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. 7–11), 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, metal-work, 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 substructure 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 in construction, he might say a word upon one or two points

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

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.

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 Damoodah river, consisted of ten spans of 200 feet each, and the piers were built on single 26-foot brick wells, without any external iron

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 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 Bradford Leslie.

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 appreciate 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 Sir Douglas Fox.

[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. 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. Barry.

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. Robinson.

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.

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.

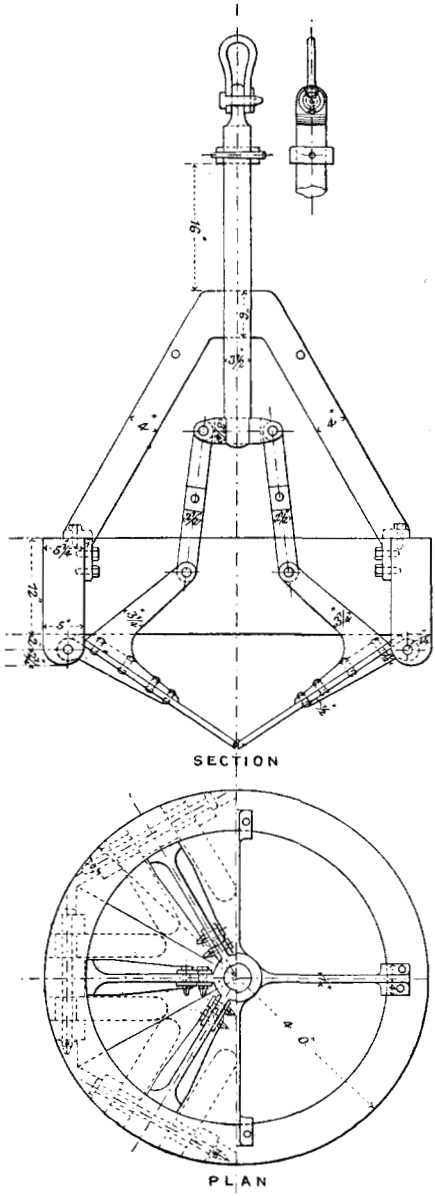
Mr. Riddell. monsoon. The strata through which the cylinders were sunk consisted of moorum with large stones, conglomerate of kunkur, moorum, and gravel, and impacted sand and moorum. (Moorum was supposed to be decayed trap-rock; it was like a hard clay or marl.) On the last of these the cylinders were 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.

Mr. Mosse.

Fig. 2.



CEYLON GOVERNMENT RAILWAY EXCAVATOR.
Scale ½ inch = 1 foot.

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 Kelani River, and the dredger used was designed 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. 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.

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

[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 two diverse 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 $\frac{5}{8}$ 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

[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.

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.

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 staging for the complete structure 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

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 the arched 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. Sir Bradford Leslie.

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 $\frac{1}{2}$ or $\frac{3}{4}$ 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-ropeway, 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.

Mr. Parsey. cost of erection in this country was between £3 and £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

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.

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 8, 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 girders, 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, and 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

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

Mr. Hayter.

had to be raised an additional height nearly equal in extent 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, they were gradually made deeper. 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 within certain limits 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 became so much attenuated that, notwithstanding there was no greater strain anywhere than the conventional 5 tons per square inch on iron, or $6\frac{1}{2}$ 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 of great depth. 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.