Discussion.

The PRESIDENT, in moving the vote of thanks, remarked that the Paper contained a number of interesting points to which he would like to refer, but he preferred that the discussion should come from the members, and he would therefore only refer to one matter. Very great care had been taken, in making the piles, to grade the aggregate and measure the water with which the concrete was mixed. Engineers were all aware of the effects of grading the aggregate and proportioning the water when tests of concrete were being made; but very often those things were not quite so carefully done when concrete was mixed on works. There was an idea that things were sometimes more roughly done abroad than in this country; but the Paper described an instance where very special care had been taken in carrying out work, and he thought the tests showed that it had been very well repaid. The President.

Mr. M. F.-G. WILSON observed that the removal of the soft clay over the site and refilling before the construction of the pier was begun was a bold but wise course. If an attempt had been made to remove only a portion of the clay and then put a fill on the top of the remainder, bad slips would have been sure to result. He had had a good deal of experience of that class of material, and had found that pressure on the top of the soft clay was likely to result in serious slips. At the same time, the removal must have been difficult, as the rock was nearly 80 feet below low water. It would be interesting to know how it had been dredged. Similar work had been done, he thought, in Alexandria, where soft material had been removed before the works were constructed; the excavation in that case did not quite reach the rock, but it went down to a considerable depth, and the work was quite successful. He was not clear about the experiment made to determine the density of the fill. The boxes were filled with water and gravel; the water was then drawn off; and it was stated that the gravel was then in the same condition as in the actual fill. He would have thought that the fill would have been full of water. It was not quite clear how the piling formulas were worked out. On p. 54 the Author gave a formula which depended upon the final penetration, whereas on p. 76 he stated that it was not possible to obtain any information about the bearing-values of piles from the penetration. Experiments had been made on the driving of piles of different shapes, and finally the very long tapering point had been evolved; but it was not explained how that had been arrived at; Mr. Wilson.

Mr. Wilson. the experiments showed that it did not matter whether the pile was pointed or not. A number of experiments on piles had been made at Trafford wharf by Mr. H. A. Reed, M. Inst. C.E., who had also found that a square-ended pile would drive almost as easily as a pointed one. Another point about the formula was that two piling-engines were used, one an ordinary quick-acting steam piling-engine giving about 100 blows a minute, and another in which the hammer was raised by steam and dropped freely. One formula was used for both those pile-drivers, but the results must have been very different in the actual driving. Mr. Reed had pointed that out[1] very clearly in his account of the experiments at Trafford wharf; after one of the quick-acting steam-drivers had driven the piles as far as it could, a free-falling weight had been able to drive them considerably farther. He thought it was generally agreed that quick-acting pile-drivers were not very good for bearing-piles, because it was difficult to estimate the bearing-power of piles driven by them. They were, however, useful for sheet piling. The result of the driving of the piles at Vancouver, however, seemed to have been satisfactory, because those that had been tested had yielded satisfactory results. He would have welcomed more information about the water/cement ratio; it was not very much used in England, but he believed it was much used in America. At all events, the concrete used resolved itself into an ordinary 1 : 1½ : 3 mixture, which appeared to have been quite satisfactory. About 4½ cubic feet, or about 28 gallons, of water had been used per cubic yard. That, presumably, had been varied by formula as required. He was doubtful whether such refinements were worth while. A rather similar proportion of water had been used years ago on the Dover harbour works, where, however, the quantity had been judged by an inspector, who, when he thought the concrete wanted more water, gave orders for it to be added. The Author stated that there were no cracks, and therefore the concrete would stand a certain tensile stress. He thought the general opinion now was that concrete would not stand any appreciable tensile stress without cracking, and any concrete in tension, if examined microscopically, would be found to contain numerous very small cracks. After piles had been lifted and stacked in such a manner that they were in a state of strain, it was found that small cracks had developed and the piles sagged. He thought that might be an indication of the phenomenon of plastic yield, dealt with in the recent Paper[2] by Dr. Oscar Faber, M. Inst. C.E.

[1] Minutes of Proceedings Inst. C.E., vol. 221 (1926), p. 78.
[2] *Ibid.*, vol. 225 (1928), p. 27.

Sir E. OWEN WILLIAMS observed that the idea of using a gravel filling and then driving piles into it before the gravel had consolidated by lapse of time was fairly novel. The Author stated that no sign of settlement had been experienced. That was very fortunate, and he could imagine that it was a fact because the filling had been deposited under water. The Author stated that, when the gravel was water-run into a box, it weighed 135 lbs. per cubic foot. It was difficult to criticize the figure without knowing the specific gravity of the aggregate; but it would be difficult to get a first-class concrete made with a minimum of cement to weigh 135 lbs. per cubic foot, and he could not see how aggregates mixed together without cement in the voids could weigh so much. His experience of mixing aggregates under ideal conditions of grading was that it was very difficult to get the weight of the mixed material to exceed 127 or 128 lbs. per cubic foot. The reason was that, once a certain percentage of sand was exceeded, the density began to fall to that of sand. The heavy weight of the dredged aggregate might be accounted for by high specific gravity of the particles; however, he could not consider that as the sole reason, because specific gravities did not vary to that extent. The formula on which the piles had been designed involved buckling considerations. Buckling could, of course, only exist with shear. There was a very considerable quantity of vertical steel in the piles, but the quantity of lacing steel, which took the shear and which must be present if the column was a long one designed on buckling formulas, was the minimum that could be put into any column. The ¼-inch square binding-wires placed 12 inches apart were inadequate, and that accounted for the cracks which occurred in the columns after driving. Mr. Wilson appeared to consider the controlling of the water-content as an unnecessary refinement. If that refinement was superfluous, why bother about the percentage of cement or even a specification at all? His experiments had shown that no material in concrete was more important than the water. For instance, 10 per cent. too much or too little cement made exactly 10 per cent. difference in the strength of the concrete; 10 per cent. too little or too much water made exactly 20 per cent. difference in the strength of the concrete. He would rather be particular about the water and careless with the cement, and even then the quality would, he believed, be twice as uniform. In spite of the precautions taken, however, the results on p. 59 showed a wide variation. A range from 4,560 lbs. per square inch for the best five to 3,780 lbs. per square inch for the worst five out of forty-four test-cylinders was not of the order experienced with

Sir Owen Williams. good work in this country. That could be caused by variations in the cement or in the proportion of water. In view of the precautions taken to proportion the water, that variation must be entirely due to the proportion or the quality of the cement. If the cement was not measured by weight it was quite easy for its volume to vary widely. He knew of one case where a contractor, because the cement was not actually required to be measured by weight, constructed a machine which trickled the cement into a box and made a cubic foot weight 50 lbs. instead of 90 lbs.! If cement was measured by weight, the engineer obtained what he wanted, which was the material; if measured by volume, he often got merely air. On pp. 73 and 74 the Author referred to a test-pile that had been cracked very badly and then driven where it would be exposed to sea-water. The cracking of a pile indicated that the steel had been stressed beyond the elastic limit, and when the elastic limit was exceeded watertightness ceased. One of the defects of a concrete ship as against a steel ship was that the factor of safety of watertightness depended on the elastic limit; when the reinforcement was stressed to the elastic limit owing to an accident, the structural strength was not in any way reduced, but owing to the extension of the steel the concrete cracked very seriously, whereas in a steel ship the steel dinged but did not cease to be watertight. He thought the same reasoning was applicable to a pile. If the reinforcement was stressed beyond the elastic limit, watertightness and resistance to corrosion could not be expected. Therefore, he thought the experiment was rather like testing a structure to destruction and then patching it up again to see how much more it would stand. The Paper did not give costs, probably for very good reasons, but it was nevertheless unfortunate. A comparison between different types of construction and the reason why the particular method had been adopted would be interesting. He had made a few rough calculations in connection with an alternative form of structure, in which the front of the pier consisted of a continuous sheet-pile wall. That would save the whole of the decking, and there would not be very many piles. The present king piles, nearly 2 feet square, were placed 10 feet from centre to centre, so it would not need many extra piles in that row to form a solid wall, which could be tied from side to side of the pier and within which a solid gravel filling could be placed. The whole of the superstructure would then rest on the filling, but in that respect it would be no worse than at present, as it did so now, but through the intermediary of piles. He found that the approximate saving in cost by such a method, taking into account the saving in the cost of the decking, would be 25 to 30 per cent.

Mr. H. J. DEANE observed that, in proportioning concrete on a water basis, it was very difficult to estimate the quantity of water actually contained in the sand and gravel. Information as to how that had been done would be of use to those who had to carry out similar work. The piles had been allowed to mature for a very long time, amounting to 8 or 10 weeks in bad weather. In view of the capacity of the pile-driving plant, it seemed that the pile-yard had accommodated 1,000 piles or more. Thirteen piles a day had been driven, and 10 weeks' supply would be 715 piles. It would be of interest to know what accommodation had been provided. The Author referred to penetration curves, which were always interesting, and he hoped they would be added to the Paper. There had always been considerable controversy about pile-driving formulas. He thought there were about thirty or forty formulas in existence, some having a term in the denominator which represented the factor of safety; but in the old *Engineering News* formula and also in the revised one mentioned in the Paper, there was no suggestion as to the factor of safety. If that factor was taken as 8, which was the usual value, the results of the Author's tests showed that at least 50 per cent. more carrying-capacity was provided in the piles than was actually required, and that neglected the factor of safety, whatever it might be. Could the Author say what the actual factor of safety was? It was a great pity that the piles had not been tested more completely, because a test to destruction in such a class of fill had never been made before to his knowledge, and it would have given some idea of the carrying-capacity of piles driven under such conditions. The Author's figures fell very considerably short, he believed, of the ultimate carrying-capacity of the piles. Sir Owen Williams had commented on the results of the tests of the concrete. Taking the average ultimate strength at 28 days in each case as a unit, the average ultimate strength at 28 days of the highest five in set (*a*) was 1·2 and of the lowest five 0·83; and taking the next set (*b*), the corresponding figures were 1·2 and 0·82, which showed extraordinarily consistent results. The ratio of the two averages was 1 to 0·84. He was interested to learn that Sir Owen Williams considered that divergence to be unnecessarily wide. In the tests recorded in a Paper[1] by Professor T. B. Abell a variation of more than 100 per cent. occurred, that was, approximately 30 per cent. variation from the mean. In some tests with which he had been concerned some time ago very similar Mr. Deane.

[1] "Reinforced Concrete for Ship-Construction." Minutes of Proceedings Inst. C.E., vol. ccxi (1921), p. 225.

Mr. Deane. results had been obtained. He looked upon the results given by the Author as being really very good, and he attributed the quality of the concrete to the care taken in proportioning the aggregate on the basis of the fineness-modulus, which, however, was rather costly in practice. There was always a liability of getting slight variations in the proportions, and that, in his view, accounted for all the differences in the concrete tests. He thought it would be worth while to specify a standard aggregate for concrete tests, just as a particular standard for sand had been specified for testing cement. He did not think there would be a satisfactory comparison between one set of concrete tests and others until grading was standardized. It would be interesting to know why the particular design of pier had been adopted. It might be that a question of cost was involved. It might have been cheaper to put in the quantity of reinforced-concrete work described in the Paper rather than put in more filling, but that was not obvious. It appeared from *Fig. 1* that the slope of 1 in 2·5 was unnecessarily flat, considering that there were big piles comparatively close together helping to resist any tendency of the fill to move outwards. He imagined it would have been quite reasonable to allow a slope of 1 to 1½ up to low water and a slope of 1 to 1 above low water, provided the necessary precaution was taken to use heavy stones on the surface. That would have saved 50 per cent. of the reinforced-concrete decking and a considerable number of piles, and it would have enabled the front piles to be considerably reduced in size. Even if the actual costs could not be given, he would appreciate some information about the relative costs of the fill and the reinforced-concrete work, as that would be very useful to engineers who might have to consider similar designs.

Mr. Swan. Mr. A. D. Swan observed that he was particularly interested in the Paper because the Author had formerly been his assistant in Vancouver, because he had had the privilege of visiting the works, and, further, because he, rightly or wrongly, had sometimes criticized the design adopted. In the design of other works of a somewhat similar nature a few hundred yards away in Vancouver very careful estimates had been made of the cost of constructing a pier with a fill of gravel, reinforced-concrete piles, and the same slope, as compared with the system employing cylinders. He thought he might clear the air a little by saying that the firm that constructed the concrete structure had had nothing whatever to do with the filling, which had been put in by different contractors several years before the design of the superstructure had been decided. He had ventured to criticize the adoption of concrete piling, in view of his previous experience. He had been asked to examine another very large concrete-pile pier at Halifax, Nova Scotia, where the piles had cracked very badly indeed. It was well designed and had been well supervised, but the fact remained that the piles were very badly cracked and were to-day sheathed with timber from low water up. The same piling-engine and the same rate of driving had been used on the work at Vancouver as had been used a few years before at the Halifax pier; and he thought the engineers were to be congratulated if it was a fact that only 2 per cent. of the piles were cracked. He did not think the cracking of the Vancouver piles would be very serious, because the water was not very salt there, and, further, there seemed to be a lot of oil floating on the surface, which he thought helped to preserve the concrete. He would very much appreciate some particulars of cost. Mr. Swan.

Mr. JAMES WILLIAMSON did not think it was possible to select any better material for the filling, once it had been decided to carry out the work in that fashion, because gravel was one of the best materials for driving piles into. Usually, if the gravel was already in place, it was not possible to drive very far except by means of a water-jet, and in view of the relatively small mass of the hammers described in the Paper he did not think it would have been possible to drive the piles to the depth they had been driven without the use of the water-jet. The Author stated that the bearing-values of the piles had been checked by the *Engineering News* formula with a constant of 0·3 in the denominator. There was, he believed, a great deal of confusion about the dynamics of driving piles by a hammer, and he did not think that any formula of the type in which the resistance was based on the product of weight and fall of the hammer, without regard to the weight-ratio of hammer and pile, was of any use. There were two main stages in pile-driving: in the first the pile was hit by a hammer and set in motion, and in the second the resistance of the earth stopped the pile. The effectiveness of the impact was a function not so much of the energy as of the momentum of the blow. If W denoted the weight of the hammer, P the weight of the pile, V the velocity of the hammer at the moment of impact, and v the resulting velocity of the pile and hammer together, then the momentum of the hammer before striking was WV. After the impact the total mass in motion was $W + P$, and the momentum was $(W + P)v$. Equating the momenta gave $v/V = W/(W + P)$, that was, the ratio of the velocities before and after impact was the inverse of that of the masses in motion. The kinetic energy before impact was $WV^2/2g$, and the kinetic Mr. Williamson.

Mr. Williamson. energy of the total moving mass after the impact was $(W + P)v^2/2g$. Therefore the kinetic energy was reduced by the impact in the ratio $W/(W + P)$, and the resulting kinetic energy of the blow was $(WV^2/2g)\ \{W/(W + P)\}$. In actual practice the available energy would be even less than this. The following example related to a 10-ton pile being driven by hammers of various weights from 1 ton to 10 tons, the fall being that necessary to give a blow of 20 foot-tons in each case:—

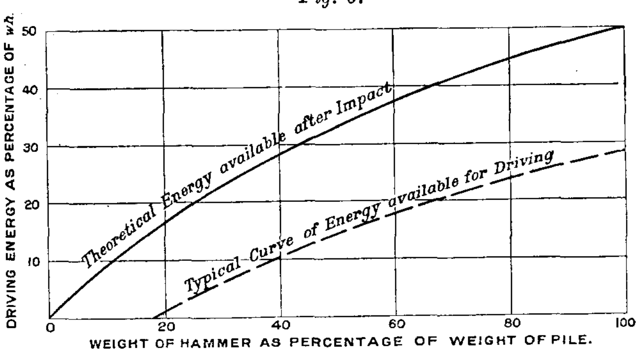
Hammer-Weight.	Fall.	$W + P$.	V.	v.	Kinetic Energy after Impact.		Kinetic Energy Lost by Impact.
Tons.	Feet.	Tons.	Ft. per Sec.	Ft. per Sec.	Foot-Tons.	Per Cent.	Per Cent.
1	20	11	35·9	3·3	1·8	9	91
2½	8	12½	22·6	4·5	4·0	20	80
5	4	15	16·0	5·3	6·7	33	67
10	2	20	11·3	5·6	10·0	50	50

These figures showed that the driving effect was much greater with a heavy hammer than with a light one for the same energy of blow, and the risk of cracking the pile would be considerably greater with a light hammer and a high velocity than with a heavy hammer and small fall. A further point was that the quantity of coal required for the driving of a pile would be much less with the heavy hammer than with the small one under conditions of equal energy of blow. When the hammer was very much lighter than the pile it might not be possible to drive the pile into the fill, but by using a hammer of suitable weight a large part of the kinetic energy was effective in driving the pile. It was therefore evident that any formula based directly on the product of hammer-weight and fall would be nothing but a delusion. When a graph was plotted of the relationship between the weight of the hammer, expressed as a percentage of the weight of the pile, and the resulting kinetic energy, a curve such as that in *Fig. 6* was obtained. When a long pile was driven in sticky ground, the effect of the impact was not felt through the whole pile at once, and the movement of the pile-head might be quite considerable before any motion reached the point; in other words, a wave of compression travelled down the pile, the friction of the material on the surface of the pile coming into action at once, and a certain amount of energy was required to overcome that effect before the point could move. The energy required to overcome friction and the elastic compression of the pile itself was for given conditions roughly constant, and the

Mr. Williamson.

resulting effective driving energy at the pile-point was indicated by some such curve as the lower one of *Fig. 6*, which showed that over a certain range of weight-ratio of hammer and pile there could be no driving, and that increase in weight of the hammer had a very great effect, as shown at the right of the diagram. If the hammer weighed half as much as the pile, it was certain that there would be ample energy after impact to force the pile-point down. In the work under discussion there were piles ranging up to 16½ tons in weight. Such heavy piles required to be designed for handling and not for driving. When a pile was lifted off the casting-platform by two points, it was important to choose the points of lifting so that the bending-moment would be a minimum; that occurred when the positive and negative moments were equal in magnitude, and for a parallel-sided pile the points of support should be about

Fig. 6.



one-fifth of the length from the ends (0·207 *L*). The bending-moment was then 0·021 *WL*. When piles were hoisted into the leaders they were usually lifted at a single point, which, of course, induced a very much higher bending-moment than did two points of suspension. The bending-moment was a minimum, 0·043 *WL*, when the single point of suspension was distant 0·293 *L* from the head of the pile, the point being on the ground. On the basis of those figures, with the first method of lifting the stress in the steel of the piles in question was about 11,500 lbs. per square inch. The Author stated that the maximum stress was 12,000 lbs. per square inch. He did not indicate how the piles had been lifted into the leaders of the pile-driver; assuming that they had been lifted at one point, the steel stress would have been 23,000 lbs. per square inch, and the concrete stress 1,000 lbs. per square inch. The handling of long concrete piles was always difficult, and he did not

Mr. Williamson. think it was generally understood how rapidly the handling became more difficult as the cross section of the pile increased. The weight of the pile could be taken as proportional to Lb^2, where b was the breadth, and the bending-moment under any given condition of lifting would be proportional to $(Lb)^2$. The resistance to bending of a pile of rectangular section was proportional to bd^2, when d was the depth. Therefore for a square pile $(Lb)^2$ was proportional to b^3, that was, $L^2 \propto b$, or the limiting length for handling varied with the square root of the breadth. If a 12-inch pile with a certain proportion of reinforcement could be handled safely up to 50 feet long, a 24-inch pile with the same proportion of reinforcement could be handled safely under similar conditions if it was not longer than 71 feet. A large number of piles had been driven in connection with the recently-completed Barking power-station, and the specified blow had varied with the weight of the pile and the weight of the hammer. Some of the piles were 14 inches square and ranged from 25 to 46 feet in length; the specified set was 1 inch for six blows, and the hammer was to weight not less than 3 tons. The specified blow increased with the weight of the pile, being 9 foot-tons for piles 25 to 29 feet long, and increasing to 12 foot-tons for piles 40 to 46 feet long.

Mr. Reinhold. Mr. G. C. Reinhold remarked that Mr. Swan had mentioned cylinder foundations for the piers; it had occurred to him that in the shallow inlet which the Author described, with a comparatively small tidal flow, it would have been quite possible to use reinforced-concrete cylinders founded on the sandstone, and it would be interesting to know whether that alternative had been considered.. Possibly it would have obviated dredging and filling. He preferred the octagonal section as opposed to the square section for piles. An octagonal pile was not as strong as a beam; but the distribution of the reinforcement appeared to him to be more symmetrical than in the square section, and it was an advantage that the sloping sides of the octagonal section permitted the piles to be picked up by an arrangement of grapnels such as had been described[1] by Mr. Reed. Mr. Reed mentioned that the time allowed for the maturing of piles at Manchester was 28 days, as against 40 days in the case under discussion. Mr. Reed added that the 28 days had subsequently been reduced to 14 at the request of the contractors, and that in no case had the piles cracked owing to lifting-stresses. He saw no reason why the Author should have abandoned the use of a lifting-arrangement, because the appliance Mr. Reed had described

[1] Minutes of Proceedings Inst. C.E., vol. 221 (1926), p. 86.

had apparently been successful. The choice of a flat tapered point in preference to an armoured point might have been justified in the present case because the formation of the ground was known, but considerable risk was taken where the ground was virgin and obstructions like boulders were likely to be met. Mr. Reed also mentioned in the Paper referred to that very different results had occurred in the driving of the several piles of a group, and that he had introduced a square point, which enabled the pile to be driven much more easily than piles with a shoe, the explanation being that the square end shattered the strata and reduced the skin-friction. Subsequently, however, the square-ended piles had been found on redriving to give quite as high a resistance as those with shoes, showing that the ground had tightened up subsequently, possibly because other piles had been driven nearby. As considerable trouble seemed to have been taken to grade the aggregate, it would be interesting to know whether the stones were water-worn or angular. If water-worn, it might have been worth while to crush the aggregate, because angular particles made a better concrete than round stones. Had any attempt been made to pitch the piles by using a crane? That method had been adopted frequently in this country, and invariably, he believed, with good results. Considerable economy in time had resulted, and the piles had been driven very well when automatic hammers were used. Mr. Reinhold.

Mr. A. D. Keigwin remarked that there did not appear to be any real reason for adopting the tapered pile-point, and it must have added to the difficulty of casting the piles. Although there was a saving in material, the point was considerably weakened. The use of the water-jet would blow quite a big hole in the fill, and the wedge action due to the tapered point would be lost. There might, however, be an advantage in the tapered pile, as experiments had shown that such piles driven in mud would give about 50 per cent. more bearing friction per square foot of surface than a square pile gave. No armoured protecting-shoes had been provided, and to drive concrete piles in a gravel fill without protecting the toes was rather a dangerous practice. The use of the water-jet would help to get the pile down. The Author stated that the water-jet was stopped for the last part of the driving; further information about that would be useful. He had seen many years ago a sample of steel sheet piling that had been driven through a gravel bed and afterwards exposed by an inspection-trench. The bottom 4 or 5 feet had been twisted out of the grooves, bent up, and very badly damaged, and some of the piles were torn. He could quite imagine a concrete pile being rather similarly damaged. More information would be Mr. Keigwin.

Mr. Keigwin. acceptable with regard to the proportioning of the concrete. The crushing tests showed that a strong concrete had been obtained, but it was not necessarily a dense one, as was desirable in work exposed to sea-water. He thought the permeability test showed it was fairly water-tight. He had used Mr. W. B. Fuller's method of making mechanical sieve-analyses of sand and stone, plotting the results on curves, and combining the curves so as to conform with the theoretical curve Mr. Fuller had laid down. When the aggregate was mixed, another sieve test was made, and if it conformed with the theoretical curve the aggregate must be nearly correct. Not everybody had a series of standard sieves, but a set of sieves could be made quite easily, and it was better to use them than to depend on guesswork. In the tropics very heavy showers of rain occurred, and if work was stopped owing to rain, the proportion of water required on resumption of work might be quite different from the amount used when the work was started at the beginning of the day. Sir Owen Williams had cited a case where cement had weighed 50 lbs. per cubic foot; Mr. Keigwin had always considered that a cubic foot of cement should weigh not less than 94 lbs. The contents of a box 12 inches square and 13 inches deep filled from a heap of cement weighed about 94 lbs. He had not had experience of a concrete-shoot except as an onlooker. In Japan he had seen one being used ; the first batch came down and stuck half-way down the shoot, and the second had so much water in it that it came down like a mountain torrent and overloaded the distributor, which collapsed. He did not like the idea of shooting concrete into small sections such as a pile, because there was so little control over the mixture. He would rather see it put in by shovel and rodded, and the sides of the mould hammered with a mallet so as to produce as dense a surface as possible. He thought it was always advisable to leave on their beds as long as possible piles more than 30 feet long, because when they were removed they were generally wedged up at one end and badly treated, as had been suggested. He had used the two-point system, and by putting in additional reinforcement to resist the bending-moment he had had very satisfactory results. In driving concrete piles he had used a short dolly with a cap embracing the concrete pile-head. Various cushions of fibre, boards, etc., had been used, but he had always found that the best results were obtained by using cushions made of old cement-sacks—or something of that sort—filled with sawdust, putting two or three pads between the dolly and the pile, each 1 inch thick when bedded down. The 1,600 gallons per minute discharged by the water-jets must have blown very large holes in the bank and washed away the small

Mr. Keigwin.

material which otherwise would have contributed materially to the frictional bearing-power. The piles had to carry the load rather on their points. The disadvantage of a central water-pipe was that there was always a chance that stones or clay might be forced up the nozzle during driving, and the jet was thus put out of action. Upward-flow jets would be of some advantage in reducing skin-friction, but he did not think they were really desirable, as they would prevent the central pipe from being cleaned by temporarily raising the water-pressure. He thought that the points of some of the piles that had been driven in the bank had been a good deal more damaged than might be anticipated, because the foot of the pile was of plain concrete, and the section was weakened by four upward-flow jet-holes. There was also a possibility that large stones wedged in the central hole might have burst the concrete and reinforcement. He did not think there was any fear of deterioration under sea-water, but it was certainly advisable to take precautions above the water. He had found in tropical climates that damage to reinforced-concrete work started at about mean water level, and he had found it up to 100 feet above sea-level in the reinforced-concrete gutter of a warehouse. The concrete, being porous, acted like a sponge and breathed the salt-laden damp air in and out according to the variation in humidity existing from day to day; the salt that was left behind by evaporation gradually reached the steel and caused it to rust and burst the concrete; and once that action had been started it was very difficult to stop. In fresh water only normal deterioration seemed to take place, such as might be due to rain-water penetrating through shrinkage-cracks in deck-slabs, etc. He had seen concrete made with waterproofing compound used on a repair job at mean water-level, and it was a complete failure. The failure was considered to be due to the rust that had formed; chipping and wirebrushing were insufficient to remove it all, and the rust had started again and burst the concrete. He thought if sandblasting had been available the job might have been more successful. He was inclined to favour some form of impervious coating rather than waterproof compounds in the concrete, as it appeared advisable to aim at making the surface airtight rather than watertight. If it was watertight it was not necessarily airtight. Every precaution should be taken to form a non-porous concrete mixed with sufficient water, and no more, and the surface might be painted with oil, tar, silicate of soda, or some other coating.

*** The Author's reply will be found at p. 110.