Correspondence.

Mr Beckett Mr. Clifford Beckett expressed the opinion that close attention should be given to the remarks made by the Author of the Paper on the Curzon bridge, that it was of the very greatest importance in designing wells for deep foundations to provide sufficient weight in the steining itself, instead of depending on artificial weight to complete the sinking. The latter course was not only very expensive in itself, but also represented money spent on work for which there was no return in the shape of added steining. The addition of artificial weight also occupied much time, and much was again lost in removing the weight after the sinking. When the bridges over the Orissa rivers were built,[1] the whole of the wells sunk under ordinary conditions, with certain exceptions, were filled with clean sand to within a short distance of the top of the steining. In all cases where the wells rested on sand the settlement was so small during the erection of the superstructure as to be negligible, but in cases where the wells rested on clay settlement was observed. That was due he considered to the fact that during sinking in clay cavities were left round the curb into which the sand tended to escape, whereas in the former material the sand followed the well down and filled all cavities. When wells rested on sand, sand-filling might be used with economical results throughout the depth of the well, but in clay it was better to use a concrete plug, unless time could be given to permit of the settlement taking place. Wells were presumably used either to obtain a foundation below the limits of scour, or to obtain a foundation on better material than that available nearer the surface. In either case protection against possible scour would be given round the wells on the surface. Should such scour extend to the level of the bottom, nothing in the shape of hearting would be of any avail to prevent the well so scoured from tilting, or to prevent loss of the whole well. If scour could not extend to the level of the bottom, and thus permit the sand-filling to escape, sand had proved in Mr. Beckett's experience as good a material as any other for filling throughout, provided time was given to allow of its consolidation before the concrete cap was put on the well. Mr. Beckett's conclusions were :—

[1] W. T. C. Beckett, "The Bridges over the Orissa Rivers on the East Coast Extension of the Bengal-Nagpur Railway." Minutes of Proceedings Inst. C.E., vol. cxlv, p. 268.

Mr. Beckett.

(*a*) That the steining of wells should be of such a thickness as to provide ample weight for sinking purposes without artificial assistance.

(*b*) That to save money, sand-filling should be utilized throughout the well up to the top cap of concrete, except where there was reason to fear that there might be cavities outside the curbs into which the sand-filling might escape, and when there was no time to allow the consequent settlement before completing the superstructure. In such cases a plug of concrete of varying thickness might be used. Such a plug, however, should fill the very bottom of the well without any intervening sand, otherwise the object of using it would be frustrated.

With regard to the Netravati bridge, the Author had stated that it was found impossible to dry the wells, sunk in stiff clay, with the pumping-plant available, but perhaps that may have been due to the fact mentioned in connection with No. 6 well, viz., that before starting that well borings were taken "at what should be the centre of the two dredging-holes." On occasions when such borings have had of necessity to be taken, on the actual site to be occupied by a well, Mr. Beckett's experience was that they might give the trouble which the Author experienced. Care should be taken that all borings not absolutely required on the actual site of a well should be made clear of the alignment of the bridge, as was done on the Curzon bridge. With reference to the bedding of the wells on the rock known to exist at depths varying between 25 feet and 60 feet below low water, the question naturally arose whether time and money might not have been saved by the use of compressed-air below the point at which the wells touched the laterite bed, open sinking being used as far as that point.

Mr. Brodie.

Mr. J. B. Brodie pointed out that the chief feature of both bridges, apart from the constructional details, was the contraction of the waterway by approach banks protected by wing bunds at the bridge abutments. In both cases, and particularly in that of the Curzon bridge, the river had been trained towards one bank, and it seemed to be a matter for enquiry, why that was done in preference to training the river towards the centre of the waterway, and bridging there, with approach banks and protecting bunds on each side. Accretion of the banks of the river would be less liable to occur under those conditions and silt might be expected to deposit in the shoal waters formed towards the banks. It was a moot point whether the curved end of the training bund of the Curzon bridge was all that the Author claimed for it. There had been several instances of failures, but these failures might not

Mr. Brodie. have been due to the design of the bunds so much as to the inefficiency of the protecting stone facework. There did not seem to be any established theory to warrant the curvature referred to in preference to that adopted for the bund of the Netravati bridge.

Mr. Fowler. Mr. F. D. FOWLER stated that the Curzon bridge was not, after its being taken over by the Oudh and Rohilkhand Railway in December 1905, exposed to any heavy floods up to the time he left in April 1907, when the area between the training-bund and the left bank was silting up and the sarpat grass and mimosa bushes on the back slopes had taken a firm hold. The design of the bund was in his opinion well calculated to secure the object aimed at. The arrangement for dealing with the expansion and contraction of the girders by anchoring the permanent way at the abutments and at the fixed ends of the girders was a very satisfactory method of meeting the difficulty. At the Author's suggestion notices were attached to the girders at each end of the bridge containing instructions to the permanent-way staff as to the maintenance of the permanent way over the bridge and of the bunds.

Mr. Haughton. Mr. W. R. HAUGHTON congratulated Mr. Gales on the successful completion of the Curzon bridge. With regard to its design and construction there was little to be said: it followed the usual lines of such work in India and appeared to have been carried out in an economical and expeditious manner. Mr. Gales was fortunate in the work being situated in a district where labour was plentiful. In some parts of India, in Assam and Eastern Bengal for instance, all labour had to be imported at great expense. Owing to the heavy rains the working season there was practically limited to the period between November and June. The agriculturists of the district would only work in their fields, and the imported coolies would not remain on the works during the rains; and all this had a very adverse effect on the cost of works in those localities. Opinion was not unanimous that the best alignment for the guide bund had been selected. Mr. Haughton shared the view that the best alignment for guide bunds was that which approached most nearly to the *vena contracta* form. When constructing the Dharlla bridge on the Eastern Bengal State Railway he had made several experiments with models of guide bunds about 10 feet long which confirmed that view. The models were placed in the river-bed to represent a *vena contracta*, on sands, in water running 18 inches deep at a velocity of 2 feet to 3 feet per second. Their position relative to the current was varied so that their longitudinal axis lay, first, in the same direction as the current, that was, so that the current flowed straight between the model bunds; secondly, so that the longitudinal axis of the bunds was at an angle to the current; and these two

Mr. Haughton.

positions were observed (*a*) with the small mouth of the *vena contracta* up-stream and (*b*) with the models reversed and the large mouth up-stream. The results obtained showed in many respects how such bunds were affected by the stream. It gave a clear idea of the development of scouring action at the up-stream ends of the bunds and along their faces, and of the trend of the currents between them with the water flowing straight, or entering at an angle, as would happen if the current before entering the up-stream openings between the bunds slewed to the right or left banks. Generally it was found that with the smaller mouth of the *vena contracta* up-stream, the current fanned out, and by the time the water arrived at the down-stream end its velocity was fairly uniform across the width of the channel where the bridge-site would be situated, and consequently it gave a level bottom right across. That was much the same whether the stream entered straight or at an angle. With the wide mouth up-stream and the current flowing straight towards the models the results were very different. The current always attacked the head of one of the bunds more than the other, and would always confine itself to one side of the channel between the bunds, thus giving deep water along the face of one bund and shallow water along the other; it was impossible to get it to take a straight course between the bunds. With the models placed at an angle to the current the results were worse than when their axis was in line with the current, that was, the water hugged one or the other of the bunds much more than when the longitudinal axis of the bund and the direction of the stream were the same. Looking at the plan of the guide bund of the Curzon bridge, it might be predicted that if the Ganges should slew hard over to its left bank above the guide bund, it would put a very heavy strain on the piers on the right side of the bridge. It was seldom possible, however, at bridge-sites to place guide bunds economically on the exact alignment desired. The banks seldom allowed it, or the main channel might be in the way. But there could be little doubt but that the nearer the *vena contracta* form was approached the more evenly and the straighter the current would cross the bridge-site and the less danger there would be of the water concentrating on a few of the piers and causing heavy scour. For very many years after a bridge on sand foundations had been built, the necessity existed for carefully keeping daily flood soundings round all the piers, and great responsibility lay with the engineer in charge of it. That was especially the case when the banks or approaches guiding the stream towards the bridge splayed outwards up-stream. It was therefore necessary in order to get an even flow through the bridge, Mr. Haughton. that the guide bunds should be designed to secure it. It was not generally known how rapidly bridges of the class under consideration could be constructed. The Dharlla, the Sankos and the Gangadhar bridges on the Dhubri extension of the Eastern Bengal State Railway, built under Mr. Haughton's direction, might be instanced. The actual time of construction of the Dharlla bridge from setting the first curb to the passing of locomotives was 11 months, and that of the Sankos and Gangadhar bridges, built a year later, 7 months. These bridges were of practically the same type. There were respectively eleven, ten and six spans of 150 feet on circular wells $26\frac{1}{2}$ feet in diameter sunk in sand to between 75 feet and 85 feet below low-water level. The first well-curbs of the latter two bridges were set in the middle of December, and the bridges were crossed by locomotives in the first week of the following July. Each bridge had heavy approach embankments and heavily-pitched guide-bunds. Before the actual work of construction was commenced about 50 per cent. of the bricks had been burnt, and 25 per cent. of the stone had been collected. Coal was brought by river 350 miles; stone by river 30 miles, and by rail 50 miles; and limestone was brought from a distance as great as 400 miles. There were in the three bridges 2 miles of guide-bunds, 2,900 tons of ironwork, and 2,300 linear feet of well-sinking. The wells on these bridges were designed to give a sinking effort of 3·09 cwt. per square foot of skin area in water. A lighter sinking effort was tried on the Dharlla bridge by reducing the thickness of the well steining from 7 feet 6 inches to 5 feet, but it was speedily abandoned as the wells would not go down even with heavy dynamiting and pumping. In the Curzon bridge double hexagonal wells were used. Circular wells possessed the advantage that a greater sinking effort was obtained with an equal sectional area of masonry, and in Mr. Haughton's opinion they were more easily sunk. He considered that "blowing" was less with circular wells than with double hexagonal wells. Circular wells, however, offered greater obstruction to the current than those of hexagonal form. In the Sankos bridge a layer of conglomerate was met with about 60 feet down, and that tilted one of the wells slightly; it was, however, broken up with heavy rail droppers and dynamite. On the Dharlla bridge the sinking of the wells was continued during the floods by building up lengths of the pier superstructure, leaving holes for dredging. The filling was subsequently put in through these holes. In the Sankos bridge one of the piers was pitched on and sunk through an artificial island in 18 feet of water.

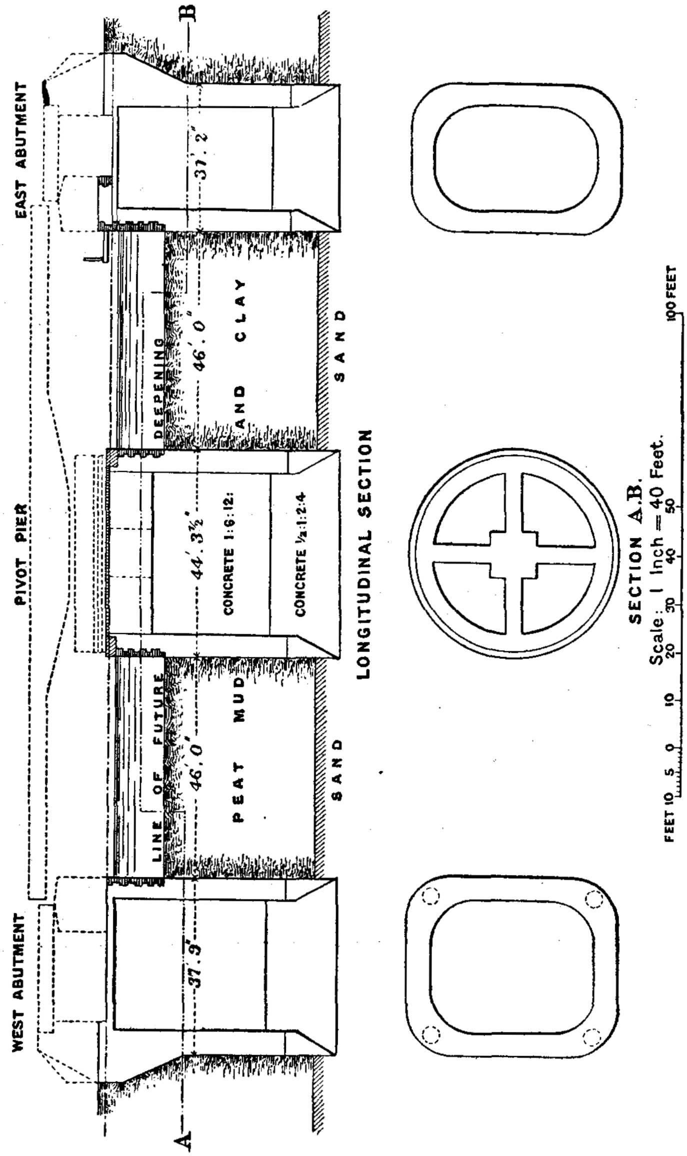
Mr. Joosting. Mr. P. JOOSTING furnished the following description of a well foundation executed in 1907, in connection with the construction of

Mr. Joosting.

a swing-bridge to carry the railway between Utrecht and Rotterdam and the Hague across a canal near Gouda. As the ground was found to consist of peat, mud and weak clay to a depth of about 43 feet, and of sand lower down, it was decided that the pivot-pier and abutments should be founded on solid blocks reaching 5 feet down into the sand; piling being rejected, as the peat, mud and clay were of weak consistency. As the tenders for pneumatic sinking were considerably higher than that for well-sinking the latter course was adopted, as shown in *Figs. 3* (p. 70). The pivot-pier and the abutments were each to be founded on a single well. The well for the pivot-pier was circular, having a diameter of 44 feet 3½ inches; the wells for the abutments were of rectangular section, respectively 44 feet 3½ inches by 37 feet 9 inches, and 44 feet 3½ inches by 31 feet 2 inches. In view of the weakness of the ground each well was suspended during the sinking by means of four wire-rope tackles, each tested to bear 125 tons. The tackles were attached to scaffolds, each scaffold consisting of four piles, of which two were driven inside and two outside the well, the piles being joined by timber framing. The lower part of the well (19 feet to 20 feet) was made of reinforced cement-concrete 1 : 2 : 4, an angle-bar forming the cutting-edge. The construction of these lower parts of the pivot-pier well and the well of one of the abutments was shown in *Figs. 4* and *5*. The concrete was reinforced by vertical rods ⅞ inch and 1 inch in diameter, placed 10 inches apart, and by several horizontal rods of the same diameters. Four suspension-bars, 4 inches in diameter, bent to form loops to which the tackles were attached, were embedded in the concrete. Over these bars cylindrical holes, 3 feet 5 inches in diameter, were left in the walls of the well. The sides of the holes were reinforced by a spiral wrapping of ¾-inch rod. First, on a scaffolding, a ring 10 feet high was made on the site. As soon as the concrete was set, the tackles were fastened to the suspension-bars and the ring was lifted 3 inches or 4 inches by means of the hoists. Then the scaffolding on which the ring was made was removed, and the ring was sunk 7 feet or 8 feet and was then built upon in the following way. A wall of brickwork was built on the outer and the inner sides of the wall round the well; and the space between these walls was filled with concrete, the well being sunk as the walls round the well were built. Inside the well a steam-hoist was placed on a scaffold on piles for the dredger. As the well was bedded 5 feet into the sand, the tackles, after being loosened from the suspension-bars, were removed and the tackle-holes that had been left were filled with concrete. Then the piles inside the well

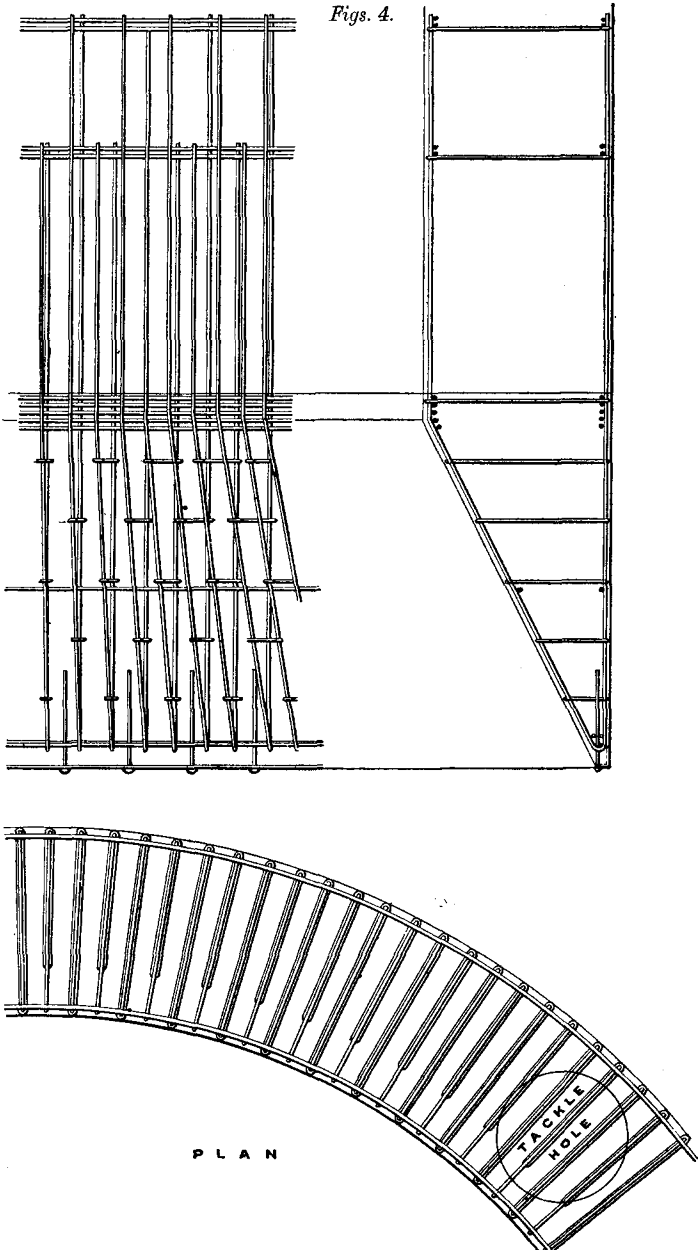
Mr. Joosting.

Figs. 3.



Mr. Joosting.

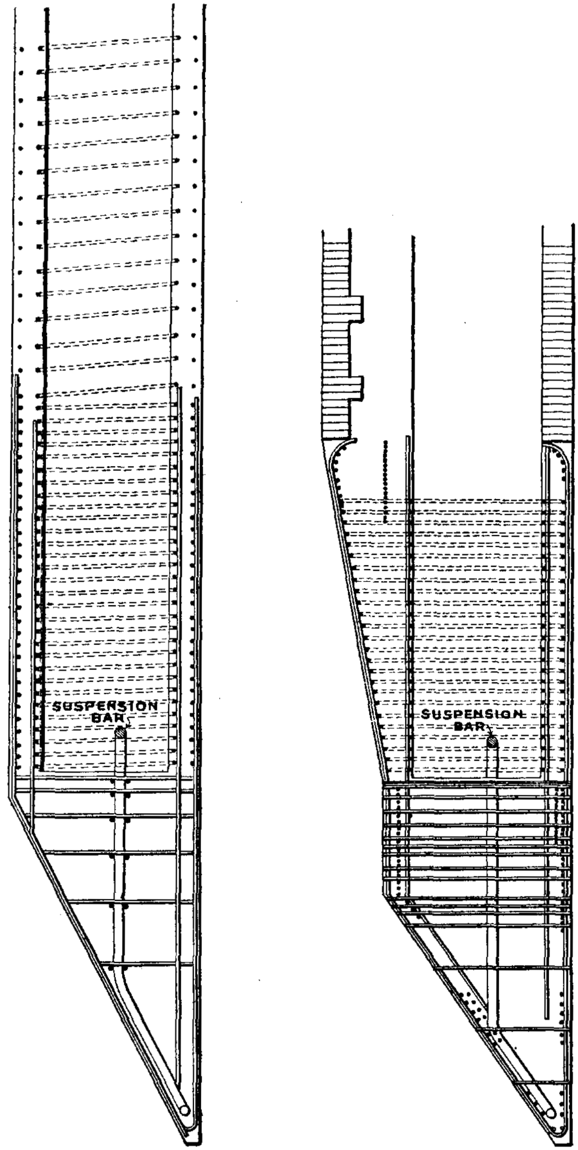
Figs. 4.



SCALE: 1 INCH = 5 FEET.

Mr. Joosting.

Figs. 5.



ROUND WELL RECTANGULAR WELL
VERTICAL SECTIONS THROUGH TACKLE HOLE
Scale: 1 Inch = 5 Feet

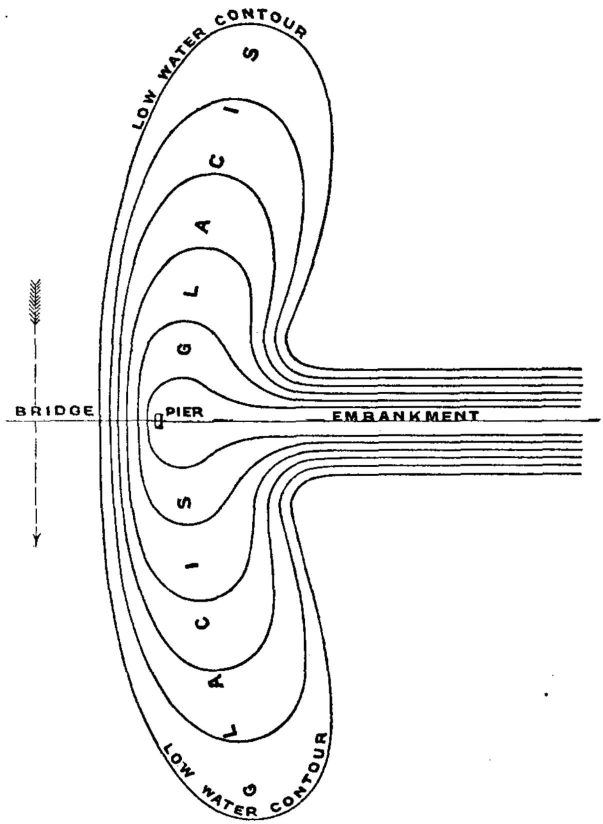
were pulled or sawed off and a bed of concrete 15 feet thick was laid in the dredging-hole. When this was set, the water was pumped out of the well, and the dredging-hole was further filled with cement concrete. No great difficulties were met with. On the 1st May, 1907, a beginning was made with the piling for the scaffold in the pivot-pier well; on the 1st July, the sinking was commenced, and by the 31st August the well was sunk to the full depth of 48 feet 3 inches. On the 2nd September, 1907, the sinking of the east abutment-well was begun, and on the 22nd October the sinking of that well was finished. The sinking of the west abutment-well was commenced on the 21st October, and was finished on the 7th December. Mr. Joosting.

Mr. K. S. LAURIE observed that the flow of the River Ganges during the season 1907–8 approximated fairly to that shown for 1904–5, and as far as could be inferred from the experience acquired to date the success of the arrangements for the provision of a waterway was assured. In spite of the dead set made by the river against the curved end of the left training bund, excessive erosion had not so far taken place, and it was difficult to imagine circumstances under which the bund could be more severely tested than during the last heavy floods of the 1907 monsoon. The rail approaches were all that could be desired, but there was little doubt that the convenience of vehicular and foot traffic had been sacrificed to them. If a string of bullock-wagons happened to be passing, the road approaches were almost impassable at the two spans of 45 degrees to the centre-line. The surface of the roadway over the bridge left much to be desired, as it followed the troughing, while at each expansion joint the roadway was racked to pieces and the iron plate laid over the metal for safety was apt to be canted up by the loose stones. At the recent doubling of the Tonse bridge Mr. Laurie had laid this plate under the metal, and in that case, although the latter became loose, it was never dangerous. Mr. Laurie had had many experiences with kunkur lime similar to those described by Mr. Gales, and owing to its uncertainty it had been practically superseded by Sutna lime on all the works with which he was associated, the reliability of the latter leading to economy and a greater sense of safety when it was used on outlying works. The expansion of the rails on bridges of this description had not proved on the East Indian Railway system so simple a matter as on the Curzon bridge. On the former, the rails were fastened over the fixed ends of the girders by spikes through the rails themselves, the rails over the centre of the spans and over the expansion ends being left free to slip under the dog spikes. Mr. Laurie.

Sir Bradford Leslie.

Sir BRADFORD LESLIE considered the Curzon bridge to be one of the most important Ganges bridges; not only did it connect the trans-Gogra districts with Bombay, but by the construction of 35 miles of a standard-gauge link between the north end of the bridge and the Suriawan station of the Lucknow-Bareilly-Benares line, it would afford an alternative connection between Benares and Allahabad, the strategic importance of which would be appreciated by the military authorities. The roadway on the top of the bridge apparently added 50 per cent. to the cost of the superstructure; for merely local cart traffic it might not have been justifiable to incur this additional cost, but having regard to the possible developments of motor traffic, roadways in connection with bridges assumed a degree of importance they did not formerly possess. One feature which was absent from the earlier bridges, but which seemed to be fashionable in modern Indian bridges, was the half-mile long training-bund with a line of railway on the top, considered to be necessary in consequence of the restriction of the waterway caused by the bridge to half the natural width of the river. The function of this training-bund was presumably to guide the flow in a direction normal to the bridge. When the river was low a small quantity of water was discharged by shallow and devious channels, the current was but feeble, and its scouring effect was not dangerous. When the river rose 30 or 40 feet, the gradient and velocity were greatly increased, its bed was scoured far below the sandbanks by which its dry-season channels were obstructed, and the conditions were entirely altered; the direction of the current became parallel to the general direction of the river and therefore normal to the bridge, and consequently training bunds were superfluous. Having decided to close one-half or two-thirds of the natural width of the river it became necessary to protect the embankment carrying the railway over the river-bed against erosion. To effect this a tee-head was required to check lateral flow parallel to the embankment, and to hold up a cushion of dead water in the re-entrant angle formed by the embankment. A rubble-stone protected slope of $1\frac{1}{2}$ to 1 or 2 to 1 in front of the abutment, merging above and below bridge into a groyne or glacis formed with an easy slope of, say, 6 to 1, as indicated by the contour-lines on the sketch (*Fig. 6*), was the natural and most effective and, therefore, economical treatment. On the up-stream side such a glacis opposed no sudden obstruction to the normal flow, absorbed its momentum gradually, and diverted it through the bridge; on the down-stream side the glacis facilitated the flow off and the gradual distribution of the current over the full width of the river without causing dangerous eddies. It was the want of such a glacis at the extremity that was fatal to the spur built to protect the Goalundo promontory at the terminus of the Eastern Bengal Railway in 1869. The curved end of this spur consisted of concrete blocks standing at a slope of $1\frac{1}{2}$ to 1 with an apron of rubble stone. When in the month of July or August of that year the fall of the Brahmapootra river afforded Sir Bradford Leslie.

Fig. 6.



a free outlet to the Ganges flood, a whirlpool was formed on the down-stream side, which undermined the spur and engulfed it. Although the scour of the river-bed was 180 feet deep along the up-stream side of the spur, it sustained the full force of the Ganges flood without damage, showing that an apron of stone-metalling formed an efficient protection against parallel flow. It was not until the spur was underscoured by the whirlpool formed

Sir Bradford Leslie. in its rear by the abrupt extremity that it failed. Some idea of the force of the whirlpool might be formed from the fact that the "Princess Alice," a railway steamer 250 feet long, was caught in it and spun round like a top. That experience and the repeated instances of the failure of the heads of training-bunds, indicated the necessity for receiving and dismissing a river-flood by well-formed glacis. With an incline of 1 in 6 the portion of the glacis above low water would extend some 260 feet from the centre line. There would, of course, be no difficulty in forming this portion to its correct contour, protecting it with rubble stone as required, and surrounding it with a stone apron to be let down by underscour at the toe. The portion of the glacis above low water was the most important, and if the stone apron acted satisfactorily, the extension of the glacis below low water might be unnecessary. Any such extension below low water level was most likely to be required on the down-stream side of the bridge, and for that purpose a reserve of stone would be kept above bridge so that it could be dropped down-stream in boats and deposited in any incipient cavity eroded in the wake of the glacis.

Mr. Skinner. Mr. Frank W. Skinner noticed that the general design of the Netravati bridge and the relation of span to piers did not conform to the generally accepted rule that, conditions permitting, the greatest economy was secured by making the cost of the substructure approximately equal to that of the superstructure, thus increasing the span length with the difficulty and expense of building the piers. It was probable that the observance of this rule would have doubled the length of the spans and would have reduced considerably the total cost of the structure, besides effecting what might be a much more important advantage, namely, diminishing the obstruction to the river and reducing the risk of changing its regimen. Notwithstanding the Author's reference to successful practice in previous cases, in the reduction of the waterway of the original channel to produce scouring and deepening of the main channel, Mr. Skinner considered that course extremely hazardous, and distrusted the long solid approach bank on the west side. Such construction was not adopted for the great American rivers which had shifting channels, notably portions of the Mississippi and Missouri rivers, where at low water there was a shallow depth and slow current over a width of a mile or two of soft sedimentary bottom, in which the channel made great and rapid changes at flood times. Where bridges were situated at such sites, the channel spans were usually from 350 feet to 550 feet long, and the margin between high and low water was crossed by steel viaducts often several thousand feet in length, with spans probably alternating 30 feet and 60 feet. That construction

Mr. Skinner.

was expensive, but it presented a minimum obstruction to the current, and in many cases great care was taken to prevent scour of the bottom by carpeting it and the banks with a solid continuous covering of willow mattresses a foot or so in thickness, woven with wire and covered with a heavy rip-rap ballast, and sometimes anchored in addition. It would be interesting to know if any special consideration determined the construction of temporary artificial islands to protect the piers during the first stages of sinking. If not, it would appear that they could have been advantageously omitted by the adoption of a type of pier shell which could be partly built on shore, launched, towed to its position and quickly sunk, perhaps in a dredged pit. If danger from ordinary current, flood, navigation or drift were apprehended, it could be provided for by driving a pile protection or anchoring breakwater scows around the pier. In the reconstruction of the wrecked pier of the Cornwall bridge across the St. Lawrence, above Montreal, Canada, a large wooden pneumatic caisson was sunk in water nearly 20 feet deep with a current of 6 miles an hour, and at first rested precariously on a high pile of debris from the overturned old pier. The caisson was supported only at parts of the cutting-edge several feet above the river bottom, and weeks were occupied in sinking through the old pier by blasting and cutting under the edges of the caisson. This hazardous work was successfully executed inside a protection formed by piles driven up-stream to break the force of the current. Piling was started several feet up-stream of the required position, and after being driven the piles were not released until a cluster had been chained together; a second cluster was then driven, and both clusters were braced together, thus developing strength to resist the current. Large bridge-piers and waterworks intake piers had been built in cylindrical steel open caissons floated to position, sunk and dredged down. More often wooden cribs had been used which were not intended to be watertight, but which served to prevent any considerable flow of water. They were provided with ballast pockets filled, as the crib descended, with rock, besides which temporary ballast was, if necessary, piled on the top. The cribs terminated above the river bottom and below low water, and were filled with concrete deposited under water, above which the shaft of the pier was built above water-level in an open coffer-dam, which was usually detachable, and could be used on all the piers successively. From a careful study of the conditions described in the Paper, it seemed probable that the piers could have been constructed at a considerable reduction of time and cost by means of open coffer-dams of interlocking steel sheet piles. Recent

Mr. Skinner. improvements had developed a new type, called the spring lock steel sheet pile, which combined great lightness with perfectly watertight joints and protection during driving, ensuring accuracy in engagement and great economy, and enabling coffer-dams to be constructed equal to riveted caissons. These possessed the great advantage of sectional sinking, enabling the units to be driven where it would be impossible to sink the complete structure, concentrating the force on a few inches of sectional area, and allowing for local obstructions above which the segments could be stopped while the rest of the wall was driven until the obstructions could be removed from inside. With such construction no leakage took place through the walls, the only inflow being through the bottom, and such as could be easily dealt with by steam-pumps. In such a case as that referred to in the Paper, the piles need have been driven only a short distance into the clay to ensure the bottoms being sealed, after which the interior could have been excavated in the open and the rock easily reached. Mr. Skinner had recently designed and constructed circular caissons of spring lock piles, of moderate dimensions, which had proved absolutely watertight and efficient. One at Rochester, New York, was driven before excavation was commenced, through 7 feet of dense sand and 13 feet of hard clay, and was perfectly dry under an unbalanced head of 19 feet of external water-pressure. Great economy was imperative, and the pile-segments were made as light as possible, being constructed from 20-inch by $\frac{1}{4}$-inch plates, giving a total weight of about 19 lbs. per square foot. This type of sheet piling, like every other form used in America, was patented, but all of them were on the market at a price little higher than commercial shapes and structural steel. The essential features of the type were the watertight joint and the wide range of dimensions, enabling the units to be made of any dimensions attainable with rolled plates. Special driving methods provided for its installation with any width and thickness. The joints were made with pairs of curved bars, slightly interfering, so as to spring a fraction of an inch in engagement and to produce two surfaces of positive contact separated by a clearance at the crown to reduce friction. That provided for irregularities of construction and maintained a tight joint, which could be applied to any type of body or web. In America, where timber was still comparatively abundant and cheap, steel falsework was seldom used for bridge erection, and old rails were never used for falsework. Making the connections, assembling the members and levelling and preparing the footings of the towers as shown in Figs. 4, Plate 2, was expensive, and the connecting rings, at the centre

Mr. Skinner.

of the panels of diagonal rods, would never be used. The rods would either have loop ends, pin-connected, and sleeve-nut adjustments, or screw ends and bevelled washers. The erection of girders and even trusses by the use of pontoons, utilizing the tide for loading and unloading, was common in America, but in such cases the span was always riveted up complete and handled as a single unit, and the tidal action was usually supplemented by the use of water-ballast pumped out of the pontoons to expedite the lifting. The spans were erected in the usual manner at the required elevation, and were carried on towers built on the pontoons, which enabled them to be deposited directly on the bridge seats of the finished piers. The lifting stool illustrated in Figs. 5, Plate 2, was an admirable device, except that it necessitated double duty in the simultaneous lifting of both adjacent spans, where only one need have been handled at a time, and all might have been adjusted independently with two instead of six stools. The device of following up the vertical posts with sand-filling in the masonry wells was especially good. An economy might probably have been effected by substituting simple timber cribbing for the stools, and carrying the jacks, one under each truss-end, on the cribbing, keeping the truss bearing constantly or wedged tight as the jacks were operated. One of the most daring examples of the erection of a bridge by the use of boats had been afforded by the Brunot Island bridge across the Ohio river, near Pittsburg, where a 523-foot single track, pin-connected span, weighing about 900 tons, was erected on falsework about 80 feet above the river in a position at right-angles to its permanent situation, out of the way of heavy barge traffic between the bridge piers which prevented the construction of falsework there. The framed timber falsework bents were set 20 feet above water-level on longitudinal lines of I-beams supported by the transverse caps of pile falsework bents between which nine large barges, nearly full of water, were placed. When the water was pumped out of the barges they raised the I-beams and falsework from the pile bents, and the entire permanent and temporary structure, weighing about 1,800 tons, was safely towed to position between the tall masonry piers. Water being then again admitted to the barges, the span was safely deposited on its bearings. Eleven 156-foot, pin-connected spans of the Belle Island highway bridge at Detroit, Michigan, weighing nearly 90 tons each, were erected in pairs on shore false-work, and then skidded transversely to temporary piers in the lake, near shore. A pair of barges connected by Howe trusses and thoroughly braced together was towed between the temporary piers

Mr. Skinner. and pumped out to lift the span; they then carried it a mile to the site, where they lowered it into position on the permanent piers. Fourteen double-track riveted-truss spans of about 220 feet each, for the Coteau bridge, across the St. Lawrence river, Canada, were successively erected on high falsework on shore, and skidded complete to towers on a pair of barges braced together. The barges were towed 3 miles down-stream, and safely landed their loads on the bridge piers, notwithstanding the fact that one span broke loose from the tugs, and was turned round by the current which ran at 7 miles per hour. It was impossible to turn it back, so slight changes had to be made to allow it to be seated in reverse position on its piers. Where the Intercolonial Railway crossed two branches of the Miramichi river, near Newcastle, New Brunswick, there were two single-track bridges, each having six 204-foot spans about 30 feet clear above the river, which is there subject to a tide of 2 or 3 feet and exposed to wind storms. In 1902 the old spans, weighing 200 tons each, were replaced by spans weighing 241 tons each, erected on the same substructure without any serious obstruction to traffic being caused. Two parallel sets of pile falsework, of the proper height, were prepared close together some distance from the old bridge and nearly parallel to it near the shore, and on them the two new spans were erected, one being riveted while the other was being assembled so as to expedite the work as much as possible. Two 26-foot by 84-foot wooden scows, 8 feet deep, with braced towers on their decks, were placed between the falsework intermediate bents, symmetrically with the centre of the bridge, and water ballast was pumped out until, with the rising tide, they lifted the span clear of the falsework. They were then towed to the site where, with a falling tide and the admission of water ballast, they deposited the span on the pier seats just vacated by the old span. For removing the old spans two similar scows were provided, spaced 87 feet 6 inches apart and connected by a pair of transverse wooden Howe trusses, 197 feet long, 17 feet 6 inches deep and 17 feet apart between centres, with top and bottom lateral bracing. The scows were floated under the old span with their trusses in the planes of the bridge trusses, and lifted the latter clear of the masonry, supporting them at panel points. As the new span was towed into position the old span was towed away, and, for the first bridge, each span was swung 90 degrees and was deposited with the ends resting on two trucks on two landing-platforms. After the scows were removed the trucks were pulled ashore and the span was jacked up to release them and afterwards was taken to pieces at leisure. When the second bridge was reconstructed, a year later, it

Mr. Skinner. was not practicable to provide a long water front for the disposal of the old spans in the way described, so the old spans and the trusses supporting them on the scows were deposited on pile bents in the river, and the span was dismembered by a gantry running on a track supported by the lower trusses.

Mr. Spring. Mr. F. J. E. Spring stated that his interest in the Netravati bridge was enhanced by the fact that, when Consulting Engineer for Railways to the Government of Madras, he had persuaded the Madras Railway engineers to apply to the estuarial bridges of the Cannanore branch, of which the Mangalore branch was a later extension, the system long ago adopted in Northern India but not until then practically applied on the south-western coast, of narrowing rivers to a breadth only just adequate to carry their maximum discharge, instead of bridging them across from bank to bank without regard to the causes which had led to the flood water being of unnecessarily great breadth. The introduction of that system in Indian practice had been due to Mr. J. R. Bell, M. Inst. C.E., and thus it was that the crucial part of the series of works used for such narrowing had come to be known throughout India as a "Bell bund." The training system in question was still in an experimental stage when in 1888 Mr. Spring, under Mr. Bell's direction, applied it to the Chenab at Sher Shah; but it had now long passed that stage, having been tried and proved in all kinds of rivers and by many floods, its weak points ascertained, and the original design modified in detail, while Mr. Bell's principle had held its own and been retained.

Engineers without Indian experience found difficulty in conceiving the wide wastes of waters presented to view by most of the great Indian rivers during flood time. Those who made the tour of India during the winter months, passed in railway carriages, perhaps several times in a day, over great bridges 1,000 feet to 10,000 feet in length. And yet at any one of such places no water of a greater breadth perhaps than that of the Thames at London Bridge might be visible, and what there was of it seemed to meander about in a wide desert of sand, usually clinging to one bank or the other for a mile or two at a time. But in the hot-weather months in the north when the Himalayan snows were melting, and in the south when the monsoon had burst, the great rivers would be found full up from bank to bank, with a strong current between the bridge abutments varying between 10 feet and 100 feet deep. Moreover, the traveller might be shown cross sections at any bridge-site in which the profile of the river-bed in flood time would be found to be deeper, perhaps by 10 to 50 feet, than that seen by him in the cold weather. In other words, the waste of sand seen in the cold weather

Mr. Spring. would have passed forward *en masse* to a depth of 10 feet to 50 feet, to the sea, to be replaced by a fresh amount of similar sand resulting from the disintegrating action of ice and of atmospheric agencies.

Ordinarily, and in India until recently, engineers had looked on the cross-sectional profile of a river, made perhaps in the dry season, as a fixed thing irrespective of the erodibility of the material of the river-bed. They had, in fact, treated the cross-sectional profile of the river largely as if it were rock right across, even when it was of pure sand to a depth of 100 feet or more, as was the case in most of the great Northern Indian rivers. In their view "narrowing" had connoted the raising of the level of the flood surface up-stream of the bridge, and the creation of a current of greatly increased velocity at the bridge-site. Thus, with English traditions of law-suits resulting from raised flood-levels, engineers had refrained from tampering with the river-breadth, even though such abstention might cause a bridge to cost £100,000 extra, as would have happened in the case of either of the two rivers under notice. Such a course of action might be, under special circumstances, justifiable enough if the cross-sectional profile showed rock at the surface right across. But it was now recognized that, synchronously with a rise of flood-level, there occurred a scouring and a deepening all over the sand bed of a narrowed river until the eroding and resisting forces balanced each other, when it would be found that the flood-level remained precisely as it was before narrowing took place, while the depth at the bridge-site had increased until the capacity for discharge purposes of the narrowed section had become equal to that of the original section. There was no longer room for doubt as to that being the right way to deal with the crossing of rivers like the Ganges. But in rivers like the Netravati debouching on the western coast of India directly from a mountainous country and not through erodible alluvium, such narrowing as that described in Mr. Napier's Paper relied for its justification less on the expectation of deepening the bed at the bridge-site than on the fact that much of the water to be crossed was not true flow but backwater. In such cases great extra erosion of the bed was not counted on as an essential feature of the engineering of the narrowed waterway. There was much in both the Papers, in connection with the details of the well-sinking, etc., which might be usefully commented upon, but in the means applied there was nothing of very novel interest. The notes furnished by Mr. Gales on the curve of sinking-effort were especially valuable. Mr. Spring desired to endorse all that Mr. Gales had said about the supreme value of heavy wells, especially for depths greater than, say, 50 feet. A heavy well would keep sinking continually, thereby cutting off the outside material which the grab ought not to have to excavate. A light well would only drop at long intervals, say two or three times a day, and a foot or two at a time, or even, as Mr. Spring had known, as much as 15 or 20 feet in one movement, and between the drops the grab would be busily engaged in dredging out far more than the net contents of the well to be sunk. Moreover, fast sinking meant straight, and therefore cheap, sinking. Another point of interest was the clean sand filling put into the bottom of each of the Curzon bridge wells. Mr. Spring's practice was to go farther, and to fill with clean sand up to the top of the interior corbelling, leaving the sand a few hours to settle into every crevice. That practice had been adopted as the result of experience and of a study of certain settlements of foundations mentioned in Papers read before The Institution; and the wisdom of it seemed to be fully justified by the fact that of a certain fourteen wells sunk to 80 feet below low water no measurable settlement had occurred afterwards, except in the case of one well where there was a settlement of 3 inches several months after the completion of the pier, because, owing to a misunderstanding on the part of an assistant, the precaution referred to had been omitted. The method described by Mr. Napier, whereby certain of the girders of the Netravati bridge, after being floated out on to the top of the piers a little above water-level, were supported by stools, the legs of which stood in holes in the masonry—filled by dry sand as the girders were gradually jacked up—was first used by the late Mr. H. Digges La Touche, M. Inst. C.E., in the case of an exceptionally high bridge on the Bellary Kistna State railway about 1886. Mr. Spring believed that a model of it was now in the museum of the Madras Engineering College. The method was excellent; for the dry sand trickled in under the stool-legs as fast as they were lifted, and the girders could not well drop more than an inch if a jack collar should leak. The double octagonal well, the use of which was spreading in India and the farther East, had been evolved by Mr. Spring in 1900 from the double hexagonal well devised by Mr. J. R. Bell. He ventured to suggest that those desirous of studying the methods whereby, in India, great rivers have been held between the abutments of railway-bridges and of irrigation-weirs, should consult his book[1] entitled "River Training and Control on the Guide Bank System," in which the subject had been treated very fully. Mr. Spring.

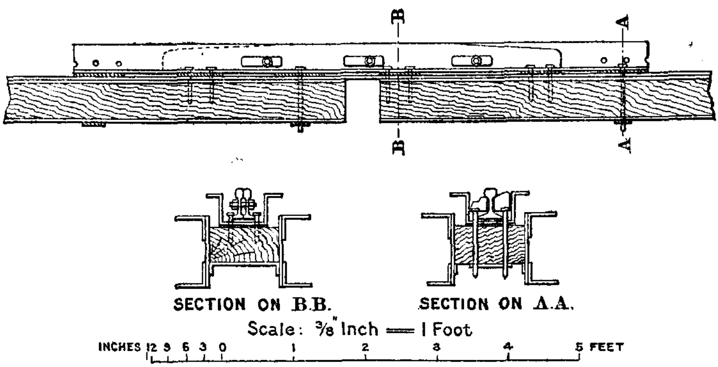
Mr. E. W. Stoney observed that the training-bund at the Mr. Stoney.

[1] A copy of this work is in the Library of The Institution.

Mr. Stoney. Curzon bridge had an apron 100 feet wide and 4 feet thick, the slope having a stone covering 3 feet 6 inches thick; while at the Netravati bridge the apron was only 15 feet wide and 3 feet thick, the face slope pitching being 2 feet thick. It would be interesting to know why there should be such a very striking difference in the design of bund apron in these bridges, one being nearly seven times as wide as the other, as well as being thicker. It was stated in the Paper that the Curzon bridge apron was made double the width of the scour expected. Mr. Stoney entirely agreed as to the great importance of weight in wells; and considered that for this reason and on account of its greater durability stone, when procurable of good quality at a reasonable price, was to be preferred to bricks for well-steining. Mr. Stoney considered that in sinking wells and cylinders through sand, which was in a fluid state, being saturated with water in Indian rivers, its pressure and the consequent skin friction must increase in proportion to the depth sunk, and that view was supported by numerous observations made by him when sinking the cast-iron cylinder piers of the Chittravati bridge. With regard to the creeping of rails, when Mr. Stoney was Chief Engineer of the Madras Railway, great trouble was experienced by the creeping of rails on the Kistna bridge which had twelve spans of 300 feet; there was on each pier a fixed and a roller bearing, so that the fixed and free ends of the girders came next each other; and the expansion and contraction of one girder had therefore to be provided for at each pier. The rails were of flat-footed type, laid in a wrought-iron trough which formed a guard, this being secured to a timber laid in a trough; over each pier there was originally a rail expansion splice joint, 5 feet 6 inches long, of the form shown in *Figs. 7*. These joints gave continual trouble for several years; on two occasions the actual scarf or switch-rail broke, while the stud bolts were broken several times, one by vertical shearing, the bolt being at the time near the centre of its slot. Those joints were renewed early in 1902, and the rails were anchored to the trough at the centre and fixed end of each girder by bolts through their webs and the sides of the trough; since that was done, there had been no further trouble. The actual maximum movement of the free ends of the girders had been found not to exceed 1½ inch, and that was readily taken up at the rail joints, of which there were ten in each span. The flat-footed rails on the Papaghni bridge, the Chittravati bridge, and the Pennair bridge were originally bolted to longitudinal timbers laid in wrought-iron trough rail-bearers, the rails being free to expand and contract at the fish-joints.

The girders were 139 feet 8 inches long, and rested on a fixed bearing at one end, and a roller at the other end, two roller bearings coming on alternate piers; the rails kept in perfect line and gauge for some 12 years, and no trouble was experienced, until the then government inspector insisted on the bolt-holes in the rail flanges of a rail at each girder free end being slotted; this was done and proved most unsatisfactory. There was always a rattling noise as the trains passed over, the bolts worked loose, and cut against the sides of the slots, and these rails got out of gauge and required continual supervision. They had since been removed, and replaced by unslotted rails as originally laid. The maximum movement of the adjoining free ends of these girders between 6 a.m. and 3 p.m. Mr. Stoney.

Figs. 7.



was carefully measured in April, 1901, the hottest time of the year, with the following results:—

On the Papaghni bridge	$\frac{3}{4}$ inch
,, ,, Pennair ,, ...	$\frac{3}{4}$,,
,, ,, Chittravati ,, ...	$\frac{5}{8}$;

and that movement in two girders was easily taken up by the rail joints. The point to which Mr. Stoney desired to draw particular attention was that in order to avoid trouble on girders the rails should be anchored in such a way on each span as to prevent their creeping when laid on longitudinal timbers, etc.; and that for moderate spans elaborate expansion joints were not required, and became a source of trouble and danger, if the rails were not prevented from creeping. When flat-footed rails spiked to cross sleepers were used it was only necessary to anchor the rails firmly behind each abut-

Mr. Stoney. ment, and to allow them to move on their bearing plates, if such were used, or their sleepers. With reference to the Paper on the Netravati bridge, the width of the apron, 15 feet, appeared very small, and it would be interesting to know why such a narrow one was used; it appeared to have failed to protect the south-east end of the south bund. It was stated that this was extended 700 feet, but no information was given as to the section used, or how its slopes were protected, or what width and thickness of apron was used. It would be interesting to know how the successive 4-foot lengths of the well sunk in pier No. 6 were joined together, and how the first length was got into place, and kept in position while being sunk; full particulars of the manner in which such exceptional difficulties were overcome were of great interest and value. It would also be interesting to hear which method of getting out buried dredgers proved the best and cheapest. The Author might also say if 5 rupees 4 annas per 100 for pneumatic riveting included the net cost of the pneumatic plant, air-compressor, etc. The description given of the mode of floating out the girders was not clear. It was not stated how far apart the girders were placed on the stools, nor whether the holes in the masonry for their legs were left filled with sand, or if this was removed and replaced by concrete.

Mr. Thompson. Mr. H. J. THOMPSON observed that the Author of the Paper on the Netravati bridge had referred to the very careful investigations made to determine the maximum flood-discharge of the river. This was essential at the Netravati and other rivers crossed by the West Coast Extensions of the Madras Railway, not only with a view to the provision of sufficient spans for the discharge of the flood-water at safe velocity, but also because the civil authorities and the land-owners were apprehensive that the large reduction in the water-ways contemplated would result in flooding above the bridge to such an extent that during the monsoon the rice fields would be submerged for several days at a time, and the young rice destroyed. In determining the waterway of each of the bridges that risk was carefully guarded against, and no damage had resulted, while the contraction of the waterways had effected a saving of £266,000 for bridging on the Azhikkal-Mangalore Extension alone. The value of the Wild dredger in excavating clay and other hard soils had been referred to. The late Mr. Harrison Hayter, Past-President Inst. C.E., sent out to India, about 20 years ago, two of those dredgers as part of the plant for the construction of the cylinder bridges on the North-West Line of the Madras Railway. At the Papaghni bridge, it was then found that when fitted with back tines these grabs would excavate hard material which other types of dredger were unable to

Mr. Thompson.

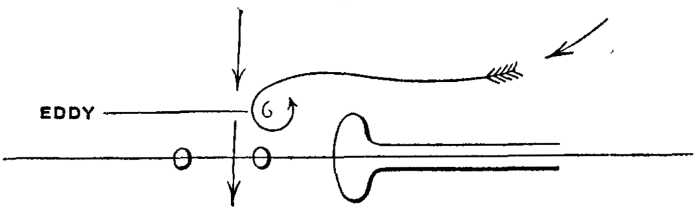
penetrate, and since that time similar results had been experienced in the construction of numerous other bridges in Southern India. What was now required in India was an efficient undercutter which Mr. Gales had correctly stated as "yet to be designed." The trouble with No. 6 well occurred when Mr. Thompson was in England on leave, and Mr. Napier, to whom the construction of the bridge was entrusted, as Executive Engineer, was responsible for the satisfactory solution of the difficulty which arose in founding the pier. Mr. Thompson desired to take this opportunity of placing on record his high appreciation of the zeal and ability displayed by Mr. Napier throughout the construction of this bridge. The method of lifting the girders on stools was jointly devised by the late Mr. H. C. D. La Touche, M. Inst. C.E., and Mr. Thompson some 23 years ago, for the erection of the girders of the Dhorabavai viaduct, and with slight modifications had been frequently used in India since. The design of the training-bund of the Curzon bridge was a departure from previous Indian practice, and it would be interesting to know the effect of a great flood similar to that which occurred in 1875. The curved end of large radius would probably lessen scour at the end of the bund, but the splaying of 1,200 feet in length of the bund at an angle to the axis of the channel was likely to prove a source of trouble in the event of a heavy flood. A similar splayed bund was the cause of heavy scour around the piers of one of the largest bridges in Southern India during a great flood 5 years ago; and a well founded 60 feet below low water was scoured to within a few feet of the curb by the swirl set up. With regard to the question of skin-friction, Mr. Thompson's experiments had shown that the increase for depth was comparatively small. Careful experiments made at the Papaghni bridge with iron cylinders lined with masonry [1] showed that the increase in resistance to sinking in sand at 57 feet below the river-bed, as compared with the first 12 feet, was 0·58 cwt. to 0·96 cwt. per square foot. The avoidance of top loading by increasing the weight of the steining was desirable, and it had been the practice for many years on the Madras Railway to use stone where obtainable for the steining of wells, even at increased cost, in preference to brick, in order to reduce the delay and cost of external loading and the risk of canting. The wells of both bridges under notice were constructed on steel curbs, but in recent bridges Mr. Thompson had used reinforced-concrete curbs for square, circular, and double octagonal wells. Such curbs were much cheaper than steel curbs, and could

[1] Minutes of Proceedings Inst. C.E., vol. cxxii, p. 189.

Mr. Thompson. be readily constructed at bridge-sites difficult of access for carts laden with heavy steelwork sections.

Mr. Gales. Mr. GALES, in reply, observed that Mr. Beckett's unrivalled experience in well-sinking on a large scale made his endorsement of the views put forward in the Paper in regard to the provision of weight in the wells themselves particularly gratifying. It was to be regretted that he had not offered a criticism as to the amount of sinking-effort to be provided for such sinking in recent alluvial deposits. With regard to the filling of wells, Mr. Gales was led to interpose the concrete plug below the top of the concreting, by the fear that if any sinking of the well should occur under the superstructure, the sudden resultant pressure might burst the steining. The concrete plug was not made to fill the dredging hole because of the feeling that the well would be more stable, in case of sinking, with the sand to distribute the pressure at the base, than if it then rested on a base of unyielding concrete the lowest point of which might act as a pivot. In reply to Mr. Brodie, in dealing with a river of any magnitude, the bridge had to be built wherever the main channel happened to be, and this was usually under one bank or the other in the case of a river with permanent banks. If, at an obligatory site, the main channel of such a river was in the middle, the construction of two expensive guide-banks in one season would be entailed, greatly increasing the risk of failure to complete before the floods. If Mr. Brodie could give specific instances of failure of bunds having curved ends as advocated by Mr. Gales, with details of any such failure, the information would be of the greatest value to engineers in India where important works of this nature were in contemplation. Mr. Gales agreed that in ordinary cases, when a pair of artificial guide-banks had to be constructed, what Mr. Houghton termed the *vena contracta* form was desirable; but when the permanent bank could be utilized in place of one of the artificial guide-banks it was preferable, as Mr. Spring pointed out, to make the obligatory artificial bank a copy of the permanent bank as far as possible. Expansion joints at the ends of long girders in a metalled roadway were a source of difficulty, if the sliding cover-plate were placed below the metalling as advocated by Mr. Laurie: either the roadway was racked to pieces or expansion was prevented, causing incalculable damage to the girders and piers. If, however, as in the Curzon bridge, a diapered cover-plate were placed at the road-surface to work on a timber retaining-baulk, the worst that could happen would be an unevenness in the roadway which could be diminished by good maintenance. The short glacis advocated by Sir Bradford Leslie would not seem to provide sufficient security against attack of the approach bank by a bend of the river, as indicated in Mr. Robertson's sketch; for, although a river in a sufficiently high flood would run straight through a bridge, dry-season bends were known to occur frequently in alluvial rivers and were sufficiently dangerous when occupied by a three-quarter flood. Nor must the effect of the eddy scour on the foundations of the first pier or the glacis itself be overlooked in the case of any considerable quantity of water flowing along the approach bank to meet the full force of the direct current through the bridge. With regard to the American practice on the Mississippi and Missouri rivers, described by Mr. Skinner, of spanning the main stream by means of large spans and crossing the rest of the *khadir* (as it would be termed on the upper Ganges) by short spans of 30 to 60 feet, it was not clear how the main stream was prevented from taking a disastrous course through the approach viaducts protected by Mr. Gales.

Fig. 8.



perishable willow mattresses, and how the subsidiary channels were dealt with. If, in an erodible alluvium, the "permeable-dyke" action of the short-span viaducts were sufficient to maintain the main channel through the main spans without other training-works, the study of similar Indian rivers from a fresh point of view would become necessary.

Mr. Napier. Mr. NAPIER, in reply to Mr. Brodie's remarks upon the training of the Netravati towards one bank, stated that the reason for this was a simple one, but was not mentioned in the Paper. Below the bridge-site there were on the north bank wharves used for loading coffee and tiles, and the channel leading to these wharves had to be kept open. The training of rivers by the use of Bell bunds and the consequent reduction of the length of the bridge had been so successful in India that the Author could not agree with Mr. Skinner that the practice was hazardous, if carefully carried out. The construction of temporary islands on which to pitch the curbs was determined by considerations of cost; the pier shell advocated by Mr. Skinner would have been much more

Mr. Napier. expensive. With regard to Mr. Stoney's observations, the extension of the south-east bund was of the same section as the original, except that in the last 100 or 150 feet the apron was gradually extended to a width of 100 feet, which protection was carried round the head. The reinforced cement well sunk inside well No. 6 was practically monolithic although constructed in 4-foot lengths, because the reinforcing-rods were continuous and the concrete top of one length was always broken before the fresh length was added. The cost of riveting was exclusive of the original cost of plant.