Extension of Ballard Pier, Bombay

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Mr Bertlin

The Ballard Pier extension was constructed at the same time as the Bombay Dock expansion scheme, which was started in 1964 and finished around 1970.

58. Possibly the most interesting part of the Paper is that concerned with the design and construction of the quay. Although there are certain standard approaches to the design of quays, the optimum solution for a given set of conditions may not be easy to find. Horizontal loading differs considerably from one quay to another, and with the introduction of containers vertical loading has considerably increased in the last few years. Quay heights also vary greatly, not only to accommodate different vessel sizes but also to take account of tidal ranges. Other factors affecting the design are the condition and level of the sea bed and the exposure of the berth, but the most important one is undoubtedly the soil properties, both of the foundations and of the back-up material. The question as to whether the quay is to be constructed under water or in the dry has to be decided and the use of monoliths, caissons, cofferdams, cylinders, sheet piles and suspended deck construction must all be considered.

59. The design described in the Paper, which involves a method of construction which has not been frequently used, might be developed with advantage for other locations besides Bombay. The idea of a buttress wall with arches from buttress to buttress has seldom been adopted in recent quay design, which is surprising in view of its many advantages: a block work wall or a mass concrete quay built in a cofferdam would have entailed much more concrete and in consequence would have been considerably more expensive. The method adopted requires little heavy plant, an important point when the length of quay is limited and its cost cannot be spread over a long length of wall.

60. The customs hall roof was originally designed to be of self-supporting aluminium curved segments which would have made a very economical form of construction. Unfortunately, the Indian aluminium companies refused to roll curved segments, and conventional trusses had to be substituted.

61. The Architects for the central concourse and customs sheds were Mathew Ryan and Partners. Their names should be added to the Acknowledgements in the Paper.

Mr D. Jones, Chief Engineer, British Transport Docks Board

The Paper makes little reference to the additional trade needed to justify the extension of Ballard Pier, and perhaps the Authors can give some information on this point. In particular I should like to know whether the revenue from such additional trade was regarded as being sufficient to support the investment, or whether there is an element of subsidy in the investment in the facilities of the Port of Bombay.

63. I was very interested in comparing the design of the dock walls with that in the extension of the Alexandra Dock (now Indira Dock), described in earlier papers.^{1,2}

One of those walls, a substantial gravity wall, was also built in the dry behind a cofferdam, and was built of in situ concrete. The east wall of the Ballard Pier extension is built of precast concrete units, and was built in the wet. What interested me was that the Indira Dock wall buttresses were anchored with stressed cables to the bedrock, with consequent saving in mass. It is not clear to me from the Paper what circumstances prevented a similar advantage being obtained in the Ballard Pier design. Was there no advantage in saving some mass in the precast concrete sections of the Ballard Pier extension by this means, or was there some reason for not using the same design?

64. Another factor that interested me was a reference to the benefit gained because the wall buttresses helped to dissipate wave energy during the monsoon period. There is some mention in the Paper that the outer gates of the lock to which the Ballard Pier forms a lead-in wall sometimes suffered from buffeting by waves. On the other hand, with vessels berthed at Ballard Pier and its extension that advantage would not be quite so pronounced. It seems that a hydraulic model of Bombay Port was available. Was the effect of wave reduction due to the presence of buttresses tested on a model, and was the difference in effect with ships berthed there compared on the model? Finally, has the problem of waves buffeting on the outer gates been made worse or is it no problem at all?

65. The passenger concourse and baggage halls provide an elegant and substantial building. It is a pity that the original intention of building the roof of aluminium barrel vaults on prestressed beams could not be carried out. The reason for the adoption of a reinforced concrete frame to support a steel roof is given as the saving in plant which might otherwise have been necessary for handling a different form of structure. I would have thought that for the baggage hall a steel portal form of construction might have been more economical, notwithstanding the problem of the viewing gallery.

Mr F. L. Terrett, Lewis and Duvivier

It would perhaps add to the interest and value of the Paper if the Authors would expand a little on the hydraulic model studies. What was the aim of these studies and what was learned from them?

67. I will, however, confine my comments mainly to the east wall. Anyone who is concerned with the design and construction of works in the sea will agree that the main weakness in any such structure is the joints. It is here that the deterioration begins, and the detailing of the joints therefore merits the greatest attention. A feature of this wall is that it was constructed of very large units so that there were few joints, which is a particularly good point. I should like to know more about how in fact the joints were made.

68. On the section there is a note which states that the gaps between the units were sealed with sausage joints. I should like to ask how these sausages were placed. Was this by some sort of caulking operation by divers after the units had been placed, or were they incorporated in the actual placing of the units? Were the horizontal joints in the units merely dry joints, or were there spacers or shear keys, so that in tremieing the concrete through the holes in the units grout would seal the joints between one and the next?

69. Probably the most important of the joints in this structure is the vertical joint between the buttresses and the arch units which carries the thrust from the ground pressure. Fig. 4 shows a vertical cavity which I presume again was filled with tremied concrete. If that was so, I should be interested to know how the slots at the front of the joint were sealed.

70. Over the last few years I have been concerned with the construction of a breakwater using very large precast concrete units, and the joints between one unit and the next have proved very troublesome. Admittedly the situation is much more exposed than the Ballard Quay, and the units, which are essentially arched in the same way as the arches at the back of this wall, are designed to transmit transient wave loading through the joints rather than ground pressure.

Fig. 13. Precast concrete breakwater caissons showing method of jointing

71. Figure 13 shows the design of the joint in question. Following very rough weather, some of the planks on the seaward side of the joint were broken and washed out, and some poor concrete was found at the back of them. It was necessary to drill down through the joint, insert a plastic tube and fill it with grout under pressure. At the same time the joint at the seaward edge was modified and widened so that it was possible to get a second tremied pipe down.

72. I should like to know how the bottom unit of the buttress of the east wall was in fact founded. Looking at the section in Fig. 4 there is some concrete at the front and back. Were shutters used, and in situ concrete placed between them as a foundation for the bottom unit?

73. The Paper mentions that the foundations of the terminal building were of conventional design, using 400 mm square reinforced concrete piles. I presume that these piles were driven after the fill had been placed. I wonder whether any problems were experienced in driving them through such a thick layer of granular material, which appears to be about 15 m from top to bottom. Some of the piles at the back of the quay appear to have been driven through the rubble backing, and I should like to know how that was achieved. There is also a reference in the Paper to pile tests, and it is mentioned that two settled excessively under load. What was done with those particular piles?

74. Finally, it would be useful to know the length of time the job took to construct, and the final cost.

Mr R. L. Triggs, Edmund Nuttall Ltd

The part that interested me particularly is the same as that which interested Mr Terrett, the east wall. There are not many gravity walls built these days. This one is of a particularly sophisticated design and I think a very happy one. It suits ideally the physical circumstances, though it is admittedly very kind of God to have arranged the bedrock at precisely the right level.

76. I am a constructor rather than a designer, but I am concerned with the recesses formed by the arches. I take the point that these are useful in absorbing the energy of the waves running perpendicular to the wall towards the lock, but I wonder how a wall such as this stands up to waves coming in from the east? I have seen a box with an opening on the exposed side, admittedly in the Bristol Channel, which had its top blown

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off by the waves. Evidently Bristol Channel wave heights are not encountered here, but it is a restriction on this particular design.

77. As I understand it, it was the Engineer's intention to build up the buttresses from 15 ton blocks. The Contractors, I take it, made the decision to change, I suppose for the purpose of saving money? I am a little surprised as it has always seemed to me that the concept of building up units from small blocks is a most economical one. There were derricks already there for another purpose, and the alternative of handling 180 t blocks of concrete required the building of several pieces of special plant.

78. Turning to Fig. 4, I assume that the line at the bottom of the wall is of in situ concrete placed under water to form the foundation for the buttress. Was this levelled by divers, or was some more sophisticated method used?

79. When it came to handling the arches at the back of the construction, how were these placed: were they put in by crane, or floated in? They look awkward to float. On the left hand side of Fig. 4 a jacking point correction is mentioned. Were these units simply lowered on to a prepared concrete bed, or was there any requirement to level them to bring them perpendicular.

80. Finally, I should like to know the rate of advance which was achieved. The method of construction used seems to be an economical one, but not very fast. How long was needed to achieve the construction of a 12 m 'bay'?

Mr R. B. Hill, Cementation Ltd

Quays are normally built to support vertical and horizontal loads, but there is very little indication in the Paper of what forces this structure is intended to withstand.

82. Normally the horizontal forces involved are those of a ship berthing, those it will exert on the quay when it is berthed, and lastly the force of waves. I am not familiar with this part of Bombay, but it appears to be a fairly open situation: monsoons have been mentioned and waves, from which I gather it is not a particularly sheltered location. A great deal of thought was probably given by the Authors to the problems of ship berthing, safe moorings and to properly operating the ships while they were at the berth. Ships of 30 000 t are sizeable from an inertia point of view, and I would have thought that matters such as berthing velocity were quite important. There are no details on the energy absorbing characteristics of the quay fendering system. I understand from master mariners that there are two types of quay: those that absorb energy, which are easy to get alongside, and those that do not, which should be avoided like the plague because of the damage they do to ships. It seems to me possible that the Authors here have designed one of the latter sort. I would like to know whether that is so.

83. It does seem to me that the problems of berthing are a characteristic of this type of open quay. Are there any currents? What are the wave forces, and what is the direction of tidal or stream flow? What sort of tidal characteristics are there, if any? What problems were foreseen and did they in fact eventuate in operation while berthing ships of the size described in a variety of circumstances of wind and wave? I should be grateful if the Authors could enlarge on their approach to these problems and the experience gained from operations since construction.

Mr M. L. Wolfe-Barry, Lewis and Duvivier

I should like to know what loads the fenders are designed to withstand. I notice that the face on which the fenders are fixed is slightly curved, rather more so than that in the Indra Dock extension. I should like to know precisely the reason for the curvature. Was it for fixing the rubber fenders more securely? Has there been any damage caused to the fenders by chafing against the chains that secure them?

85. In the reference to the terminal building mention is made of shear connectors between the main beams and the columns to withstand earthquake forces. Could the Authors give details of these?

Mr K. N. Archibald, Peter Fraenkel and Partners

I should like to know if the cost of specialist equipment was spread over the whole dock development.

87. I was rather confused about the time at which the work was carried out. The Paper seemed to indicate that the work was completed at a date later than the rest of the dock expansion. If this work had been undertaken as a separate contract, possibly by local contractors, would the same form of construction have been adopted?

88. With regard to sheet piles it is stated in many papers, including the Author's excellent report to the National Ports Council, that sheet piles in the past have deteriorated rapidly in Bombay; but with the recent advances in better quality steels, was detailed consideration given to the use of sheet piles either in the dock expansion scheme or the extension to the Ballard Pier?

Mr E. L. Barron, Peter Fraenkel and Partners

The Authors state that the actual cost was naturally greater than the contract price. Since the World Bank was involved one would expect tenders to have been obtained basically under the FIDIC conditions of contract, but what terms were stipulated or agreed regarding escalation, and what were the major claims for additional payment?

90. In particular, did the failure under test of two piles driven in an area which had been disturbed during construction of the previous pier involve additional payment because the contractor had relied upon the borehole information referred to in § 11, assuming this was made available to tenderers?

91. Did the credit given for the foreign exchange component affect the design, either by increasing or (as might be inferred from § 37) limiting the amount of imported material?

92. In the paper by Lindsay *et al.* on berths at Hong Kong,³ the effect of the import credit arrangements materially affected the quay structure design, or in that case two different designs in the same location, and in marked contrast to the Ballard Pier extension the conditions of contract did not include a fluctuation clause, nor even provision for extension of time owing to typhoons.

Mr Bertlin

Mr Jones raised the question of the economic justification of the Ballard Pier extension. This development, which was carried out at the same time as the dock expansion scheme, was originally intended to provide a berth for liners and cruising vessels. It was, however, recognized in the planning stage that the future of large passenger ships was doubtful and, for this reason, the customs sheds were designed to allow them to be used as cargo transit sheds, if so required. In the event it has been found that the layout and shed and concourse details have provided ample flexibility, and the quay is used for a wide variety of vessels, including cruising and pilgrim ships and general cargo and grain carriers.

94. The justification for the development is that some 30–40 vessels were always to be seen in the harbour waiting for a berth and it was obvious that it was essential to increase the number of berths in the port. This fact was recognized for many years before the development was implemented and many alternative plans were drawn up and discarded before the one finally chosen was approved. It was also accepted that this development was but a beginning and should be considered as an interim measure pending the preparation of a long term master plan, which would embrace detailed economic justification for any developments recommended. This master plan, which was prepared during the implementation of the interim scheme, not only fully justified the development already undertaken (showing a return on capital of over 20%) but also a major new port on the east side of the harbour.

95. On the question of ground anchors, the Indira Dock wall was constructed in the dry and the foundations and construction were continuously subject to very close

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inspection. In the case of the Ballard Pier extension, involving a deeper wall and construction in the wet, it was felt that there was some risk of corrosion of the anchorages, if such had been used.

96. Model experiments were undertaken to measure the extent to which the buttresses would be of help in dissipating wave energy at the lock gate entrance to Indira Dock, and the effect of a resonance chamber was also investigated.

97. A reinforced concrete frame was chosen for the terminal building in order to economize in steel and because it would need less maintenance.

98. Mr Terrett raised the question of hydraulic model studies. The only use made of such studies of direct relevance to the Ballard Pier extension was in connection with the effect of the buttresses on the wave conditions at the outer lock gates of the Indira Dock as mentioned above.

99. Mr Terrett also raised the question of joints. I strongly recommend the 'sausage joint', as it is extremely effective and simple to use. Such a joint is illustrated in Fig. 14. A canvas hose is pushed into a slot formed between the blocks. Under water the operation can easily be done by a diver, and such a joint can be made not only watertight but airtight. It was first used at Tranmere⁴ in World War I and has been extensively used since, e.g. in the Dover train ferry dock construction. In World War II, when steel was in very short supply it was used to seal the joints in a diaphragm made of precast elements which was used in a shaft sunk under compressed air, where it was found to make a perfectly airtight joint.

100. The foundations for the bottom buttress units were formed of concrete contained within a bagged concrete wall. The concrete surface was screeded to level by divers. The foundation piles were precast concrete piles: there was no problem in driving these through the reclamation, which did not contain any boulders.

101. The cost of the work as tendered in 1964 was as given in Table 1. The actual cost of construction of the east quay wall (1968) amounted to £711,700, of which 84% (£601 000) was for quay wall and decking, 8% (£57 700) for the rubble bank, 5% (£34 600) for excavation, and 3% (£18 400) for bollards, crane tracks, etc. The cost per metre run of quay amounted to £2150 (1968 prices).

102. Mr Triggs queries the ability of the wall to stand up to waves coming from the east, that is, normal to the line of the wall. In Bombay such waves are never great and were of no concern, bearing in mind the heavy superstructure. In cases where considerable waves are to be anticipated it might be a wise precaution to vent the chambers.

103. The wall was originally designed with 15 ton blocks, so that a 15 ton derrick could place them. I am in agreement with Mr Triggs that such a method would have been more economical than using bigger units. However, the Contractor wished to build the wall in the way it was, in fact, built and as the end result is no less satisfactory,

Table 1

	Rps	£
Dredging	3 304 200	247 815
Deep water quay		
East wall	10 096 979	757 273
South wall	2 813 880	211 041
Reclamation	3 655 381	274 154
Terminal building		
Pile foundations	1 538 974	115 423
Superstructure	10 621 570	796 618
Signal Tower	390 122	29 259
Roads and drains	1 290 873	96 815
Total	Rps 33 711 979	£2 538 398

Fig. 14. Typical sausage joint

his proposals (with some modifications) were approved. The normal rate of progress was one 12 m bay in about 3 weeks, but this was largely dependent on foundation preparation rather than rate of buttress construction.

104. **Mr Hills** would like to know the design loading. The horizontal loading for which the quay is designed is 4.4 t/m^2 with in addition a 10 t mobile crane operating anywhere. The quay is designed to absorb the energy of a 30 000 ton ship berthing at 300 mm/s. The original intention was to use one layer of tubular rubber fenders but the Indian factories could not extrude the size required, and so two layers, an outer one of 450 mm dia. cylindrical tubes and an inner of 300 mm square section were used. The maximum current at the berth is normally about 1.5 knots, but in monsoon conditions may be as high as 2–2.5 knots. The mean spring tide range is 3.7 m but the difference in level between the highest and lowest recorded tides is 5.8 m: 10% of waves are higher than 0.9 m. There have been no difficulties in berthing vessels alongside and the good absorbent qualities of the fendering, as compared with the old Ballard Pier, are much appreciated.

105. **Mr Wolfe-Barry** also raises questions about the fenders and damage caused to them. There were some initial difficulties, due to the cylindrical fenders sliding down the chains. This was overcome by placing a stopper in a bottom link. There has been no trouble from chafing of chains, but a catamaran with sharp metal corners caused considerable scoring of some fenders until the pontoon was repaired and fendered.

106. In answer to **Mr Archibald**, the work described in the Paper and the dock expansion scheme were both carried out as a single contract, but the Ballard Pier extension was the last part of the contract to be completed. The timing and choice of contractor did not influence the design. An attempt was made, however, to decrease the foreign exchange component, for example, by using reinforced concrete in place of structural steel in the terminal building.

107. As **Mr Archibald** mentions, sheet piles have deteriorated rapidly in Bombay in the past and, even with the better quality steel and methods of protection now available, it was not considered advisable to use these when good alternatives at no great extra cost could be used.

108. **Mr Barron** raises some contractual matters. The contract conditions were the standard FIDIC conditions with a number of special provisions. Increases in wages, as compared with wages at time of tendering, were reimbursed. Any increases had to have the approval of the employer. Similarly, increases in cost of materials were also reimbursed.

Mr J. G. Berry

In reply to **Mr Wolfe-Barry's** question on earthquake forces, according to the building codes, Bombay is not in an earthquake area. However, shortly before construction had started an earthquake occurred and buildings were damaged in Bombay. The designs

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were checked, using a factor of $\frac{1}{10}g$, and some modifications were made to enable the buildings to withstand the horizontal forces involved. The increase in cost was quite small.

References

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