 55 feet, gave a ratio of 0·18, agreeing very well. In the case of metallic caissons sunk in gravel or sand the value of this coefficient had been found to be from 0·4 to 0·6; but its value would be greatly influenced by the unknown degree of the cohesion of the soil in the deep beds. The ruptures occasioned by the explosion of dynamite might be referable to the want of space, for in the vast caissons at Brooklyn powder was employed without danger. However, cylinders of 8 feet 2 inches had been quoted at Palma del Rio on the Guadalquiver, where explosives were used to produce a kind of earthquake, with

Mr. Gaudard.

a view of prompting the descent. The last observation he would make with reference to the Chittravati bridge was that with foundations which were at once sufficiently costly, and abundantly safe, European practice would certainly have increased the width of the spans and connected the girders. The bridge at Bordeaux had piers of the same calibre—that was to say, they consisted of double columns, 12 feet in diameter, but without tapering at the top—which carried girders of 254 feet span, and that with a double line of railway. The foundations had been carried down to the gravel (by compressed air) at a mean depth less than that at Chittravati, viz., 25 to 56 feet below the bed; while the total height of the columns was from 78 to 87 feet. It did not appear that the very convenient process of erection employed at Chittravati should constitute an imperative reason for abandoning the continuity of the girders. In an analogous case, Robert Stephenson united the tubular girders of the Britannia bridge over the piers, although their acquired deflection rendered the continuity imperfect. But now that the method of accurately calculating the deformations was known, the theoretical conditions admitted of being more perfectly realized. When a new girder in the series had been lifted into place, it was only necessary to give to its forward extremity a super-elevation, so as to make the rear extremity prolong tangentially the deflected line of the preceding girder; and then, when the riveting was done, the letting down of the forward extremity upon the bed-plate would procure for the preceding span the relief afforded by continuity in respect of the dead load.

Mr. Gillott.

Mr. Thomas Gillott noticed with approval in the Chittravati bridge that the plates and angles in the boom-joints, where separated for shipment, were broken with splices, and not square across, as was often done. This involved more riveting on the site and greater risk of damage in transit, but made sounder work; and he asked the Author whether any injuries occurred during conveyance, such as would cause him to alter the breaks of the plates and angles, had such a design to be repeated. The number of rivets in each span requiring to be put in on the site (11,336) was equal to seventy-seven rivets per ton of work, which was somewhat high, seeing that the bridge had not a plated floor; and he would ask the Author what percentage of loose rivets put in by the native workmen had to be cut out on inspection. Some of the important ones connecting the cross-girder ends through one boom web, gusset, and vertical strut, appeared as though they would have to be knocked down single-handed (*i.e.*, by one man), and if the points were heated in a fire it would not be easy to

Mr. Gillott. get the holes well filled under the rivet-heads. This led him to point out the advantage of the portable compressed-air riveters which he had recently adopted, and by which the greater part of the work could have been closed. A portable furnace with an air-blast would heat 200 or 250 ¾-inch or ⅞-inch rivets of average length per hour, with a consumption of about 1½ gallon of creasote oil, costing in this country 2*d.* to 2½*d.* per gallon; and as they were heated throughout their length, the holes were far better filled than when only the points were made hot, as was done when an ordinary fire was used. As an air-pressure of 45 lbs. per square inch would suffice for ⅞-inch iron rivets, there was no trouble with leaky joints, or burst hose-pipes, and the work of one of these machines was equal to that of three sets of hand-riveters. This was an important item in the erection of bridges, and he would direct attention to the advisability of the designs being prepared so that power-riveters could be used as much as possible.

Mr. Hogg. Mr. C. P. Hogg remarked that with reference to the information given by Mr. Stoney as to surface-friction in sinking the cylinders of the new Chittravati bridge, it might be observed that the friction per square foot of imbedded surface depended not only on the nature of the strata, but even to a greater extent on whether the cylinders were exactly vertical, for the greater the deviation from the vertical, the greater would be the friction per square foot. In the Alloa railway bridge across the Forth, erected in 1882–84, there was nearly 2,000 lineal feet of cylinder sinking. The cylinders were 5 feet, 6 feet, and in some piers 8 feet in diameter. During the progress of the works several good opportunities occurred for accurately observing the surface-friction, and the engineers, Messrs. Crouch and Hogg, MM. Inst. C.E., found it to vary from 2 cwts. to 5 cwts. per square foot, the higher rates being observed when the cylinder was out of the vertical, or on resuming work after the operations had been suspended for several weeks. One of the 8-foot cylinders was sunk 74 feet below the river-bed through the following strata:—

	Ft.	Ins.
Silt and sand	2	0
Muddy sand, clay, and stones	14	0
Sandy mud, and stones	14	0
Running sand, mud, and stones	17	0
Hard sand, stones, and clay	2	0
Blown sand	14	0
Clean sand	9	0
Hard gravel, sand, and clay	2	0
Total	74	0

At the finish, the surface-friction was 2·37 cwts. per square foot of imbedded surface. In the observations made at the Alloa bridge there was nothing to show that, under similar circumstances, the surface friction increased per square foot as the depth increased. This had been quite confirmed by observations made during the sinking of the caissons of the Dalmarnock bridge, just completed by Messrs. Crouch and Hogg across the Clyde at Glasgow. The caissons for the piers of Dalmarnock bridge were constructed of wrought-iron, and were sunk by the pneumatic process from 50 to 55 feet, through fine muddy clay and sandy mud. They were of an oblong form, with parallel sides and semi-circular ends, the dimensions at the cutting edge being, length 63 feet, and width 9 feet, and at 56 feet above the cutting edge, length 62 feet 3 inches, and width 8 feet 3 inches. On account of the large area of imbedded surface the observations were of considerable value. The results were given in the accompanying Table, and might be compared with those on p. 290 of vol. li. of the Minutes of Proceedings. The net sinking-weight in the Table was the weight of the caisson, concrete, air-locks, &c., minus the lifting force due to the air-pressure in the working chamber at the moment the caisson began to sink. The values of the surface-friction were probably somewhat high as the caissons were slightly twisted. Mr. Hogg.

TABLE OF SURFACE-FRICTION AS DEDUCED FROM OBSERVATIONS MADE DURING THE SINKING OF THE CAISSONS OF DALMARNOCK BRIDGE, GLASGOW, BY THE PNEUMATIC PROCESS.

Caisson.	Depth of the Cutting-Edge below the River-Bed.		Area of the Imbedded Surface of Caisson.	Net Sinking-Weight = Weight of the Caisson, Concrete, &c., minus the Lifting Force due to Air-Pressure.	Surface-Friction per Square Foot of the Imbedded Surface of the Caisson.
	Feet.	Ins.	Square Feet.	Cwts.	Cwts.
No. 1	38	9	5,251	18,974	3·61
	46	6	6,301	24,674	3·92
	49	5	6,684	25,754	3·85
	53	5	7,211	25,754	3·57
No. 2	47	1	6,380	22,594	3·54
	53	0	7,155	24,640	3·44
	54	1	7,301	24,640	3·37

Mr. Macdonald.

Mr. Charles Macdonald observed that the Paper presented by Mr. Robertson, on the Lansdowne bridge, being confined to a description of the mode of erection, with but general reference to the design, must necessarily narrow the range of discussion within limits which were scarcely adequate to the importance of the subject. The problem was to construct a bridge across a clear opening of 790 feet, without the use of temporary supports from the river-bed; and as a matter of course, with due regard to the cardinal principle that the best engineering was that which most fully answered its purpose at the least cost. The cantilever type of superstructure was doubtless selected by reason of the fear that the false works required to sustain a simple girder during erection would be carried away by drift. At this distance, and without sufficient knowledge of the river in question, it was impossible to say whether a different design would not have been advisable. If there were any periods of quiet water on the Indus, and if such a period (which need not exceed eight weeks) could have been relied upon at any given season of the year, it was safe to say that a plain truss of 800 feet span, between the centres of the end supports, could have been substituted for the present design at a greatly reduced cost. Assuming, however, that the cantilever type was the most available, it was not probable that the particular arrangement adopted at Sukkur would be repeated, from motives of economy, at least. Referring to the table of weights it would be seen that after deducting roadway and rails, the structure weighed 3,220 tons, distributed as follows: from anchor to centre of pillar, 420 tons, each side; from centre of pillar to centre girder, 1,062 tons, each side; centre girder, 256 tons. From this it appeared that the weight per lineal foot of the several divisions was as follows:—

$$\text{Anchor arms, } \frac{420 \text{ tons}}{247\cdot 77 \text{ feet}},\ 1\cdot 7 \text{ ton, or } 3{,}808 \text{ lbs.}$$

$$\text{Cantilever arms, } \frac{1{,}062 \text{ tons}}{310 \text{ feet}},\ 3\cdot 42 \text{ tons, or } 7{,}660 \text{ lbs.}$$

$$\text{Centre girder, } \frac{256 \text{ tons}}{200 \text{ feet}},\ 1\cdot 28 \text{ ton, or } 2{,}867 \text{ lbs.}$$

The disparity between these figures indicated an unscientific division of lengths, as between the central span and the cantilever arms. An increase of the length of the centre span would undoubtedly result in a decrease of the total weight of the bridge. The most striking feature, to an American engineer, in this table

Mr. Macdonald.

of weights, was the excess of material required over what would be considered the best practice in the United States. It was quite within bounds to assert that a saving of at least 30 per cent. might have been made by a re-arrangement of the general proportions and modification of details so as to permit of economical erection; and this, without in the least impairing the strength or durability of the structure. It was to be regretted that the cost of the Sukkur Channel was allowed to appear in this connection, as the tendency was to confuse the statement of cost of the Rori Channel, which was the only one calling for special remark. The item marked ironwork for the Rori Channel was put down at Rs.17,01,000, which, converted into pounds sterling per ton (assuming the value of the rupee to be 1*s.* 5*d.*, and the weight 3,316 tons) became £36 6*s.* 8*d.* Probably a considerable part of this cost was to be accounted for in the expense of assembling "the entire steel-work upon a timber scaffold in the makers' yard before shipment," as reported by the Author. A bridge which was properly designed, and faithfully inspected during its manufacture at the shops, was certain to come together on the ground; and there could be no excuse for compelling the purchaser to pay the extra expense of shop erection, unless it was to shift the responsibility of accuracy from the shoulders of the engineer to those of the manufacturer. Hundreds of thousands of tons of bridge-work were erected in America every year; and, if a single span had been assembled at the shops during the past decade, it had been the exception to a universal rule. The methods pursued in erection appeared to have been judicious and economical, considering the difficulties inherent in the design. The cantilever presented most favourable conditions for the men in the field, when the details were so arranged as to permit of movable derricks. In this case, if the original design had involved a permanent tie from the top of the pillar to the middle of strut III, with a suspender from this intersection to the floor, and a strut upwards to the horizontal tie, a great saving in weight and in cost of erection would have ensued. The erection appeared to have cost £12 3*s.* 6*d.* per ton, irrespective of some small items of general expense. This was equivalent to 2·63 cents per pound, American money; and was about double what similar work was done for in that country. It was scarcely reasonable, however, to criticize the cost of work when men were subjected to a normal temperature of 100 degrees, with a maximum of 180 degrees in the sun. The wonder was that so much was accomplished, under such unfavourable conditions.

Mr. Macdonald. The delays occasioned by the removal of boulders from many of the cylinders would seem to indicate that the pneumatic method of sinking might have been used to advantage in the Chittravati bridge. It was a matter of surprise to note the high cost of what little was done by this process as compared with dredging and diving. In America, in all western rivers where the bottom was liable to scour, it was the custom to sink masonry piers by compressed-air, the caisson containing the air-chamber being constructed of timber. By this method it was comparatively an easy matter to remove obstructions, and when the element of time was considered the total cost of the work was greatly reduced. In the case of the Indian rivers, where masonry was not required to resist ice, it was a good practice to build cylinder piers; but it would be quite possible to connect the cylinders in pairs by an air-chamber at the bottom, supplying the weight for sinking by piling loose stone upon the space between them, and if necessary carrying up a concrete lining inside. By this method the boulders which caused so much delay in piers Nos. 10 to 14, could have been taken up through the air-locks at moderate cost, and nearly all the expense attending the loading and unloading of the cylinders would have been saved. The superstructure of the Chittravati bridge was said to be of the Murphy-Whipple type. This was rather a strained application of the term. Messrs. Murphy and Whipple were pioneers in developing a system of bridge construction specially adapted to rapid and economic erection, in which the principal members were connected by pins, and the only field-rivets required were of secondary importance. A truss, such as either of these gentlemen would have designed for similar spans to those at Chittravati, could have been coupled up and made self-sustaining in a few hours, and the completion in every detail assured within three days. In the bridge described in this Paper there were no less than eleven thousand three hundred and thirty-six rivets to be driven in each span before it was ready to be lifted into place; and this fact should make an engineer hesitate before selecting a type of construction which involved so many chances of imperfect work in the field, to say nothing of the increased risk of loss from flood, owing to the prolonged exposure upon the supports; or of the extra cost of doing work by native labour which might have been done to better advantage at the shops. The amount of metal put into bridge trusses in India, judging by the examples described in recent professional papers, could not be accounted for upon any rules of economic proportion with which American engineers

Mr. Macdonald

were familiar. The train-load could not be heavier than that in use in the United States, and the factor of safety was substantially the same. Why, then, should a span of 140 feet over all weigh 146 tons 12 cwt. in India, while a span of the same length, strength, and durability, weighed but 80 tons in America? It would be of interest to know whether the equation of cost between the piers and superstructure was such as to give minimum results for the completed structure. The total cost was given as £101,428, which seemed excessive for the length of the bridge involved; but in the absence of detailed statements, it was impossible to determine where the excess, if any, arose.

Mr. Seyrig.

Mr. T. Seyrig said, that in the erection of the Sukkur bridge, it became necessary to employ successively several different methods of work. This appeared to go a long way towards deciding whether the original design of the structure was entirely adequate. It was at once elaborate and complicated. The apparent simplicity of the general lines seemed in a large measure to have lost its advantages in the complication of the details. It had also led to the result that in the erection very heavy parts had to be handled. Except in special cases, it could not be advantageous to lift pieces weighing as much as 14 tons, and this would most probably have been avoided if the work on the spot had been more considered while designing. Bearing in mind the questions of ease and safety, and more especially economy of erection, the best practice would limit the weight of parts to be lifted to 2 or 3 tons, and this was particularly the case when rope tackle had to take the place of staging. As it was, the erection of a single span had necessitated not only some important wood staging, and a complete set of rope tackle, but also a temporary iron staging for the central span. The result told upon the total cost, which amounted, including special plant, to about Rs.811,000, or £57,450 for 3,316 tons. Making allowance for all special circumstances, distance, &c., £17 6*s*. per ton was certainly a very heavy price when compared with what had been realized elsewhere, owing to better provision in design.

The difficulties encountered (and so frankly stated by the Author of the Paper on the Chittravati bridge) during the sinking of the cylinders, were typical of such undertakings, and they seemed to raise once more the question whether it was really best to sink cylinder-foundations by dredging. It was true that in soft ground and at moderate depths it could be easily and safely managed; but the slightest accident would sometimes upset all provisions, often more than doubling both time and cost. In the Chittravati

Mr. Seyrig. foundations, the pneumatic process had been resorted to when emergencies occurred. It was barely satisfactory, the plant being old, and the cylinders often cracked through previous blasting operations. Under such circumstances, it was impossible to consider the work done, and its cost (443 rupees per lineal foot), as at all representative of what it should have been if the greater part of the sinking operations had been done pneumatically. The mean cost of sinking, deducting the portions done by hand-labour, was 42 rupees, or £2 19*s.* 8*d.* This price could certainly have been considerably lowered if pneumatic appliances had been used throughout, and it was moreover certain that the possibility of examining the ground during the process of cleaning the bearing surface, and of laying and ramming the concrete when the excavation was completed, were advantages which increased the value of the whole work to such an extent that Continental engineers now almost universally avoided any method which did not insure the examination of the foundation ground *in sitû*, and at the same time prevent the inconvenience and danger of depositing concrete under water.

Mr. Wilson Mr. Joseph M. Wilson remarked that the two bridges under discussion presented widely different conditions in reference to design and facilities for erection. While the total length of the Chittravati bridge was considerable, the spans were comparatively short, and allowed the adoption of an economical type of superstructure, which called for no special comment, except that in noticing the American form of outline with its familiar name of "Murphy-Whipple," he could not but observe the absence of pin connections, which to an American mind would have considerably facilitated the erection. The engineer was to be commended, however, for the skill with which he had availed himself of the natural advantages of the location, in constructing the sub-structure as well as the superstructure, and for having successfully completed the work in what Mr. Wilson believed to be a very short time as compared with Indian work generally. It was well known that the development of pin-connected trusses of this type, having vertical compression and inclined tension web-members, had reached high perfection in the United States. The uncertainty of the strain, however, in the inclined web-members towards the centre of the span, where ties and counters occurred in the same panels, together with other considerations, had led some engineers, himself among the number, to favour the adoption of triangular trusses, where certain web-members were exposed to alternating stresses of tension and compression, according to the position of the moving load. He had had considerable experience in the inspection of bridges in service, and had never observed any wearing action in the pins of structures of the "Murphy-Whipple" type, even after years of use, and in cases where the pins and links were not designed according to the most modern ideas in reference to areas of bearing surfaces, bending moments, &c. His attention had been called, however, to the case of a bridge of his own design on the triangular system, where an action was noticed on the pin which had never been observed before. It was a small structure in which the effect of the variable live-load was severe as compared with the dead-load. After it had been in service for about five years a change in the alignment of the road necessitated the removal of this bridge to another location. In taking it down it was discovered that the pins had been worn into grooves at the bearings of the links, in some places as much as one-eighth of an inch in depth, these grooves being almost as clearly defined as if cut by a tool. The pins and links had been well proportioned for bearing surface, and it was evident that the result had been due to the turning of the pins in place. It was thought that the action of the alternating stresses in the links, first a push and then a pull, caused this rotary motion, and that if the pins had been secured from turning the difficulty would not have occurred. Where the stresses in each member of the truss were always of one kind in the same member as in the "Murphy-Whipple" type, giving a constant bearing on the pin, there did not appear to be this tendency to revolve. Mr. Wilson.

He observed that the Sukkur bridge, in common with other cantilevers, presented an obvious mode of procedure in the erection, but the large sizes and weights of the members to be handled required careful treatment, and the work seemed to have been well carried out. As there were evident delays in the receipt of material from England, no criticism could be made on the time taken for the erection.

Mr. Hayter. Mr. Harrison Hayter, Vice-President, would, in the absence of Mr. Stoney, reply to the correspondence in so far as it related to the Chittravati bridge, and had not been noticed in his previous remarks. Much of the correspondence was from America, and it was useful to know the views of American engineers on English practice. In reply to Mr. Bouscaren, he assumed that Mr. Stoney had not used an inside curbing of masonry to assist in sinking the cylinders of the piers because he would not desire to contract the working space, and also, probably, Mr. Hayter. from the difficulty of fitting masonry to a surface where there were flanges, ribs, and bolts; this objection would not hold in the case of concrete which was used for the filling inside the cylinders, and which no doubt also would cost much less than masonry. As regards the adoption of the pneumatic process for this purpose, he had used it extensively, but he was opposed to it if it could be done without, especially if the cylinders were in deep water. Men working under air-pressure did so at a disadvantage both as regards progress and bodily discomfort, and often at the sacrifice of health. He did not believe that the cost would in any way have been lessened, as Mr. Seyrig also seemed to think, if the pneumatic process had been adopted throughout, and he considered Mr. Stoney had done well in limiting its use. Mr. Hayter had used elsewhere cylinders entirely of wrought-iron up to the conical length, but they added to the cost and were not so readily put together as cast-iron cylinders made in segments bolted to one another. All that was necessary was to have the bottom length of wrought-iron as he had done in the Chittravati bridge, and if this were made strong enough to take the strain, there was little fear, under ordinary conditions, of the cast-iron cylinders cracking during the process of sinking. Mr. Jules Gaudard was right in the supposition that he had designed the bridge with independent girders throughout, instead of continuous girders, in order to facilitate erection. Continuous girders could not have been so readily dealt with, and would have involved more riveting, and of a more difficult character. Continuity also added to the complication where the sides of the girders were composed of struts and ties and not of solid platework, and there were more parts not duplicated. He did not believe that any saving in cost would be effected by connecting the girders together over two or more spans in a case like the Chittravati bridge. He preferred two cylinders instead of one for the piers. A better base to the piers was thereby secured, and the surface-friction was reduced to a minimum in sinking. In designing bridges for India, and in like places where the climate was hot, and where the locality of the structures was at a distance from manufacturing centres, the greater the facilities that could be afforded to the engineers who erected the work, the more probable it was that success would be ensured and expense saved. He was not aware that any injury had resulted during transit by the plates and angle-irons where they were separated for shipment being broken with splices and not square across. He had followed both

Mr. Hayter.

plans, but he found that if the ends were well protected with temporary timbers they reached their destination uninjured, and sounder work (as Mr. Gillott remarked) was the result when the girder was erected. He believed that there was no more likelihood that there would be loose rivets with native riveters than there would be if Englishmen were employed. There was no reason, however, why machine-riveting, either actuated by steam, water or air, should not be introduced in India as well as in America or England. He agreed with Mr. Hogg that the surface-friction encountered in sinking cylinders depended not only upon the nature of the strata penetrated, but also upon the cylinder being kept vertical, and the table Mr. Hogg had sent was instructive. Compared with that given by Mr. Stoney it appeared that the surface resistance was much less in the case of the Chittravati bridge than in that of the Dalmarnock bridge, owing no doubt to the different conditions. Mr. Macdonald, from his connection with America, was probably unaware of the very proper restrictions imposed upon engineers with regard to iron bridges in England and India. The Chittravati bridge was designed with the authorized factors of safety, and with a limited allowance for deterioration, which was desirable now that iron bridges were being continually renewed or strengthened owing to oxidation and decay. He would not, as he had already said, sacrifice efficiency by making girders of the excessive depths sometimes introduced in America, but which would not be tolerated in England or India, and he considered that no material saving in weight would result if the deep girders were so braced and tied as to be as efficient as they could be made. The equation between the cost of the piers and superstructure was such, he believed, as to give the best results for the completed structure. Although the length of the spans was the result of a suggestion from India, they quite met his approval as being the most economical to adopt considering the conditions; and that the design of the Chittravati bridge was as suitable as could be devised seemed to be evident from the fact that whilst it was a rigid structure the cost was very low compared with that of other bridges across rivers of a like kind. Mr. Wilson seemed to prefer pin-connections, which Mr. Hayter had largely used, and which Mr. Wilson said would to an American mind have facilitated erection. The practice, however, in England differed from the American in this respect. The use of pin-connections was now rather the exception here than the rule, and the reasons for this preference should apply with greater force to iron structures which had to be transported

Mr. Hayter. to and erected in India. The accurate fitting necessary and the liability to alteration of shape by transport and climatic changes were unfavourable to the adoption of pin-connections on a large scale in such places as India.

16 December, 1890.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Papers by Mr. Robertson and Mr. Edward Stoney, descriptive of the Sukkur and of the Chittravati Bridges respectively, occupied the evening.

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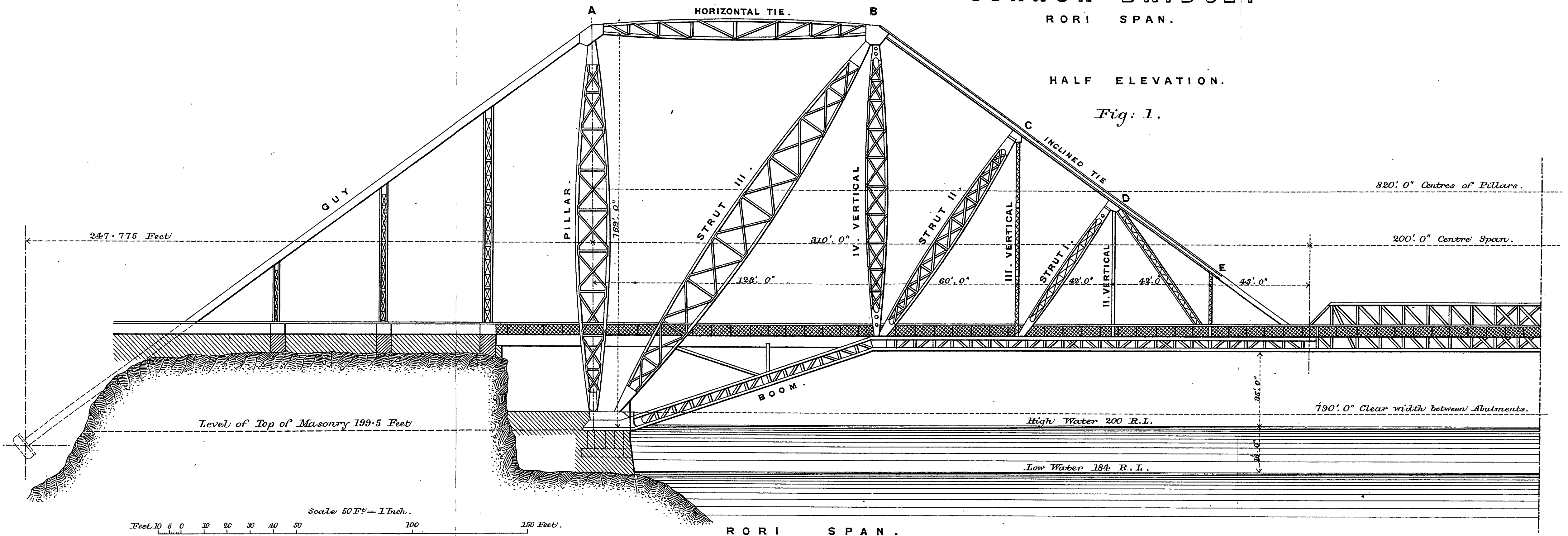
PLATE. 4.

SUKKUR BRIDGE.

RORI SPAN.

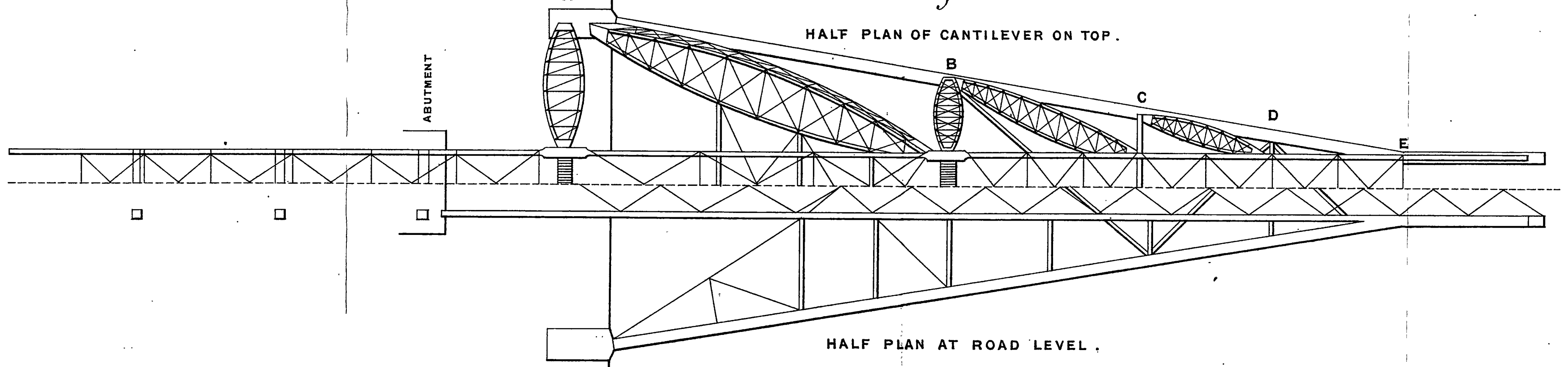
HALF ELEVATION.

Fig: 1.



RORI SPAN.

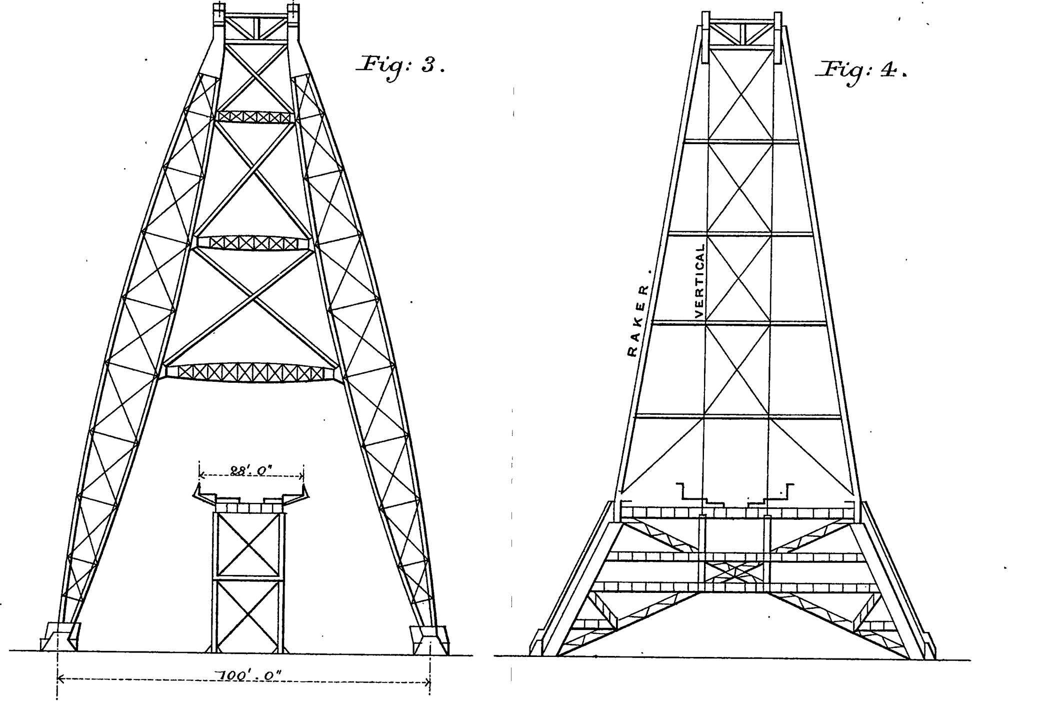
Fig: 2.



Scale 50 Ft = 1 Inch.

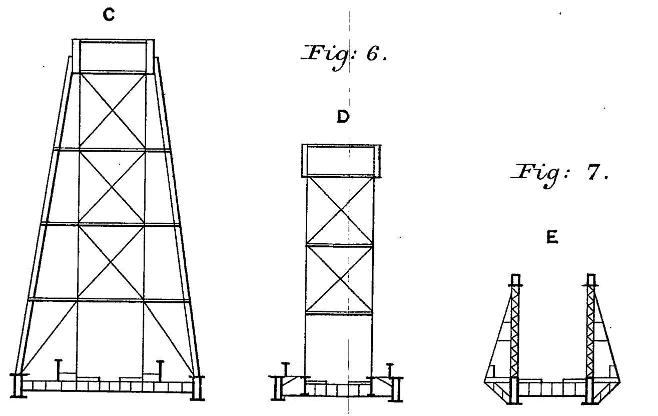
Feet 10 5 0 10 20 30 40 50 100 150 Feet.

Fig: 3. *Fig: 4.*



CROSS SECTIONS.

Fig: 5. *Fig: 6.* *Fig: 7.*



CROSS SECTIONS.

F.E. ROBERTSON, DELT

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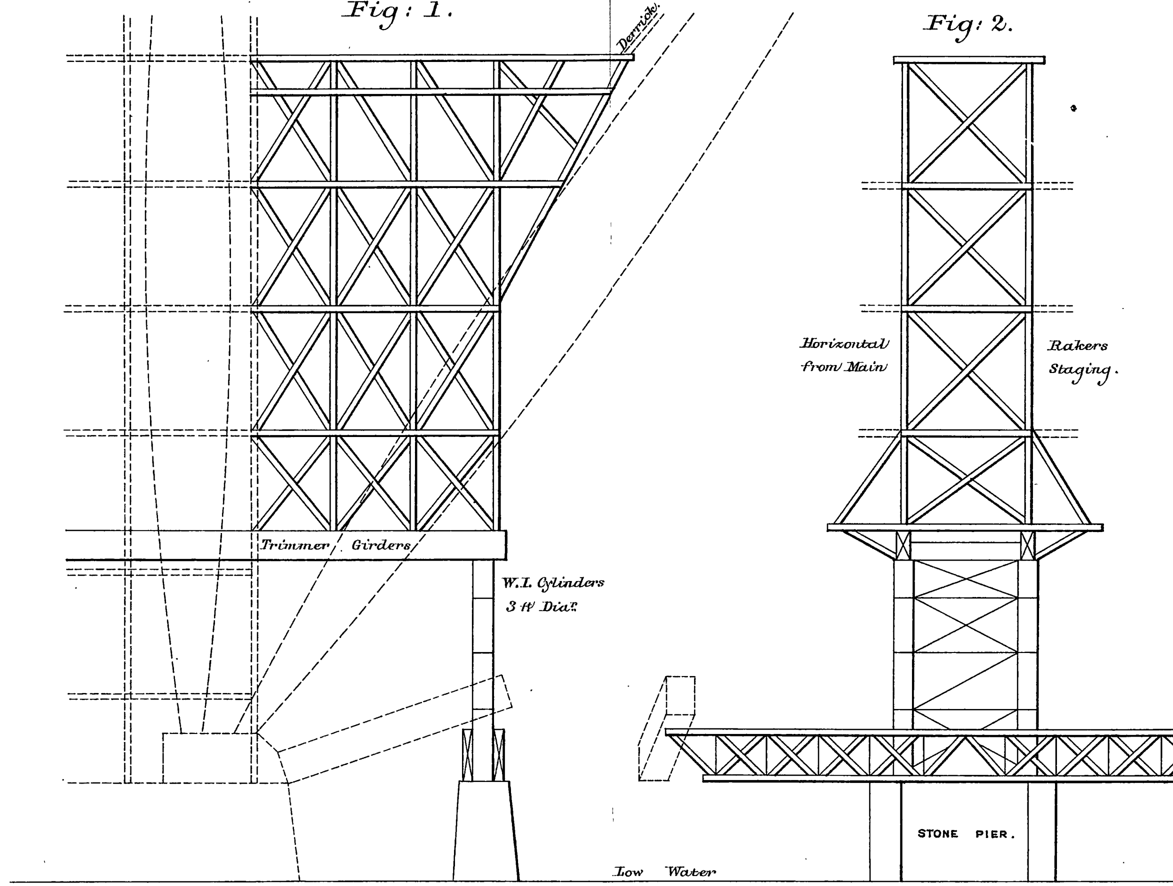
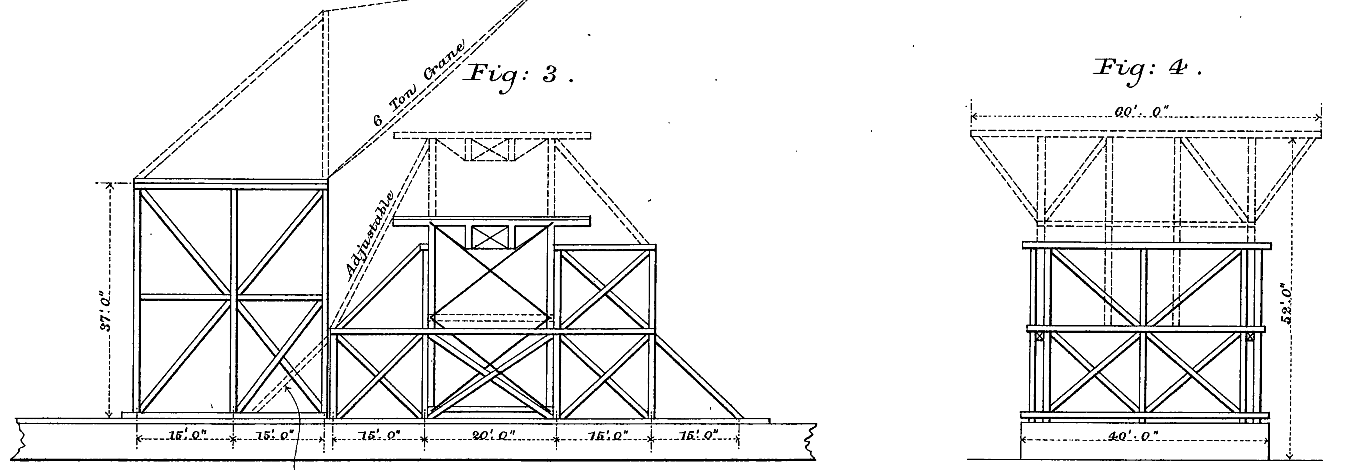
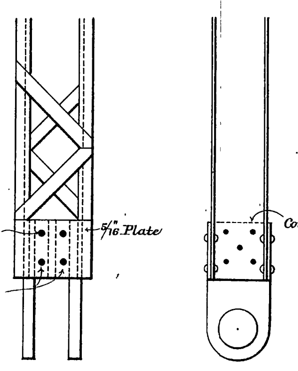
SUKKUR BRIDGE.

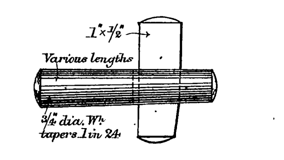


TRESTLE FOR ERECTION OF 111 STRUT.

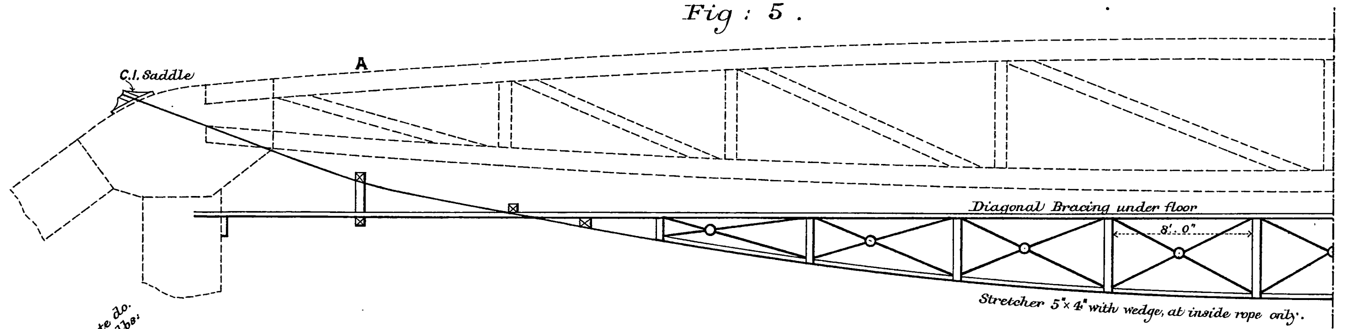


MOVEABLE CRANE TRESTLE AND LIFTING PLATFORM ON BARGE.

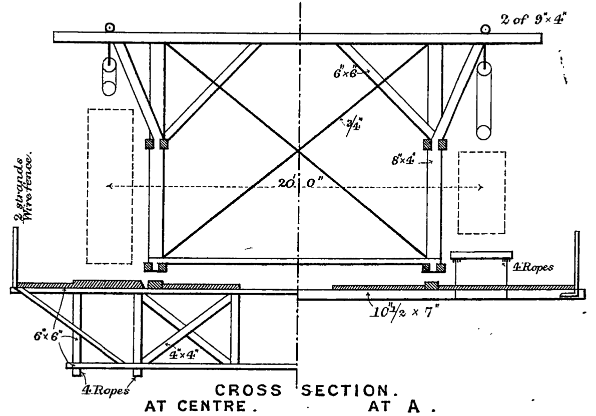




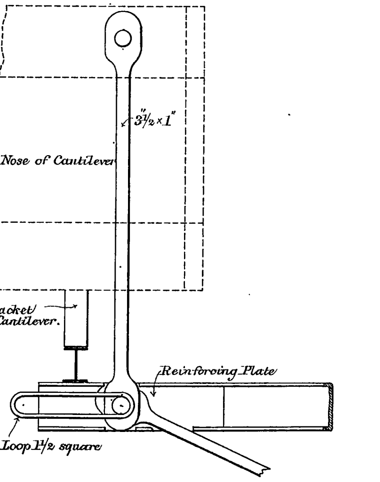
¼ Full Size.

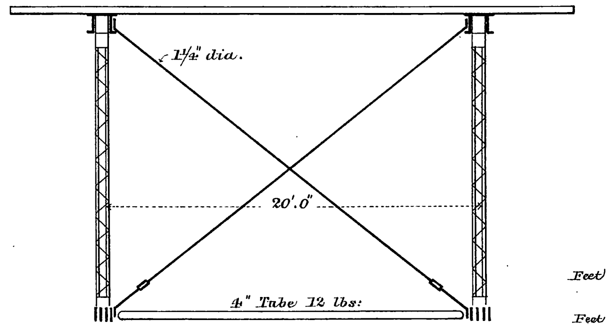


STAGING FOR HORIZONTAL TIE 123'.0" SPAN.



CROSS SECTION.
AT CENTRE. AT A.

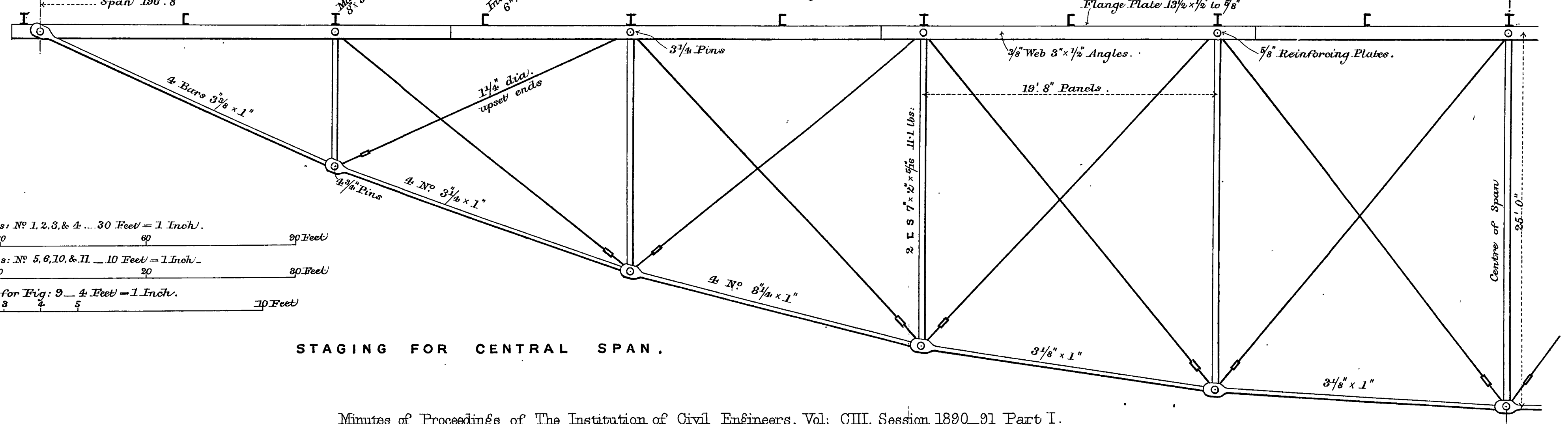




Scale for Figs: No 1, 2, 3, & 4 .... 30 Feet = 1 Inch.

Scale for Figs: No 5, 6, 10, & 11 _ 10 Feet = 1 Inch.

Scale for Fig: 9 _ 4 Feet = 1 Inch.



STAGING FOR CENTRAL SPAN.

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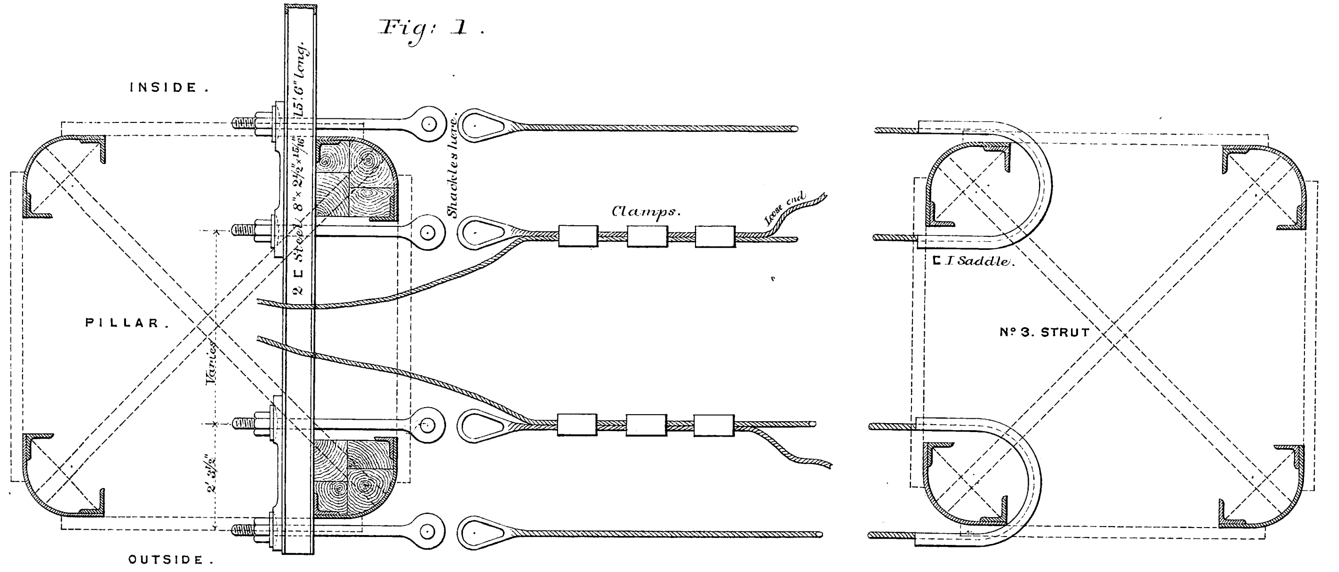
SUKKUR BRIDGE.

PLATE. 6.

Fig: 1.



ARRANGEMENTS OF TIES.

Fig: 2.

SECTION ON *a.b.*

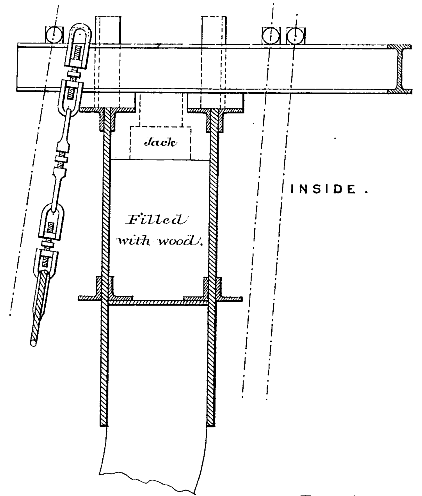
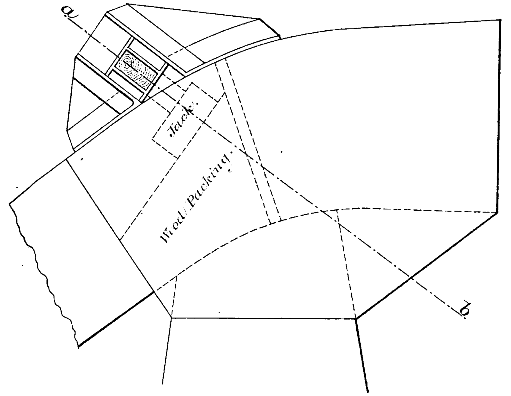
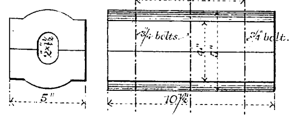


Fig: 3.



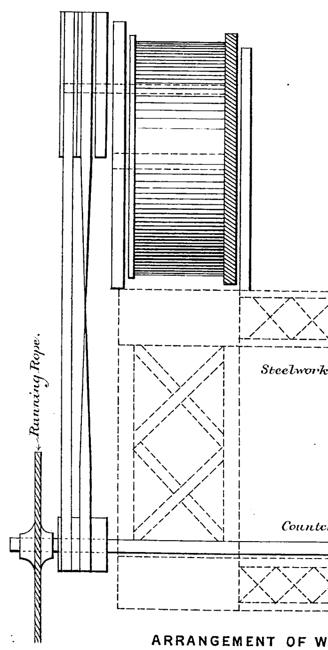
ARRANGEMENT OF MAIN TIE.

Figs: 4.



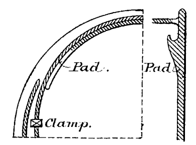
DETAIL OF CLAMP FOR TIES.

Fig: 5.



ARRANGEMENT OF WINCH.

Fig: 6.



METHOD OF SECURING ROPE TO BARREL.

Fig: 7.

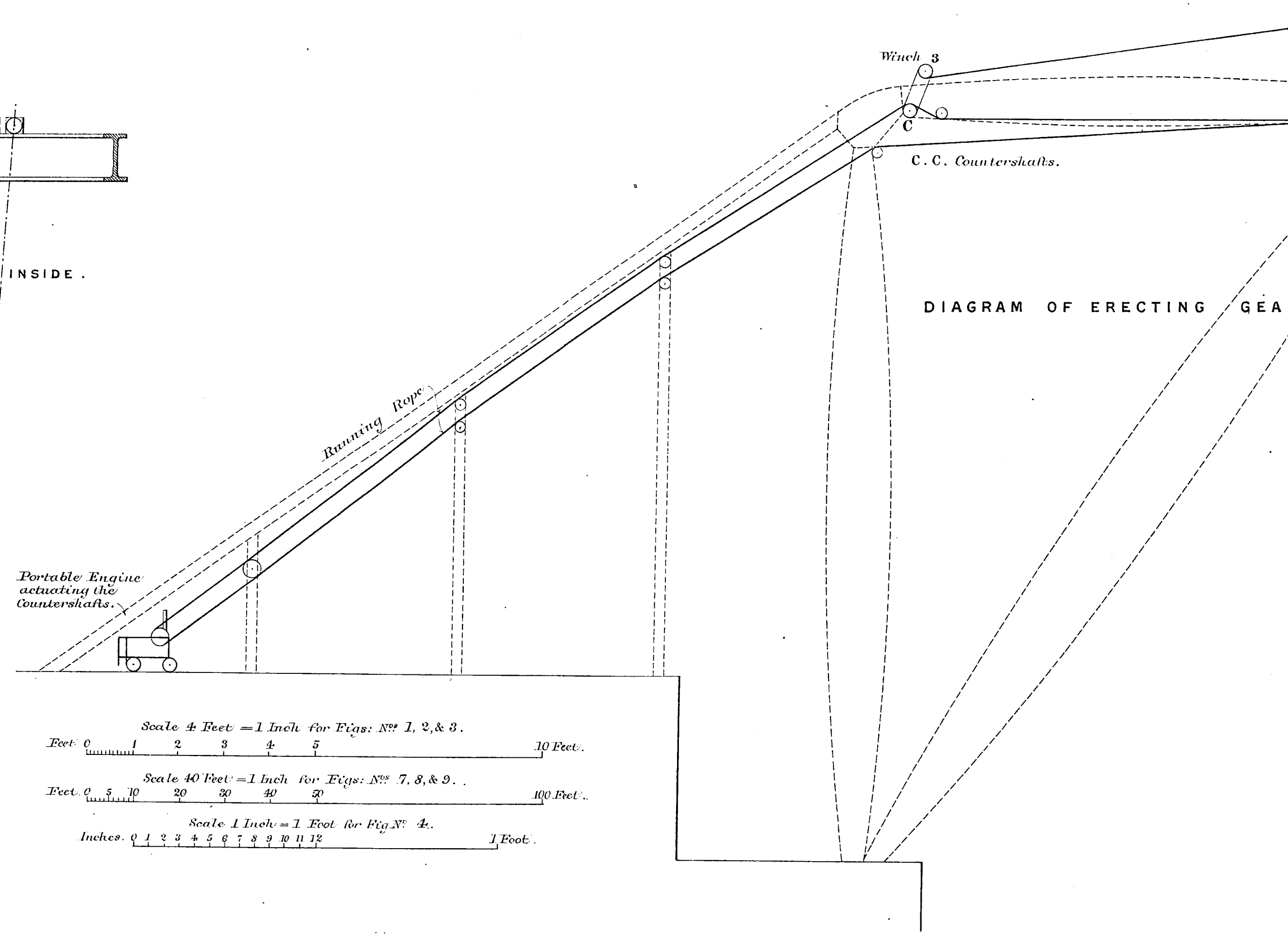


DIAGRAM OF ERECTING GEAR.

Scale 4 Feet = 1 Inch for Figs: Nos 1, 2, & 3.

Feet 0 1 2 3 4 5 10 Feet.

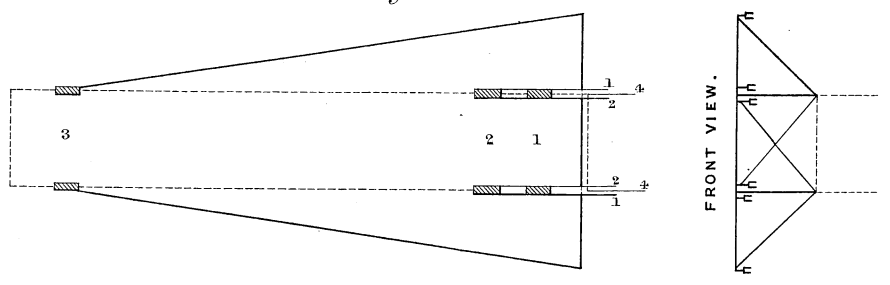
Scale 40 Feet = 1 Inch for Figs: Nos 7, 8, & 9.

Feet 0 5 10 20 30 40 50 100 Feet.

Scale 1 Inch = 1 Foot for Fig Nº 4.

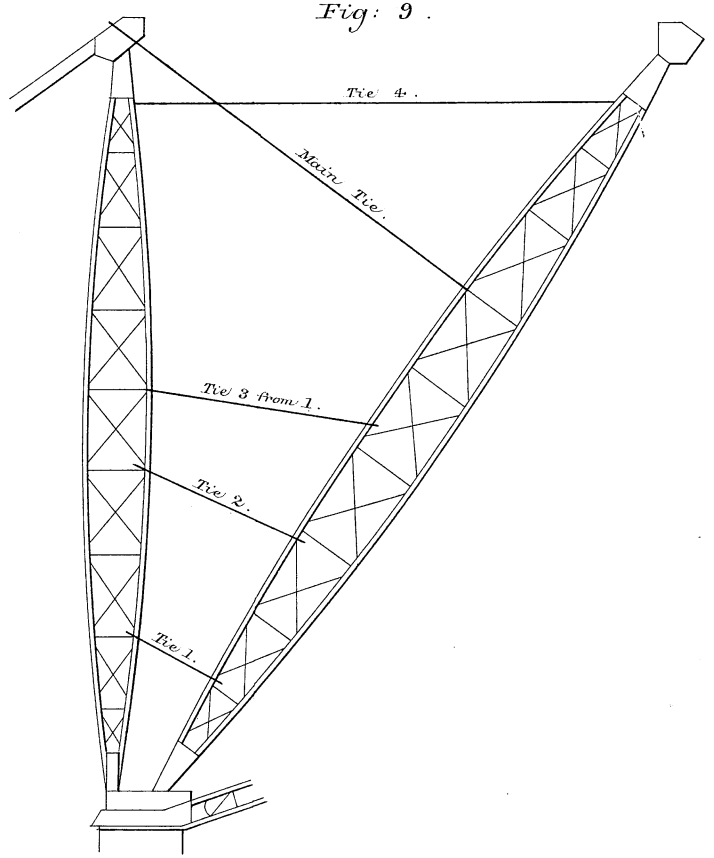
Inches 0 1 2 3 4 5 6 7 8 9 10 11 12 1 Foot.

Figs: 8.



PLAN.

Fig: 9.



TIES FOR ERECTION OF III STRUT.

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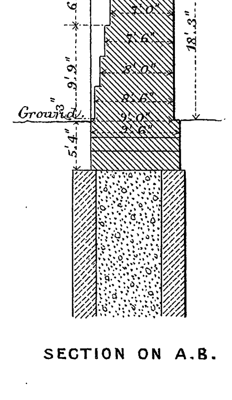
CHITTRAVATI BRIDGE.

PLATE. 7.

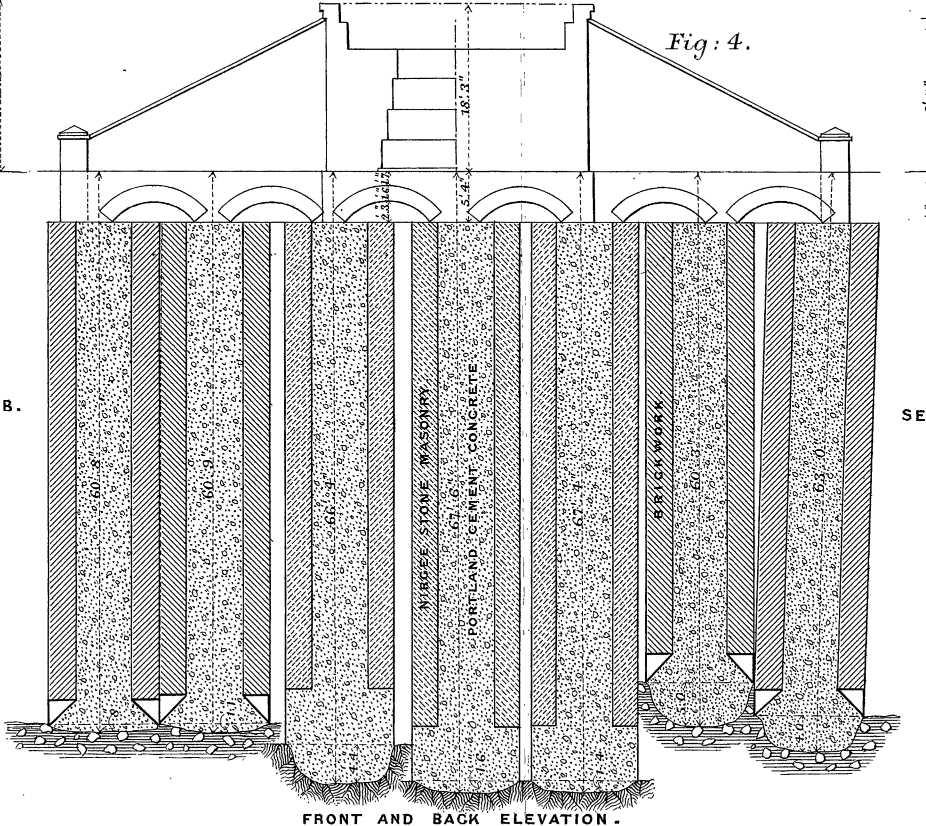
Fig: 1.

Fig: 2.



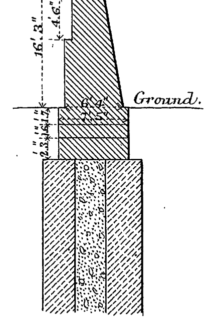
SECTION ON A.B.

Fig: 4.



FRONT AND BACK ELEVATION.

Fig: 3.



SECTION ON B.C.

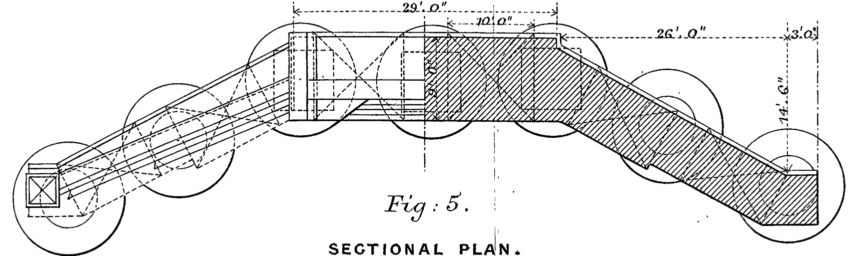


Fig: 5.

SECTIONAL PLAN.

Fig: 6.

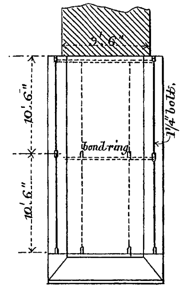
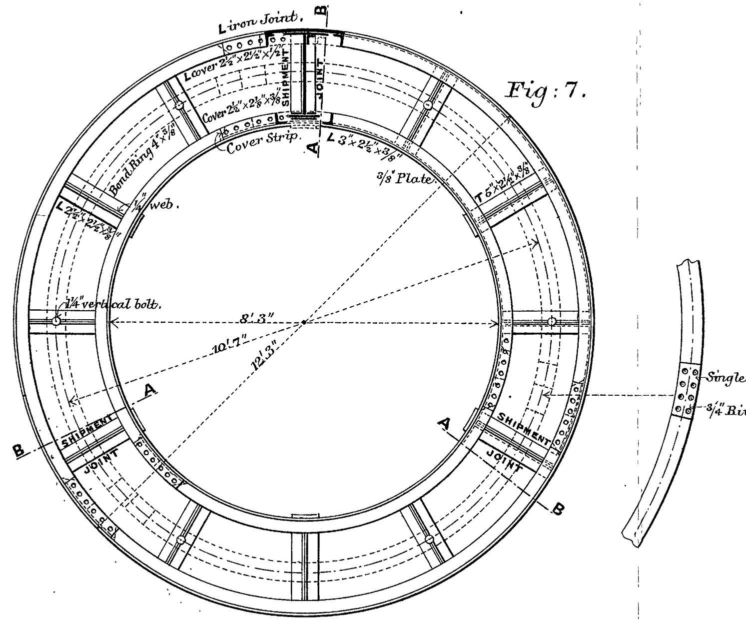


Fig: 7.



WROUGHT IRON WELL-CURB.

PLAN.

Fig: 10.

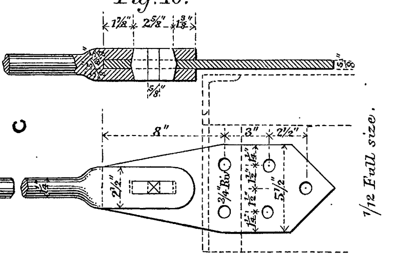


Fig: 11.

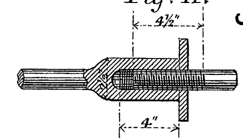
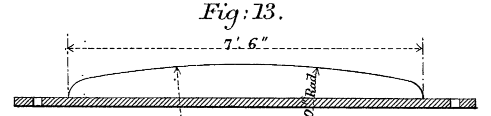
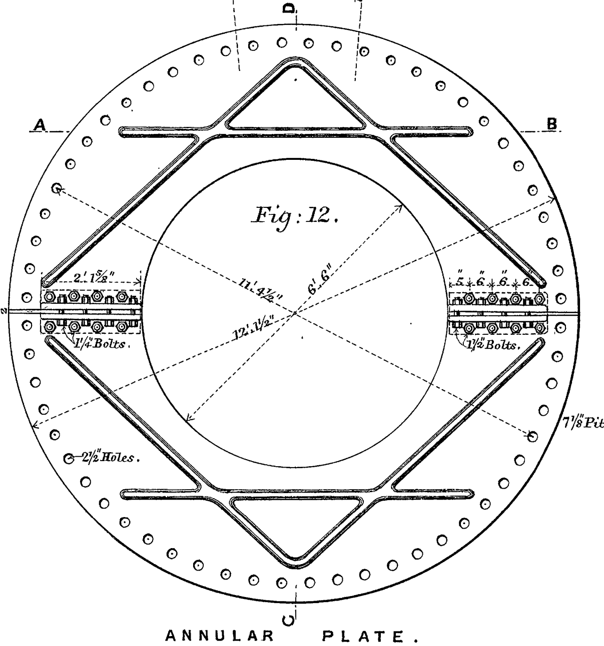


Fig: 13.



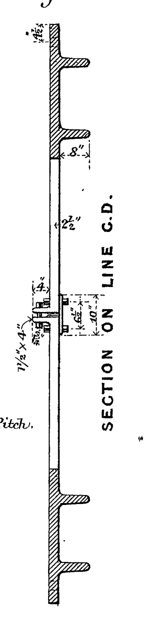
SECTION ON LINE A.B.

Fig: 12.



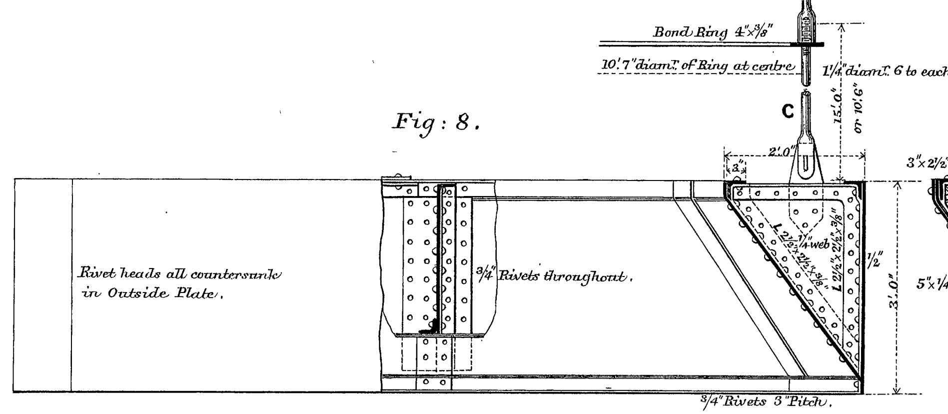
ANNULAR PLATE.

Fig: 14.



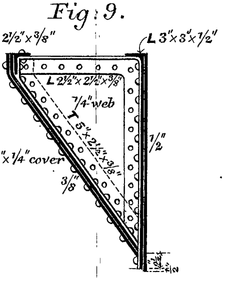
SECTION ON LINE C.D.

Fig: 8.



SECTIONAL ELEVATION.

Fig: 9.



SECTION AT A.B.

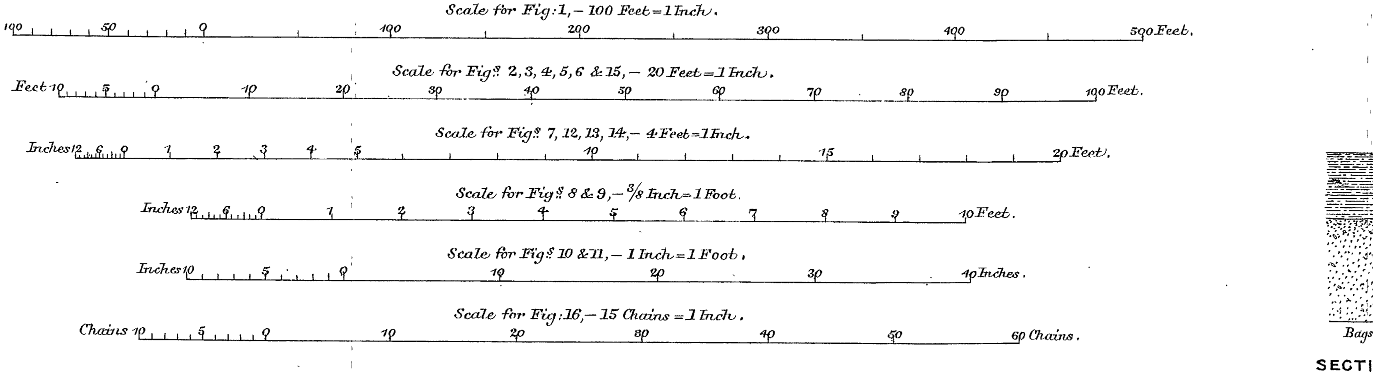
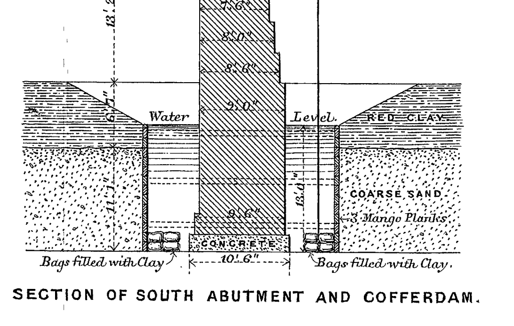
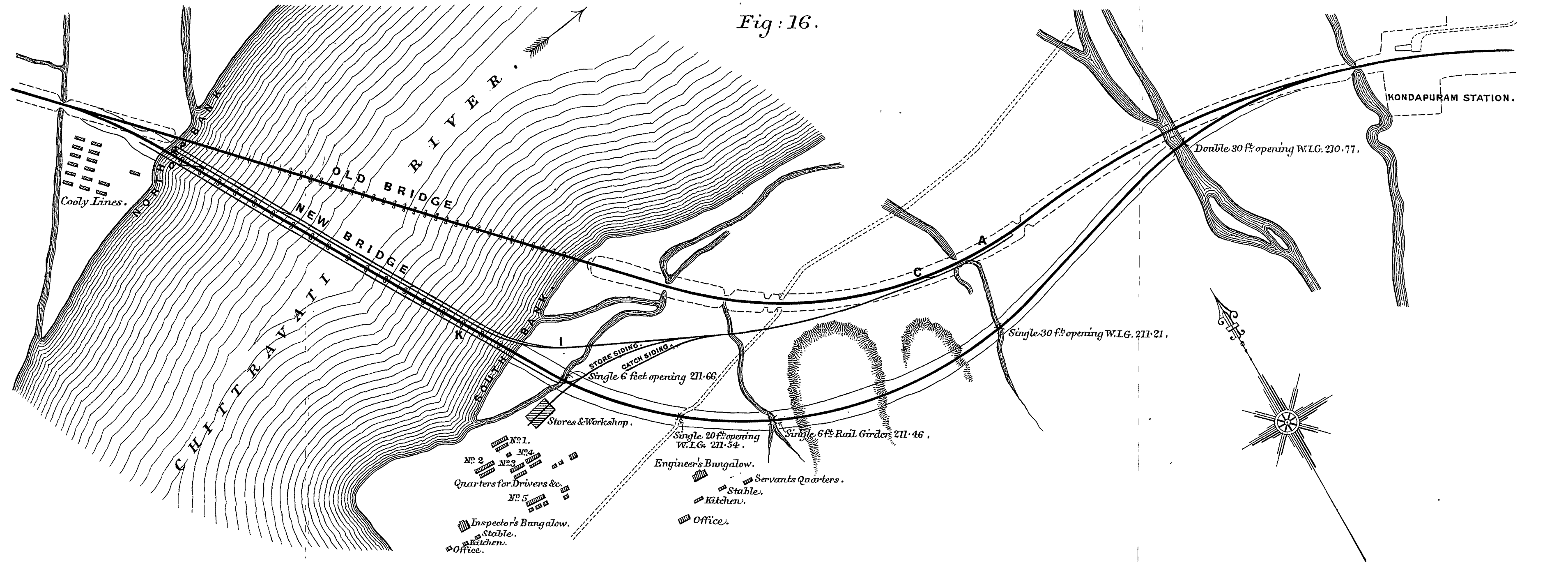


Fig: 15.



SECTION OF SOUTH ABUTMENT AND COFFERDAM.

Fig: 16.



GENERAL PLAN OF APPROACHES, BRIDGE AND WORKS.

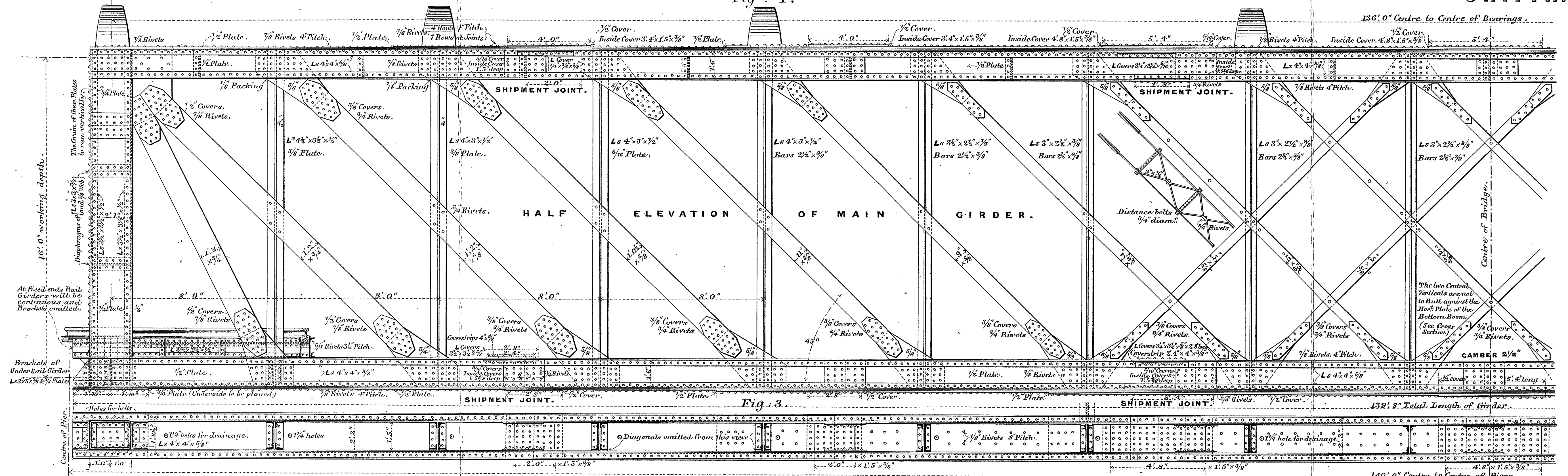
E. W. STONEY, DELT.

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

CHITTRAVATI BRIDGE.

PLATE . 8.

Fig: 1.



HALF SECTIONAL PLAN OF MAIN GIRDER.

Fig: 2.

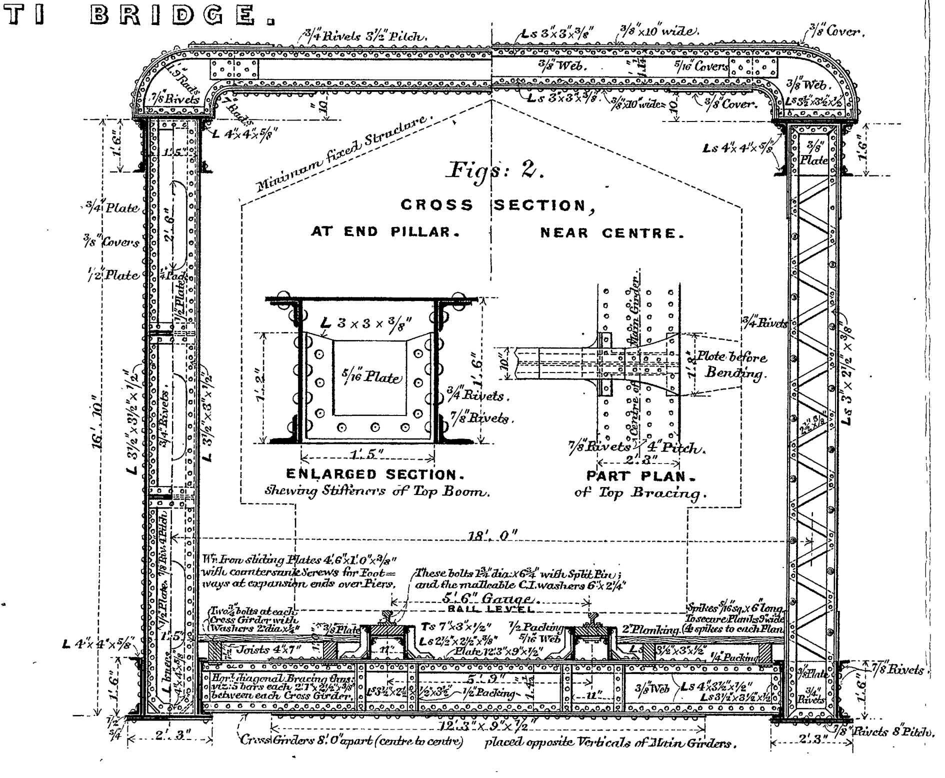


Fig: 4.

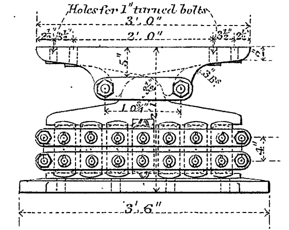


Fig: 5.

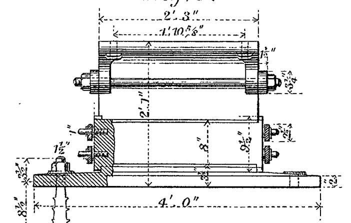


Fig: 8.

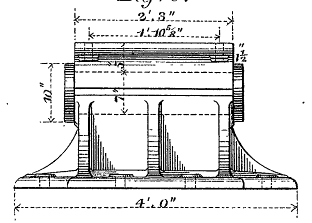


Fig: 9.

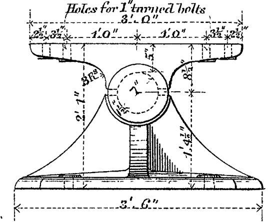


Fig: 6.

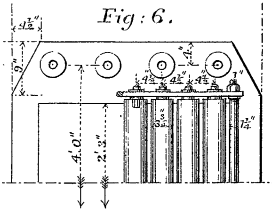
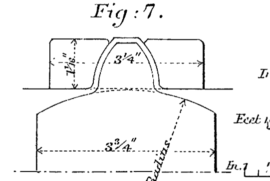


Fig: 7.



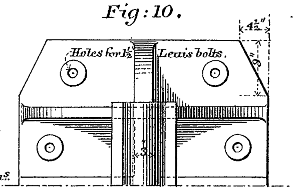
Scale for Figs. 1, 2, 3, 11, 12, 13, 14, 15, 16, 17, 18.—3/16" = 1 Foot.

Scale for Figs. 4, 5, 6, 8, 9, 10, 19.—3/8" = 1 Foot.

Scale for Figs. 20, 21.—20 Feet = 1 Inch.

Scale for Fig: 7.—1/4" = 1 Inch.

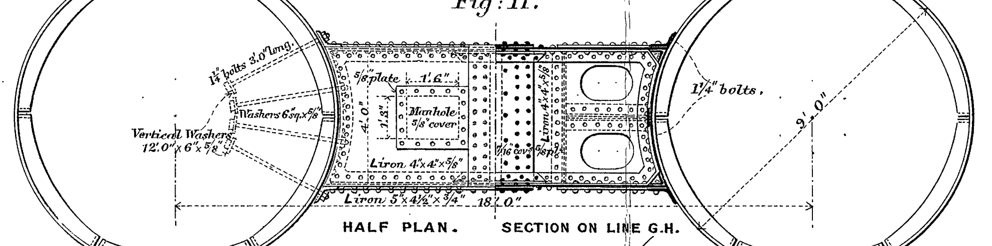
Fig: 10.



ROLLER BEARING.
CAST STEEL.

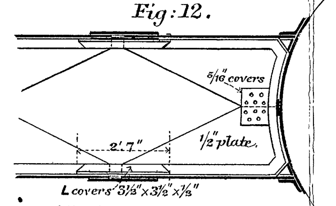
FIXED BEARING.
CAST STEEL.

Fig: 11.



HALF PLAN. SECTION ON LINE G.H.

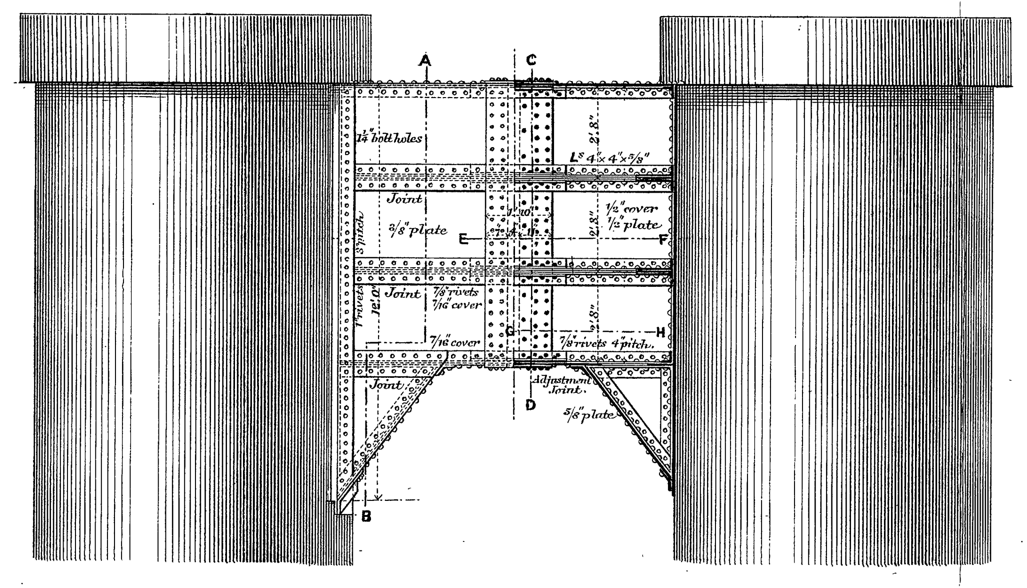
Fig: 12.



SECTION ON LINE E.F.

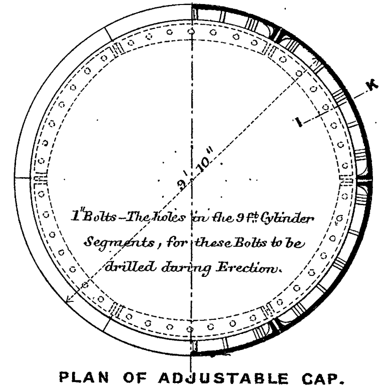
NOTE:

Rivets shaded and black are to be sent out loose.
Holes for Rivets shaded black to be drilled in the 5/8" Plates and in the 4"×4"×5/8" L irons during Erection in India.

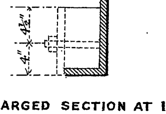


SECTIONAL ELEVATION.

Fig: 14.

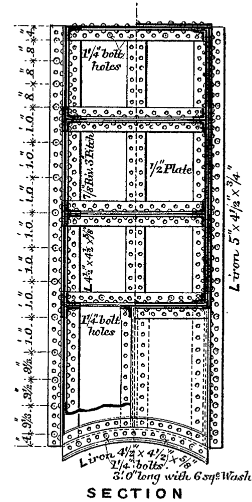


PLAN OF ADJUSTABLE CAP.



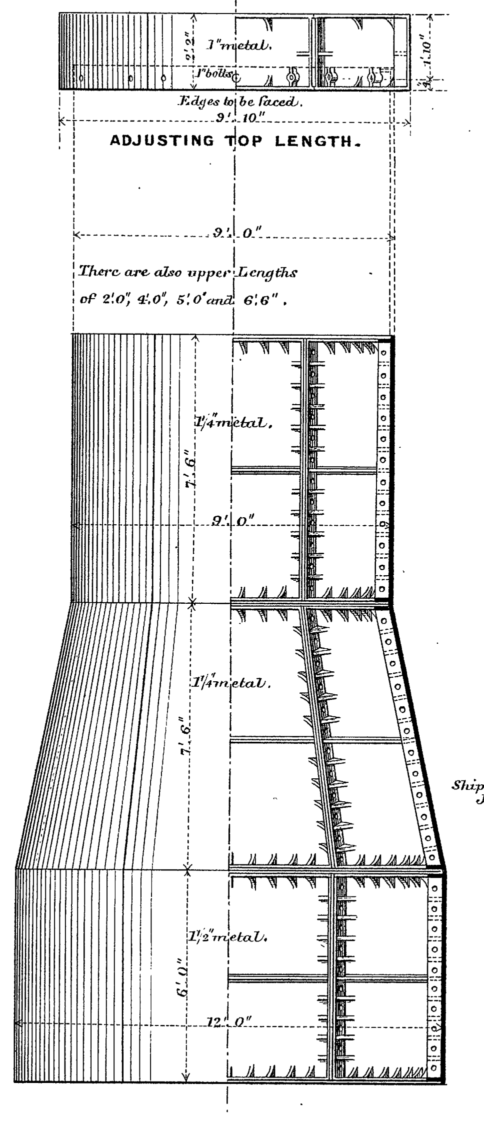
ENLARGED SECTION AT I.K.

Fig: 13.



SECTION ON LINE A.B. ON LINE C.D.

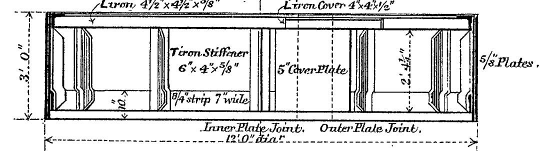
Fig: 15.



ADJUSTING TOP LENGTH.

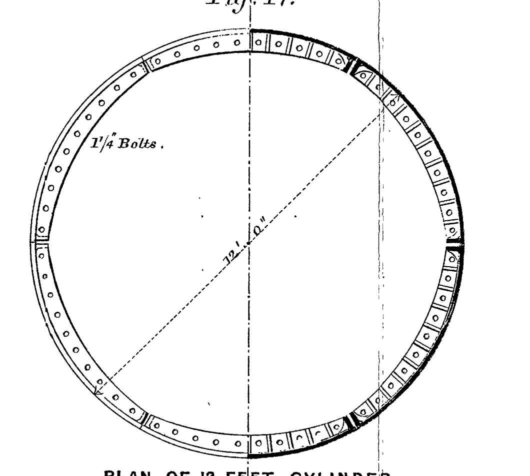
There are also upper Lengths of 2'0", 4'0", 5'0" and 6'0".

Fig: 16.



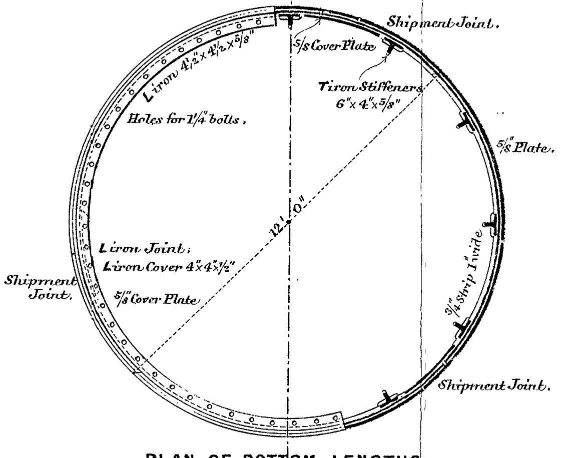
WROUGHT IRON BOTTOM LENGTH.

Fig: 17.



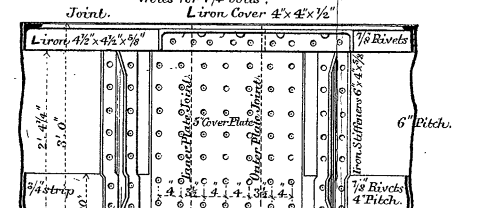
PLAN OF 12 FEET CYLINDER.

Fig: 18.



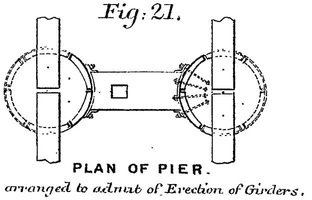
PLAN OF BOTTOM LENGTHS.

Fig: 19.



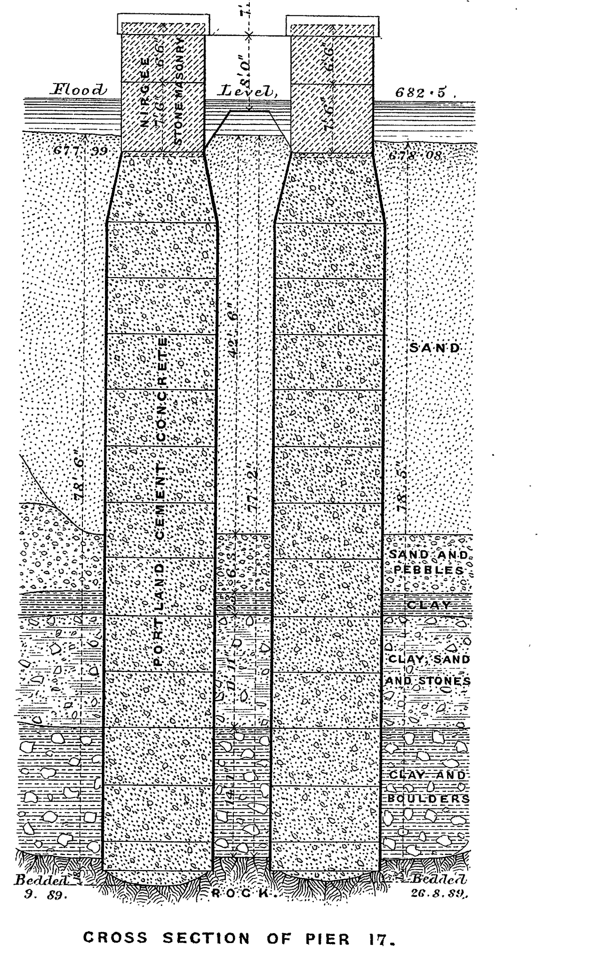
ENLARGED VIEW OF SHIPMENT JOINT.

Fig: 21.



PLAN OF PIER.
as arranged to admit of Erection of Girders.

Fig: 20.



CROSS SECTION OF PIER 17.

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