Dr. Faber. driving at the site of the new offices of the London Electric Railways at St. James's Park station. There the trouble had been cured by silencing the exhausts of the pile-drivers. The steam pile-driver was not very suitable where it was desired not only to drive the pile into the ground but also to fix it firmly when it was driven. The large number of blows of the steam pile-driver, as compared with a few heavy blows of the drop hammer, undoubtedly caused much more vibration in the surrounding soil. Some of the timber piles driven at Northfleet by a steam-hammer had actually come up again and floated away. When they had been driven by a drop hammer to the same depth they remained fixed in the chalk, so that for that particular purpose a drop hammer was much more useful.

Correspondence.

Mr. Case. Mr. A. HAVELOCK CASE observed that the piles apparently had been unduly punished, having regard to the load that they would have to carry; and a minimum penetration of 12 feet into the solid chalk seemed to be somewhat unnecessary, unless it was to provide for that factor of the design required to resist the drawing of the piles by an overturning-moment. Interesting information was given (p. 293) regarding the resistance of piles to extraction, but it was well known that the resistance of piles to drawing varied within wide limits, even with piles of the same structure.

He suggested that the effect of a blow from a ship coming alongside, serious enough to overturn or even materially damage the structure, would not necessarily draw the raking piles, but would probably displace the deck by bending the piles to the point of fracture, and cause them to break away from the under side of the deck-beams, the stiff deck being strong enough to withstand the blow, but the piles failing to do so. The three horizontal comparative forces P indicated on Figs. 5 were suggestive, and were closely involved with the interesting question of impact of ships dealt with on p. 293. The Authors gave the kinetic energy of a 12,000-ton ship moving at a speed of 1 foot per second as 187 foot-tons. He gathered that that was arrived at by applying the general principle of gravity units thus: $(12{,}000 \times 1^2)/(32 \times 2) = 187$; but he suggested that gravity, or the force of impact due to falling bodies, was not the only one applicable to a ship moving under the influence of some horizontal force, such as its own steam or the wind, any more than it would be to a locomotive charging into a buffer-stop or a projectile coming in contact with an armour-plate. It was optimistic to

Mr. Case. expect that less damage might be expected from a large ship carefully handled than from a small ship coming alongside any wharf; surely mass was the factor that told.

The absence of raking-struts, especially longitudinally, was noticeable in the Authors' design, and evidently they considered that any tendency to distort the parallelogram of the wharf lengthways was not sufficient to justify diagonal bracing or raking piling. The Authors appeared to defend the omission of bracing of such structures between deck-level and low water (pp. 291 and 292) and to suggest that raking piles rendered such bracing unnecessary. He had had experience of repairs to such unbraced structures and was reluctant to agree entirely with the Authors. For instance, a reinforced-concrete jetty in the Thames with a deck 40 feet wide, 16 feet above Trinity high water, and 51 feet above the river-bed, carried on 15-inch by 15-inch piles with no bracing between deck-level and low water, but provided with raking piles to withstand the thrust of a ship coming alongside, had received severe injury by the impact of an ordinary Thames lighter which had drifted against the upstream-end of the jetty when being towed downstream, light, on the ebb tide. That injury had cost about £1,000 to repair. Three 15-inch by 15-inch concrete unbraced piles had been smashed and four unbraced timber fender-piles had been carried away, resulting in the collapse of part of the overhanging deck, whilst the lighter had suffered very little injury. He thought that if that jetty had been provided with bracing it would have escaped serious injury, although the drifting empty lighter might have suffered.

Mr. Cullen. Mr. E. A. Cullen expressed his complete agreement with the views of the Authors respecting the stability obtained in a pier or jetty by the use of diagonal piles, and the resultant economy. The impact of present-day vessels up to 12,000 or 14,000 tons gross register, when berthing, was severe at times, and bracing above low water only was quite inadequate. The following was a brief description of a reinforced-concrete pier designed by Mr. Cullen in 1922, and built at Bowen, Queensland. The length was 500 feet; the width, 84 feet; the depth, in berthage on each side, 26 feet at low water springs; and the deck-level, 17 feet from low water springs. The pier was built primarily for coal-export, and carried a big travelling electric transporter crane of 80 feet span with a 20-ton trolly for each side, and it had accommodated vessels of 10,000 tons gross. The design adopted was transverse tiers of six piles spaced at 16 feet between centres, the longitudinal spacing between tiers being 10 feet. Each tier was braced transversely above low water, and certain tiers were braced longitudinally also.

To provide stability, five pairs of raking piles were driven at the outer end, one pair to each tier in opposite directions, raking at an angle of 60 degrees, and five pairs of rakers were also driven about the middle of the pier. The internal piles were 18 inches square, those in the sides being 20 inches square, and they had all been satisfactorily handled by lifting from points one-fifth of the length from each end. All the piles had been driven, by a 47-cwt. monkey dropping 7 or 8 feet, through hard clay to rock, the depth in the ground ranging from 10 to 20 feet. A pad of old cement-bags, about 6 or 8 inches thick, was placed on the pile-head, over which a ½-inch steel-plate cap was placed, the cap being about 12 inches deep, and on top of the cap another pad of loose bags was placed. Although the bags under the cap fired once or twice during driving, no damage had been done to the pile-heads. His practice was to use a pile mixture of 3 : 4 : 5, as he considered that economy in cement was misplaced in making piles. Mr. Cullen.

A method of applying bracing and walings above low water, which he had used successfully, was as follows: Holes to take the reinforcing steel bars of the walings and braces were drilled through the piles by a jack-hammer, which drilled rapidly and easily. An air-pressure of 70 lbs. per square inch, used at first, set up acute vibration in the pile during drilling; the pressure was reduced to 36–40 lbs., when the hammer drilled quite fast enough and the vibration was negligible. The holes were drilled about ½ inch larger than the rods, and when the latter were placed therein the holes were well packed with mortar to fill the spaces around the rods. The braces and walings were thus easily constructed, and the pile was not damaged by being broken away.

The Authors' method of fendering would not be found to answer well in waters where marine pests were active, unless a treatment by poison could be applied that would ensure a reasonably long life. The practice in Queensland was to use stout piles of turpentine (*Syncarpia laurifolia*) driven, with the bark on, a short distance into the ground and secured at deck-level to a heavy hardwood longitudinal beam 12 inches square with a second 12-inch beam secured thereto, and checked into the head of the fender-pile so that the latter only projected a few inches outside it. In addition, soft pine logs about 2 feet in diameter and 30 feet long were suspended at intervals outside, but against, the fender-piles at about high-water level. With regard to the force of impact when a vessel was berthing, he considered that the ship itself had some elasticity, which modified the impact.

Dr. Brysson Cunningham observed that the Authors claimed, with every justification, that the jetty was probably one of the Dr. Cunningham.

Dr. Cunningham. first works of this character for which rapid-hardening cement had been used. Almost simultaneously, that was, towards the end of 1925, he had been engaged with Mr. A. Havelock Case, M. Inst. C.E., in the construction of a wharf for Messrs. H. Covington and Son at Wennington, a little higher up the Thames, in which "Ferrocrete" was used for the piles and framing. The use of that material had been due, in the first instance, to the need of providing supplies of piles for the piling-machines without waiting the lengthy period required for hardening in the case of normal Portland cement; after consideration, "Ferrocrete" concrete of composition $1:1\frac{1}{2}:3$ had been adopted for use throughout the entire structure below the deck, which was of timber. As "Ferrocrete" was at the time rather a novelty, careful investigations was made into its suitability, and he satisfied himself that the material could be safely employed. The piles had generally been driven 10 days after moulding, and, in one case at least, 7 days after moulding, without any harmful results. Indeed, the work had been carried out by the contractors in an exceedingly satisfactory manner. He had naturally inspected the piles closely and had found them quite sound after driving. In particular, he had looked for signs of hair cracks, but while there might have been some of microscopical size, there did not appear to be any in evidence to the unaided eye. He mentioned that, because he had heard on reliable authority that there was a risk of the formation of hair cracks in concrete made with that cement, and he would like to ask the Authors whether there had been any experience of the kind at Northfleet, and whether a cause and any preventive or remedial measures could be suggested. Obviously the matter was of the utmost importance in regard to reinforced structures in a marine environment. The piles at Wennington were 14 inches square and ranged from 45 to 50 feet in length. They had been driven to a set of 100 foot-tons per inch for the last eight or ten blows, as compared with a set of twice to four times that intensity adopted by the Authors at Northfleet. He was inclined to view a succession of blows of an intensity of 200 to 400 foot-tons per inch as somewhat excessive and tending to produce disintegration of the piles. The jetty at Wennington had to carry not only locomotives and rolling stock, but also an installation of cranes, the weight of each of which, including a grab and contents, was approximately 40 tons. The set obtained had proved to be ample to secure the requisite support for the bearing-piles.

Mr. Fawcett. Mr. P. N. FAWCETT remarked that the Paper was of great value to engineers who had to construct jetties and wharves in rivers and harbours. The question of the impermeability of the concrete piles was of the utmost importance, and he was surprised to see that a slump of only 1½ inch had been allowed; fuller particulars of the amount of moisture in the sand and the quantity of water used would be of value. In the report of the Committee of the American Concrete Institute on "Concrete in Sea Water," it was stated[1] that the use of dry concrete was exceedingly dangerous; and that an excess of water seemed to reduce the resistance to salt water. The tests carried out at the Charleston Navy Yard, Boston, Mass., in which various specimens had been exposed to tidal and air action since 1909, appeared to show that a ratio, by volume, of water to cement of about 0·5 to 1 produced the best and most impermeable mixtures, or a ratio, by weight, of water to dry ingredients of between 9 and 10 per cent.[2] In making piles for the construction of a reinforced-concrete jetty erected on the sea-coast in the Gulf of Pechihli, he had used a mixture of 94 lbs. of "Ferrocrete" cement, 1·6 cubic foot of sand, and 2·8 cubic feet of granite stone, half broken to pass a ¾-inch and half to pass a ⅜-inch sieve. The voids in the sand were 41 per cent., and the sand contained 2½ per cent. by weight of moisture. It required 21 lbs. of water per cubic foot to inundate it, in addition to which 5 lbs. of water per cubic foot of sand was added, making 41 lbs. of water per 94 lbs. of cement, and giving a ratio of water to cement of 0·45 to 1 by weight and 0·66 to 1 by volume. The weight of water was 8·5 per cent. of the total weight of the ingredients, and 10·5 per cent. of the dry aggregate. The slump was 7 inches in all cases, and a mixture was produced that flowed easily and did not appear to be too wet, no water collecting on the surface. From experience gained in using the slump test, it would seem to be exceedingly difficult to measure a slump of 1½ inch, and it would be of interest if the Authors would say whether they found the mixture sufficiently fluid to be rodded around the reinforcement without leaving voids. Mr. Fawcett.

Mr. W. T. Halcrow remarked that the works described were of special interest as they departed from the more orthodox designs usually adopted for reinforced-concrete jetties, and the type evolved would appear to give much greater rigidity than the more usual cylinder construction. An important advantage was the minimizing of the work to be carried out in situ between high and low water. Jetties designed on the system of groups of piles encased in concrete cylinders and not braced below low-water level had given satisfaction in practice for 20 years. While he fully appreciated the points put forward by the Authors in the paragraph at Mr. Halcrow.

[1] *Concrete and Constructional Engineering*, vol. 19 (1924), p. 249.

[2] *Engineering News-Record*, vol. 86 (1921), pp. 121 and 373.

Mr. Halcrow. the foot of p. 291, it would be instructive if they would state whether a cylinder design would have cost more under the conditions with which they had had to deal. It was not clear from the reference made to the cost of the structure whether dredging was included. Assuming that it was, and for purposes of comparison making a reasonable reduction, it would appear that the cost, excluding equipment, was about 53*s.* per square foot of deck-area. The cost of two piers he had constructed within the last 2 or 3 years, both of the cylinder type, worked out at a lower figure, although the loads to be carried were heavier and the depths of water at low water and general requirements were similar to those in the case of the jetty described in the Paper. On p. 293 reference was made to data secured during the extraction of piles by means of wreck-lighters. He had on several occasions endeavoured to obtain reliable figures from that operation, but he had not been satisfied with the results. It would be of interest if the Authors would say how they had measured the pull required to draw the piles.

Mr. Mitchell. Mr. JAMES MITCHELL remarked that the raking piles, with the horizontal brace just above low-water level, were well adapted to produce a stiff structure. It would, however, be interesting to have details of the calculations supporting the statement that the transverse strength of jetty No. 3 in Figs. 5, Plate 5, was only one-tenth of that of jetty No. 1. The use of precast members, to which reference was made on p. 296, had important advantages where work had to be carried out near low-water level. It was difficult, in the short time available after the water had left the place, and before it again covered it, to get the surfaces thoroughly cleaned, watertight shuttering fixed, the concrete placed, and the upper junction made good. There was, however, no reason for believing that well-proportioned concrete, made with an ample quantity of water, was likely to suffer by immersion in brackish water shortly after it had been placed.

The question of the blow in foot-tons for which a jetty should be designed was very complex. In addition to the factors mentioned by the Authors, there were those of the amount of ground-swell, or of current, at the site, and the method of handling the vessels, whether by tugs or otherwise. The statement that large vessels were handled with greater care than small ones introduced a somewhat novel principle of navigation, but it had to be kept in view that what had to be provided against included such contingencies as the snapping of a hawser, the effect of a sudden squall of wind, and the deflection due to a strong current. The ranging of a large, fully-loaded vessel, lying alongside a jetty during a heavy ground-swell, put a severe tax on the structure. Mr. Mitchell.

Reference was made in the Paper to the advantage of being able to pitch piles at right-angles to the ground-surface. It appeared probable that some trouble had been experienced in that respect, during the driving of the line of piles which raked backwards from the face of the jetty, and the design of the piling-frame used did not seem to be adapted for dealing with any shooting-away of the foot of the pile. Perhaps that was what was referred to in the statement that the frame "would have been even more convenient if a certain amount of lateral movement had been provided for." So much had been heard of the cracking of concrete piles, and non-axial driving was so apt to lead to this result, that perhaps the Authors would say whether any cracks had been observed, and what means had been adopted for their detection. *Fig. 8* (p. 299) was interesting, especially in view of the claims sometimes made for the advantage of striking blows in rapid succession. The effect of a period of rest on the bearing-capacity of a pile must, however, be in general very uncertain, and must be largely affected by the degree of homogeneity of the ground, and the effect of the vibration, or change of direction, of the pile, in disturbing the surrounding material. Thus, while a stoppage of 14 days produced a marked effect on curve 14 R 6, yet a stoppage of 20 days had no apparent effect on curve 5 R 3. It was explained on p. 293 that the piles had been driven by means of a 4-ton monkey (presumably a simple drop-hammer) falling 5 feet, to a maximum set of 0·1 inch, and reference was made to the Authors' formula for the safe load on such piles. It was not stated whether a helmet had been used in driving the piles, but in any case there was so much uncertainty about the weight-carrying capacity of piles that a figure such as the 91·4 tons, which professed to give the safe resistance of the trestle to the nearest 2 cwt., was apt to lead the young and inexperienced engineer to imagine that knowledge of the subject was much more precise than was really the case.

With regard to the statement that "an excess of 10 per cent. of water may reduce the strength of concrete more than does a reduction of 10 per cent. in the cement-content," there appeared to be frequently a tacit assumption that what might be called "sloppy" concrete remained sloppy until it set; the fact being apparently overlooked that concrete was a mechanical mixture of cement, stone, and water, and that as soon as it was deposited the heavier materials sank through the water. In addition to that, the lower layers were consolidated by the weight of those above them. The elimination

Mr. Mitchell. of the water in excess of that required for the setting of the cement did not appear to have any detrimental effect on the concrete. Undoubtedly the undue disturbance of very wet concrete, especially where there was much free water on the surface, was harmful, and led to the production of laitance. Generally speaking, however, when the thin layer of this substance had been removed, the remainder of the concrete was found to be perfectly good. He had seen large quantities of concrete made, with wide variations in the degree of wetness, a large part of it having been deposited directly in the sea, and he had invariably found that the best work, as tested by picking, drilling, or blasting, was produced by concrete of such a consistency that a man would sink in it up to at least the knees. It was well to remember that it was not very long since, on the strength of certain laboratory experiments, engineers appeared to vie with each other in the production of dry concrete. The experiments in question were still valid, but there had been a remarkable change of opinion about the conclusions to be drawn from them.

Mr. Thorpe. Mr. W. H. THORPE remarked that he was interested in the condition obtaining when the long piles were suspended at the points defined, and, passing by the results given by the Authors, which were calculated in the ordinary way and which it was desirable to know, he found that by calculating for tension in the steel and in the concrete, the concrete remaining resistant to tension, the stresses were 285 lbs. and 2,960 lbs. per square inch respectively for concrete and steel, using the modular ratio of 15. As stated in the Paper, less rigid care in suspending the piles, with consequent increase of stress, had induced cracks. These results were of value in connection with the design of works to hold water. He had for many years, in designing such work, endeavoured to ensure that on the water face the tensile stress in the concrete should not exceed 250 lbs. per square inch, using the same modular ratio, the load being perfectly inert. The stress so calculated might not be a strictly correct result, as the modular ratio was a cover for various effects which changed with age and moisture conditions; but results so estimated were of value when considered in connection with experience of executed works giving good results.

Mr. Taylor. Mr. TAYLOR, in reply, observed that he was generally in agreement with what Dr. Faber had written (p. 340), but, with reference to Mr. Case's remarks on the piles, he desired to add that they showed no signs of punishment. His recollection was that only one head had been split in driving the 186 piles. A few piles had developed cracks before they were pitched, owing to slight errors in manufacture or handling. Those had all been discarded. A few had developed circumferential cracks during driving; but that had been entirely during the earlier stages of the work. Careful consideration had been given to those cracks, but investigation had indicated that there was no reason to suppose that they were due to the use of "Ferrocrete" and, in view of their very small opening, the piles affected had been left in situ. The cracks had now entirely sealed themselves. Those piles were open to inspection by any engineer who was sufficiently interested to make an examination at low water, for which every facility would be provided. His general impression was that, given careful manufacture and handling, cracking need not cause any trouble whatever. Mr. Taylor.

With reference to the proportions of cement and water, he thought that an excess of cement was a mistake, as it encouraged shrinkage and consequently cracks. So long as there was an ample margin to secure dense concrete, nothing further was required. It was extremely difficult to give figures for the water-content, and, moreover, he did not think they would be very useful, as they would necessarily vary with different classes of aggregate and possibly with the cement also. The slump test was a useful check on uniform consistency; but the actual consistency to be used could only be determined by practical experience, and he thought the mixture used was equivalent to that mentioned by Mr. Mitchell, in which a man would sink about up to his knees. He did not consider that the elaborate rules prepared in America could be applied in practice, unless the resident engineer was authorized to vary the mixture in accordance with practical requirements. From frequent observation during the progress of the works, however, he considered that a slump of $1\frac{1}{2}$ inch gave a mixture that was, on the whole, very satisfactory, and he thought that this figure had been maintained—especially for the piles—as consistently as was practicable.

The cost of the dredging and the dolphins was about £21,000, leaving for the structure itself £51,000, which, on a deck-area of 23,000 square feet, came out to about £2 4*s*. per square foot.

Several correspondents, notably Mr. Case and Mr. Mitchell, had referred to the possibility of damage from large ships and appeared to have little confidence in the Authors' expectation that the blow from a large ship would not usually in practice be proportional to its size in comparison with smaller ships, owing to more careful navigation. Mr. Mitchell suggested that this "introduced a somewhat novel principle of navigation": that would be outside the Authors' purview, but he felt convinced, after many years' experience in providing berthing-facilities for ships of all sizes up to those

Mr. Taylor. referred to in the Paper, that there was in practice substantially less increase of risk due to large ships than calculations would indicate.

Dr. Faber. Dr. FABER, in reply, observed that Mr. Case had questioned the need for driving 12 feet into the chalk. He thought it would be generally agreed that a pile structure merely resting on a surface would not be satisfactory; and, having regard to the scale of the work, a penetration of 12 feet did not seem excessive. Indeed, Mr. Case went on to suggest possible damage to the piles by bending, and the effect of fixing the lower ends of the piles in direction was to halve any bending-moment in the piles as compared with the condition when the bottom ends were free. He knew of no other computation for the kinetic energy of a 12,000-ton body moving at 1 foot per second, but if Mr. Case would contribute an alternative treatment it would be instructive.

He entirely agreed with Mr. Fawcett as to the undesirability of concrete being too dry if the best resistance to corrosion was to be obtained. As to the $1\frac{1}{2}$-inch slump test, he would not like to be too sure that that had really been worked to. Indeed, on his visits his impression had been that the concrete was a good deal wetter than that. He was not too enamoured of the slump test, but he had satisfied himself by inspection that the wetness was right, and the mixture had been fluid enough to be rodded around the reinforcement without leaving voids.

He felt that it was difficult to comment on the comparison of cost suggested by Mr. Halcrow without having any details of the jetties in question, or any means of computing their lateral resistance, but it was his general experience that piled structures of the type described gave lateral resistance more cheaply than did cylinder designs.

It would, unfortunately, occupy too much space to present in detail the calculations for the transverse strengths of the three jetties in Figs. 5 asked for by Mr. Mitchell, but he was quite satisfied with the substantial accuracy of those figures. A certain number of small cracks had appeared in some of the piles during driving, due no doubt to the combination of vibration with the tensile stresses induced in the concrete by shrinkage. But they had largely healed themselves, no doubt by drawing on the residual undissolved cement left in any rich concrete for some time after it had set. He had, in point of fact, suggested a coating of hot tar or other protection, but that treatment had not been approved as being necessary. With reference to Mr. Mitchell's suggestion that the safe resistance of a trestle should not be so precisely stated, he thought he was justified in giving this figure as the result of calculations based on certain assumptions which had been stated. He quite agreed, of Dr. Faber. course, that those basic figures were themselves subject to a margin of error; but that seemed to be no reason why the calculation should not be made as accurately as possible for the sake of consistency and comparison. He disagreed with Mr. Mitchell's contention, which he understood to be that excessively wet concrete would cure itself by the sinking of the heavier materials to the bottom. It was true that after a certain degree of wetness was reached the excess of water separated itself and was left on top. But experiment showed that under these conditions the concrete was more porous and less strong than that made from a drier mixture. He agreed, however, that the proper wetness was a compromise between various requirements, and that too dry a concrete was at least as dangerous as one that was too wet.

Calculations made on the basis of the concrete's resisting tension were always of interest, and he agreed with Mr. Thorpe that for reservoirs they might be as important as those made (as they always should be additionally) on the alternative assumption of concrete cracked, when the structure should still be strong and stable, even if apt to leak. But the tensile stresses calculated by Mr. Thorpe would be so greatly increased by shrinkage stresses and vibration that it was difficult to deduce much from them.

Several correspondents had referred to the value of the hold on the piles in the ground during driving. Three concrete test-piles 18 inches by 18 inches in section were driven, about May, 1925, into the harder chalk. No. 1 was driven 4 feet $9\frac{3}{4}$ inches and drawn by two lifting-lighters with a pull estimated as between 45 and 50 tons. That estimate was based on the submergence of the end of the lighter under the pull, as was regularly done by those in charge of such lighters. Taking the figure as 45 tons, the average adhesion was 1·57 ton per square foot. The other two gave similar results. Those results were also consistent with some cited by Sir Cyril Kirkpatrick (p. 315) and other speakers. It did not seem unreasonable to allow $59\frac{1}{2}$ tons safe resistance to drawing in a pile with 12 feet penetration as a minimum, when test-piles with only 4 feet $9\frac{3}{4}$ inches penetration required a pull of 45 tons to draw them.