		4 days	7 days	28 days
E4	Number of cubes tested	—	6	22
	Mean crushing strength, lb/sq. in.	—	3,875	5,085
	Minimum crushing strength, lb/sq. in.	—	3,300	3,970
	Standard deviation	—	—	621
	Percentage below specified strength	—	Nil	Nil
F1	Number of cubes tested	—	20	26
	Mean crushing strength, lb/sq. in.	—	3,353	4,267
	Minimum crushing strength, lb/sq. in.	—	2,488	3,266
	Standard deviation	—	—	535
	Percentage below specified strength	—	Nil	Nil
F2	Number of cubes tested	—	36	51
	Mean crushing strength, lb/sq. in.	—	3,271	4,847
	Minimum crushing strength, lb/sq. in.	—	2,305	3,060
	Standard deviation	—	713	823
	Percentage below specified strength	—	Nil	Nil
F3	Number of cubes tested	—	5	19
	Mean crushing strength, lb/sq. in.	—	3,490	4,814
	Minimum crushing strength, lb/sq. in.	—	2,239	2,954
	Standard deviation	—	—	—
	Percentage below specified strength	—	Nil	5·3
F4	Number of cubes tested	—	6	15
	Mean crushing strength, lb/sq. in.	—	2,584	3,651
	Minimum crushing strength, lb/sq. in.	—	2,052	3,078
	Standard deviation	—	—	—
	Percentage below specified strength	—	Nil	Nil
B/W mix No. 4	Number of cubes tested	—	—	22
	Mean crushing strength, lb/sq. in.	—	—	4,342
	Minimum crushing strength, lb/sq. in.	—	—	3,203
	Standard deviation	—	—	431
	Percentage below specified strength	—	—	Nil

The Paper, which was received on 27 May 1955, is accompanied by eleven photographs and twenty-three sheets of drawings, from some of which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared, and by five Appendices.

Discussion

Professor A. L. L. Baker (Professor of Concrete Technology, City and Guilds College) said that, as a former oil company engineer, he could appreciate the difficulties and experiences of the engineers and the contractors on that job. Oil companies always wanted a harbour and jetty constructed at such a speed that, if a tanker left another part of the world, the construction would be started and finished before it arrived! That desire for speed influenced the design very much.

He had not seen driving of rakers off the deck done before, but had often thought that it would be a very good idea, and he was pleased to see that it had been done.

He wondered if the contractors had considered tubes instead of hexagonal piles. He thought the tube was the ideal structural unit for a pile and now that tubes were becoming more plentiful, particularly on an oil-company job, it might be worth while using tubes as piles instead of rolling two separate sheet-piles and welding them together to make one hexagonal section, but no doubt there were difficulties.

He was very pleased at the small standard deviation in the cube test results on the concrete. That was especially praiseworthy in the Middle East, and it appeared that the contractors' quality control and methods were well ahead of Codes of Practice in the United Kingdom. It was high time that Codes and Practice related standard deviation and the mean of the cube tests obtained, or which were anticipated, to the permissible stresses in design.

With regard to the jetty design, of special interest to him, he noticed that every precaution had been taken to protect those valuable tankers as much as possible. A breakwater had been built, in addition to a shock-absorbing jetty. In the usual manner, figures of kinetic energy absorbed had been given; those were interesting and valuable and confirmed that with fairly large vessels speeds of collision of 0·5 to 0·75 ft/sec could occur at not very exposed sites. That meant that quite frequently 1,000 in.-tons of shock absorption might be required to stop one of those tankers. The rubber fenders, which he thought were satisfactory in some ways appeared to provide the kinetic energy, but nothing had been said about the impact force. In Papers on jetties the kinetic energy was often quoted but not the ultimate impact. The figure for the ultimate impact was vital because the ultimate impact determined the number of raking piles required in the jetty to resist the maximum horizontal force, which was also taken of course by the tanker, a relatively very weak structure. He felt that engineers did not know enough about the strength of tankers, and he would like to see naval architects engage in a discussion at the Institution with engineers on the subject.

He found from Lloyds Shipping Registry that I/Y was only 40 in.^{3} for the average longitudinal frame of a tanker and that the frames were spaced at about 34 in. On a 30-ft span a 14-ton point-load acting centrally on one frame would produce yield in the steel. If the full 1,000 in.-tons shock absorption which the rubber fenders were capable of absorbing was used and Fig. 25 was followed, it could be deduced that an impact force was reached finally of 200 tons, so that if the full absorption value was to be used the tanker might receive a blow of almost 200 tons. That might be quite concentrated, because the fenders came to the vertical position only when they were pressed right back, and the tanker would very rarely lie exactly parallel to the jetty. It was therefore quite possible that the whole of the collision might be concentrated at one point.

That might be painting a rather pessimistic picture. Experience would show whether those fenders received very hard wear and occasionally dented a tanker's hull, and he would be very interested to know the results.

Fig. 34 showed a model of a recently developed gravity fender which was the basis of an alternative solution used at another berth where similar tankers were going to moor. The fender could recede about 5 ft and could move longitudinally 2 or 3 ft.

Fig. 35 showed the fenders as actually constructed. It could be seen that a blow which would cause an impact of 200 tons on a fairly rigid rubber fender would produce an impact of about one-third that value because the movement of the fender was about three times as much, and it would also be distributed over three fenders because the fenders automatically aligned themselves with the side of the tanker. Furthermore, they had a parallel travel instead of tending to take up a sloping position and so concentrating the pressure on one rib only in the tanker.

There was one other question regarding the figures of shock absorption. In some of the blows 40% of the kinetic energy was absorbed by the fender; that agreed fairly well with the proportion of the blow generally considered as taken up with a swinging blow when only one end of the tanker in a swinging motion hit the fender. In other cases, however, as much as 100% of the kinetic energy was taken up by the fender. Could the Authors add a little explanation on that point? He thought that those blows occurred either with the tanker pressing practically amidships or they must have been almost head-on blows against the fender.

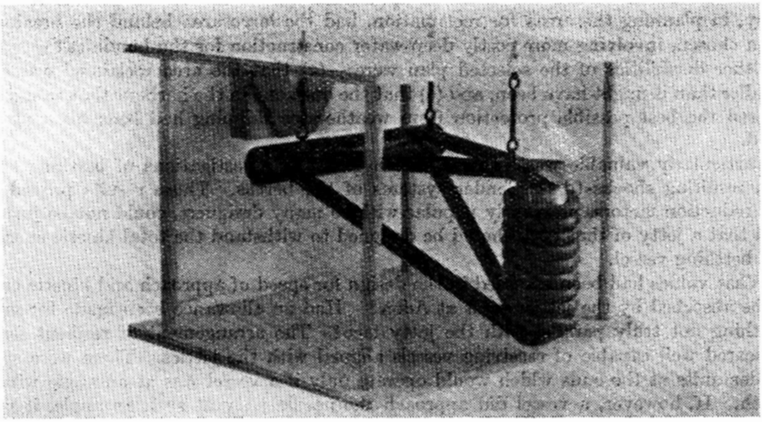

FIG. 34

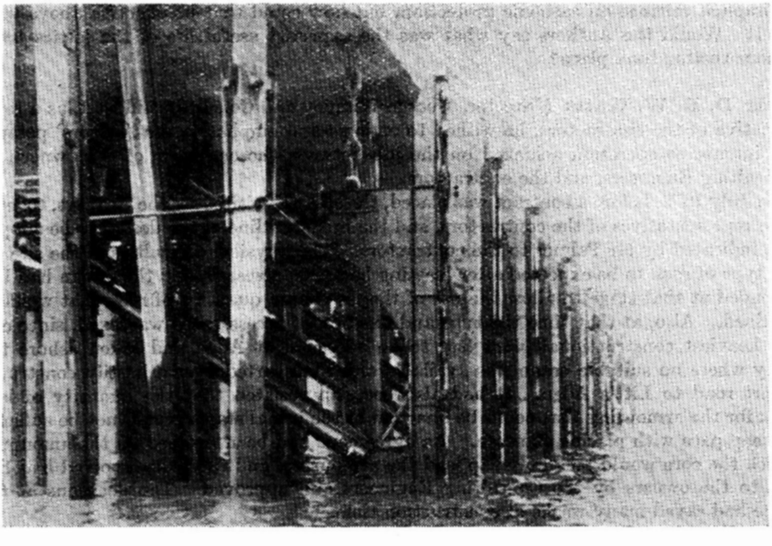

FIG. 35

Mr A. H. Beckett (a Chief Engineer of Sir Bruce White, Wolfe Barry and Partners) said the Paper was of particular interest to him because he knew the site well, having spent several months there for the other Consulting Engineers mentioned, Sir Bruce White, Wolfe Barry and Partners.

Under their direction he had taken charge of the hydrographic survey, and was puzzled by the alignment subsequently chosen for the breakwater. Accepting that speed of construction was essential and that weather protection had dictated the position of the roundhead, why had the costly construction in deep water been chosen instead of utilizing the natural features and shallow water provided by Low Island and Pinnacle Rock? Why, in planning the areas for reclamation, had the large area behind the breakwater been chosen, involving more costly deep-water construction for the bundings?

Other disabilities of the selected plan were:—(*a*) that the area reclaimed was much smaller than it might have been, and (*b*) that the one zone in the harbour that would have offered the best possible protection from weather for shipping had been filled up with sand.

Particularly valuable was Table 1, which gave the investigations of berthing speeds and resulting shocks to the fender systems of the berths. Those results proved that the reduction factors, previously popular with so many designers, could not be justified, and that a jetty of that type should be designed to withstand the total kinetic energy of the berthing vessel.

What values had been assumed in the design for speed of approach and kinetic energy to be absorbed by the jetties built at Aden? Had an allowance been made for vessels berthing not truly parallel with the jetty face? The arrangement of resilient fenders appeared well capable of receiving vessels aligned with the jetties. There were special fender units at the ends which would operate only if a vessel was at an angle with the berth. If, however, a vessel did approach the needle jetty at such an angle, it would not be stopped by the fenders at all. Instead it would collide with the approach trestle.

The clean, bold, and ingenious design of the jetties illustrated how the great bugbear of construction work between high and low water could be avoided. The extensive use of mild steel for jetty construction in an atmosphere where steel corroded quickly indicated an implicit reliance on cathodic protection, but how could that be effective above water level? Would the Authors say what was the expected useful life of the jetties before serious rusting took place?

Mr D. R. W. Watts (Director, George Wimpey and Co., Ltd) said that, as a representative of the contractors, he wished to endorse and emphasize the Authors' point on the intense co-operation achieved on the job between the engineers of the owners, the Consulting Engineers, and the contractors.

In July 1952, before a contract was placed, the site was visited by the Authors, together with representatives of the contractors, and the broad outline of the design to be adopted was indicated by Mr Palmer to the contractors. The physical difficulties of the site and the type of rock to be expected after blasting had been assessed, and the design had been amended at that stage to allow the use of the maximum quantity of rock that would be attained. Also, at that time the type and location of access roads was fixed, since even the heaviest constructional plant had to be offloaded at Aden and taken ashore to a quay where no suitable crane was available and then carted over a hastily constructed desert road to Little Aden. It had also been appreciated that the quantity of large rock for the armouring that could be quarried in the initial stages would not be sufficient to keep pace with placing the core. An agreement had been reached on the amount by which the core would be allowed to lead the armouring, and the risks involved had been put to the owners by the Consulting Engineers and approved. The decisions at that stage had saved many weeks of construction time.

There was another point worth emphasizing. It was the chartering of the troopship *Dorsetshire*, which had taken the pioneer party from the United Kingdom to Aden and had been anchored there as a floating hostel for about 400 men for the first few months and used also as a temporary office and stores base, thus allowing the permanent construction to start at the same time as the temporary works.

Again, in the design of the jetties, the contractors had given to the Consultants the date by which the structural members would have to be ordered to allow them to catch the available rollings in the mills. With that date always in mind, various schemes had been discussed, and finally the scheme which allowed the speediest erection, together with satisfaction to the Consulting Engineers from the engineering point of view, had been adopted.

Mr P. A. Scott (Partner, Sir William Halcrow and Partners, Consulting Engineers) said that it was refreshing to read of a job of such magnitude which had finished not only before time but also below target cost. On p. 375 the Authors had drawn attention to the type of contract that gave rise to those happy results. The Authors did not say "gave rise" but he suggested that that type of contract had given rise to them, because recent experience of the more normal type of contract applied to a job of that size and distance from civilization had made him wonder if in many cases a target contract of that type was not in the long run more satisfactory both from the client's and the contractor's point of view. Where speed meant money to the client, it almost certainly was. But success depended upon the selection of a contractor who could produce and maintain an efficient organization, otherwise the final result was a costly and late job.

Apart from that aspect of the Paper, his chief interest was in the breakwater construction and the quarrying, and he proposed to confine his remarks to those two aspects. Time had obviously prevented use of a hydraulic model to test the section adopted for the breakwater, but would the Authors have used one had time permitted? An observed height wave of 10 to 12 ft was mentioned in the Paper, but for what height and period of waves was the breakwater actually designed? How had the wave heights been measured? That was well-nigh impossible to do accurately, and on two other harbours with which he was concerned two different types of wave-meter were being installed. Both of them were new developments; the one so far installed had had many teething troubles and that prevented a continuous record of waves. With the second one, the conditions precluded its installation for 2 or 3 months yet.

On the breakwater section adopted, Fig. 3, Plate 1, showed a change of slope on the seaward face occurring 1 ft below low water spring tides, whereas the more usual practice was to flatten the slope at a point below the lowest level at which wave action could be expected, say, a wave height below low water. Had there been any reason for that, apart from the obvious saving of rock? The Authors had drawn attention to the fact that the core was brought up to the rather unusual height of 2 ft above high water spring tide. Had that resulted in the loss of any considerable quantity of core material from wave action? He gathered that the breakwater was founded on a sand bottom. As a result, had any great settlement of the rock into the sand bottom been noticed? He noted that the concrete capping, according to Fig. 33, Plate 2, had been placed from 9 to 15 months after the core, which was not very long; he wondered if there had been any considerable settlement and cracking of the concrete core capping. Finally, on the breakwater, what relation existed between the measured profile of the breakwater and the net quarry excavation? Those were figures of particular importance in assessing any breakwater of that kind before it was actually built. Could the Authors give the number of man-hours per ton of rock?

Could the Authors add to the already interesting data on the quarry working given on p. 356 and in Appendix III? What was the height of face that was worked at the quarry and had it been necessary to remove much overburden? At what depth from the surface had the headings been driven? What had been the section excavated and the usual burden or distance from the face? How long had those headings taken to drive and load? Finally, assuming that the rock had been all transported by Euclids, how had the contractor managed to stockpile the armour stone, shown in Fig. 5, to the height at which it appeared to be stocked without a lot of double handling?

Mr L. E. Nobel (K. L. Kalis Sons, and Co., Ltd) said that, as a representative of the dredging contractors concerned, he had no questions to ask because he had been very intimately concerned with the work, but he would like to mention three points because they recurred on all jobs, at any rate where dredging was done. The first concerned organization. As the Authors had mentioned, the organization had worked very smoothly. The reason for the smoothness was twofold. First, a good organization was essential, but could not be worked without the right personalities and on that job those personalities had been there. Then, as to the pure mechanics of organization, what had struck him on that job was that the executives had had time to discuss and to observe personally. That was not new, but its application had been rather striking with rather striking results.

The second point was that of tolerance. The tolerance on that job had been 1 ft, which a dredging contractor would normally consider very reasonable; yet the average dredging depth below that specified had been 18 in.—in other words, there had been 6 in. unpaid for. That was unsatisfactory to the contractor. Why had the dredging been carried beyond the tolerance? It was not because the tolerance had encouraged the dredging contractor to go deeper; it had been a question of sheer necessity. The soil conditions varied greatly from place to place, and it had been necessary to take into account that whilst in one place a certain depth would be sufficient, it might be insufficient in another place. It had been impossible to plan the whole operation from 50 yd to 50 yd to get that correct. In other words, there had been an inclination to make dredging deep enough in any case to avoid coming back. The result was that at some spots there were depths of 2 ft and even more than the specified depth and in other places only a few inches, with an average of 18 in.

He had often thought about what was a practical and fair tolerance. One method which to his knowledge had been applied was a tolerance which took into account the specifying of an average as well as a maximum. For instance, on the job at Aden, an absolute maximum of, say, 18 in, could have been specified, with an average of not more than 1 ft. That would have given the contractor a little more, but not all of his over-dredging. Another method to give approximately the same result and very simple to apply (it had also been worked before) was a tolerance which was paid for in any case. The specification stated that a certain minimum depth was to be attained, but the contractor would get paid for another foot and could do what he liked. On the job at Little Aden it would have given exactly the same result as the first method.

The third point was echo-sounding. The job had been the first where his firm had used echo-sounding for measurement for payment. The results had been reasonable enough, but during the job the echo-soundings sometimes gave queer results difficult to explain. One difficulty for the dredging contractors was that during the dredging the dredger-master had used a hand lead, because the dredger echo-sounders could not be provided. That had given a considerable difference from the results of the echo-soundings. Again that was a reason—reverting to the second point—why the depth had been so great in some cases. He did not know what the solution was, because echo-sounding had come to stay. Hand-lead soundings could not be used on jobs like Little Aden, but echo-sounding had to be handled with care and its applications should be studied further. It had recently come to his knowledge that the penetration of the supersonic waves depended on the frequency. Two types were available of 30 kc and 15 kc. It appeared that at 15 kc the wave penetrated deeper into the soil, particularly light soils, and therefore gave different results from the 30-kc set. That might be a pointer to the way in which an echo-sounding apparatus might be chosen for a particular type of soil.

Mr K. A. Spencer (Spencer & Partners, Consulting Engineers) observed that ships could be dry-docked for painting, but steel jetty piles could not. That point seemed to have occurred strongly to Mr Beckett who had rather taken the owners to task for using steel piles. However, for an oil-company jetty timber could not be adopted and whilst reinforced concrete could be used, the reinforcement was susceptible to corrosion and was more difficult to protect cathodically. Formerly the bugbear of civil engineers designing steel jetties had been the inability to maintain the piles below low-water level, but that could now be achieved by cathodic protection. Obviously the amount of current required to protect a structure was a direct function of the amount of bare steel, so it was advantageous for it to be coated.

The cathodic protection of jetties Nos 1 and 2 at Aden Oil Harbour was effected by a 150-A transformer-rectifier located on either side of each of the two approach sections.

The negative return cables were connected to the jetties and the positive leads fed graphite-anode ground-beds in hydrofill behind the sea wall. The system had worked very well for both jetties and dolphins. Initial design for No. 3 and No. 4 berth jetty called for four 150-A transformer-rectifiers, but temporary electrical drainage during construction of the jetty gave full protection with the low figure of only 375 A, so the fourth unit was not used. The coating was very well carried out, but some deterioration had, however, taken place and the fourth transformer-rectifier was being installed.

For marine structures hot-applied bitumen enamels were infinitely superior to cold-applied bitumen paint, and provided that civil engineering considerations allowed, the coating should extend to the toe of the piles. Experience with completely coated piles drawn at both Kuwait and Aden had shown that surprisingly little coating was removed below ground level. If coating was left off, say, the bottom 10 ft of the piles, there was a wastage of electrical current.

With reference to corrosion above low-water level it was shown on the Mina al-Ahmadi Jetty at Kuwait that appreciable protection had been achieved by cathodic protection to 6 or 7 ft above low-water mark, which had exceeded expectations.[1] In any event, steel structures could be maintained above low-water level by painting, whilst cathodic protection was effective for the submerged parts.

Mr C. W. N. McGowan (Head of Civil Engineering Division, Kuwait Oil Co.) said that he would like to ask a few questions. First with reference to p. 352 which dealt with the type of sea bottom encountered at the site, had the sea bottom been found similar in most respects to the sea bottom revealed at Mina al-Ahmadi in the Persian Gulf during the planning stage of the latter harbour? That sea bottom had already been described in an Institution Paper.[2] Secondly, to what extent had the bottom at Aden been prepared to receive the dumped material in view of the fact that the sea-bed was composed largely of hard shelly material? He would like to know what steps had been taken to prevent any tendency to side-slipping occurring.

On p. 352 it was also stated that it was very unfortunate that at the Port of Aden, including Little Aden, full records of wind had not been kept. It would be of immense value to consultants and port authorities if an invitation, perhaps emanating from the Sea Action Committee of the Institution, could be issued on a world-wide basis, to commence such records immediately for regular future maintenance, and also to collect together complete information on port characteristics, such as changes in the weather conditions throughout the year, rise and fall of tides, periods of heavy seas, marine growth, an analysis of the sea water, the temperature range throughout the year and other data in the form possibly of a global ready-reference manual for consultants and others.

Mr Scott had also referred to the wave height of 10 to 12 ft. That appeared rather greater perhaps than at Mina. There the length of the wave had been measured to be approximately 150 ft; he did not know what the length of the wave was at Aden.

On p. 353 he noticed that the main aim of the consultants had been to cater for the easy and safe handling of giant tankers. That statement had been endorsed by Mr Palmer in his opening remarks. Yet, according to p. 355, the dredged depth had been taken down to no more than 40 ft below chart datum, which he supposed meant 40 ft below low water. He could put the point in the form of a question or as a matter of interest; if taken as a matter for noting, then he would say that at Mina a tanker, the S.S. *Sinclair Petrolore* (which he believed was the largest oil tanker in the world) had called in November 1955 and taken away no less than 51,000 tons of crude oil, and with that load her mean draught had been 40 ft 9 in. She had been to Mina again and taken a second load giving a draught of 40 ft 11 in. So it seemed, therefore, that the Port of Aden would

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[1] C. W. N. McGowan, R. C. Harvey, and J. W. Lowdon, "Oil Loading and Cargo Handling Facilities at Mina al-Ahmadi, Persian Gulf." Proc. Instn Civ. Engrs, Pt II, vol. 1, p. 249 (June 1952).

[2] See p. 252 of reference 1.

not accommodate a tanker of such size. It might be the policy of the oil company concerned; he did not know, and perhaps the Authors could give some enlightenment on the point. At Mina the depth to which the oil pier had been constructed was 50 ft at low water, about 10 ft more than the dredged depth at Aden. The length of the ship to which he had referred was 765 ft and the beam 106 ft. He believed that in Japan two tankers were to be constructed of no less than 84,000 deadweight tons with a length of 815 ft and a beam of 125 ft. (*Queen Elizabeth* and *Queen Mary* had a beam of 118 ft.)

On p. 358 it was stated that the roundhead concrete thickness was 6 ft. What steps had been taken by the consultants to prevent undermining by the sea of that large mass? He noted on p. 359 that the piles had been sand-blasted and coated with three coats of Wailes Dove No. 50. Mr Spencer had remarked that he did not care for the cold-applied coating, but would prefer the hot-applied coating. Hot coal-tar enamel had been used at the Mina pier, but as a result of extended trials with a considerable number of paint coatings, No. 50 had been replaced by another type of coating; at the moment it was chlorinated rubber. Whether the use of that type of paint was going to be continued for all time he did not know. Very shortly there would possibly be another series of extended trials to see whether there were other more suitable coatings now on the market. The first set of trials were commenced in 1951 and completed in 1953, and, of course, since their commencement about 4 or 5 years had elapsed, and the development of coatings in the paint industry today was rapid.

What was the estimated life of the rubber blocks, especially in the severe climatic conditions at Aden? Had the Authors considered the use of retarders in the concrete to prevent the very rapid setting times mentioned in the Paper? Had they felt that in the making of the concrete at Aden it had been preferable to avoid the use of retarders?

Mr J. H. Jellett (Docks Engineer, Southampton Docks, British Transport Commission) supported Professor Baker's suggestion that the subject of berthing impacts should be discussed between the Institution and naval architects. He had himself previously made that suggestion. Lloyd's underwriters should take part in the discussion, because they had a distinct interest, not so much in the case under consideration, where the same authority owned both the dock and a substantial proportion of the ships that berthed in it and where the expense of providing a resilient fendering was more easily justified, but with the ordinary commercial port where ships belonging to other owners sustained the damage and where the reason for anything more than the normal type of protection was not always obvious to those who had to pay for it.

He noticed that it was stated that the fendering was designed to take the normal berthing impacts, and he assumed that the figures in Table 1 were to be regarded as those normal berthing impacts. The problem, however, that the maintenance engineer had to consider was the abnormal berthing impact which always would take place.

How had the breakwater armouring behaved in practice? The maximum size of blocks specified was 11 tons, although an occasional 20-ton block was allowed. In many situations that would be regarded as a very light block for a breakwater armouring.

He had had a transient responsibility for the port of Newhaven, and had found that during the years protection of the breakwater had been carried out by 10-ton blocks. There had been no particular scientific reason for the 10-ton blocks except that was the maximum capacity of the only available crane for loading them on to the vessel used for dumping them. Feeling that those blocks were not performing any useful service, he had had a survey made, and some of the blocks had been found carried as much as 500 ft from the toe of the breakwater, which indicated that the protection they afforded against seas in the English Channel was not very great. He would therefore be interested to know whether any drawdown of the seaward slopes of the breakwater or the rubble mounds had been experienced.

In the Paper reference was made to arrangements to allow a crane to come along the top of the breakwater for maintenance, but he would be interested to know what permanent maintenance organization and plant was available.

Had any consideration been given to examining the welding by ultrasonic methods? At Southampton an all-welded structure had recently been completed which, although nominally designated a shed, had main first-floor beams about 125 ft long and 6 ft deep, all-welded, with one main joint butt-welded at the middle, so that the importance of securing an absolutely flawless weld in those joints particularly needed no emphasis. All those welds had been examined on site with ultrasonic equipment and one or two doubtful ones had been further examined by X-ray. On every occasion ultrasonic equipment was found to be, if anything, a bit pessimistic about the condition of the weld than in fact the weld justified. They had followed the practice, mentioned by the Authors in the Paper, of ensuring that all site welding was downhand, and special manipulators had been made to rotate the girders on the site so that both flange and web joints could be welded in the downhand position. He was sure that explained the very high standard of welding secured throughout the job.

He would like very much to see the more general adoption of a pile-set 48 hours after the pile had been driven. That would undoubtedly lead to considerable economies and the avoidance of unnecessary lengthening of piles which, once they had been given the chance to settle down, were adequate for the loads they were designed to support. One of the Authors would remember a case in which a number of piles which had failed to take their set had been lengthened and then, when the extensions had suitably matured and the pile frames had been brought back, not one of them could be persuaded to start again. So the expensive extensions had then had to be equally expensively cut off!

He wished he could look forward to a greater use of the system of placing contracts—a system in which the contractor could be selected before the design had proceeded very far. There was no doubt that that would lead to considerable economies in construction when the design could be matched to the particular capabilities and layout of the contractors' arrangements. It was not likely to become widespread whilst so many employing authorities in the United Kingdom attached what he could only describe as an odour of sanctity to the lowest tender secured by competitive tendering.

Finally, on p. 355, the turning circle had been given as 1,600 ft. The nominal turning circle in the upper swinging ground at Southampton was 1,400 ft and *Queen Elizabeth* had been turned in it at midnight.

Mr E. Loewy (Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) said that the importance of wave data certainly could not be over-emphasized. He would like to enquire apart from questions about wave height, whether data concerning lengths and direction had been available, or what had been done in the absence of them. In the last resort, would it not have been possible to carry out—if the decisions had been made early enough—some kind of model experiments not merely on the breakwater cross-sections but on the alignment of the breakwater as well? Breakwater cross-section models usually did not take long to make; valuable time was often lost in getting approval for their construction. Much valuable information could be obtained in about 3 months; he thought that, if those decisions could have been made in time, progress of the contract work need not have been held up and further economies might have been possible.

The cross-section of the main breakwater in Plate 1 showed the armour stone increasing in thickness to approximately 20 ft at the portion where there was a kind of beaching of the core. He thought that an excessive thickness for material that was always difficult to get and to place, and believed that model experiments might have shown possible economies there. Perhaps the answer might be that it was desired to place the core purely by tipping and the side slope of the core was consequently its natural slope. Might it not have been cheaper and quicker to flatten that slope and thus reduce the volume of armour stone? Could the Authors state the average density of the stone? Could the Authors also explain whether, in checking the breakwater slopes, they had always been able to carry out surveying from the crane boom whenever they needed to do so? Had there been a fairly constant swell, as might have been the case, it must have been extraordinarily difficult to do even though the crane boom was available. Similarly, how had it been possible to ensure that the 12-in. thickness of blanket really was there as so neatly drawn on the cross-sections? Why had the hexagonal piles been filled with concrete, and had that been to protect them or to increase their load-bearing capacity? It must have been expensive and taken quite a long time.

With regard to construction of steel jetties by the widespread use of welding, had that widespread use been instituted for speed or to obtain structural continuity? He thought that a certain amount of high-strength bolting would have been permissible or even to be encouraged from the point of view of speed.

With regard to the form of contract, he congratulated the Authors and all concerned that they had been able to do the job at less than the revised target value. Would it be possible to find out whether any system of costing had been instituted so that a check was available throughout the course of the work upon the economy of construction? That was a bone of contention whenever such a contract arose. He was given to understand that in manufacturing industry no firm of any standing could hope to proceed with profit unless costing was instituted all the time. The extent to which such systems could be applied to civil engineering always seemed debatable; yet it was just in target contracts of that kind that such systems would have their greatest merit.

*** **Mr W. J. H. Rennie** (Director, Charles Brand & Son, Ltd) observed that the Paper would have been more valuable if methods of construction had been more fully described; he thought that on works of such magnitude and complexity a member of the contractors' staff might have been associated with the Authors in the preparation of the Paper.

The complete absence of cost was very disappointing; whilst it seemed reasonable to spend £1½ million on 6,000,000 cu. yd of reclamation and dredging, it was more difficult to understand the expenditure of a further £6¼ million on the four tanker berths, the rubble mounds, and the breakwater. Would a sub-division of cost for the latter items help to clarify the figures given during the discussion?

The siting of the quarries at the root of the breakwater was very fortunate and no doubt the short haul influenced the adoption of Euclid wagons in construction of the breakwater and rubble mounds. Could the Authors give some further details of the quarrying, such as the type of explosive used, the methods employed for drilling and firing, and the size of the labour force? Their views on the efficiency of the heading blast system of quarrying would also be instructive. At Pulau Ubin, the island in the Johore Straits where Mr Rennie's former firm, Topham, Jones and Railton Ltd, quarried the granite rubble for the Johore Causeway, the more conventional methods of working a face in 20 to 25-ft benchings were adopted—the average monthly output from that quarry amounted to 52,000 tons. That compared fairly closely with the average output of the seven quarries at Aden; 42% gelignite was found to give the best results and the average ratio of stone produced to explosives used was higher than the best obtained on any one of the heading blasts recorded in the Paper.

Mr Rennie could not agree with the Authors' statement on p. 357, that "in the past breakwaters have been constructed largely by tipping all material, including the core, from rock trays". He believed that the most efficient and satisfactory method of placing rubble, and the one more usually favoured, was with floating craft using hopper barges for the underwater work; segregation was then minimized and the natural slopes more readily maintained. Could the Authors provide cross-sections showing the actual profiles of the breakwater and as tipped to show how closely the slopes formed by direct tipping from the Euclid wagons conformed to the theoretical sections? How did the actual quantities agree with the theoretical measurement?

Mr Leslie Turner (Principal, Leslie Turner & Partners, Consulting Engineers)

*** This and the following contribution were submitted in writing upon the closure of the oral discussion.—Sec.

mentioned that in connexion with the design of the welded jetties, he could bear testimony to the hectic speed with which the design had had to be produced and which had gone on for many months.

Owing to the nature of some of the intersections it had been necessary to construct full-size "mock-ups" in the office, to ensure that welders could gain access in order to carry out their work effectively.

During progress of the design the inevitable modifications had had to be made, owing to the availability or otherwise of the various sections. They were accommodated without delaying the work through the close collaboration of all interested parties. In general, the design followed modern standards adapted to suit site conditions, particularly rapid erection on the site. It would have been noted that the steel had come from different sources, some from the United Kingdom and some from the Continent, and it reflected great credit on the organization of the whole team, the consulting engineers, and the contractors, that the steelwork had fitted together smoothly and without trouble. At the same time it was a tribute to the Resident Engineer and his staff for any improvizations and resource on site in order to maintain and even improve on the tight programme for the whole enterprise.

The successful conclusion of the project in advance of schedule was significant proof that British engineering was on its toes and was ready to tackle work under the most onerous conditions of time and place.

The Authors, in reply, were pleased that Professor Baker had referred to the speed of construction, and also to the system used for driving the raking piles from the deck structure of the jetties; they were also glad to receive his commendation of the concrete quality control, since he was an acknowledged expert in that field. The alternative of using tubular piles had indeed been carefully examined during the design stage, but the advantages of the hexagonal piles were twofold; in the first place the hexagonal section provided a better moment of inertia in one direction than the circular section, and secondly, it had been decided that handling and fixing of the temporary bracing would be appreciably simpler with the flat surfaces of the hexagonal piles. Professor Baker was also an acknowledged expert on fendering, and his remarks on that subject were very instructive. The jetties at Aden had been designed to take, without serious overstressing, an ultimate thrust of 1,000 tons at any group of fenders at either end of any one of the four tanker berths, and Professor Baker's calculations for an individual fender confirmed that. Up to the date of the meeting there had been more than 400 berthings in the oil harbour, and apparently only one case of rather minor damage had been recorded. No damage had been caused to any of the ships during that period. The Authors were interested in the figures showing the new design of gravity fender; "Baker type" gravity fenders had been in use for 8 years at the Kuwait oil jetty and had received more than 10,000 berthings; one difficulty experienced at Kuwait had been that the comparatively long travel of the gravity fender required the supporting brackets to project many feet out from the jetty edge, and in a few cases those supporting brackets had been badly damaged. With regard to Professor Baker's question about kinetic energy, the Authors believed that fenders should be designed to take, on occasions, the full kinetic energy of a berthing vessel. They agreed with his comment that there was a variation from 40 to 100% in the absorption of the theoretical blow according to the Table of figures given for the actual energy absorption of the fenders. There were, however, a number of uncertain factors that should be taken into consideration when examining those percentages. The ship had almost certainly been either accelerating or slowing, it had probably been swinging, and a tug had been pushing or pulling on either side; it was scarcely possible to bring all those factors down to a mathematical basis. The Table of results given should therefore be regarded as an indication only of the magnitude of the blow that might be expected. An interesting point was that the maximum possible movement of the fenders was 15 in. and during the whole period of the records the maximum movement recorded was 13 in. That showed that the blow allowed for in the design was certainly of the right order. The tests had now been discontinued, since the amount of work in recording every berthing accurately was considerable.

The fender groups were spaced at 165-ft centres, so if the tanker hit fair and square the point of impact would not be far enough removed from the centre of gravity of the tanker for the blow to be very much reduced.

The Authors thanked Mr Beckett for the valuable results obtained from the hydrographic and borings survey which had been carried out under his supervision. With regard to the alignment of the main breakwater, that had been very carefully studied, and a number of alternative alignments had been drawn out and considered, including an alignment picking up Low Island and Pinnacle Rock. It had been decided, however, that a breakwater on that alignment would have left the turning circle rather too much open to the south-east and the breakwater had therefore been moved farther north and aligned in a north-easterly direction to give better protection from the monsoon. The area of ground between berths Nos 1 and 2 and the breakwater had been reclaimed in order to provide space for road access and jetty buildings and also for the large number of oil pipes leading to those jetties. The general shape of the reclaimed area had been fixed partly by the presence of rock, which limited the outline of the area dredged to — 40, and partly in order to avoid an excessively long pumping distance for the reclaimed material. The Authors agreed with Mr Beckett that the full kinetic energy of a berthing tanker would have to be absorbed by the fenders on occasions, and the usual velocity assumed in berthing calculations was 1 ft/sec. Vessels berthing not truly parallel with the jetty face were catered for by the two fender piles sited at an angle at the outer end of each fender group, and they had received the first impact from tankers on a number of occasions. So far, however, no tanker had come within striking distance of the approach trestle. The steel structure of the jetty would certainly require careful maintenance in the humid atmosphere of Aden and, as suggested by Mr Beckett, the steelwork below low water was dependent on cathodic protection. The steelwork above water level was accessible for normal maintenance and, provided that was properly attended to, the Authors believed that the life of the jetties would be anything from 50 to 100 years.

Mr Watts had well brought into the picture the considerable amount of temporary work which had been necessary to enable construction to start. That important aspect was perhaps not sufficiently brought out in the Paper. There was certainly a great deal more involved in starting work on a bare peninsula, 25 miles from the nearest habitable town or place where plant could be unloaded, in providing the necessary access road through blowing sand, and in arranging accommodation, than there was when starting a similar work in the United Kingdom. The contractors deserved warm praise for their excellent planning and organization.

Mr Scott had pointed out the advantages of the target cost form of contract and there was no doubt that for the Aden job it was the only form of contract which permitted an immediate start with the work. The difficulty was to fix the target price at a figure which would provide a real incentive to the contractor. If the target price was fixed at too low a figure, the contractor might perhaps lose his incentive as the work neared completion. Under normal circumstances the Authors preferred the more usual schedule-of-rates contract, although they agreed that in many cases, particularly for works abroad, the most satisfactory contract was one tailor-made to fit the needs of the employer, the plant, and capabilities of the contractor. The acceptance of the lowest tender did not always, in present-day conditions, provide the most satisfactory results.

The breakwater had perforce been designed without prior model tests; had there been plenty of time to spare, such tests would, no doubt, have been asked for.

Various possible methods of measuring wave heights had been considered, particularly with the object of an early commencement of wave readings. All mechanical methods had been abandoned and the contractor's first job had been to construct a small dolphin just outside the site proposed for the roundhead. On it had been mounted a board with black and white bands 12 in. wide so that in all weathers fairly accurate wave heights could be read with a good pair of field glasses from the adjoining cliff top. The breakwater design had been based on an assumed maximum wave height of 14 ft, which was 2 ft above the maximum storm wave in Tawayih Bay, observed during the storm of July 1951, which had caused appreciable damage to the Admiralty breakwater at Steamer Point on the Aden side of the Bay. The change of slope was at mean low water springs, since that provided a "strong point" at the level where heavy wave action might, on occasions, be expected and also, as pointed out by Mr Scott, reduced the total volume of stone.

No appreciable quantity of rubble had been lost from the core in rough weather. On one or two occasions there had been a shaking-down and flattening-out of the core but on each occasion it had been made good by about half a day's tipping. No appreciable settlement of the core into the sea bottom had been experienced. It had been checked first by the quantities and secondly, by observing the sand levels on either side of the breakwater; had there been appreciable settlement the level of the sand would probably have been raised on either side and that had proved not to be the case. The Authors agreed that the concrete capping had been put on the breakwater very quickly after the tipping had been completed and some settlement was expected. It was for that reason that the concrete had been divided into 16-ft lengths with ½-in. joints between. The most recent report from the site indicated that there had been no uneven settlement, but since no concrete levels had been taken recently, it was possible that the whole breakwater had gone down evenly.

Net quarry excavations had not been measured, since the contractors had made a number of blasts in so many places that an accurate measurement in situ would have been a major operation. The voids in the armour as placed were of course considerable; it was thought that they might be about 50% and those in the core about 40%, though a large proportion of them had been filled later with sand during the process of reclamation.

The output of stone per man per month varied considerably with the output of the quarry, reaching a maximum of 550 tons in the autumn of 1953 when production had been greatest. It had later fallen to 220 tons when output had been less and a larger percentage of big stone had been required.

The quarry faces had varied considerably but the object had been to keep them about 60 ft high. Quarry "C" had been worked on two levels with that object. The quantity of overburden had been negligible. Prior to driving each heading a survey had been made by the contractor to plan the tunnels and position the charges; the plan of the headings had varied considerably, a T-head with two or three chambers being the most common. The section of the tunnel had been the minimum in which the men could work and was about 4 ft 6 in. high by 3 ft 6 in. wide. The hot and humid conditions had not assisted rapid driving and a little more than 6 ft in two shifts had been an average daily advance. The armour stone shown in Fig. 5 (facing p. 354) was some of the 8–11 ton armour for placing round the roundhead and had been stockpiled in view of the difficulty of obtaining all the large blocks at one time. Normally the stone blocks had been unloaded by the Lima 2400 directly into position in the breakwater.

Mr Nobel had raised the important but perhaps rather controversial question of the tolerance to be allowed in a dredging contract. If the rate in the Bill of Quantities was to represent truly the cost of dredging and was therefore to be applicable to either increased or decreased quantities without disadvantage to either party, the amount of tolerance allowed should be sufficient to enable a good dredging contractor to clean up to the minimum depth without dredging appreciably deeper than the tolerance line. The matter was complicated by the question of spillage while dredging the adjoining cut and during the period of contract, but to achieve the desired result the tolerance would vary with the material to be dredged. In the case of loose sand such as had been encountered generally at Aden, the tolerance necessary to achieve the above object had been shown to be greater than that allowed, and in another similar contract it might possibly be increased above the usual 12 in. With regard to Mr Nobel's remarks on echo-sounding, the area had been sounded every month in order to produce the monthly measurement. The echo-sounder had been, on those occasions, working over areas where there was often an appreciable depth of silt which had not yet fully settled, and it was at that stage that variations between different sounders, and more especially between the sounder and the lead, might be expected. It was not considered that there should be any appreciable difference in the readings taken after the silt had had time to settle and in any case the contract under discussion had provided for a check with a lead of specified type, which check had in fact been carried out.

Some valuable information on the cathodic protection system at Aden had been contributed by Mr Spencer (the Consulting Engineer responsible for the design of that part of the work). It was a pity that some deterioration had been recorded in the coating of the piles in the finger jetty, but presumably the additional transformer would prevent further trouble. Hot-applied enamel had been carefully considered, and the only reason it had not been adopted was that the cold could be more quickly applied and the jetty construction time shortened thereby. The Authors agreed that piles should be coated for their full length.

The vital question of the depth of water to be provided for large-size tankers had been ably discussed by Mr McGowan. The dredged depth in the oil harbour at Little Aden had been agreed after careful consideration by the Oil Company. It was perfectly true that about 50 ft of water existed at the large oil jetty of Mina-al-Ahmadi in Kuwait, but the position of the head of that T-head structure had been largely determined by the need to allow sufficient manœuvring space inside the head for tankers to come into the berths on the shoreward side of the long jetty head; that manœuvring space had resulted in the head being sited at a distance out from the shore where the depth of water was 50 ft. Had the Aden jetties been designed for 50 ft at low water, their cost would have been considerably increased, probably by at least 50%, and possibly by 100%, taking the usual rough and ready rule that the cost of a jetty increased in proportion to a figure between the square and the cube of the depth. The sea-bed at Aden was generally of soft material and only a small fraction of the 6,000,000 cu. yd dredged had proved to be too hard for pumping ashore. No attempt had been made, therefore, to prepare the sea bottom before placing the breakwater, since it had been considered that there was no appreciable danger of side-slipping. The 6-ft-thick concrete parapet along the top of the breakwater was well protected by a 5–8-ton layer, as well as by an 8–11-ton layer, of wave-breaker blocks on the outer face of the breakwater. The parapet had been constructed in short lengths to allow for some settlement in case some of the smaller material immediately under the concrete should be washed away.

The life of the rubber blocks used behind the fender piles could only be estimated, for the Authors knew of no case where similar blocks had been in use sufficiently long to require changing. The blocks were protected from the sun and their life would not be less than 10 years and might be considerably longer. The use of retarders in the concrete had been considered but it had been thought preferable to cool the water, and that cooling had achieved the desired result.

The Authors were in full agreement with Mr Jellett's observation that the problem of the abnormal berthing impact was the main concern to the maintenance engineer. A jetty structure, however, had to be designed to stand up to the *heaviest probable* loads, using normal working stresses. In addition, the Authors' practice was to give a reasonable reserve of strength in the main jetty structure to withstand reasonable overloads. It would be prohibitively costly to design a jetty to take the greatest load which could possibly be caused by a giant tanker coming bow foremost against the jetty at a speed of several knots; that would have to be treated as an accident. The whole problem of the design of fendering to protect structures against damage from ships, and also to prevent excessive damage to the ships, could with advantage be discussed between civil engineers and naval architects, and the Authors hoped that Mr Jellett would take the lead in fathering a joint Paper to the Maritime Division of the Institution. The wave-breaker blocks in the main breakwater had been designed in a somewhat similar manner to the jetties, namely to withstand forces rather larger than the maximum forces normally expected; as already stated they had been designed for 14-ft waves. No doubt 10-ton blocks would not be sufficient protection against a strong south-westerly storm in the English Channel, as Mr Jellett had found in the case of Newhaven.

With regard to the future maintenance of the breakwater, one of the Manitowac cranes used on the erection of the refinery had been retained for that purpose, together with Euclid wagons for transporting the blocks. A small stock of stone had been left at the quarry, sufficient to deal with any minor settlement, and the quarries could easily be re-opened should larger quantities be required. On the inside of the slab on top of the breakwater the filling had been brought up to the same level, so as to provide a roadway for the crane and Euclid wagons.

The alternative of ultrasonic testing for the welding had been considered and the Authors agreed with Mr Jellett that ultrasonic tests would probably detect smaller flaws than those observed with gamma ray. The great advantage of the gamma, or X-ray, was the permanent record of the weld; the inspectors on the site saw the photographs and after that they were available in the office for all to see; the moral effect of that was considerable.

With regard to contract procedure, if a job of that size had to be designed and built in 2 years, the contractor should be given the word "go" at the same time as the design was started. An advantage of the more normal procedure, where the design was completed first, was that different contractors could use their experience and ingenuity to propose different methods of carrying out the work, and that often led to a substantial economy in the cost of construction.

Mr Loewy had commented on the design of the main breakwater, in particular the thickness of the layers of armouring stone, and also on the use of model tests. In the case of the Aden breakwater, the overriding criterion had been speed of construction and the core had therefore been brought up to a greater height than usual and tipped from Euclids, and the steep side-slope of the core had therefore fixed the inner edge of the armouring. The outer face of the armouring had been built above water to the steepest slope considered safe and that slope, as had already been pointed out, had been steepened below low water level. It was therefore very doubtful whether model tests could have led to any economies; in any case there had been no time to carry out any model tests. There had been no data at the site regarding size and direction of waves, but from a study of such storm-wind data as existed for that part of the world it had been concluded that the worst storms occurred in the south-west monsoon; one such storm was known to have produced waves estimated at 10–12 ft in height. It would certainly be helpful to engineers responsible for the design of harbours if records could be kept in all ports of the world, as suggested by Mr McGowan, of such important data as wave heights.

Mr Loewy had asked about the average relative density of the stone; it was 2·57.

Mr Loewy had also mentioned the importance of costing, but the difficulty in a civil engineering contract was to produce the results in time for any effective action to be taken. In the case of Aden, the Oil Company had placed considerable reliance on the good-sized team of engineers and inspectors, provided by the Consulting Engineers, to ensure that the work was economically carried out. It had been possible to carry out surveys of the breakwater from the crane boom more or less as required. A heavy lead had been used and no great trouble had been experienced from the normal swell.

With regard to the blanket of stone on the inside of the rubble mounds and breakwater, the procedure used had been to check the core slope before placing the blanket seal, for the inside slope of the core varied somewhat in plan, being over-thickness in places due to rapid tipping; in addition there were the turning places. The first layer of the seal had then contained extra material, owing to the irregularities in the core to be filled up before coming out to the angle of repose. The second layer had been very closely to the specified thickness. The hexagonal piles had been filled with concrete to protect them; once the operation had been organized it had not taken a great deal of time, forty-six jetty-head piles in berth No. 2 had been hearted in 2 days. The welding of the steel jetties had provided structural continuity; it had been quick; and had resulted in a smooth and clean surface for sand-blasting and painting.

Mr Rennie had asked about the efficacy of the heading blast system of quarrying; it had been found to be the best system to provide the quantities of large wave-breaker stones required and, except for the latter stages of the work all the small stone had also been needed. With regard to the method of construction of the breakwater, the Authors agreed that many breakwaters had been constructed by dumping from barges, although there were several months each year when that would have been a very difficult operation at Aden. The point the Authors had intended to make was that the introduction of tipping from Euclids introduced the disadvantage of some segregation. The breakwater section as built followed closely the theoretical section on the seaward side. On the inside, turning places and a certain amount of over-tipping for other reasons, had resulted in the quantity of core material being in excess of that in the Bill of Quantities. Although seven quarries were mentioned at Aden they had not all been operating at the same time. Various explosives had been tried in the early stages of the work but open cast gelignite had proved to be very satisfactory and had been mainly used in the later stages. The Paper unfortunately could not be extended in length to include a contribution from the contractors on their construction methods. The total cost of the project appeared high, but it should be remembered that present-day costs were probably three times their pre-war figure, and that the Aden contract had been carried out at considerable speed, demanding more plant and more staff than usual.

The Authors thanked Mr Turner for his interesting contribution and also for the considerable help given by his team of designers in working out the details of the welded joints; the full-size models of the various joints had been extremely useful.

The closing date for Correspondence on the foregoing Paper was 15 May, 1956. No contribution received later than that date will be published in the Proceedings. —SEC.