Discussion.

The CHAIRMAN said he had great pleasure in moving a vote of thanks to the Author for his valuable contribution to the Proceedings of the Institution, and he trusted there would be an interesting discussion on the Paper by those engineers who had had experience of putting in bridge-foundations in other difficult situations. The Chairman.

Mr. F. R. UPCOTT remarked that he took a special interest in the work described in the Paper, because about 33 years ago he had been employed on docks and canal-locks at the site of the Rupnarayan bridge: further, he had had several opportunities of visiting the bridge while it was being built, and had also been present at the official inspection in 1900. The railway between Calcutta and Madras certainly afforded more examples of bridge-building than perhaps any other railway in India: running, as it did, parallel to the sea-coast, and crossing the three large deltas of the Mahanadi, over which there were bridges aggregating about 4 miles in length, all spans of 150 feet; the Godavari, which he thought had a bridge something like 2 miles in length; and finally the Kistna, where there was another large bridge, of about the same length as the one described in the Paper. Of all the bridges on that line, the one under discussion was the greatest work, and the most interesting; it was also one of the few examples in India of bridges over tidal rivers. He thought there were only three or four other instances, notably on the Hugli, above Calcutta, and on the Bombay side of India. Of course 33 years was a long interval; but he was under the impression that the layers of blue and yellow clay, which the Author had depicted in Fig. 2, Plate 2, were rather hypothetical. If his own memory served him aright, when building the locks at that place—the foundations of which were of course not so deep as those of the bridge—he had encountered silt. He had also found lumps of what he had at first thought to be clay; but after being kneaded, and immersed in water for 24 hours, they had entirely dissolved. The Author said that the clay which he had tried crumbled when dried in the air. He believed the Author must have magnified the qualities of the soil with which he had had to deal. With regard to the sinking of the caissons, three out of eight piers had been founded by sinking caissons on artificial islands in the bed of the stream; and he Mr. Upcott.

Mr. Upcott. thought that method was to be strongly deprecated. In former days, curbs had generally been of timber, and of course it had not been possible to sink them as in the present instance, where they had been of iron, and where it had been possible to float them out. There was nothing in the Paper to show the cost of the islands; but he was led to think that, given sufficient depth of water to float either the barges which carried the caissons or the caissons themselves, a good deal of money and much trouble would have been saved if the islands had not been made. In the construction of islands such material as branches of trees and sand-bags and bricks were used, and were often carried down along with the caisson as it sank. There was danger of these getting under the cutting edge, and causing a great deal of trouble; because when working at such a depth as 80 feet it was impossible to send down a diver to clear the cutting edge. Therefore he thought that, given sufficient depth of water to float out the caissons—as appeared to have been the case at the Rupnarayan bridge—that plan should be followed always. Apparently much of the sinking had been done by "jumping" the caisson; that was, when it could not be got to sink, instead of increasing the load, excavation was carried on below the cutting edge, and when a big hole had been dug, the water was pumped out as rapidly as possible, and the well went down. When it did so, it generally canted, and there was no possible means of keeping it vertical. He noticed that the water had been baled out; but in sinking a caisson it was of the utmost importance, when a hole had been dug underneath the curb, to get out the water as quickly as possible; perhaps the Author would explain why, in a work of that magnitude, the water had been baled with wooden buckets instead of pumped, when there must have been several pumps available. That method of sinking, which of course disturbed the soil more than did any other, probably explained the phenomenon which the Author mentioned, namely, that when a caisson canted to one side and steps were taken to right it by dredging, it went past its proper position and canted to the other side; the reason being that the caisson was practically in a state of flotation. The soil outside was going down and the soil inside was being blown up by the water. He did not know whether an estimate had ever been made of the ratio of the volume of the material taken out, to the volume of the well, in sinking a well of the dimensions in question, 80 feet or 90 feet deep. It would be very interesting if that ratio could be ascertained. He would like to know how the Author arrived at his

Mr. Upcott. assumption that the support due to skin-friction on the portion of the caisson below the river-bed was 5 cwt. per square foot. While the caisson was being sunk, and the earth was going down on the outside as well, he did not see how the skin-friction could possibly be estimated. If a hole could be dug underneath the caisson, equal in cross-sectional area to the caisson, and the latter were then forced down by a weight on the top, an accurate measure of the skin-friction would be obtained. The skin-friction of a wrought-iron caisson was very different from the skin-friction of a rough brick well. When a brick well was required to be sunk easily, it was a common practice to have it pointed and rubbed quite smooth on the outside. With regard to the Bruce and Batho dredger used in sinking the caissons, for the information of those members who might not be familiar with that dredger, he might mention that it was hemispherical in shape, the four leaves meeting at one point, and being actuated by four levers from the interior. He did not know why that particular kind of dredger had been used in place of the ordinary grab-dredger, which was common enough in England as well as in India; but whatever might be the reason, he thought the result clearly established the superiority of that method of dredging over what might be called the Bradford Leslie plant. No doubt there was a good deal to be said for that plant, and he believed there were engineers present who had actually used it, and would probably be able to speak in its defence. It might have been very much out of order when the Author used it; but the whole Paper showed clearly that that method of sinking was not nearly so effectual as the ordinary dredger. He did not understand why the engineers of the Rupnarayan bridge had not tried another form of dredger. The Bruce and Batho dredger had followed the introduction of the Bull dredger, of which the old native spade or "phaura," having the blade and the handle placed at an angle of about 60°, was the parent. In the erection of the girders the tide had no doubt been a great help. In conclusion, he wished to express his appreciation of the way in which the work had been carried out.

Mr. Robertson. Mr. F. E. Robertson thought the Paper was a very interesting account of an important work, which, by good management, aided in one instance by good luck, had been brought to a happy conclusion. The Author mentioned that the Damodar and Cossye rivers were likely eventually to discharge entirely into the Rupnarayan. That was a good example of the tiresome ways of Indian rivers, which always did what they ought not to do. On looking at the map accompanying the Paper (Fig. 1, Plate 2), it

Mr. Robertson. would be seen that the Damodar had formerly flowed into the Hugli north of Calcutta; and at the point where it made a sudden turn southward at a right angle, there was an immense length of viaduct which had been built on the East Indian Railway about 50 years ago, since which time the river had never gone under it. The place was entirely free from floods now, due partly to irrigation embankments, and partly to the apparently natural tendency of the rivers to work to the west. It was highly probable, as the Author pointed out, that the Rupnarayan would eventually have to carry the whole of the water from those rivers. He quite agreed with Mr. Upcott in regard to the alleged blue and yellow clay. He had often received a report that a well had arrived in "good hard clay," with an enquiry whether sinking might be stopped. His answer had always been the same—namely, an instruction that a piece of the material should be put into a tumbler of water and left there for a night: and he had never known a single instance in which the "good hard clay" had not been found to be impalpable mud by the morning. He strongly suspected that would be found the same with the "clay" mentioned in the Paper, especially as it was stated that a quantity of half-decayed timber had been found in it. The matter was really a question of terms. He would call clay a geological deposit; but recent alluvial deposits, however hard they might appear to be, should, he thought, come under the classification of silt. At all events, the practical test was whether the material would stand exposure to water. No doubt in bulk, in the ground, it would; but if a piece were placed in water the test was whether it would or would not melt. He also agreed with the sentiments expressed by Mr. Upcott in regard to what was known as the Bradford Leslie sinking-plant. When first used on the Gorai Bridge it had no doubt been the most efficient dredging-apparatus available; but such improvements had of late years been made in ordinary dredgers, that the plant was scarcely needed; especially as it had the disadvantage that with it the sinking of the caisson could not be governed so well. With a dredger, one side could be dredged more than another; but the apparatus used could not be controlled in that way, because it dredged straight ahead. On p. 267 the Author spoke of the lime kunkur for masonry, having been ground in a special mill, while that for concrete had been used just as it came from the mill. He did not see why the mortar for the concrete should be treated worse than the mortar for the brickwork. The essence of hydraulic lime-making was, that the material should be ground to an impalpable powder; because, as

Mr. Robertson.

with cement, particles that were not so ground were more or less inert. The allowance for skin-friction was of course a very uncertain quantity, but he did not think 5 cwt. per square foot was an unreasonable amount to assume for such a deep foundation. With regard to the method of building up the piers under the girders, he might mention a convenient device which had been used in India for that purpose. The girder was supported at the bearings on four legs—wooden legs for small spans and iron legs for large spans. In building the pier, a little chimney was left around the legs; the span was then jacked up, and the chimney was filled with sand, these operations being repeated until the full height had been attained. By that means the trouble entailed by two sets of packing was obviated, and the method was much handier than changing jacks and packing. The cost of the bridge was stated per lineal foot of waterway. Although that was a common system in railway work, the statement was not of much value for purposes of comparison unless the circumstances were precisely similar; and he suggested that for such purposes the area covered by the bridge from the bottom of the foundations to the top of the girders would afford a more reasonable basis. The cost per lineal foot of a bridge consisting of 40-foot or 30-foot spans on shallow screw-piles would bear no comparison with the cost, stated in the same way, of a bridge requiring deep foundations. It would be interesting if the Author could complete the Paper by adding further details of the cost, especially the cost of the piers in relation to that of the girders. Lastly, he desired to allude to the official test of the bridge, and to object not so much to what the Author said in the Paper, which was only the customary form of statement, but to the whole idea and principle of the accepted method of testing. A test load was run on to the bridge, and it was said the deflection was so much, the implicit assumption being that that was a guarantee of the strength and safety of the bridge. In his opinion such an announcement was altogether mediæval in character. He regretted to see that at the last International Railway Congress a resolution had been passed to the effect that such tests were indispensable guarantees of the safety of the public. The root idea of that view must surely be the mediæval one that when a structure had been built, and had had put upon it a load under which it did not fail, it was strong enough for its purpose. The facts were just the reverse. Most of the members would be able to recall instances in which, after test loads had been applied to bridges and other structures, and they had been pronounced to be satisfactory, they had promptly failed.

Mr. Robertson. One of the most ludicrous instances which he could remember was the Embabeh Bridge, which had been described in the Proceedings of the Institution.[1] Some months after a "satisfactory test" at the opening of the bridge, the swing-span girder had split and broken in half. It had been patched up, and the bridge had been tested again; the verdict having then been that it was strong enough. A week or a fortnight after the test for the second time, the bridge had broken again on the other side. That indicated the value of such testing, on which he need not expatiate. He invited engineers to think what such a statement of the load and deflection amounted to. If the actual maximum unit-stress in any of the members, or in all of them, were stated, such information would be really interesting; the bare fact that the deflection was so much with a specially heavy load was not of much importance. The lightest load told as much as the heaviest. It was also said in the Paper, as usual, that the bridge had shown no permanent set. What permanent set should be expected even from an official test, after running trains over a bridge? The statement was accepted because it was the usual method of stating the result of the Government official test. The subject was a side issue in regard to the Rupnarayan Bridge; but it was highly interesting, and he would like to know why that mediæval custom was perpetuated in Government testing at the opening of bridges in the twentieth century.

Mr. Copperthwaite. Mr. W. C. Copperthwaite remarked that he had recently had a good deal to do with caissons, and he would like to know how it was that the Author seemed to have had the singular good fortune to sink all his caissons to the same depth, whether they were in clay or in yellow sand. No doubt there was a good reason for that, and he would like to hear it. A layer of blue clay was shown on the section (Fig. 2, Plate 2), the thickness of which, so far as he could measure it, might be anything between 20 feet and 30 feet. If that was blue clay, he did not understand why the caissons had not been stopped on getting fairly into it. Nothing was said in the Paper as to whether there was any batter on the outside of the caissons. The question of batter on caissons of the character described had been ventilated more than once in the Institution,[2] and he thought the general opinion of those most qualified to give one had been that caissons without any batter were the easiest to sink; but he

[1] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 206.
[2] *Ibid*, vol. cxxx. pp. 80–89, and vol. cl. pp. 8–84, *passim*.

would like to know the Author's views on the point. With regard to the operation of righting the caissons, and their tendency to continue to move over after removal of the load, he thought that was generally the case if the weight was kept on until the caisson arrived in its correct position. If it passed the least bit beyond that position, it followed the line that the cutting edge had made. In Figs. 9, Plate 2, the cutting edge of the caisson was shown as having two plates, one inside and one outside, which made an angle of about 11° with each other. The practice in England was to make the cutting edge much more obtuse. In the Blackwall Tunnel the plates of the cutting edge had made about 33° with each other; in the Greenwich Tunnel about 34°: and he believed he was correct in stating that in the large caissons for the new Rotherhithe tunnel under the Thames the angle was to be about 35°. Consequently, the "cutting edge" was not a cutting edge at all, but was simply the ordinary thickened skin of the caisson, sharpened off so as to enable it to sink into the ground a little more easily. With such a cutting edge as was shown in Figs. 9, if the weight on one side of the caisson were increased too much, the cutting action would at once be intensified; and, owing to the edge being so acute, there would be no chance of its burying itself before it went too far—as had always happened in the caissons he had had to work with. He thought there must have been some particular reason for giving the cutting edge that angle. Lastly, he wished to refer to a matter which was purely a question of detail, but one which would often arise in the future, namely, pneumatic riveting. Curiously enough, about the time the Author had had to struggle in India with a cast-iron riveter, with a gap of 4 feet and a large air-cylinder, working the snap by means of a cam, he had had a similar riveter at work at Greenwich; and he could bear out the Author's statement that the big gap riveters were inconvenient to work with in any case. The inconvenience was less when working in a horizontal straight line, because then a traverser could be fitted up above, and the heavy riveter, which weighed about 1 ton or $1\frac{1}{2}$ ton, could travel fairly freely from rivet to rivet; but when working on curves heavy gap riveters were very troublesome indeed. There was another difficulty, so far as home work was concerned, which did not present itself in India, namely, that at the end of the punch the pneumatic gap riveter made a noise like the bark of a dog, and the people in the neighbourhood of Greenwich had raised strong objection to that noise. His experience had been almost exactly the same as the Author's in the use of the Boyer pneumatic hand-riveter. When he had started work with

Mr. Copperthwaite.

Mr. Copperthwaite. the machine, one single compressor, working at between 70 lbs. and 80 lbs. per square inch, had been used, but it had been found that that pressure was not high enough. The result had been that in putting a rivet through two $\frac{1}{2}$-inch plates and two angle-bars the neck of the rivet had been driven up hard, and a very good joint had been made; but on cutting out the rivet it had been found that the other two plates near the angle-bar were not a tight fit. Working at a pressure of 100 lbs. per square inch, and with only two plates and two angle-bars to go through, the work had been very good indeed. He could not speak with regard to larger rivets, but he had worked with $\frac{7}{8}$-inch and $\frac{3}{4}$-inch rivets, and with a pressure of 100 lbs. per square inch it was quite possible to have thoroughly good work through $2\frac{1}{2}$ inches of metal. He would not like, however, to say that pneumatic hand-riveters, as at present arranged, did good work with thicker material.

Mr. Molesworth. Mr. H. B. MOLESWORTH observed that there were several large bridges in India similar to the one described in the Paper: they were common on deltaic formations; and a comparison of one or two of them with the Rupnarayan Bridge might possibly be of interest. For instance, in the Dufferin Bridge[1] at Benares, built in the years 1881–87, the caissons were 65 feet long by 28 feet wide; in the Rupnarayan Bridge they were 63 feet long by 22 feet wide. In the Benares Bridge the foundations extended to a maximum depth of 145 feet below low-water level; in the Rupnarayan Bridge to an average depth of about 88 feet. In the Benares Bridge there were 20 feet of water at low-water level, in which the caissons had had to be pitched; in the Rupnarayan Bridge there were 17 feet as a maximum. The Benares Bridge was 356 feet from centre to centre of piers, and the Rupnarayan Bridge 314 feet; there were 50 feet of flood in the Benares, and 12 feet of tidal flood in the Rupnarayan. The chief difference between the two bridges was that in the Dufferin Bridge the steel work in the caissons had been confined to what was necessary to pitch the wells which had been started in deep water; in the Rupnarayan Bridge the caissons had apparently been continued from the curb right up to low-water level. The Rupnarayan Bridge was, in fact, cased in steel from the curb up to low-water level; the other bridge was built in brickwork on curbs. At the Dufferin Bridge there had been a serious accident to the deepest foundation. The excavation had been carried down rather too deeply below the curb, and there had been a sudden falling-in of the clay, and an uprush of water, which had

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 13.

burst the brick wall. A piece, 62 feet in depth by 40 feet long, had been forced outwards, and had eventually fallen over into the river. That was about as bad an accident as could well occur in a foundation of that sort; especially as the bottom of the piece which had fallen out had extended several feet—20 to 30 feet, he believed—below the bed of the river. The repairs had cost 13,000 rupees, or about £900. If the steel skin on the Rupnarayan Bridge had been confined to what was absolutely necessary to pitch the wells, he presumed there would have been a saving of something like 825 tons of steel, costing something like £40,000. Although no reason was assigned in the Paper, there probably had been a reason for putting in the steel skin; but at first sight it appeared as if £40,000 had been spent as an insurance to save a possible loss of £900. The Kistna Bridge, built about 1890, had caissons, as far as he could remember, about 40 feet by 20 feet, which were sunk to about the same depth as the Rupnarayan caissons. They were built entirely of granite, in ordinary lime mortar, and the steel work was confined to what was necessary to pitch the wells; there had not been the slightest trouble or accident of any sort in sinking them. Mr. Upcott had mentioned that he did not approve of "running" wells, as it was called in the Punjab, that was, sinking wells by taking out water to make them start. If an excavation was made about 10 feet or 12 feet below the curb, and water was then taken out, the chances were that the well would cant, as Mr. Upcott had described; but, as the experience at the Benares Bridge showed, it was rather a risky thing to dig down too deeply below the curb. The sinking ought always to be carefully watched; and when any considerable distance below the curb, say 4 or 5 feet, had been attained, a little water ought to be taken out, and the well would generally sink. He had never seen any trouble arise from the wells canting when they were carefully moved by taking out the water. With regard to the use of Sir Bradford Leslie's sinking-arrangement for the wells, he would like to ask how the Author had managed with sinking-apparatus designed for a circular well, in caissons which appeared to have had three sinking-chambers in them: had the rotary borer been used in the central chamber and supplemented by dredgers in the two end chambers; or had the two end chambers been left to look after themselves, with a deeper hole in the middle? He thought it was a great compliment to pay to the inventor, to use his apparatus—designed for the erection of a bridge at a time when well-sinking had been absolutely in its infancy, and when the only apparatus at the disposal of the engineer had been the Milroy

Mr. Molesworth.

Mr. Molesworth. excavator [1]—for the construction of a bridge some 35 years later. He did not know whether any of the members had seen that excavator, but he remembered, from his early experience in India, that the sand-pump which had been in general use at the time of the construction of the Gorai Bridge had been the most cumbrous and slow piece of mechanism that could possibly be imagined. So far as he knew, at the time Sir Bradford Leslie's boring-apparatus was designed there had been absolutely nothing in existence in the way of a dredger which would excavate clay.

Mr. Benedict. Mr. ERNEST BENEDICT mentioned that he had had charge of the Gorai Bridge where Sir Bradford Leslie's boring-apparatus had first been used. There was a great difference between the Gorai and the Rupnarayan Bridges, and what was suitable for a cylindrical caisson was not necessarily suitable for such caissons as those under discussion. One difference was that, whereas at the Rupnarayan Bridge there was 18 feet of water, at the Gorai Bridge there was 90 feet of water; and he was not aware that the cylinders in the latter case could have been sunk in any manner different from that actually adopted. Moreover, under the Gorai Bridge there was a strong stream. In the present instance, also, there was a strong stream, at the top of high water and probably also close upon the ebb; but here the engineers had had the advantage—if such it could be called—of the stream going in both directions, so that it could be utilized both up and down; whereas at the Gorai Bridge it had always been a matter of pulling against the stream. The section of the river-bed (Fig. 2, Plate 2) was the most amiable section of an Indian river he had ever seen. His experience was, especially with oval piers, that in silt such as that described tremendous holes were formed. Even at the Gorai Bridge piers, there had been as much as 70 feet of scour round the first cylinders, so that the other cylinders had had to be sunk 40 feet deeper. But in the present instance there was no evidence or mention of scour. It was true that the tide would eventually fill it up again if it did take place; but he had known serious scour to occur in a few hours. When in charge of the whole railway, including the Gorai Bridge, in 1871, he had been informed by telegram one night that the first cylinder was only 18 inches in the ground: there seemed to have been nothing of the kind in connection with the Rupnarayan Bridge. One great difficulty in India, where he had had a good deal of experience, was in protecting piers from scour, and in

[1] Minutes of Proceedings Inst. C.E., vol. xxviii. p. 339.

protecting abutments from being taken in the rear. The Paper said the banks were maintained by the Irrigation Department: he had had some experience of that department, and had found that the banks under its charge had a habit of giving way sometimes in the high floods; so that to rely upon them was to depend on a broken reed. In the diagrams he could discern no abutment-wall, and he would like to see a large plan of the bridge showing roughly the low-water stream and the high-water stream, in order to judge if there was danger of such scouring as he had known to happen not far from the site of the Rupnarayan Bridge. He referred to a spot on the Eastern Bengal Railway, not many miles from Calcutta, where, out of the solid ground, a hole like a punch-bowl, 90 feet deep and 1,000 feet in diameter, had been scoured in a few days, resulting in the entire disappearance of a viaduct 210 feet in length, on screw piles 70 feet long. He agreed with Mr. Copperthwaite that it was odd that, having blue clay, which might have been silt but did not scour, the engineers should have pierced it and thereby made so many weak spots, when they had reached a strong place where they could have stopped the sinking. The saving thus effected might have been applied in going lower in the yellow clay, where they depended almost entirely on skin-friction. Mr. Benedict.

Mr. Cuthbert A. Brereton enquired what had determined the particular spans adopted. It was not quite clear whether, at the time the design was made, the full depth to which the pier should be taken had been determined. With regard to the caissons, the angle of the cutting edge was markedly sharp. The Author mentioned that in sinking it had been found to be weak, and certainly, judging from his own experience of such things, it would appear to be so, because the difficulty of sinking a caisson was connected with the shoe. If the shoe was sound and strong there was little difficulty in sinking satisfactorily; but if once the shoe went wrong all sorts of trouble arose. The design appeared to have been determined by the central cross wall, which showed an angle of about 30° for the cutting edge, which was that usually adopted. But the outer edge at the ends and sides of the piers had been simply made to follow whatever angle would be in keeping with the height as governed by the central wall. That did not seem quite a satisfactory way of proceeding, and it would have been better, he thought, to reduce the thickness of that central wall and put more on to the sides. With regard to encasing the whole of the piers in iron and leaving it in, of course the question arose as to the desirability of spreading the founda- Mr. Brereton.

Mr. Brereton. tion within a caisson, and thus getting a greater base, as against having a vertical face and trusting to skin-friction. Perhaps the Author could say whether any tests or experiments had been made which had led to the adoption of the vertical face for the piers—leaving apparently a very limited base—and trusting more to skin-friction. When iron cylinders were used there were means of spreading the base, working inside with smaller dimensions, and thus reducing the vertical weight on the foundation.

Mr. Williams. Mr. G. B. WILLIAMS remarked that he had endeavoured to make some comparison between the cost of the Rupnarayan Bridge and the probable cost of a similar bridge constructed in England under like conditions. Though it was rather difficult to make an exact estimate from the data supplied in the Paper, yet, assuming that the same amount of material was used, and that the piers took the same time to sink, and the girders the same time to erect, he believed the bridge would have cost £260,000 in England. If the value of the rupee were taken at 1*s.* 4*d.*, the actual cost of the bridge in India worked out at £256,000. But he thought the purchasing-power of the rupee in India must be more than 1*s.* 4*d.* Taking it at 1*s.* 6*d.*, the cost of the bridge would work out at about 10 per cent. more in India than in England. He thought it a pity the Author had not supplied more detailed information as to the cost of the various parts of the bridge, so that a comparison might have been made with other bridges of the same nature. The cost of the Dufferin Bridge worked out at Rs.1,610 per lineal foot; that of the present bridge was less, namely, Rs.1,463 per lineal foot. The contract price paid for brickwork seemed rather high at first sight, considering that the bricks, being made on the spot, must have been, comparatively speaking, of inferior quality; and it compared unfavourably with that paid for the same work during the construction of the Dufferin Bridge, namely, Rs.23·10 per 100 cubic feet. He would like to know if the Author had ever compared the cost of native labour in India with the cost of similar unskilled labour in other countries. Forty years ago, his father, Mr. M. B. Williams, M. Inst. C.E., had gone into this question rather fully, so far as the various countries of Europe were concerned, and he had come to the conclusion that at that time unskilled labour had been worth practically the same all over Europe. At present the cost of unskilled labour, and of the lower classes of skilled labour, such as that of platelayers' assistants, blacksmiths' strikers, carpenters' labourers, etc., worked out at about the same in South Africa as in England. The amount of work done by the South African native and by the English labourer seemed to be in the ratio of about 1 to $2\frac{1}{2}$, and the wages were in about the same ratio. At p. 268 the Author spoke of the live load as being 1 ton per lineal foot, and he afterwards spoke of the bridge being loaded with two 80·6-ton locomotives. That would mean, of course, a much higher load on the 100-foot spans. He would like to know whether the Author could say what live load was assumed in designing bridges of moderate span—say 100 feet to 200 feet—in India. He was led to ask the question by investigations which he had made some time ago as to the strength of wrought-iron lattice- and plate-girder bridges on a railway in Wales. The directors of that railway had been thinking of using 75-ton tank-engines, with a view to more economical working; and they had asked him to ascertain if the bridges on the line would stand the weight of such an engine. He had found only two bridges on the whole line which would stand engines of the weight proposed. Such engines would have produced a stress on the members considerably in excess of the stress which a bridge of that kind would usually be expected to bear. He imagined the same state of things must obtain on many other railways in England, and in other countries. On the Netherlands Railway in South Africa, 56-ton to 60-ton locomotives were used, though the bridges were evidently only constructed to carry the earlier type of locomotives, weighing about 40 tons. He would also like to hear how the equilibrium-bars and hooks had been attached to the shoe of the caisson in the Rupnarayan Bridge. That point did not appear to be clear from the diagram or from the description. Mr. Williams.

Mr. R. E. ELLIS asked whether the Author had found any sediment formed in lowering the concrete through water in the wells, and whether the concrete had set well and properly. In India he had found concrete which had been lowered through the water form a curious impalpable silt, which, when allowed to settle, formed a very fine slurry. He believed the cement in the case he had in mind had been Belgian cement, but he had had a similar experience with some native-made cement. It would be interesting to know whether any other engineer had found the same result from lowering concrete in boxes through water. He hoped the Author would deal carefully with some of the remarks which had fallen from Mr. Williams in regard to the value of native labour, and with the estimate made by that speaker as to the relative cost of the work, because he thought such statements could scarcely pass unchallenged. Mr. Ellis.

Mr. JOHN GRAHAM remarked that the four middle panels of the Mr. Graham.

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Mr. Graham. Rupnarayan Bridge were counterbraced, and he was somewhat surprised to see counterbracing in a modern Indian bridge. The main object of the web members in open-web trusses was to convey the sheer to the abutment in the most direct manner. If there was counterbracing, when the train reached the fourth panel the stress might be taken by the vertical and one diagonal, or by the diagonal in the other direction. The old Warren girder was, he thought, a sound design so far as that point was concerned; and he believed counterbracing had been invented by the Americans in order to have something different from English practice. He considered it was altogether wrong. His experience was that counterbraces, being tension members, were the longest and flimsiest members in the bridge, and at certain times there was no stress whatever upon them. Initially there was a certain amount of permanent set established; later on, the intense heat of India expanded them considerably, and they never seemed to recover entirely. Consequently they vibrated; and he had even found them broken through at the first rivet-hole, from excessive vibration. If they were done away with, and if one compression member were substituted for the two diagonals, there would be obtained the minimum number of members in the truss and the principles of the Warren girder, with the compression members as short as possible. For caissons he thought mild steel was the ideal material. He had always admired it since he had first noticed it in the caissons of the Forth Bridge; and he was surprised that it was not more generally used for smaller cylinders. He believed it could be used with good effect in cylinders as small as 11 feet in diameter. The main thing in getting cylinders down was weight, and when the load could consist of portions of the permanent structure, it was a considerable advantage. With a cylinder 11 feet in diameter, there could be a 2-foot ring of concrete between an inner and an outer skin of steel plating, and the cylinder would go down easily. He sincerely hoped he had had his last experience with cast-iron cylinders. He believed the records of the Institution bore witness to the trials and troubles of engineers in getting them down; and if his suggestion were adopted, he thought many of those troubles would be avoided. A cast-iron cylinder, weighted with, say, 400 tons of rails piled on the top, which, when it had been hung up went down 18 inches or more suddenly, was not a desirable thing to have to deal with. Moreover, for every 9-foot length of cylinder it was necessary to take that load off and on, which was no light matter. When sinking some cast-iron

Mr. Graham.

cylinders he had had opportunities of taking careful note of the skin-friction. The sinking had been carried out by means of divers, and frequently there had been a space of 18 inches entirely clear below the cylinder, which had then been supported entirely by skin-friction. Sometimes it had been hung up in this way for 2 or 3 days, and it had been necessary to let off charges of dynamite in order to set it in motion. He had found the skin-friction to vary between 6 cwt. and 4 cwt. per square foot. Engineers at home seemed to be keenly interested in the cost of bridges, particularly in the details, such as the separate costs of the spans and piers. The theory seemed to be that the most economical bridge was that in which the cost of the piers and of one abutment equalled the cost of the main girders. He believed that worked out very well; and it would be desirable in bridges of the kind under discussion to state separately the cost of the piers and that of the main girders. There were many opportunities for obtaining particulars of cost in that form in India, and as reliable information of the kind would be very valuable, he would welcome the issue of instructions by the Government of India that the accounts should be returned in such a way that it could easily be obtained.

Sir Guilford Molesworth.

Sir GUILFORD MOLESWORTH, K.C.I.E., Vice-President, mentioned, with regard to the economic ratio of cost of spans to cost of piers, that he had always made it a practice when in India to keep the cost of the superstructure, as far as possible, rather in excess of the cost of the piers; because the cost of the superstructure was a fairly definite figure, whereas that of the piers was very uncertain.

Mr. Read.

Mr. R. J. G. READ thought the Paper was a straightforward account of the erection of a well-conceived and skilfully executed work; and there was very little in it that he could find fault with. There appeared to be a good deal of difficulty in the erection of bridges in India, on account of the ever-changing character of the rivers. He had lately perused an account[1] of a striking illustration of the same thing in the erection by the Russians of the bridge over the River Amu Daria, beyond the Caspian Sea. The river flowed past the town of Charjui, and illustrations were given showing the manner in which the course of the river had varied during 4 years. In 1888 it had been close to the town; in the following year it had moved away a short distance; and it had assumed a different course in each of four

[1] Mémoires de la Société des Ingénieurs Civils de France, 1900, p. ii, p. 342.

Mr. Read. successive years. The bridge built by the Russians for the railway line had had to follow the river, and finally consisted of twenty-five spans, of about 197 feet each, costing about £720,000. It was stated that in the end it had been found necessary to confine the course of the river by the construction of "submerged groynes." No doubt many of the members had read recently an account of a river in America which had left the city of Nebraska on one side and had departed 2 or 3 miles from its former course. He would like to know what was the greatest divergence which had been allowed for in the spans after the piers were sunk. He believed they were not all sunk exactly to the spans given on the diagram. He would also like to know what method had been adopted for setting out the piers and for fixing exactly the positions of the caissons on starting the sinking. A good deal had been said about the skin-friction of the piers. He understood that skin-friction in soil of a soft, muddy nature was not nearly so high as in sand; the coefficient of friction increasing with the fineness of the material, provided it was clean, like sand or gravel, but not if it was mud or soft silt. Perhaps the Author could give some explanation on that point. Mr. Robertson had criticized the method of testing a bridge by loading it with a train, and had characterized it as a mediæval custom. He did not altogether agree with that view. A custom might be mediæval and yet not obsolete. The mere putting of a single load on a bridge to test it would show how much it deflected and recovered at the time; but that was not the only criterion of the qualities of the bridge. Whoever tested the bridge went over it carefully beforehand, was well aware what were the stresses imposed upon the various members by a particular load, having regard to the design, and also saw that the joints and connections were properly made. If there was a good joint in one place and a bad joint in another, the test-load would not give a true indication of the strength of the bridge. In a Paper on recent progress in American methods of bridge-construction, read before the American Association for the Advancement of Science, Mr. H. S. Jacoby had pointed out that the tests imposed on nearly all the railways in the United States consisted of loading the bridge with two of the heaviest locomotives that could be obtained, followed by a train of uniform composition; and he had quoted statistics to illustrate the augmentation of the proof-loads during the previous 8 years. In 1893 there had been only two railways out of seventy-seven which imposed loads exceeding 4,000 lbs. per lineal foot. In 1901 there had been ninety railways out of one hundred which imposed that load, or loads exceeding it, the maximum having been increased from 4,200 lbs. in 1893 to 6,700 lbs. in 1901. The same writer had further stated that the scientific and practical researches effected in the subject had led to the elimination of methods of testing recognized as being inefficacious, and had allowed to survive only those which indicated with sufficient exactitude the aptitude of the structure to fulfil the objects expected of it. That, Mr. Read presumed, was the object of all testing of bridges. Mr. Read.

Mr. F. R. Upcott wished to explain, in reference to Mr. Read's remarks, that from information he had gathered from a Russian engineer in charge of the Trans-Caspian Railway, the bridge referred to, over the Amu Daria (the Oxus), had first been constructed by the Russian engineers as a temporary bridge of wood, on piles; and the River Oxus had then been trained by temporary fascine embankments into a permanent channel. That having been done, the Russian authorities had built the permanent bridge which now crossed the Oxus at Charjui. Mr. Upcott.

Sir Frederick Bramwell, Bart., Past-President, remarked that, having seen the sinking of the northern shaft of the Thames Tunnel, he might mention that there had been a cast-iron curb on the ground, and on the curb the brickwork had been built 25 feet high, according to his recollection, before making an attempt to sink the shaft. Then the outside of it had been rendered with cement, and greased. Sir Frederick Bramwell.

Mr. R. St. George Moore observed that it was stated in the Paper that about 4 tons per square foot was the weight on the sand foundation after having penetrated through the clay. He would like to know whether any settlement had been noticed after imposing the full load on the piers, and whether any adjustment for settlement had had to be made. Mr. Moore.

Mr. W. H. Thorpe thought it was commonly accepted, broadly speaking, that the cost of the superstructure should equal the cost of the piers. It seemed to him that for a river of given width, while the total cost of the piers would vary with their number, and the total cost of the girder-spans inversely as the number of openings, the total cost of the flooring, though constant, would be of varying relative importance. He suggested that, in fixing the economical relation of the costs, the floor should be entirely left out of account, and comparison should be made as between the total cost of the main girders only and the total cost of the piers. Mr. Thorpe.

Mr. Graham explained that he had meant the cost of the main girders only; he had not intended to include the flooring. Mr. Graham.

The President. The PRESIDENT, referring to Mr. Ellis's enquiry as to concrete sunk under water, remarked that many years ago he had had to examine some concrete in a dock-wall which had failed. A good section had been exposed by excavating through the wall to a considerable depth, and not layers only but in some cases pockets of material looking very much like pipe-clay, and containing neither sand nor stone, had been disclosed. At the time the engineers had been much puzzled to account for the occurrence of such layers of clayey material.

The Author. The AUTHOR, in reply, explained that he had used a general term, namely, "silty clay," to describe the soil which had been sunk through. Only analysis would show what the soil really was, but for practical purposes it behaved as a clay. As it had always been intended to found the piers on the underlying bed of sand, no trouble had been taken to find out the exact nature of the soil. Both "silt" and "clay" were commonly used in a very vague way. It would have been very difficult to commence sinking caissons Nos. 5, 6 and 7 otherwise than from islands. At low water the depths at the different sites varied between 2 feet and 4 feet, which would have been insufficient to float the staging. The bottom of the river consisted of fine silt which was continually shifting, and which scoured away at once if there was the least obstruction to the tide. There was no sound bottom on which to place runners whereon the caisson-shoes could have been dragged to their sites; and even if there had been, their weight, 75 tons each, would certainly at high water have made the procedure risky. The objections to floating out the shoes were the difficulty, the expense, and the time required to make them watertight. As they drew 8 feet of water, the operation of getting them into position would have had to be carried out in one tide. Had they been floated into position, it would have been impossible to control the sinking until they had reached the hard soil: the silt would have scoured away at once, and the shoes would have tilted over in any direction. The islands had cost approximately Rs.5,000 each. Boxes had been considered more efficient than pumps for lowering the water in the dredging-chambers. Each box lifted about $1\frac{1}{2}$ ton of water, or about 300 gallons; the boxes took no time to rig up; the dredger was unhooked and the box was fastened to the rope from the steam-hoist. Pumps somewhat similar to the pulsometer had been used in connection with Sir Bradford Leslie's plant, but they had not reduced the water as quickly as boxes, and had moreover given much trouble in fixing and keeping in order, especially when the lift was large. The

V-shaped bottom enabled the box to empty itself. The skin-friction had been taken at 5 cwt. per square foot for two reasons. In the first place, in an actual experiment, one of the wells of the land spans, 19 feet 6 inches in diameter, had refused to move when 40 feet in the ground, and it had been cleared down to the cutting edge. It had been found to be supported by skin-friction alone, which calculation showed to be about 5 cwt. per square foot. Secondly, previous Papers published by the Institution seemed to agree that 5 cwt. was a reasonable figure. Bruce and Batho dredgers were, he thought, now accepted in India as the most satisfactory for such work. Practically all the well-sinking on the east-coast section of the railway of which the bridge formed part, amounting to a length of sinking of over 3 miles, had been done by means of those dredgers. One advantage which they possessed over some others was that only one rope was required. Sir Bradford Leslie's plant had been put into first-rate order before use. Theoretically it was excellent, but in practice too much time was lost in lifting it up and down. Sometimes the sides of the hole fell in and blocked the arms; sometimes it jammed itself in the bottom: and sometimes it was found to be running clear of the bottom and doing no work. At times it was difficult to make sure that it was working properly. The method of raising girders referred to by Mr. Robertson had been discussed in the present instance. In dealing with a weight of over 500 tons per span, however, it had been considered less risky to use a method by which each step was clearly visible. Approximately the cost of the girders was half that of the piers. If girders for two roads had been erected the cost of the girders would have been equal to that of the piers. Taking the area from the bottom of the foundations to the top of the girders—a comparison suggested by Mr. Robertson—the cost per square foot was approximately Rs.9·5. He was not able to state the figures for other large bridges in India. Where native labour had been employed in riveting up the different parts of the girders, a test-load was useful in showing whether the work had been done properly. The design of the caissons with the steel skin carried from the cutting edge to the top had been taken from the Hugli Bridge, and the caisson was of similar design. It was slightly shorter and narrower; but in other respects it was exactly the same. It had been necessary to have acute cutting edges at the ends of the dredging-chambers in order to give sufficient space for working the boring-plant, each chamber having a separate apparatus. No doubt that caused the semi-circular ends to be rather thin, and rendered it necessary to

The Author.

The Author. carry the steel skin up to the top. The weak point in the caisson was the cutting edge of the side of the centre dredging-chamber. The Rupnarayan Bridge differed considerably from the Dufferin Bridge, in that the Rupnarayan was a tidal river, and there were strong tides flowing practically all the year round. It was impossible to build masonry in those tides, and prevent the tide washing the mortar out and damaging it. Without a steel skin it would probably have been necessary to commence the new brickwork always above high-water level, which would have increased the weight of the caissons and their height above the bottom of the river, and added to the difficulty of sinking them straight. The caissons had all been taken down to the same depth—the top of each caisson being at dead low-water; they were designed with a height of 88 feet, sufficient to allow of their being founded on the top of the sand. There had been no difficulty in taking them down to the exact level required. One caisson which had moved out of its correct position while sinking, had been corbelled out at the top, and it had been taken down a few feet farther. That had been done only in order to prevent the batter from appearing at low water. There was no batter on the outside of the caissons. There was a reinforcing plate about 3 feet deep on the outside of the cutting edge; this, though slightly enlarging the diameter of the caisson at the bottom, probably had no effect at all upon the sinking. The caissons had been taken through the bottom layer of blue clay into the sand, as the sand had been considered a more reliable foundation, and capable of carrying a greater weight. The blue clay found in that part of Bengal was absolutely worthless as a weight-carrier. With regard to scour, the top of the hard silty clay might be taken as the true river-bed. On the east side there was a large deposit of very fine silt. If there was an excess of water, such as came down during the freshets in the rains, that silt was scoured away and the section was thus increased. No scour had ever been observed in the hard silty clay, though it had been carefully looked for. Mr. Williams's remarks appeared to show that he judged from the price paid for labour in India that the bricks used were inferior. He did not think any engineer who had been in India would admit that. The bricks were burnt on the spot, and were thoroughly sound and good. The equilibrium-bars had been brought down to one point, and attached to the caisson by a hook under the cutting edge. Sediment on the concrete had certainly been noticed.