Discussion.

The Author, after showing lantern-slides illustrating the work, referred to some samples of timber exhibited at the meeting, which had been taken out of the old foundations. Their excellent condition had justified the whole of the original timber being left in place. American rock elm was specially mentioned by Captain Laffan in his report upon the bridge to the Board of Trade in 1849, where the interesting fact was recorded that the rock elm piles had caught fire at the top when driven by a Nasmyth hammer. The Author did not know whether this timber was used at all now, but in an interesting book,[1] written by Thomas Laslett, an Admiralty Inspector of Timber, it was stated that 2,000 to 3,000 loads of this timber were imported into each of the London and Liverpool markets at that time; and the writer specially mentioned its durability under water. It was the slowest-growing timber known, only increasing in diameter 1 inch in 14 years. It would be interesting to hear if any other members had had experience of American rock elm. The Author.

Mr. G. E. W. Cruttwell remarked upon the forethought displayed by the original engineers and builders of the bridge. The river had originally been only 3 feet deep at low water, but the depth had increased since to 27 to 30 feet. That must be far deeper than anything ever contemplated when the bridge was built, and yet it was still standing and, after underpinning, was as good as new, if not better. He was surprised to see the wonderful state of preservation of the timber, especially the rock elm. His own firm had used that timber extensively up to the early part of the present century for fendering in front of jetties, etc., and they had found it very useful as a hardwood; it was tough and not liable to flake off, and it did not split. In recent years they had had to give up the use of it, on account of its cost and the difficulty of obtaining it. He could support the Author's opinion of its durability; and, if it could be obtained at a reasonable price, his firm would be only too glad to resume its use. It was stated (p. 176) that the steel sheeting around the south pier had been driven to a depth of Mr. Cruttwell.

[1] "Timber and Timber Trees." London, 1875.

Mr. Cruttwell. 31 feet 6 inches. Fig. 2, Plate 6 showed that the surface of the yellow freestone was about 22 feet below low water. According to that, the piles were driven about $9\frac{1}{2}$ feet beneath the surface of the yellow sandstone, on the north side of the south pier; it seemed curious that it should have been necessary to drive to so great a depth, and he imagined that the piles had been rather punished in the process. The Author had proceeded with great caution in taking out the underpinning holes. From Fig. 5 it appeared that quite small holes were first opened up, measuring about 35 to 40 square feet; but towards the end of the work the size was increased, holes Nos. 27 to 29 measuring 180 square feet. Possibly it had been found, as the work went on, that it was safe to increase the size of the holes. He found the average area of the thirty-one holes to be 87 square feet. The Author stated that no two adjacent holes had been dealt with at the same time, the concrete of one being allowed to set before the adjoining hole was disturbed. How long was it before the adjoining hole was taken out? In regard to the north pier, it was said that there was evidence of a very slight displacement of material immediately under the concrete of the south face of the pier, but that it had not been thought necessary to underpin or take any remedial measures, except to drive sheet piles around the pier. He thought it was rather a pity that sheet piles, which apparently came only up to low water, having been driven, steps had not been taken to make absolutely sure of the pier. He would like to have the Author's assurance that he considered the pier to be absolutely sound, for, on reading the Paper, it did not seem to him perfectly safe to leave it in that condition.

Mr. Savile. Mr. L. H. SAVILE remarked that the Author had been able, by his foresight, to anticipate what might have happened to the bridge and to take steps to find out whether it was happening. Having made his investigation, he had prepared a detailed scheme for dealing with the damage, which scheme had been carried out in a most satisfactory manner, with the result that the bridge had now been made safe. The work reflected the greatest credit on the Author and on those who had had the difficult task of carrying his proposals out in detail. It would have been interesting if the Author had added to Fig. 5, Plate 6, the actual positions of the shafts, as it would have been easier then to follow how the various sections had been dealt with in the order in which they were numbered. In view of the statement that in adjoining sections of the underpinning one had not been dealt with until the other had set, it was a little difficult to see how it was that the numbers of some of the adjoining sections were consecutive, namely, Nos. 5 and 6, Nos. 9 and 10, Nos. 21 and 22, and Nos. 31 and 30. A possible criticism of the method of underpinning concerned the making of the joint with the underside of the original concrete by forcing in cement grout. No doubt that probably made a satisfactory junction, but a better method might have been to stop concreting, say, 3 feet from the top, and, after that had set, to build the last portion in brickwork up to the original concrete. What had happened to the bridge showed the importance of allowing in any bridge of that sort a more than sufficient margin for scour, because, as Mr. Cruttwell had said, the engineers who built it could never have realized how greatly the scour would be increased by the blocking of the river by the piers of the bridge. In India, where he had had experience of bridges over sandy rivers, it had been often necessary to carry piers down 80 or 90 feet below the level of the sand, because in the rainy season probably 40 or 50 feet of sand would be alive. Mr. Savile

Mr. H. H. Dalrymple-Hay observed that the Paper was very welcome at the present time, because the subject dealt with had been in the public mind for close on 2 years in another connection. Therefore, as the matter was not only of local and municipal, but also of national and international interest, the Author was to be congratulated on having brought the Paper before The Institution. The method of underpinning described was one with which most engineers who had to do with that class of work were quite familiar. The way in which it had been carried out was most commendable. The Author discovered, as a result of his examination of the foundations, that on one side of the south pier there was soft liquid mud, then sand; these were overlying what was designated in Fig. 2, Plate 6, as "freestone ramble"—he did not know quite what that meant, and would be glad if the term were explained—and below that there was a bed of freestone. Captain Laffan's report was quoted as stating that there was 31 feet of mud and 4 feet of gravel, and then some clay, and below that hard stone. That report did not apply in connection with the south pier; and he assumed that it only applied to the centre and north piers. The strata sloped down towards the centre of the river, and for that reason the foundation of the south pier had not required such long piles as had the other river piers. Compared with the other two, the south pier was comparatively simple to underpin. He thought that in all the cases the designers had been fortunate in finding the hard "freestone ramble" on which to terminate the piles, because they had actually had to depend entirely upon the end bearing resistance of the piles Mr. Dalrymple Hay.

Mr. Dalrymple-Hay. upon a good bottom. Above that there was, comparatively speaking, soft material, and the whole of the top of the piles was bonded in good concrete. A bridge built on that system, therefore, stood as it were on a number of stilts, and if the work had been left simply in that condition, with no other protection, it might have been anticipated that trouble would ensue. The engineers therefore left the double coffer-dam in, to protect the foundation, which protection rendered the bridge perfectly safe; and he thought that, if that coffer-dam had not been removed, and even if the Author had not put in concrete, the bridge would have gone on carrying the load as it had done formerly, because as long as the sides were protected from scour, the load would remain wholly on the piles in that particular case, and no advantage would be obtained from the concrete. Those piles were very heavily loaded—about 58 tons per pile—and it was, no doubt, very wise to bond the whole foundation together and distribute the load over the ground, so that, if the piles failed, the load would be taken by the concrete itself. He was interested to see that the piles were in good condition. His view was that, if timber was below water, it would last practically for all time: that had been found in the present instance, and the fact ought to be noted by every engineer. He knew of other similar cases, and members who had larger experience than he had found the same thing to be true. In underpinning foundations of the type described, consideration should be given to providing lateral support to the pier rather than taking the load at the bottom. By lateral support he meant protection against the possibility of scour. The steel dam had been driven well below the level of the foundations. There was no doubt that the method of excavation adopted had been economical and right in the particular case of the south pier; but, if the Author attempted to make an open excavation at the north or centre piers in 36 feet of mud, he would find it impracticable: the result would be a high head of water outside the dam and nothing inside to counteract it, and the dam would have to be carefully strutted and would be unduly costly. The obvious way to overcome that difficulty was to apply the elastic reaction of compressed air in a closed chamber to balance the water-pressure outside against the dam, and render the foundation capable of being excavated. With the open type of excavation, while excavation was proceeding, the clay was loosening itself, and when the load came on there was a small settlement, which all engineers tried to avoid. That was due to the fact that the clay had been breathing up from exposure. With a foundation for which it was not necessary to make a wide excavation, it was better to use compressed air, so as to limit the work to as small an area as possible, because more load could be put on a clay foundation which had been excavated under compressed air than on one which had been excavated in the open, with rain killing the clay at the top. With regard to the scour, he did not quite follow from the Paper whether the depth of 27 or 30 feet below low water was attributable to scour proper, or whether it had been dredged at the request of Messrs. Armstrong, Whitworth and Company. Stephenson knew perfectly well that he was obstructing a portion of the river and would get scour, and he left the coffer-dams in. The coffer-dams had since been taken out, but Mr. Dalrymple-Hay was glad to see that the steel piles remained, because that was the saving point of the whole scheme. Mr. Dalrymple Hay.

Dr. OSCAR FABER observed that the steel sheet piles seemed to have been extremely successful. He had had occasion to use various types of steel pile, and he had found that the type mentioned by the Author was particularly successful, whereas several other types had proved unsatisfactory. The method of securing water-tightness with wire ropes and tightening-screws was interesting. It seemed to him that the forces which could be brought to play on so large a dam constructed in that manner would have been relatively so small, that he could not have hoped to make it water-tight in that way; but apparently it had been successful, and that experience was useful to have on record. In driving such piles it had been possible sometimes to omit the wedge closing-pile, which was referred to in the Paper. That required extraordinary skill and care on the part of the contractor, and he thought the arrangement described in the Paper was probably better and safer, though on smaller foundations such closing piles had occasionally been omitted successfully. In that case the piles were driven in groups, of perhaps five at a time, in rotation, each group being driven only a little way down at one time. With regard to the order of concreting the various sections described in Fig. 5, Plate 6, why had all the sections on one side been concreted before those on the other? He would have been inclined to fear that, in case of any settlement or running taking place, it might be rather dangerous to have one side of the pier supported while the other side was entirely unsupported. Why had not a few sections been completed on one side, and then a few on the other, so as to keep the pier balanced? Had any temperature-measurements of the large masses of concrete been taken? It was his experience that with modern cement, which contained much more chemically active material than the old cements, there was, when dealing with large masses of concrete, a very considerable rise of temperature when the concrete set under Dr. Faber.

Dr. Faber. circumstances where the heat could not easily get away. In an underpinning job there was very little surface for radiation or for dissipation of the heat by any other method. At the Bank of England the outer walls were being underpinned with concrete 8 feet thick and 50 feet deep, and in the previous week he had had temperature-measurements taken systematically of the concrete when it was placed, and subsequently at 3-hour intervals; 3 days after placing the concrete the temperature had risen to 100° F., from 50° F. at the time of placing. The cement was not a quick-hardening cement, with which undoubtedly a still greater rise of temperature would occur. He thought the low cost of the underpinning work was a matter on which the Author deserved congratulation; and it was particularly opportune because, as was generally known, proposals for the underpinning of other bridges were under discussion, in which very much larger figures had been mentioned.

Mr. Gedye. Mr. N. G. GEDYE mentioned that in the library of The Institution there was a set of drawings—made, he believed, 2 or 3 years after the high-level bridge had been completed—which were some of the finest drawings of an engineering structure he had ever seen. They appeared to show the foundations of the bridge and the surrounding levels substantially as they were on completion, and from that point of view they were very valuable. He had been closely connected with the early stages of the matter covered by the Paper, first as the Engineer to the Tyne Improvement Commission and later, after he had left the service of the Commissioners, when he was instructed by the North Eastern Railway Company to make a detailed examination of the foundations. In the summer of 1910 he had occasion to examine certain periodical soundings of the river in the neighbourhood of the bridge, and was rather concerned at the depth of water near the coffer-dam of the south pier, where it had been cut away 4 years previously. About that time also, small damage had been done by some craft to the timber work of the south pier, and the Tyne Commissioners had been asked to send a diver to examine the damage for some party concerned. The Tyne Commission diver who carried out the inspection told him something of what he had seen, and, as the result of that and of his knowledge of the soundings, he went down himself in diving-dress and found the state of affairs so serious that he reported it to the Chairman of the River Committee, and on his authority he went to the late Mr. Charles A. Harrison, M. Inst. C,E., then Chief Engineer of the North Eastern Railway, and gave him all the particulars in his possession. As a result, Mr. Harrison caused the borings through the foundations to be made in 1911. In 1910 the conditions were very similar to those shown in Fig. 2, Plate 6, but that section did not show what he then discovered, and confirmed in 1915, namely, that in more than one place on the north side of the south pier foundation the mud—called by the Author " black sandy mud," but which Mr. Gedge preferred to call black slurry and water—was so liquid in places that it could be swished about with the arm ; and in one place he could get his leg through the gaps in the piles. In 1910 an absolute void extended under the concrete to 6 feet below low water for some distance along the north face of the pier, and in 1915 he found that that void had extended down to the point where the words " bed of river " were shown on Fig. 2; that was, the void had increased from 6 feet to 10 feet in depth. In 1910 he used a 4- or 5-foot probe, and in 1915 an 8-foot thin steel rod, and he was able to probe in twenty or twenty-five places along the side of the old coffer-dam. He also touched, with the point of the probe, many of the piles in the second row under the foundations, and even some in the third row ; in several places he could feel the underside of the concrete with the probe. As far as he could reach with the probe he found the material was so soft that by pressure of the wrist he could move the rod about. He had no doubt that that black liquid and sandy mud had replaced the sand which was mentioned in 1849 by Captain Laffan, who described the concrete as being founded on loose sand which extended to a considerable depth. That sand had no doubt been there, and probably was under the north and centre piers to this day. On the north side of the south pier the gaps in the inner skin of the coffer-dam piling, being protected during 60 years by the outer skin and the puddle clay filling, had done no harm at all, but as soon as the outer skin was removed in 1906 the open gaps let the sand out. It was a case of infiltration of liquid mud, replacing sand. His figures of the levels of the underside of the concrete, as obtained by probing, agreed very closely with the levels in Fig. 2 ; in two or three instances he had noted the underside of the concrete as being at a slightly higher level. A point which had puzzled certain speakers was the level of the river-bed. In 1849, when the bridge was built, the range of tide at the high-level bridge was very much less than the present range of 15 feet. At that time, on account of the obstruction of the river lower down by the old Tyne bridge, which had very short spans and was a structure resembling in some ways old London Bridge, the level of high water was about 3 feet higher than at present, and low water was 5 to 6 feet higher than the present low water. The bed of the river in the centre of the channel, as shown on contemporary drawings, was practically at the level of the top of the coffer-dam shown on the Author's

Mr. Gedye

Mr. Gedye. diagram. In no part of the channels between the piers was there more than 3 or 4 feet of water at the then low water. The deepening of the channels was not due to dredging in the neighbourhood of the bridge. During the time of his predecessors and during his own time and since, no dredger had been ever allowed to go near the high-level or swing bridges for dredging. The state of affairs was due entirely to scour. The old Tyne bridge was removed about 1870 and replaced by the present swing bridge, which was completed about 1877. The lowering of the water-levels had been brought about by the removal of the obstruction caused by the old Tyne bridge and the deepening of the river-bed by dredging below the swing bridge and above the high-level bridge. The river above Newcastle was not dredged until after the swing bridge was opened. The Author mentioned 27 to 30 feet as the present depth of the channels at low water, but in 1915 there was actually in the north channel one sounding of $36\frac{1}{2}$ feet at L.W.O.S.T., where in 1849 the bed was about 2 feet above the present low-water level. He had been able to satisfy himself in 1915, when he made the underwater examination, that there was no reason to doubt the soundness of the piles. In addition to the piles which could be touched by the hand on the inner skin of the coffer-dam and in the outer rows of coffer-dam piles, he was able to probe twenty or thirty piles inside, and in no instance could he feel any sign of decay: he did not think he could prick the point of the spear into the timber more than $\frac{1}{2}$ inch. He was not surprised, therefore, to see the beautiful samples of wood which the Author had shown that evening. The section of elm was from one of the sheeting piles which were bird-mouthed into king piles, but 5 or 6 feet from the top of the coffer-dam a very large proportion of bird's-mouths were out of joint. At the level of the river-bed very few piles were perfectly jointed; the probe would go through half of them. The north and centre piers had been protected to some extent from scour by the banks of slag which had been deposited alongside the actual coffer-dams. In the case of the centre pier that had been possible without risk of encroaching on the channel, on account of the extra width given by the presence of the swing-bridge jetty. The presence of that slag accounted for the comparatively steep slopes of the river-bed at about low water. In 1915 he calculated that the maximum pile loading was not far short of 64 tons, making allowance for the increase of the live load and additional dead load since 1849, and for the effect of wind-pressure. Captain Laffan's report of 1849 gave particulars of loads which indicated an average load of $51\frac{3}{4}$ tons per pile. His own estimate of 64 tons probably agreed very closely with the Author's

Mr. Gedye. figure of 58 tons per pile, which was given as an average value. It was extraordinary that in spite of the bad state of one side of the pier there was no settlement, and the Author gave no indication of any settlement having taken place. In 1915 there appeared to be 2 inches difference of level between the bench-marks of two iron datum plates, one in the north pier and the other in the south pier. The former was found to have its mark exactly at the level of the old Tyne datum, which had been in use on the Tyne from at least as far back as the sixties. It marked a certain level 7·92 feet above Ordnance datum, one that was known to everybody and no doubt would have been set accurately. When the plate had been put in he did not know. The one on the south pier was just 2 inches lower. Presumably those plates, which were of the same pattern, had been put in on the same date. Had the Author been able to find out the reason for that difference, and whether there had been any settlement in the south pier relatively to the north pier? The statement of costs (p. 183) was of interest and value. Did the totals given include all charges for supervision and contractors' profit? Having regard to the high costs which obtained at the time when the work was carried out, the total cost must be regarded as very moderate. He congratulated the Author on a valuable contribution to the Institution's Proceedings, possessing both historical and engineering interest.

The President. The PRESIDENT remarked that he thought it fitting to allude to the great high-level bridge which was a triumph of their engineering predecessors, the Romans, the Pont du Gard, near Nimes, Provence. That magnificent structure, consisting of three bridges one above another, had stood for practically 2,000 years, and to-day was a finer instance of Roman architecture than anything that could be seen in Rome.

The Author. The AUTHOR, in reply, stated that the length of the steel piles as ordered was 52 feet, and this provided for the piles standing 5 feet above high water and being driven below the bed of the river. The piles on the north side of the pier had been actually used of the full length, but on the south side it had not been possible to drive them down so far. The driving at the finish had been very hard, sometimes requiring 200 blows to the inch. He attributed the watertightness of the dam very largely to the fact that the piles had been driven down so far. They had not been damaged by the hard driving, and the lengths cut off had been used for the protection of the north pier. With regard to the sections, as the work proceeded it had been considered quite safe to increase their size, and in some cases, owing to the irregularity of the piles, the sections would have

The Author. been rather difficult to deal with if they had been limited to the space between two rows of piles. The concrete had generally been allowed to set for 6 or 7 days before an adjacent section was opened up. The cavities under the north pier were very small, and he believed one of them had been formed by the material being blown out when the compressed air was first applied. He was satisfied that they were negligible and that it was unnecessary to do anything to them. The shafts had been sunk three on the north and three on the south side of the south pier, about 20 feet apart, between the inner row of the coffer-dam piles and the first row of the bearing-piles of the pier, and headings from these shafts had been driven between the first and the second row of bearing-piles to give access to the other sections. An additional shaft had been put down later at each end of the pier. With regard to the numbering of the sections, although Fig. 5, Plate 6, showed generally the order in which the sections had been undertaken, the whole of the excavation or concreting of a section had not in all cases been carried out continuously, and work had been going on at the same time in other sections, but in all cases sufficient time had been allowed for the concrete to set before the excavation in an adjoining section was taken in hand. He was quite satisfied that the grouting under compressed air had thoroughly filled the joint between the old and the new concrete; the special test at the east end (p. 180) had proved that the grout was travelling well and filling up all interstices, including the joint between the old and the new concrete. All the piers were protected against scour by sheet piling which extended approximately to the bottom of the river-bed, and in addition slag had been tipped on the sides of the channels adjoining the piling. Soundings taken over a period of years showed no deepening of the river below the depth to which it had been dredged on each side of the bridge. No dredging had actually been done at the bridge, but the channel had been dredged to 25 feet at low water up to a short distance on each side of it, so that the present depth was directly due to dredging. Referring to Mr. Dalrymple-Hay's remarks, Captain Laffan's description of the river-bed undoubtedly referred to the formation at the centre of the bridge. The word "ramble" or "rammel" was used in the North for a loose friable rock, and was often applied to the thin bed of shale lying above a coal-seam. The word was used in a great many counties, but generally in the form "rammel." Borings in the north of England were generally carried out by men who did boring at the collieries; hence the use of this word. He agreed that the underpinning of the south pier was a much easier work than the north or centre piers would have been; but if he had had to deal with the latter he would have considered seriously the question of carrying out the work without compressed air, especially in view of his experience of the south pier dam. In reply to Dr. Faber, the concreting of the sections on the north side had been undertaken first because the condition of the material was so much worse on that side—the sand under the south half of the pier was comparatively dry, and there was little difficulty in controlling it. No temperature-measurements of the concrete had been taken. Referring to Mr. Gedye's remarks as to the deepening of the channels, although no dredging had been done actually between the piers of the high-level bridge, the channel was dredged through the swing bridge to within 50 yards of the high-level bridge on the east side in 1912, and as early as 1877 dredging was carried out on the west side to within 80 yards of the bridge. The old Tyne bridge was removed in 1874–75, and the swing bridge was completed in 1876. A good deal of dredging was, however, done above or west of the bridge before that date, commencing in 1871 and continuing ever since; therefore, although the short length of 130 yards through the bridge had not actually been dredged, the deepening of the channels was undoubtedly due to dredging. As to Mr. Gedye's surprise at there being no settlement, it must be remembered that the piles were dependent for their bearing power on the fact that they were driven down to a rock bottom, and not on skin-friction. They were tied together at the top by a bed of concrete, and their stability would be affected but slightly, if at all, by a slight change in the consistency of the material surrounding a short length below the concrete. There had not been the slightest sign of settlement. How long the plates referred to by Mr. Gedye had been out of level he was unable to say, but there had certainly been no settlement during the 35 years he had known the bridge. Any settlement would have been noticed at once on the permanent way on the bridge. As to the cost of the work, the totals included all charges for supervision by the contractors and the contractors' profit, but did not include anything for supervision by the Company's engineer and the resident engineer. The Author.