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8492 DISCUSSION

Design and construction of the Northfleet Hope container terminal, Tilbury Docks

F. A. PAGE, R. C. CURTIS & H. G. J. MILLS

Mr Page, Mr Curtis and Mr Mills

Regarding the test on the sheet piling, some additional information may be of interest. The loads in four of the tie rods were monitored: two of these rods were instrumented at both quay and anchorage ends and two at the quay ends only. Figs 21 and 22 show that the loads in the quay ends were quite low initially at only 100–200 kN and it was not until the final placing of the 2 m of Thanet sand compacted in 30 cm layers, that the loads increased to 400–500 kN, about two thirds of the 700 kN design load. From Fig. 22 it appears that initially the anchorage loads were dissipated in friction along the rod without any load being transmitted to the anchorage, the rods being under temporary compression at this end.

81. A Stothert & Pitt 6 t vibrating roller (developing 96 t impact load) was used to compact the sand and this clearly helped to generate more realistic earth pressures transmitting loads of up to 40 t to the anchorages. If the design had been of the form in which the sheeting was driven entirely through existing soil with the face dredged after completion it is possible that the anchorage loads would have remained low, suggesting an unnaturally high factor of safety.

82. Nine piezometer tubes were also installed to monitor movement of groundwater level. Only one of these continued to function throughout the construction period and this happened to be nearest to the instrumented sheet piles. A typical result is given in Fig. 23. This shows groundwater level following the rising tide very closely, which may not be entirely accurate, and could have been distorted by the presence of the piezometer tube itself. With the falling tide, groundwater level is held just below mid-tide and this is probably a true indication of the situation at this section. The design was based on groundwater being at mid-tide level and to that extent appears to be slightly conservative.

Mr J. N. Black, PLA, Tilbury Docks

There were several reasons for choosing a site on the riverside rather than within the dock. The third-generation container ships were just beginning to be built, and we felt it would be advantageous to have a facility which obviated the need for them to go through the lock: the time-saving was important, as most of the large ships using Tilbury have to use the tide for the depth of water. Another reason was

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that the arrangement gave us an opportunity to take fourth or fifth generation ships if these were ever built.

84. Credit is due to our predecessors who built the lock in 1929 that the lock (which is of Pananax size) is large enough to take about 95% of the world's liner and container shipping of today.

85. One of the restrictions of the riverside site was the soft foreshore alluvium. Another was the fact that the 39 berth container operations had to continue during the construction period for the new facility. The price had to be fixed before the contract started, and the time of the contract had also to be fixed. Timing was important, because the facility was being built to handle the second phase of the New Zealand containerization, with lamb and fruit seasonal markets having to be met.

86. Settlement is now about 50–75 mm/year. That I think is successful and

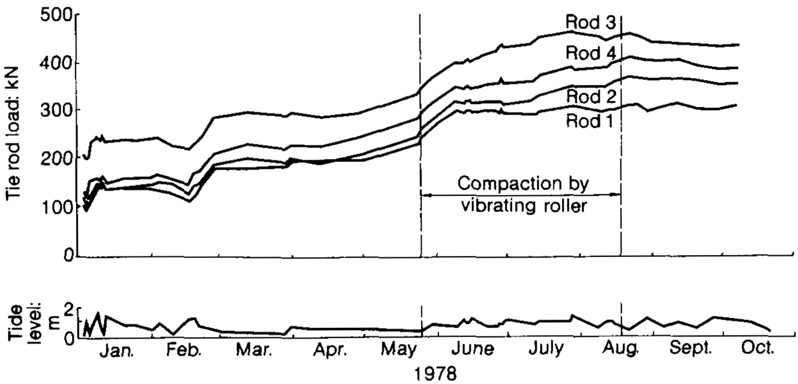


Fig. 21. Tie-rod loads at quay end

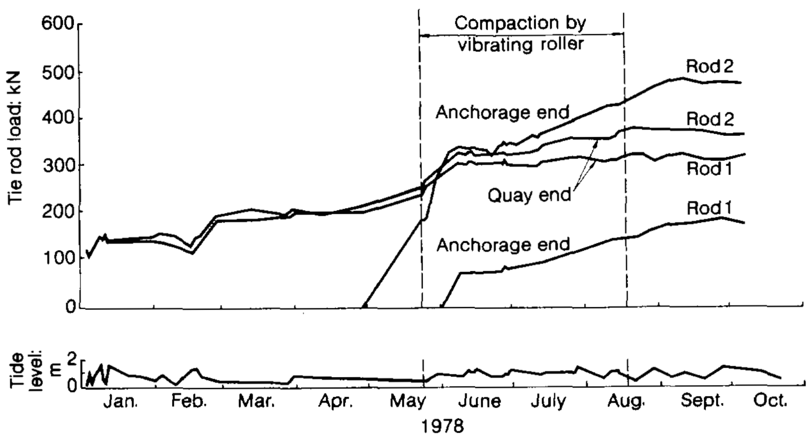


Fig. 22. Tie-rod loads at quay and anchorage ends

confirms the Engineer's ideas that surcharging the soft clay alluvium before paving the terminal would remove most of the settlement before the cargo-handling operations began.

87. As the engineering area was an uncertain one, it would have been difficult to fix a price without taking a very large risk; but the design work showed that if everything went reasonably well, we should be able to do the job within the estimated contract period and, what is more, within the price. That client was not prepared to accept a final measurement, so we agreed a base price, together with a method of indexing, and borrowed money on a phased basis to take advantage of any changes in the interest burden. We agreed that payments would be made on an annuity basis, and although we took a fair risk it worked out well. The price came out just about right, and the time for the contract was within a week of the $2\frac{1}{2}$ years we had expected.

88. The performance since the terminal has been completed has been tremendous. The terminal is now handling containers at a rate of about 200000 a year, and that represents about $2\frac{1}{2}$–3 million tonnes of cargo. The Royal Docks in their heyday handled about the same amount of cargo in conventional form through 46 ship berths in a 1000 acre estate, whereas Northfleet Hope is a facility of 64 acres and two berths. The comparison indicates the changes in technology, and indicates some of the problems that port authorities have had to face recently. This project shows that it is possible to build in difficult areas: it is possible to build in an area with a 7 m tidal range and work large container ships efficiently and well, and I hope this will be a prelude to further development on Tilbury riverside.

Mr D. E. Glyn-Woods, John Mowlem & Co. Ltd

My interest is that I was the company's agent on site for the construction of this project.

90. The contractor had recognized from the outset that a major problem would be managing industrial relations. Located as it was in the heart of dockland, the project would employ operatives who were related to or who would have social contact with dockers, whose working conditions and wage structure differed from

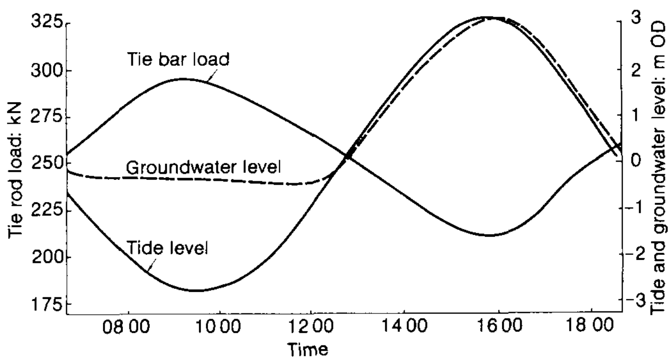


Fig. 23. Variation of groundwater level and tie-rod load with tide level: tie rod 3, quay end, 27 February 1978

those in use in our industry. Also the Thames Barrier is being built upstream, and we found that rumours from there reached the site faster than the tide could carry them. This project had its share of unrest, with some 5 months of industrial action, including several periods of 'inaction'. There was no solution to this problem, but an accommodation was reached which enabled the project to proceed to completion on time.

91. The Authors mention (§ 44) that the contractor used alternative precast concrete units to form the deck beams. High water level being near to soffit level was one reason for this proposal. A more significant factor was that by precasting units off-site the amount of over-water work was considerably reduced, with a resulting reduction in the number of operatives on site. Discussions with the PLA design engineers resulted in units utilizing the outer 150 mm of the Engineer's profile to form permanent formwork incorporating only the in situ reinforcement. These units were then loaded out as 20 t lifts, including all reinforcement for each panel.

92. I would suggest that the in situ concrete, continuously post-stressed waling connecting the tie rods to the Unissen piled retaining wall was a potential Achilles heel of the project. The rate of completion of this waling, in which one panel had to be cast, cured and stressed before the next could commence, determined the progress of the following work above and off-shore of it. Being near low water level it could only be constructed in the 2–3 h tide window, which in the winter occurred in the early morning and late evening. The slope of the filling behind the Unissen piles at this stage formed a silt trap. At each low tide silt had to be cleared before any useful work could be tackled. Placing formwork, tie rods, Macalloy bars and concrete, curing, and subsequent stressing occupied many tides, and was carried out in inhospitable conditions. The contractor recognized the criticality of this operation and spared no effort to ensure that it did not jeopardize the progress of the project. We would suggest that on future similar projects serious consideration be given to using twin universal steel beams off-shore of the retaining wall as a waling. Their use would avoid the silt trap, and (as they would not be continuously stressed together) would not be a protracted, critical, in-line operation. Protection of the tie-bar threads is a problem that all good contractors are used to solving.

93. It is to the credit of the co-operative working relationship of the PLA and contractor's site staff that this project was brought to completion on time, without any major claims, despite the many problems encountered *en route*.

Mrs M. P. Kendrick, Hydraulics Research Station

At the conference on hydraulic modelling held at this Institution in October 1981, Professor Yalin described ways in which vertically exaggerated models failed to reproduce natural conditions. He did not, however, have enough time to describe how, in spite of these disadvantages, they provided a useful tool for studying certain types of flow problem.

95. The hydraulic studies for the Northfleet Hope container berth project were carried out on an existing model which had not been designed specifically for the job, having originally been constructed for studies of the Thames Barrier. It had a horizontal scale of 1 : 600, a vertical scale of 1 : 60, and hence a slope exaggeration of 10. It was about 115 m long and extended from the tidal limit at Teddington to Southend.

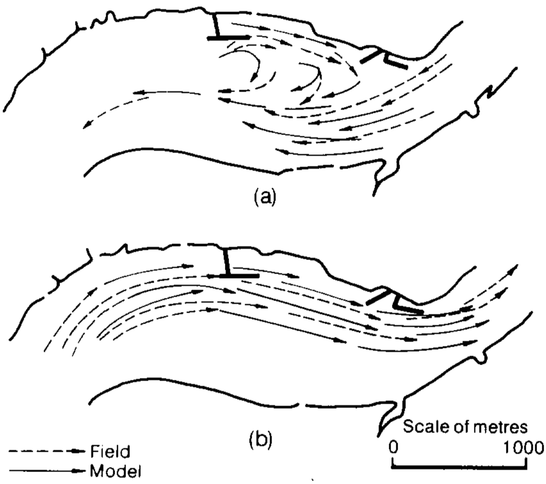


Fig. 24. Current direction: (a) flood; (b) ebb

96. It was appreciated that experimentation on the 1 : 600 model would be limited by its scales. Furthermore, it was well understood that flow conditions in Northfleet Hope are among the most complex of any to be found in the Thames estuary since they are governed by the constriction at Tilburyness at the seaward end of the reach and the tortuosity of the channel both there and round Broadness. During the early stages of the flood tide, flow along Northfleet Hope is up-river throughout the reach, but as the tide develops it becomes more and more concentrated towards the south bank, breaking away from the north bank after the bend at Tilburyness. A zone of separation is formed from the north bank to mid-river extending from Tilbury Dock to the grain terminal. A large eddy is thus created which encompasses the site of the container terminal, and flow along the northern perimeter of this eddy is seaward for the remainder of the flood tide.

97. With these considerations in mind, detailed comparisons of the strength and direction of flow in the field and the model had to be carried out before any model testing could begin.

98. Figure 24 compares field and model float-tracking results obtained at mid-flood and mid-ebb at the site of the container berth. The complex flow referred to is evident in the upper diagram which shows an eddy in the vicinity of the berth.

99. Figure 25 compares field and model current velocities measured at mid-depth at four stations—two downstream and two upstream of the area of flow circulation. These model results were extracted from measurements made to confirm that flow conditions into and out of the reach were satisfactorily reproduced on both flood and ebb. They are especially interesting in that they compare more than usually well with the field measurements in spite of the fact that the model was vertically exaggerated.

100. The tests on the project as originally proposed by the Port of London Authority produced three main findings. The first was that reclamation for the

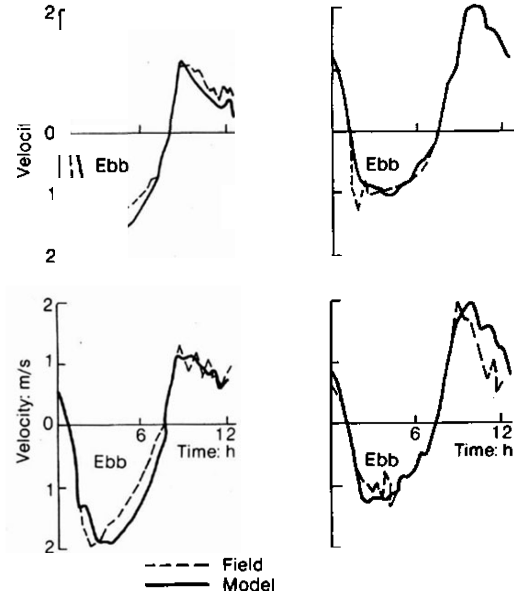
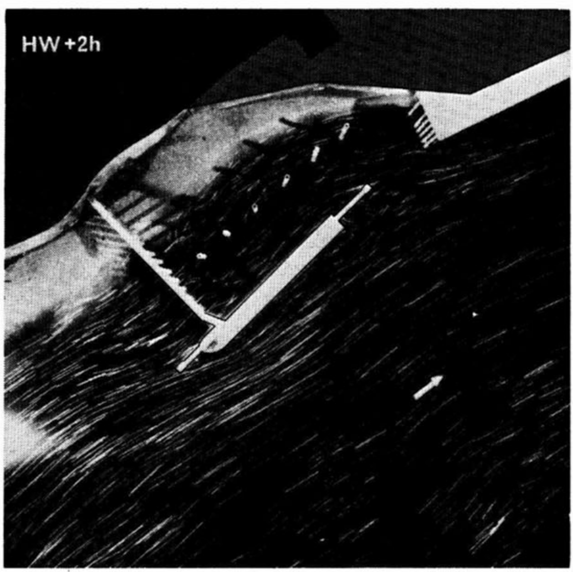


Fig. 25. Current velocity

Fig. 26. Tilbury Dock entrance

(a)



(b)

Fig. 27. Tilbury grain terminal: (a) without bull-nose; (b) with bull-nose

container berth altered the path of tidal currents on the north side of the river and as a result berth realignment was necessary to avoid high mooring forces on vessels. Secondly, the provision of adequate back-up facilities required that the reclamation should extend as far into the river as possible. This deflected the main flow further away from the bellmouth at the entrance to Tilbury Dock and so produced conditions more conducive to sediment deposition than before. The situation on the ebb tide is demonstrated in Fig. 26, which shows the formation of an eddy in the entrance to Tilbury Dock at two hours after high water.

101. The third finding was that the flow separation which has always occurred at the downstream end of the grain terminal on the ebb, due to its misalignment with tidal flow, affected conditions at the up-river end of the container terminal when the latter was extended as proposed for the second stage of development. Mooring conditions for container ships would therefore not be very satisfactory. However, further model tests have shown that improvements could be obtained by the construction of an asymmetric cutwater, or bull-nose, at the up-river end of the grain terminal. This is demonstrated by the two photographs in Fig. 27, showing conditions along the face of the grain terminal and up-river end of the container berth before and after the addition of the bull-nose.

102. This project provides a clear example of how a general purpose model of an estuary, at a cost which is low compared with that of designing and specially building a natural-scale model, can indicate the pitfalls that need to be avoided before civil engineering works are implemented. The continuing and close exchange between the Port of London Authority and the Hydraulics Research Station during the course of the studies enabled the best possible compromise to be reached so that the requirements for the container terminal could be met without prejudicing other river activities.

Mr R. E. West, Robert West and Partners

The location of a new container berth outside the enclosed dock at Tilbury was a new policy for the PLA which exposed them to the risk of altering the siltation regime of the river. It is clear that the Authors considered siltation carefully. It would be interesting to know if there have been any subsequent changes in siltation in the river, which may have been influenced by the development.

104. Another aspect of siltation concerns the impounding station for the docks which used to have inlets positioned out in the river. At the time they were built, a great deal of thought was given to positioning them, so that they took water at the top of the tide to minimize the intake of silt into the dock. These inlets have now been incorporated in the new works and conditions around them must have changed significantly. I would be interested to learn if there have been any changes in the amount of silt drawn into the dock when the impounding pumps are operating.

105. The Authors state (§ 29) that for the design of the quay, the proportions adopted for the width of the open pile structure and the resulting height of the rear sheet pile wall represented the most economical combination. I am not sure about that, because I produced an alternative design for Costain, who were one of the tenderers. For that we started the 1 : 3 slope of the gravel where it is now in the front of the berth and took it very much further back so that the wall at the rear was a very light structure. I wonder how the Authors view this design in retrospect.

106. It is always rather difficult in papers for justice to be done to the costs of

developments, which is a pity because they usually absolutely dominate planning and design. Could the Authors say how the pricing worked out in the course of the job? Were there any claims, perhaps initiated by several contractors working together in close proximity?

107. During the 1960s the development works within the Port of London were in the forefront of the nation's investment and a powerful and competent engineering team was assembled to carry out the works. It must be presumed that it was considered that this was a cheaper and better way of applying engineering expertise than the alternative available of retaining outside consulting engineers. Now, those days are past. The PLA are seeking to make economies and, in consequence, their own engineering department has shrunk and they look to consulting engineers for assistance. This appears to be a direct reversal of the often expressed justification for in-house engineering—that it is cheaper—and I would be interested in the Authors' views on this.

Mr I. S. S. Greeves, Mowlem Civil Engineering (retired)

I was disappointed that the opportunity has not been taken of recording valuable information on the SPT values in the chalk at Tilbury. This was included in Fig. 76 of the site investigation report. It would help if a copy of this could be included in the reply.

109. A large amount of work was done by the Wimpey organization in coordinating the expected bearing capacity of the various grades of chalk. During the tender period much discussion took place as to whether it would be possible to drive the 762 mm dia. tubular piles with shoes some 6 m into the chalk. It was known that open-ended piles could be driven satisfactorily, as this had already been done at the grain terminal nearby.

110. As it turned out open-ended piles would have been more costly as they penetrated some 3 m more than predicted. It was decided to drive most of the piles with shoes on into the zone 2 chalk with an SPT of 55, the set being achieved some $7\frac{1}{2}$ m below the surface of the chalk. However, one or two of the trial open-ended piles ended up in the grade I chalk, with an SPT value of 70.

111. To achieve the necessary penetration it was anticipated that a Delmag D44 pile hammer would be necessary. The weight of pile and hammer together would be 18 t. This meant 20 t or 25 t derricks being required to handle the load.

112. Having settled on heavy capacity derricks for pile-pitching it was possible to develop a scheme using large precast concrete shuttering for all the suspended deck work. One reason for this choice was the cost of providing temporary works and staging to erect the shuttering for permanent works.

113. The use of precast concrete units meant that the piles had to be positioned accurately. This was achieved by the use of a gantry with rocket leaders, enabling six piles to be pitched to very close tolerances at one setting.

114. In using a gantry it is important to pitch piles of sufficient length to achieve their set without having to return to lengthen and re-drive piles partially driven. In general this was achieved.

Mr J. G. Berry, Bertlin and Partners

Bertlin and Partners have carried out an analysis of the shape of ships' hulls for various types of vessel in order to obtain a better understanding of the contact between ships and fenders. One aspect is the flare of a ship in relation to different berthing angles. Can the Authors indicate what is a safe berthing angle for this particular berth? We find that any berthing angle over 10° is likely to be unsafe. We have also found that a quarter point berthing, which is very commonly assumed, corresponds for a vast range of vessels to about 8–10°.

116. Figure 28 shows a 6° berthing for a container ship, a little smaller than the one at Tilbury. For this particular ship, where the minimum horizontal radius is at the bow, at a particular draught one can get some fendering problems. (Bollards have not been taken into account.) Fig. 29 shows the same container ship berthing at an excessive angle of 14°, which corresponds to 1 in 4. At this angle the point of contact is nearer the bow and the flare of the hull makes damage inevitable.

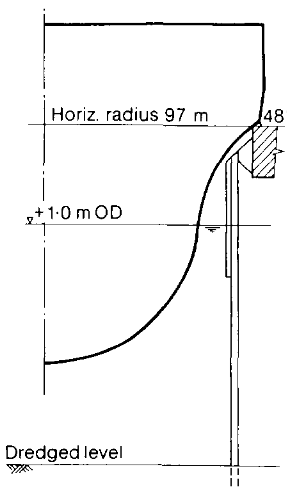


Fig. 28. Container ship berthing at 6°: section $7\frac{1}{2}$

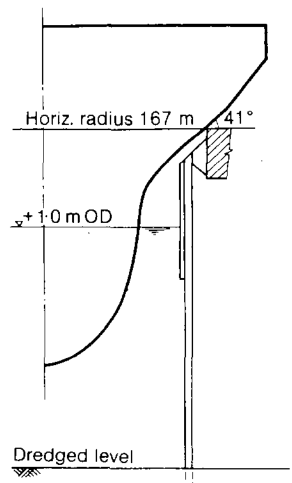


Fig. 29. Container ship berthing at 14°: section $8\frac{1}{2}$

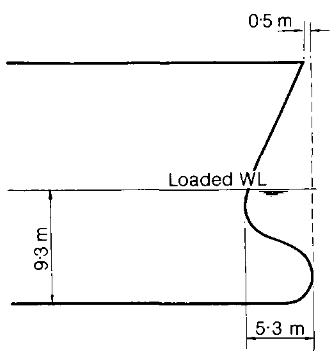


Fig. 30. Bulbous bow: second generation container ship, 197 m length between perpendiculars by 28 m beam moulded

117. The question of flare will obviously affect the berth, so I would ask the Authors whether any observations have been made. Do ships stand off the berth parallel, and are they then pushed in by tugs so that they remain more or less parallel to the berth?

118. Figure 30 shows the bow profile of quite a large second-generation container ship. We found that when the berthing angle exceeded 7°, the bulbous bow hit the quay wall. I do not know whether the Tokyo Bay class ships have bulbous bows, but I wonder whether the Authors could comment on this point.

Mr D. Jones, British Transport Docks Board

I think the simplicity of the design is very commendable. One has been aware of the problems of monolith construction in Tilbury and the use of expensive precast concrete slabs for surfacing areas overlying soft alluvium and subject to consolidation. This has been avoided in this work.

120. Can the Authors say if the statutory powers for construction of works of this kind were already held and, if so, where they were obtained, and whether it is possible to know how many future berths can be built under the same powers.

121. Does the berth have a dredged pocket to allow an unladen ship to remain afloat at the berth at low tide? If so, there is always the possibility that it will silt up. If it does, is the burden of removing that silt placed on the port authority, or does the client share some of the risks of future siltation?

122. Presumably the draught of the vessels which will be served by this berth is approaching the maximum that the river can provide for. Is there a long history of stability in the ruling depths downstream? Has there been a time when dredging was greater than it is now? Is there a dredging cycle of some kind?

123. Is the natural channel of the river close to the berth large enough for the container ships to swing, or was it necessary to dredge a swinging area?

Mr J. D. Mettam, Bertlin and Partners

It looks as if the 'mini' rail terminal is rather an awkward feature in the site (Fig. 5), and might be more a nuisance than help with such a large throughput of containers. I wonder whether you have any information on the extent to which it is actually used, and whether the space might have been better used by not having it there.

125. The centre piles under the jetty (Fig. 6) are raking piles which must provide a measure of resistance to berthing and mooring forces and to lateral movements of the wall. I presume, however, that the main forces from a heavy berthing are taken through the deck on to the steel sheet piling and into the soil fill behind the quay, and that the tie rod also takes the mooring forces. I wonder what problems the Authors had in analysing the combined action of those two ways of taking horizontal forces. I suspect that stiffnesses are quite different; and we have generally found when looking at forces needed to mobilize soil pressure that there is considerable uncertainty as to what actual movement is involved before one gets the horizontal resistance.

Mr J. R. O'Donnell, PLA, Tilbury Docks

I wish to speak on some of the hydraulic considerations covered by §§ 6–14 of the Paper.

127. Table 2 shows that the material dredged from the Tilbury bellmouth in 1977 was about 20·700 m^3 (25·5%) greater than the three-year annual average up to 1976, and this can be essentially attributed to the Northfleet Hope Container Terminal works. The subsequent increase in the three-yearly annual average from 83 670 m^3 to 121 250 m^3 (45%) is attributable to the Northfleet Hope Container Terminal works and the increasing number of deeper-draught vessels using the lock.

128. Table 3 gives figures for dredging at the grain terminal, which is immediately upstream of the Northfleet Hope berth. The dry winter of 1975–76 and the continuing drought up to November 1976 do not appear to have affected dredging requirements at the grain terminal. If adjustments are made for the abnormal dredging quantities in 1973, 1977 and 1978, the annual average dredging requirement at the grain terminal has increased from approximately 21 000 m^3 in 1975 to approximately 25 000 m^3 at present, but as the figures in the fifth column of this

Table 2. Dredging in Tilbury bellmouth

Year	Average daily fresh water flow,* million gallons per day	Annual dredge, m^3	3 year average annual dredge, m^3	Number of vessels drawing 10·5 m or more
1972	—	70 304	—	—
1973	—	62 713	—	—
1974	—	92 363	75 127	—
1975	1337	89 570	81 549	13
1976	420	60 088	80 674	18
1977	1714	101 357	83 670	15
1978	1296	120 869	94 105	22
1979	1634	128 829	117 034	24
1980	1230	114 000	121 250	26

* Measured at Teddington Weir.

Table 3. Dredging at Tilbury grain terminal

Year	Average daily fresh water flow, million gallons per day	Annual dredge, m^3	3 year average annual dredge, m^3	Number of vessels drawing 11·3 m or more
1971	—	17 284	—	—
1972	—	15 139	—	—
1973	—	9 673	14 032	—
1974	—	20 632	15 148	—
1975	1337	20 784	17 060	11
1976	420	23 101	21 505	20
1977	1714	16 435	20 107	21
1978	1296	37 209	25 582	23
1979	1634	22 167	25 270	12
1980	1230	27 000	28 792	21

table show, this increase can be essentially attributed to the increased number of deep-draught grain ships (11·3 m or more) now using this facility.

129. The evidence of both tabulations supports the conclusions of the hydraulic model testing that there would be no significant changes in the regime of the river in the Northfleet Hope and adjacent reaches and that the only increase in accretion would be in the Tilbury bellmouth.

130. Alignment of the new berth to stream flow as predicted by the modelling has also been proven in practice, as apart from one minor incident in June 1980, there have been no difficulties in berthing and unberthing the high profile container ships that use this facility, even though 110 vessels moored there in 1980 and an even greater number are anticipated in 1981.

Mr R. W. Postlethwaite, Peter Fraenkel & Partners

With regard to the reclamation, and problems in handling gravel contamined with clay, the Authors suggest that a solution might have been to use a different type of plant such as a suction dredger. I wonder whether they would care to comment further on that.

132. On the question of piling, I should appreciate clarification on the numbers of piles driven open-ended and closed-ended. At the Tilbury Lock lead-in jetty immediately downstream of the berth, we found that we had to drive occasional piles open-ended in order to get sufficient tensile bearing load capacity in those piles. Probably the Authors did not have the same problems in requiring the tensile strength.

Mr M. J. Stone, Zanen Dredging & Contracting Co. Ltd.

A brief résumé of the facts relating to the dredging and reclamation is as follows:

(*a*) tender documents issued 23 March 1976
(*b*) tender date 22 April 1976
(*c*) various meetings 12 May and 22 May
(*d*) award 28 May 1976
(*e*) commence 1 June 1976, with 4 weeks to mobilize all necessary plant and equipment.

134. During the pre-tender period much consideration was given to the dredging plant that could conform with the stated work method and provide the most economical solution. Following my experience of the 1966–68 reclamation at Tilbury and Zanen's experience in carrying out the Maplin trial embankment in 1973–74, pumping the material using a cutter suction dredger was rejected. In the two instances where cutter suction dredgers had used 'normal' cast steel sand pumps, they 'holed out' after only 60 000–70 000 m^3; and a normal pipeline with a wall thickness of about 6 mm lasted for only about 300 000 m^3, and 16–20 mm doubler plates on bends and elbows were replaced weekly. With the Ni-hard pumps available in the mid 1970s about 500 000–600 000 m^3 could be pumped before holing-out occurred, but with the same wear factor applied to the pipeline about three complete pipelines of 1500 m each would have been used. The main wear problem was caused by the triangulated flint gravel deposits of Northfleet Hope and the Lower Hope areas. In addition, it was possible that a second winning area at Divers Shoal could be used if an adequate supply of material could

not be found immediately adjacent to the reclamation site.

135. Following several estimates it was decided that a bucket dredger and two small barges following a carefully planned dumping schedule could provide a viable and economic solution, the material dumped from these barges being excavated and rehandled by two large draglines and two bulldozers to achieve the stipulated levels and gradings. The barge dumping schedule called for a very close adherence to time, place and tide. Therefore, two shift superintendents were employed to board and position each barge exactly to programme.

136. During tender evaluation we were asked to explain our method in detail to the PLA and they accepted it. Also, if the secondary winning area was to be used, this plant merely required two additional barges to be mobilized to maintain the requisite output, and by not having a floating pipeline less traffic hazard would be created by using a bucket dredger.

137. The cleaning of the clay-dredged area was completed expeditiously and without problems, despite its being close to the dock impounding pump intakes. Dredging and gravel winning started after some 2 weeks and proceeded well, dumping taking place around the clock. In the third week of gravel winning the dredger picked up a large anchor and in attempting to clear the obstruction buckled or bent the main ladder by some 10°. In situ repairs were considered, but rejected because of the time required: the whole ladder was cut into three sections, lifted out of the dredger and shipped to Holland. Its total weight was 80 t. Zanen Verstoep's shipyard in Holland worked around the clock, and the repaired ladder was shipped, returned and installed with the dredger working again within 3 weeks.

138. Shortly after, the material in the specified winning area deteriorated, being contaminated by silts and clays that made rehandling at first difficult and subsequently impossible. The dredger was frequently relocated to obtain cleaner material and a close record was taken and maintained so as to minimize any dispute over time lost and to accurately record additional costs. The difficulties were overcome and the contract was completed on 21 January 1977, 5 days ahead of schedule (including the extra time allowed by the Engineer).

139. Considerable discussion took place over the 'contaminated' gravel, the problem being that the clay and silt particles retained water, causing the gravel to 'flow' like wet concrete. The bulldozers (Caterpillar D8s) were at times becoming completely stuck and at times working with the tracks totally immersed in gravel, with the material flowing around the edges of the blade. The fill slopes would not stand at the necessary angles to enable the barges to dump within the effective radius of the draglines. By frequent site meetings at all levels of management, the situation was brought under control, a local alternative source of material was identified and a revised working method agreed. If both parties had retreated behind their respective contractual 'walls' and only maintained a strictly contractual stance, a considerable overrun of time and a substantial claim could have ensued.

140. When we started dredging, the thought of a bucket dredger using a six-anchor mooring spread was so repugnant to the river pilots that they insisted that we removed the dredger to a 'safe' position at least 1 h before a large ship entered Gravesend Reach or left the grain terminal. By frequent use of the radio, and with the support of the various officers involved, this had reduced to 5–10 min of the ship's actual arrival or departure by the completion of the works. This is a demonstration of practical and professional men working closely together.

Mr Page, Mr Curtis and Mr Mills

We are aware of **Mr Glyn-Woods'** views on the waling design, but this received a great deal of consideration before being adopted and we were not prepared to revise the design without good reason. There were pre-tender discussions with the six or seven firms who were invited to tender as we wanted to inform them of our intention to restrict the number tendering in order to get competitive prices. In this we were successful as all bar one were within a range of 10%. Drawings were provided and construction methods discussed. We particularly drew their attention to the waling design as we were anxious to get their reactions. They all gave the impression that this would give them no problem, and that they would be pleased to tender for the work as designed. Mowlems subsequently offered a saving of about £10 000 if we were prepared to accept an alternative standard waling design using twin channel sections. This was not acceptable: the post-stressed waling is particularly strong; it gives considerable additional strength to the wall causing it to act as a deep beam, ensuring a good spread of applied loads. This was particularly useful as alternate piles were bearing in different strata for the reasons given in the Paper. A standard steel waling has none of these advantages. While accepting that there were considerable problems, if we were doing the job again we would still wish to incorporate a similar detail. There was also the problem with channel sections that they have thin webs with comparatively short lives. This particular jetty design has quite a long life, and the fact that we do not have a corrosion problem with the waling, is in itself an advantage.

142. With regard to **Mrs Kendrick's** contribution, she and her colleagues deserve congratulation. We are not in a position to say whether all of their recommendations were in fact correct because we left the Port Authority before it was possible to fully assess the hydraulic situation, but we understand that the advice which they tendered was broadly correct. Parallel flow along the face of the quay was very important and this was undoubtedly achieved. After the dredging and reclamation was completed a series of float tests carried out by the PLA Hydrographic Department showed good straight parallel flow. No adjustments in quay alignment were considered necessary.

143. We were also advised that the berth itself would be self-cleansing, and this has so far proved to be the case. It was an important point, because any future maintenance dredging would have been an important factor in the operational cost of the berth.

144. In reply to **Mr West**, the design of the impounding station intakes was dealt with in detail by Smeardon *et al.*[3] The intakes had been carefully designed to minimize the intake of silt and it was important that this was not prejudiced by the new works. The HRS advised that the situation should not be seriously affected. We are not aware of the actual situation but as the impounding demand is now much reduced the PLA will have some latitude in combating any effects: the pumping period could be reduced and it could also be moved in relation to the tidal cycle.

145. The alternative design referred to by Mr West did receive consideration but was not adopted as there were a number of factors which ultimately made it uneconomic. Continuing the slope of the quay embankment into the tidal zone would have necessitated its armouring. The alternative design utilized large diameter piles with thinner walls which could not have withstood the hard driving. Also doubling the width of the suspended quay would have required a substantially

heavier design for the slab behind the crane as this would have had to carry containers stacked in a random fashion rather than in longitudinal pattern only. The alternative design eliminated the need to rehandle the reclamation material and this would not have been available for surcharging the alluvium—an essential feature of the overall design.

146. With regard to the cost of the works quoted in the Paper, actual costs have been given for all items except the quay construction. With the exception of the latter, all contracts were firm price and the final cost and its related date are given. The contract for the quay works was Baxter-indexed and cannot be related to a fixed currency value; however, while there were some substantial additional costs due to the delays incurred to the dredging and reclamation work, these were contained within the contingency sum included in the tender figure quoted and this is a fair indication of the final cost of the quay works.

147. Following the suggestion made by **Mr Greeves,** the SPT values for the chalk are given in Table 4. All values were obtained from the Wimpey Laboratories geotechnical report.

148. The penetration of the piles into the chalk is mentioned in the Paper. The question of open-ended versus shoed piles was something we were not entirely clear on when the contract was placed. Rates had been obtained for both types, and it was found that open-ended piles drove on about 5 m further than shoed piles. As the cost of the shoe was equivalent to the cost of 3 m of pile, shoes were generally adopted.

149. The contactor's precasting system was in fact very successful. The standard of finish was very good. There was considerable discussion with regard to problems of shear between the casing and the core concrete, particularly as the main beam steel was incorporated in the casing; however, all these problems were resolved, and the system was a great success. The accuracy with which the system required the piles to be driven was somewhat greater than that called for in the specification, and to that extent the contractor had to be rather more careful than he might have needed to be with a different form of construction.

150. In reply to **Mr Berry,** the fenders were arranged to suit an angle of approach of approximately 8°. Experience on this particular quay has shown it is not the bulbous bow that is the problem but the flare of the ship bow. It is standard practice to ensure that the quay cranes are placed at the opposite end of the quay to that at which the ship is going to berth to prevent any possible damage if the bow oversails the cope. The distance from the fender face to the crane legs is 3·3 m; this was fixed in consultation with the client following their experience with other terminals elsewhere in the world.

Table 4. SPT values in chalk strata

Penetration into chalk, m	SPT values			Number of observations
	Min.	Max.	Mean	
0–3	6	33	22	13
3–6	21	67	47	13
6–9	29	104	65	12
9–12	42	124	80	12
12–15	37	101	66	11

151. With the 6 m tidal range it is quite easy for a mooring line to come down and get trapped between the fender and the ship's side. The thickness of the timbers was in fact shaved off at the top to allow the ropes to drop down without getting jammed.

152. With regard to **Mr Jones'** question, the berth dredging was governed by the need to win as much filling material as possible in the vicinity of the berth. The whole of the gravel stratum between the new quay and the edge of the navigation channel was dredged clean to the chalk and by good fortune this provided ample depth for the berthing and swinging of ships at all states of the tide. There was no need to dredge chalk to achieve the required depths and consequently there are no pockets to accumulate silt.

153. It was expected that the berth would be self-cleansing due to the scouring effect of the 2–3 knot ebb tide and this has proved to be the case. No berth maintenance dredging has been required to date.

154. A ship's passage is governed by the depth over the Diver Shoal which is downstream and this requires the largest ships to arrive and depart near to high water. The navigation channel below the Diver Shoal is generally stable and only minimal dredging is needed to maintain the depths required. The shoal itself, however, is not stable: it can both accrete and scour. Considerable maintenance dredging can become necessary, although the pattern is irregular and appears to be related to fresh water flow from the upper reaches. This was the subject of a detailed investigation by the HRS and the mechanism which regulates the behaviour of this shoal is now largely understood.

155. The HRS had warned that the development could cause some increase in siltation in the lock bellmouth. This was expected to be marginal and the risk was accepted. **Mr O'Donnell's** tabulation appears to confirm this but an accurate comparison is difficult. Due to deeper-draught vessels using the docks, the bellmouth bottom had to be maintained at a greater depth shortly after the project was completed, and it is not possible to separate these two effects.

156. Losses due to scour and general disturbance by the dredger also caused additional siltation while the works were in progress but this was not excessive. Loss of material due to tidal scour appeared to be less than expected and this was borne out when dredging and fill volumes were checked.

157. In answer to **Mr Mettam's** query, road traffic enters the berth at the gatehouse north of the office block and proceeds to the transfer area south of 39 berth building. From there the containers are carried by straddle carriers which fan out from the stacking areas into the berth; there is therefore no cross-flow between the office and the workshop. The rail terminal needs to be so located that straddle carriers can enter it at the end, and with the arrangement adopted it is linked to the container park in this way. It also makes full use of an area which might otherwise have been under-utilized.

158. Horizontal forces applied to the quay are rapidly dispersed through the deck slab which acts as a massive horizontal beam. Impact forces were fed into the computer program but they had little effect on design of the deck as this was required to be of substantial construction to carry containers stacked three high. Lateral forces are finally carried into the soil by the Unissen sheet piles but the stresses induced by these are quite small. The rake to the centre piles is mainly to separate the toes and spread the load on the founding strata.

159. **Mr Postlethwaite** suggests that different dredging plant such as a cutter suction dredger could have been used and this could well have been the case. Most

of the other tenders were in fact based on plant of this kind but that using the bucket dredger was substantially cheaper. Although the contamination with clay did not seriously affect the suitability of the dredged gravel for general filling, it had the effect of lubricating it, causing it to flow round the blades of the bulldozers and making it impossible to handle in this way. As a result alternative sources of clean gravel on the opposite side of the navigation channel had to be used.

160. If the gravel had been placed hydraulically by a suction dredger, the dirty gravel could have been handled without difficulty and could have been used for general filling, the cleaner gravel being retained for the exposed embankment. Operations would, however, have been limited to the north side of the navigation channel—we would not have had the option of obtaining the material on the south side.

161. As previously mentioned, most of the tubular piles had shoes. In no case were these piles required to take substantial tensile forces which might have called for a deeper penetration. Open-ended piles were, however, driven alongside the impounding station culvert to reduce disturbance and in these cases the penetration was much greater, possibly due to local softening of the chalk adjacent to the cofferdam in which the culverts were constructed.

162. **Mr Stone** mentions the damage which totally incapacitated the dredger and we wish to confirm the speed and efficiency with which Zanen Dredging effected the repairs. Thanks to this, and to the rescheduling of the piling works by the civil contractor, the delay to the quay works was minimized.

163. The six-point mooring required by the dredger was viewed with some apprehension initially and substantial delays were expected due to river traffic interrupting dredging operations, particularly in the area adjacent to the entrance lock. The rapidity with which the dredger responded to traffic requirements induced confidence, and with good will on both sides traffic delays were made as small as possible.

Reference

3. SMEARDON R. F. G. *et al.* Engineering works at Tilbury Docks 1963–67. *Proc. Instn Civ. Engrs*, 1967, **38**, Oct., 177–228.