Discussion.

Dr. Holmstrom.

Dr. J. E. HOLMSTROM desired to raise one or two questions in connection with the open-caisson or well system of foundations, of which the Iskandar bridge provided so interesting an example. The system had been known for a great many years in India, and it was accepted as normal for the foundations of bridges on the Federated Malay States railways. It had the advantage of requiring very little skilled labour or timbering (which was difficult in that country), and the simplest of plant. Many well-foundations had been successfully sunk with no more elaborate arrangements than a few coolies working at the bottom of the well with *changkols*, a basket, a rope for lifting the basket over a pulley, and a water-buffalo pulling the rope at the other end. That method could be developed by mechanization to any extent desired, and he noticed that the Authors had utilized a locomotive crane, which, he had always contended, was the most economical method. The system was also very adaptable, as had been exemplified by the very ingenious expedient of sinking wells within a well—if he might so express it—in the case of pier 2, and also by the convenience of providing the well-foundation which had unexpectedly been required underneath the north abutment. He would like to ask the Authors whether they thought it had been necessary to use the expensive steel curbs underneath the wells. They were said to have cost over £560 each; yet the well which had been unexpectedly started under the north abutment had been provided with a concrete curb and had been successfully sunk. Would the Authors still use the steel curbs if they were confronted with the same kind of work again? It was not only a question of the cost, but there was also the point that steel curbs had to be fabricated in the shops, brought to the site—often with some difficulty—and riveted at a time many months before riveters would again be required at the bridge. A concrete curb, on the other hand, could be made very simply. It was only necessary to erect the inside and outside shuttering of the well-wall on the ground, to form a cone of mud inside giving the desired slope, to place the reinforcement in position, and then to deposit the concrete. It might be thought that on soft ground difficulty might arise from unequal settlement before the concrete had set; but in an instance that he had in mind the curb had been successfully formed in that way on an island in mid-stream, that difficulty being avoided by placing sand underneath and ramming it very hard. There had been no failure of the well-curb when obstructions had been encountered requiring blasting underneath it. Another advantage of making a well-curb of concrete was that the slope underneath could be made gradual so as to leave plenty of room for men to work while underneath the well-wall. That was a very great advantage, because there was less danger of men being trapped in the event of the well sinking suddenly a foot or two. The well-wall could also be made quite thick enough to give adequate weight. In the case he mentioned the curb had no actual cutting edge, the rim of the concrete being 6 inches wide, but it would be quite easy to make a cutting edge by having a circular angle-iron underneath the concrete. That, however, he thought, was unnecessary, as in his experience the ease or difficulty of sinking a well was governed not so much by the nature of the cutting edge as by skin-friction. It was common, as the Authors had mentioned, for a well to remain "hanging" by skin-friction although the whole of the material from the periphery underneath the cutting edge had been excavated. In such a case it was a common expedient to let the well fill up with water and to explode a stick of gelignite. Apparently the shock transmitted by the water momentarily lessened the skin-friction, and wells had been known to sink several feet when they were "hanging" that amount.

Dr. Holmstrom.

How many men had been able to work simultaneously in the particular caissons mentioned in the Paper? The speed of sinking depended mainly on that factor and on the weight of the well-wall; in that connection he thought it useful to point out that, whereas the skin-friction varied directly as the diameter of the well, the weight of the well-wall which had to overcome that skin-friction varied as the square of the diameter. There was, therefore, a very great advantage in having a large well. Furthermore, the greater the diameter the greater the thickness of the well wall which could be conveniently used while leaving an adequate opening in the middle for bringing up the excavated material. Did the Authors consider that the oblong caisson, with semi-circular ends, divided into three or four compartments, could be improved upon? It might have been better to adopt an elliptical caisson, making the wall thick enough to resist the pressure without stiffening partitions, and thereby to facilitate the removal of spoil, placing of pumps, and access of men to the well. Most of his own experience had been with twin circular wells, which had certain advantages, but were perhaps not so suitable in running water. As mentioned in the Paper, sinking was greatly delayed if it proved impossible to keep the well dry so that men could work at the bottom. When a well could not be kept dry the bottom could be broken up by repeatedly dropping a pointed rail from a catch on a crane until sufficient of the

Dr. Holmstrom.

bottom was broken up to enable it to be grabbed. Unfortunately, however, there was no satisfactory method of using such a chisel underneath the cutting edge, which was just where it was required. The only method of excavating there, when the well could not be kept dry, was for a diver to do it, generally by means of a water-jet. He would suggest that with a concrete curb it would be possible to incorporate water-jets in the curb, so that a jet of water could be forced out actually underneath the cutting edge to assist in scouring away the material. Whether or not the sinking could be carried out in the dry, he thought there was no doubt that the process of sealing the well with concrete was best done under water, because if it were attempted to do so in the dry it would be almost impossible to avoid an inward flow of ground-water through the unset concrete. The sealing was best done with the aid of a diver, who could push the concrete right underneath the overhanging portions of the well-wall; but the use of a diver was not always possible, and was not essential.

With regard to the design of bridges founded on wells, what was the Authors' opinion as to the proportion of the total load which was carried by skin-friction? His own view was that the skin-friction could be relied upon to carry at least the weight of the well-wall; but it was rather a doubtful point, and he thought it was worthy of discussion. A well was intermediate between a pile supported by skin-friction and a column which transmitted all its load to the base.

He was not at all sure that the point which he was about to suggest was sound, but he thought it was worthy of discussion. The hearting of the Authors' wells had been done, he thought, with 6–to–1 concrete. As that hearting was simply there as a filler, the walls of the well being amply thick enough to transmit all the loads, was it necessary to use concrete? Why not sand? He had described elsewhere [1] a case where wells for bridge-foundations in Malaya were being sunk into an apparently bottomless and very soft carbonaceous shale on which it had been found quite impossible to found or to seal the wells properly. The difficulty had been got over by filling up each well with sand when it had reached a depth of about 60 feet. The sand pressed itself out into the carbonaceous shale below like an enormous sand pile. The wells had then been capped, and had been found to provide a perfectly satisfactory foundation. That, again, illustrated the flexibility of the well type of foundation, which had many merits for work under such conditions as had

[1] "Railway Bridge Construction in Malaya." Journal Inst. Struct. E., vol. 8 (1930), pp. 393, 424; vol. 9 (1931), pp. 70, 119.

been described. Finally, he desired to congratulate the Authors on having given costs which were properly related to the ruling rates of pay of the labour. Such information was of very great value but was too often omitted. Dr. Holmstrom.

Mr. K. J. H. EVANS remarked that a comparison of the methods used in the two bridges was interesting, the main difference being in the use of compressed air in one case and open grabbing in the other. When he had taken charge of the contractors' work on the Iskandar bridge it had unfortunately been impossible to instal air-locks without incurring considerable delay and making changes in the design of the caissons; but he was quite convinced that, even without the unexpected difficulties met with later, the use of air-locks would have considerably shortened the job if not appreciably reduced its cost. The Iskandar caissons could generally be sunk about 1 foot in an 8-hour shift by open grabbing, but serious delay was caused by the difficulty of removing the very uneven rock and sealing the cutting edges to the rock so that the caissons could be pumped out. The graphs in Mr. Stephen's Paper told a very different story, the caissons being sunk and sealed practically at once. The method of employing a diver to build a concrete wall between the cutting edge and the rock so as to allow the caisson to be pumped out was fairly common, but it had several disadvantages quite apart from the time taken to build the wall. Firstly, a considerable proportion of the area of the base could only be inspected by the diver. In the case of the Iskandar caissons, with a sealing wall 2 feet 6 inches wide, about 25 per cent. of the base area had been covered in that way, and the foundation-pressures were highest over that part. Also, if the foundation proved to be unsatisfactory the sealing had to be cut out or the caisson had to be undercut. He would suggest that caissons on such work should be designed so that, if necessary, air-locks could be fitted without undue difficulty. Also, in such large caissons some reinforcement would be advantageous, as only very light blasting charges could be used on account of the danger of cracking, which of course materially retarded the work, and even then No. 2 caisson had been found to be cracked. The removal of the merbau log had been hindered by the weight of the caisson pushing the log farther into the sand and gravel as the surrounding material was cleared away to make the cut. Each cut through the log consisted of two separate cuts about 1 foot apart. The 1-foot section between was blasted away as the cuts were made deeper to prevent binding of the cutting tools, and to allow settling sand to be more easily blown away with an air-jet. That method was found to be quicker than making a single cut, and it had the advantage of allowing a severed length of the log to be Mr. Evans.

Mr. Evans. hauled out without fouling the adjacent lengths. The weight of the section of the log brought from the middle well of the caisson was about 6 tons. The failure of the trestlework in the 1931 flood had been due to the pressure of drifting logs against trestles weakened by the scouring away of the supporting sand and gravel. In that connection he would like to ask whether there was any record of scouring having taken place round the upper extreme edge of the pier. Was span 7 really necessary ?

The 1-to-3½ concrete of the caisson-walls seemed rather rich, as high strength was not really essential ; perhaps there had been some special reason for the proportions adopted.

Mr. Braine. Mr. C. D. C. Braine said that he had been associated with Mr. Coales in connection with the Iskandar bridge, and Mr. Coales had suggested that he should supply one link in the record of the bridge which had been of great interest to himself. In the 1924 proposals for the bridge, every effort had been made to take advantage of the beauty of the site ; it had been felt that reinforced concrete would have many advantages over steel in that respect, and some preliminary designs had been investigated. Stone and sand were available near the site. Most of those present would no doubt remember the appearance of Mr. Freyssinet's beautiful reinforced-concrete arch-bridge at Elorn in Brittany, with its open spandrels. If they could picture the Perak river winding between its densely wooded banks and spanned by just such a bridge, they would appreciate what Mr. Coales had been aiming at. Plans for a concrete arched bridge, consisting of three spans of about 330 feet each, had been drawn up by him, and Mr. Braine had had the pleasure of working on them. He had also entered a design of his own for the Hawksley Prize in the secret hope that if it were a success the Government might adopt it, but it had not been successful, and in any case the authorities in Malaya had been unwilling to accept the responsibility for so large a bridge and had called upon the Crown Agents for the Colonies to undertake the design. Their ideas had been more prosaic than his own or Mr. Coales's. The design they had adopted was, in his opinion, disappointing, and its cost had been appreciably more than the estimated cost of the three reinforced-concrete arches. Steel costing £31 11*s.* 8*d.* per ton could not normally compete with concrete at £2 7*s.* 11*d.* per cubic yard, and six river-piers were required instead of two. Most lovers of reinforced concrete would agree that there had been a golden opportunity for British engineers to show what they could do—foreign engineers, Americans in particular, seemed to have many more chances than they had of constructing large works in reinforced concrete, and therefore the loss was the greater when such an opportunity was not taken. He admitted, however, that there had probably been some very good reason for adopting steel. On the other hand, at the adjacent Chenderoh dam of the Perak River Hydro-Electric Company,[1] extensive use had been made of reinforced concrete in its most modern and complex form. Mr. Braine.

One important lesson should be learned from the actual construction of the bridge, namely, that bore-hole results should be interpreted with the greatest caution. On the Chenderoh dam [2] they had failed to disclose a most troublesome fissure, whilst on the bridge under discussion and on the Silent Valley reservoir-scheme[3] they had been entirely misleading. That was a common experience. On such large schemes percussion bores might be quite suitable for a preliminary surface examination, but when rock was encountered, it seemed advisable to explore it with a rotary and not with a percussion drill, especially as the extra overall cost of cores was comparatively small and the information obtained was positive.

Mr. Webster. Mr. T. H. WEBSTER remarked that the revolving part of the Khedive Ismail bridge weighed 1,500 tons, and he noticed that the supporting rollers were without flanges; he feared that the tendency for the rollers to work outwards would cause rapid wear on the axis-pin shoulder (which did not appear to be very large); if one shoulder got worn more rapidly than the others that particular roller would work its way out and throw its load on to the adjacent rollers. It was usual to put a flange on the inside edge so as to stop the roller from working its way outwards; the flange bore on the inner edge of the lower roller-path and had a small clearance from that of the upper path. He was rather surprised that that method had not been used in the case under discussion. The loading on the rollers appeared to be about 0·07 ton per square inch of the projected area of the roller. That was rather extravagant, and he thought that 0·15 ton per inch would probably be quite satisfactory. Most of the older swing-bridges had been operated by hydraulic engines; in such cases the hydraulic pressure could be applied to a ram on the axis so as to relieve the rollers of much of the load. With a swing-span weighing 1,500 tons, the diameter of the pivot ram could be arranged to provide a lift of 1,000 tons, leaving only 500 tons on the rollers. That, however, could not be done with all-electric operation, because then no means of lifting was available.

[1] W. J. H. Rennie, "The Construction of the Chenderoh Water-Power Plant of the Perak River Hydro-Electric Power Scheme." Minutes of Proceedings Inst. C.E., vol. 239 (1934-35), p. 313.

[2] *Loc. cit.*

[3] G. McIldowie, "The Construction of the Silent Valley Reservoir, Belfast Water-Supply." Minutes of Proceedings Inst. C.E., vol. 239 (1934-35), p. 465.

Mr. Wilson. Mr. J. S. WILSON remarked that Mr. Stephen's Paper referred in some detail to the old bridge. Could the Author give any idea of the stresses to which the old bridge had been working? It was stated that the tensile strength of the iron of the old bridge was about 21 tons per square inch and the elongation only 5 per cent. on 8 inches. He wished to point out the fact that that old material had carried all that had been expected of it for many years without its complying with all modern ideas of tests, extension, and so on. The stresses to which it had been working would therefore be of especial interest. He himself had a sentimental interest in the old bridge—it was, perhaps, the first bridge he had ever seen; it had been a fine old bridge and he regretted that it had gone. On the other hand, he was pleased to see that the four fine bronze lions had been kept at the abutments.

Sir Harley Dalrymple-Hay. Sir HARLEY DALRYMPLE-HAY remarked that the Paper dealing with the Khedive Ismail bridge was excellent in every detail, and described exactly how a bridge should be carried out under compressed air working. He would recommend it to Sir George Humphreys particularly, because in it was stated exactly what he had wanted to tell Sir George when the Lambeth bridge had been under discussion. He would, however, observe that the magnificent Khedive bridge had not been designed by a consulting engineer, and he thought that it was regrettable that public authorities should put the consulting engineer on one side.

Mr. Hawkins. Mr. L. E. HAWKINS observed that in each of the bridges under discussion one pier had presented more difficulty than the others. In the case of the Iskandar bridge it had apparently been known from the preliminary borings that pier No. 2 was going to be the most difficult. Might it not therefore have been better to start work at that pier instead of at No. 7? It appeared from the Paper that the factor of safety on the completed foundation of No. 2 pier had been somewhat less than originally intended, so that the same loading might have been adopted for all the other piers and some saving might have been made if No. 2 had been started first. In the same way, the swing-pier of the Cairo bridge, which appeared to be the most important, was not founded quite so deeply as the other piers. It appeared to have been done last, although it had taken the longest time to do; had it been started earlier, its foundation would have served as a model for the others, and a useful saving could have been effected.

Mr. Robinson. Mr. C. I. ROBINSON remarked that he spoke as an onlooker at the Iskandar bridge work. On p. 362 it was stated that Mr. Evans had been very nearly lost in the flood of December, 1931, and he thought that the meeting was extremely fortunate in having Mr. Evans present to give one or two personal points regarding the work with which he had been so ably connected. With reference to the foundations of No. 2 pier, where the configuration of the bedrock was so very irregular and the merbau tree had been encountered, Mr. Braine seemed to think that rotary drilling should have been used. He did not agree with that, but thought that the Paper emphasized the necessity of extremely close drilling on the site of such works before the foundations were undertaken. It had been most unfortunate in the case of the Iskandar bridge that the borings which had been relied upon had been done a considerable time previously, and also, as history had shown, in a very unsatisfactory manner. He felt convinced that had the borings been sufficiently close together they would certainly have revealed the presence of the tree-trunk, and would also have given a great deal of information with regard to the configuration of the bedrock, even if they had not told all the story as eventually revealed when its surface had been actually seen. **Mr. Robinson.**

Mr. Coales, replying to the Discussion on behalf of Mr. Clarkson and himself, thanked the members for the kind way in which they had received their Paper. **Mr. Coales.**

Dr. Holmstrom had suggested that concrete cutting-edges for the caissons would have been cheaper than steel, and with that statement he agreed. The estimated cost of making reinforced-concrete cutting-edges was about £300, and thus there would have been a saving of about £250 on each. The design provided for steel cutting-edges; for caissons of the size of those for the Iskandar bridge which had to be sunk to rock, the additional strength of the steel cutting-edges was a valuable consideration, and he thought that their use was desirable and justified. The bedrock was very uneven; on occasions the whole weight of a caisson was supported by a few pinnacles, and also considerable blasting had to be done to level-up the rock, so that the risk of damage to the caissons was reduced by the strength of the cutting-edge. Another factor was the time required to construct a reinforced-concrete cutting-edge and cure it ready for sinking; it was always an anxious time for all concerned when a cutting-edge was being erected on the island prepared for it in the river, and that period would have been considerably longer if concrete had been used instead of steel. Taking all those factors into consideration, it was doubtful whether the saving that might have been made by substituting concrete for steel would have been worth while. It was true that the reinforced-concrete cutting-edge to the caisson under the north abutment had given no trouble, but the caisson was a smaller one, and the construction of the cutting-edge was carried out with no threat of flooding from the river. It was fortunate that the design of the steel cutting-edges was such as

Mr. Coales. to permit the widening of the caisson for pier 2; had the cutting-edges been of reinforced concrete it might have proved easier to widen a caisson if the necessity to do so had arisen.

With regard to the number of men working underwater, the maximum number of divers employed at one time in one well was two. The divers were Chinese, employed under a Filipino foreman-diver; they had all been trained in Hong-kong and were normally employed in either Singapore or Penang. Once a well was unwatered, six or seven Chinese labourers using three pneumatic jack-hammers could work below levelling-up the rock. Prior to reaching rock, all the excavation from within the caisson was done by a grab, so that the speed of sinking through the sand and gravels was not influenced at all by the number of men who could be employed inside the caissons.

Dr. Holmstrom had suggested that it might be advantageous to provide holes so that a water-jet could be used under the cutting-edge; although Mr. Coales had had no experience of a caisson provided with a cutting-edge so made, he was aware that it had been tried, and no doubt in certain strata it would be a useful device. He was not prepared to give an answer to the very controversial point raised regarding the proportion of the dead and live loading which skin-friction could be allowed to take, particularly so in the case of a river such as the Perak which in time of flood might cause considerable scour around the piers. Actually, skin-friction resistance had been neglected in the design of the piers, and, even if that were unduly conservative, it was safe!

The use of a cheaper material such as sand instead of concrete for hearting the caissons had been suggested; that was common practice in India for hearting the wells of girder-bridges, but in the present case, owing to the thrust from the arches, the extra dead weight from the concrete hearting was advantageous and the job, although more costly, was better. Another point in that connection, which he would deal with more fully when replying to Mr. Evans's remarks, was the possibility of the caissons cracking; had the caissons been hearted with sand a cracked caisson would have been a serious matter, but as each one was hearted with concrete the cracks gave no cause for concern.

Mr. Evans had been the Agent for the Contractors, and he had very pleasant recollections indeed of working with him. Almost every point had been fully discussed between Mr. Clarkson, Mr. Evans, and himself, and he desired to pay a tribute to the good work done by the Contractors and to the great help which Mr. Evans had always been ready to give. He was in entire agreement with Mr. Evans's suggestion that air-locks would have saved time and probably expense; but the design of the caissons did not provide for air-locks, and those concerned decided, perhaps unwisely, to do without compressed air, although, in that connection, it had to be remembered that there was no suitable plant available in Malaya. Mr. Coales.

Mr. Evans suggested that the caissons should have been reinforced to provide greater resistance against the danger of cracking, and, incidentally, to permit the use of heavier charges for rock-blasting. Actually the caissons of piers 1 and 2 did crack during construction, but as they were hearted with concrete the cracks did not cause any anxiety or concern; if, however, sand or similar material were to be used for hearting it would be advisable to consider providing the additional strength which a reinforced-concrete caisson would give. Mr. Evans also asked whether any scour had occurred around the piers; it had been found that after the normal flood-season scour to a depth of 5 or 6 feet occurred at the upstream ends of the piers, but that scour disappeared during the dry-weather period, so he thought it was safe to say that there was no serious scour; even if there were it would be of small importance, as the piers were all founded in the bed-rock, and skin-friction had been ignored in the calculations for foundation-loading. Mr. Evans questioned whether span No. 7 was really necessary; the 1931 flood had proved that it was.

He appreciated Mr. Braine's remarks on the use of reinforced concrete, with many of which he was in agreement. There was no doubt at all that the engineers and contractors practising in Malaya were competent to have carried out, successfully, a reinforced-concrete structure. He thought that Mr. Braine, in advocating the use of reinforced concrete, had omitted a strong point in favour of that material, namely, its low cost of upkeep. As was well known, the cost of protecting steelwork in the tropics was a considerable and a recurring item. He thought that Mr. Braine might have driven home his arguments in favour of concrete even more forcibly had he indicated that its use would have saved the biennial or triennial cost of painting.

Mr. Hawkins pointed out that one pier had proved much more difficult to construct than the others, and, as it had been known that that would probably be the case, he asked why work on that pier had not been put in hand earlier. Reference to Fig. 5, Plate 6, which showed the construction scheme, would supply the answer to that question. The difficulties had proved to be greater than anticipated, but as the Contractors had no floating plant it had been impossible to commence work on any pier out of sequence.

Messrs. Braine and Robinson had both referred to the unreliability of the bores, and he supposed that those concerned with the construction of the bridge had been even more unlucky than usual in

Mr. Coales. that connection. The information obtained from the preliminary boring had proved to be most misleading, and it had affected both the design and the construction. He thought that it demonstrated forcibly the need for careful preliminary reconnaissance before the design of any civil engineering work was undertaken. No client ever liked to spend a lot of money on preliminary work, but he was afraid that in the present case, as in many others, the attempt to save money on the preliminary work only resulted in a greater expenditure before the project was completed, ready for the service for which it was constructed.

*** Mr. Stephen's reply will be found at p. 407.—SEC. INST. C.E.