Paper No. 6407

# The design and construction of the Queen Elizabeth Graving Dock at Falmouth†

by

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*Discussion*

**Mr G. M. Cornfield** (Civil Engineer, The British Steel Piling Co., Ltd) referred to the double-wall cofferdam. The stability of such a cofferdam against lateral distortion depended mainly on the total shear resistance of the filling material, and that depended on four factors: (*a*) the width of the cofferdam (it was obvious that increasing the width would increase the stability); (*b*) the angle of internal friction of the filling (the filling would be of a granular nature—sand, gravel, or broken rock. Clay or silt was not really suitable for the purpose); (*c*) the average height of the undrained filling (the stability increased as this height decreased, so the drainage of the filling was important and was usually achieved by providing weep-holes at a low level on the inner line of piling); (*d*) the unit weight of filling in both the dry and the submerged condition (the stability of the dam decreased with a decrease in the unit weight).

88. Had weep-holes been provided at Falmouth to drain the filling? If not, had there been sufficient leakage through the interlocks of the piling, which would have produced the same effect?

89. The possibility of constructing such a cofferdam had been under consideration at an early stage in the project. Mr Cornfield understood that it had then been hoped to use as filling a type of beach material which was available very close to the site. It had grains of irregular and unusual shape, and he believed it had been derived from shells. Unfortunately, it had been found to have a dry density little more than half that of ordinary sand, and a small dry sample in the loose condition had a density of only 62 lb/cu. ft, which meant that in order to achieve the necessary lateral stability the cofferdam would have to be about 50 ft wide. It had therefore been decided to obtain a filling of normal weight, so that a dam of the more usual width of only 30 ft would be satisfactory. Had the Authors a record of the unit weight of the ballast actually used at Falmouth?

90. It had not been clear to him why the rock excavated on site had not been used as cofferdam filling instead of bringing the ballast a distance of about 10 miles.

91. On the question of stability, had the Authors observed any horizontal movement of the top of the cofferdam, particularly under high-tide conditions and before the introduction of the raking struts? Had there been any significant bulging or deflexion of the piling between tie-rod and rock level?

92. Mr Cornfield noted that it had been possible to drive sheet-piles into the rock to a penetration of more than 4 ft, even though the rock appeared to have a strength of the same order as that of mass concrete, according to the bearing pressures mentioned in

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† Proc. Instn civ. Engrs, vol. 15, p. 49 (Jan. 1960).

the Paper. The piles used at Falmouth had been rolled from mild steel, but more recently it had been possible to obtain sheet-piles made of medium- and high-tensile steels and their higher strengths enabled relatively greater penetration to be obtained when it was necessary to drive into rocks such as sandstone, limestone, and shale, provided a hammer of adequate size was used. The Authors had stated that a 9B3 hammer was used at Falmouth, which seemed to be light for the conditions there; had a satisfactory rate of driving been obtained and had the heads of the piles been badly damaged?

93. Three other double-wall cofferdams had been described in recent years, one at Greenwell Dock[1], one at Smith's Dock on the Tyne[2], and the third at Gallions Lock[3], though in the last two cases substantial soil berms had been added to the dams to improve stability. Other types of cofferdam could be used in place of the double wall. Examples were the single-skin arch dam, also used at Smith's Dock, and the soil embankment type with a single line of piling down the centre, used at Eastham Dock[4]. At Gallions there had been a second cofferdam consisting of large concrete blocks placed under water.

94. Why had the Authors chosen the double-wall type? Had cost been the main consideration or had there been other reasons?

**Mr E. D. Neilson** (London Manager, Sir William Arrol & Co. Ltd) was interested in the pumping station, with its air-conditioning plant. Since the station was below water level, was the air-conditioning plant able to cope with the humidity generally associated with such levels?

96. The Authors had estimated (§ 59) that the use of siphons would save 25 h.p. in the rating of each pump motor. Mr Nielson had gained the impression that that was associated with the provision of a straight-through valve instead of a siphon; would the Authors enlarge on this?

97. Further information about the bilge blocks and the method of operating them would be useful.

98. Another point in which he was interested was the dressing of the masonry sill. At Falmouth the precast sill blocks had been dressed down to an accuracy of 0·002 in. Presumably, that referred to the individual blocks. Was the finished face of those blocks granolithic, and what was the mix used?

**Mr J. T. Williams** (Divisional Engineer, Port of London Authority) referred to the fact that the dock had been constructed by direct labour. In a debate[5] at the Institution some years ago it had been decided that the contract system was to be preferred to the carrying out of new works by direct labour, but the Paper had described a very interesting example of the use of direct labour and was probably the exception which proved the rule. The advantages of the direct labour system in the present case seemed to have been fully exploited by the Authors, especially so far as the time of construction was concerned, and at least they had successfully concealed any difficulties which they might have had in planning and executing the work.

100. It seemed to have been a wise decision to make the dock as wide as the site would permit, and since the floor was not primarily a structural member it had presumably not involved very great extra expense to do so. The dimensions of the dock would enable it to take most of the large ships afloat, and so far as width was concerned it seemed to be well in front of modern development; damaged vessels could draw as much as 42 ft of water, and, since Falmouth was a repair yard very close to busy shipping routes, had a greater depth than 36 ft been considered? The Admiralty might be interested in that.

101. What was the height of the centre keel blocks? Would the Authors give some details of their construction?

102. It was stated in § 7 that several sites had been considered, though that chosen

[1] References 1–6 are given on pp. 118.

seemed to be a fairly obvious one. It would be interesting to know more about the other sites and why they had been rejected.

103. In a repair yard such as that at Falmouth there might be something to be said for subdividing a large dock. Apparently only ships of 50,000 tons had used it so far, but possibly consideration might have been given even to a double-ended dock, which had been suggested as a way of giving the maximum degree of flexibility and ensuring continuous occupation from an economic point of view.

104. Regarding the Box gate, the plan in Fig. 2a showed very clearly by comparison the advantage obtained over the mitre type of gate in that the available dry-docking length for the same length of entrance wall was increased by about 30 ft. How did the cost of the gate used compare with that of other forms of gate?

105. The Authors mentioned in § 29 that the load was distributed between the upper beam and the sill by vertical bulkheads. Presumably this had led to a reasonably economic design, though the weight of steelwork seemed roughly equal to that involved in a pair of all-welded mitre gates. An economic design for such a very wide entrance might be obtained by using short subsidiary shoring-strut gates.

106. Could the Authors give more information about the type of steel which had been specified for the meeting-faces? The elimination of timber on the gate should ensure that it would rarely be necessary to remove it for maintenance. What were the plate thicknesses employed in the skin and had any special treatment been given to the plates to extend the period between repainting and to take full advantage of the use of the permanent materials?

107. The operating time for the gate was given as 6 min. Since Mr Williams was concerned mostly with lock entrance gates at very busy places, that seemed a very long time, because any additional time taken in the operation of the gates could cause a reduction in the number of vessels handled by a lock. In the case of mitre gates, the time taken was usually about 90 sec. With a gate of the type used by the Authors, would it be possible economically to speed up the operation?

108. Referring again to the plan of the dock, the vertical meeting-faces for the gate appeared to be completely unprotected from the possibility of a blow from a vessel entering the dock. Would it not have been worth while to extend the entrance wall by a few feet to provide some kind of fendering to guard against an accident of that character?

**Mr W. H. Arch** (Construction Manager, Sir William Arrol & Co. Ltd) was chiefly concerned with the gate and its ancillaries. His firm had manufactured the gate, together with all its control equipment and winch, and also the equilibrium valve. It was pleasant to read the Authors' comment that "on completion the gate was floated without difficulty into position on one tide" and Mr Arch took that as a compliment to the staff involved in the planning which was behind that seemingly simple operation.

110. In the Synopsis the gate was correctly described as probably the largest of its kind ever constructed. It was also true to say that the hauling rope was the largest in diameter which had so far been made in Europe, being, in fact, 9⅝ in. in circumference with all the pulleys, etc., scaled up in proportion. Mr Arch had been engaged recently in dealing with a Box-type gate for a dry dock entrance of only slightly less width than that at Falmouth, but with the major design difference that the installation there was designed to be able to cope with impounding within the dry dock. He wondered why such an apparently useful design feature had not been incorporated in the Falmouth gate.

111. Regarding the meeting-faces, he had often argued about what was desirable and what was practicable, and he was interested to read of the accuracies which had been obtained on the meeting-face blocks. The welding procedure referred to in § 33 had, combined with the arrangement of the steel mating-face, produced a finished product in which the steel face mated with the pre-set blocks to such a degree of accuracy that he felt sure that the rubber could be removed and still leave a tight gate. Mr Arch thought it of interest to mention, in view of Mr Williams's comments on the use of that

use of that type of dock entrance gate, that that had, in fact, been done for a lock forming a dock entrance, though of much smaller size than the gate with which the Authors were concerned. The installation was proving entirely satisfactory.

112. Referring to the use of a vernier clinometer to set the cast-iron runners for the movable bilge blocks in the concrete, why had not the normal straight-edge and machine level been used for the job? A clinometer would tend to accentuate variations in the machining of the surfaces being set.

**Mr A. F. Daniell** (Director, Industrial & Engineering Consultants Ltd) said that automatic bilge blocks had been used in the past at a number of docks, but they had primarily been intended merely as replacements for the normal side shoring, so that when the vessel was properly seated on the keel blocks the loads carried were quite small and the design margin merely allowed for wind pressure and the movement of weight while the ship was in dock. However, with the development of the very large size modern tanker with a comparatively enormous beam and a light structure, it appeared from conversations with naval architects that there was a possibility of some overstressing of the structure of the ship if the whole of the weight was carried on keel blocks, so that the question of bilge blocks changed its aspect. Had the Authors made any assessment of that factor and what proportion of the load was, in their judgement, properly taken on the bilge blocks? Did the design of bilge blocks permit any kind of measurement of the load which was actually sustained in practice?

114. With regard to the coping wall, the fencing of dry docks was a very difficult matter to arrange satisfactorily. Any kind of removable fencing tended to be removed quite frequently for access and it was always very different to ensure that it was properly replaced afterwards. The Authors had reached a compromise by having a wall about 18 in. high as a fixed concrete structure, with a removable railing above it. Had that removable section fulfilled the Authors' hopes? Had it been replaced after removal? Or had they, on second thoughts, felt that it would be acceptable to have a permanent wall 3 ft high and make the necessary adjustments to capstans and bollards, so that ropes could be handled over the top of a wall of that height?

115. Mr Williams had raised the question of the very sharp entrance to the dock in connexion with the protection of the seatings for the gate. It could also prove hazardous to the ship itself. Presumably some form of fendering was provided at the expense of the maximum available width of the dock. Alternatively, some kind of guide dolphin might be provided clear of the dock.

**Mr E. I. Loewy** (Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) commented on the statement in § 6 that time and money would be saved because design could proceed simultaneously with construction. That was a sweeping statement and he hoped that the Authors would be able to give some more information to justify it.

117. The constructional problems which the Authors had mentioned in attempting to justify the decision to do the design and construction by direct labour were normal in all dry dock reconstruction jobs. If these considerations prevailed in the instance described it might be argued that they would always prevail. Such a contention could not go unchallenged by consulting engineers and contractors. He would leave it to contractors to contest the second point, but he felt that he must contest the first one, or at least ask the Authors to give more factual justification.

118. Mr Loewy asked for further information about the costs, either in unit terms per foot of length, or per unit of volume, or in one of the many other ways in which they could be measured, after allowing for the fact that there had been already a smaller dry dock on the site.

119. Regarding siting and alignment, there appeared to be only about 1,100 ft left between the entrance to the dry dock and the outer jetty. Falmouth was comparatively exposed to the wind and it must be extremely difficult to manœuvre the very large tankers (presumably floating high out of the water) into position. Some turning of

the axis would have seemed advisable, such as had evidently influenced the designers of the earlier dry dock, to clear the end of the northern wharf. Would the Authors give some further explanation of that?

120. The statement was made in § 11 that a rectangular cross-section of the dry dock necessitated mechanical bilge blocks. Such blocks would perhaps be universal in the future, but he did not think that they were essential merely because of a rectangular cross-section; there were many dry docks of substantially rectangular cross-section which did not have them.

121. An interesting feature of the cross-sectional design was the longitudinal drain system in the form of pipes underneath the floor with side-entry gullies. Why had the Authors used what seemed to be a more expensive method than the usual side drain trenches? They apparently had not taken full advantage of such a pipe, by making the floor horizontal instead of on a longitudinal slope, which would probably have saved them about 2 ft of excavation. Would they comment on their decision?

122. The method of venting the floor was simple and interesting. Perhaps the Authors would say how successful it had been, because, usually, care was taken to avoid having leakage flows all over the floor area and to concentrate it at the side by a system of under-drains which had outlets only near the walls.

123. Had the collector trench for the ground pick-up been devised locally or was it a proprietary product? The moulded rubber strip was an interesting innovation in a feature that often gave some trouble.

124. It was stated in § 18 that the basis of the design was a shutter module; what was meant by that? It was often said that building a dry dock at Falmouth was a very simple matter and that there was no need for a design; one simply dug a hole in the rock and faced it with concrete, or even left it bare!

125. With regard to the meeting-faces of the gate, the earlier design, which he thought had first been adopted at other docks at Falmouth, used as the elements on the quoins steel strips, T-shaped in section, which were set into the concrete. It was a design which he knew had elsewhere been very successful, though it was not cheap because stainless steel was generally used. Had the Authors adopted their partially concrete construction as a result of unsatisfactory experience with that steel design?

**Mr J. C. H. Finlinson** (Senior Engineer, R. T. James & Partners) was not clear about the statement in § 14 that "a mass concrete foundation was designed to distribute the load of 100 tons/sq. ft from the keel blocks to the sound rock". Was that the pressure between the underside of the keel blocks and the concrete, and, if so, what would the pressure have been on the timber at the top of the block, assuming that there was some timber there? If the area of the timber was the same as the area of the block, was there also a pressure of 100 tons/sq. ft on the timber? That seemed a high pressure, and it had crossed his mind that perhaps what was meant was 100 tons/linear ft of keel as a load on the keel blocks, which would be easier to understand. Could the Authors say what total load per linear ft of keel they had had in mind when designing the blocks, and under what conditions that load had arisen? He thought the greatest load imposed on the keel blocks under a tanker might arise when the tanks were being tested and were full of water. In those circumstances some of the weight of the water in the tanks might be carried not only on the keel blocks on the middle line, but also either on the mechanically operated side blocks or on some other blocks.

The following contributions were received in writing.

**Mr G. A. Wilson** (Chief Engineer, Port of London Authority) said that the statement in § 43 that the fencing conformed with the 1958 draft revision of the Shipbuilding and Ship-repairing Regulations could be misleading; in fact, the latest draft regulations did not call for any expensive form of solid wall.

128. A fence not less than 3 ft high was required at or near the edges of a dry dock, and in the case of existing fencing 2 ft 6 in. would suffice. It was foreseen in the regula-

tions that it would occasionally be necessary to remove the fencing for dry-dock operations, and therefore Mr Wilson assumed that the ordinary type of stanchion and chain fence would be acceptable.

129. At Falmouth the edge of the dock appeared to be the convenient place to put the fence, because there was very little room at the side of the dry dock owing to the close proximity of other docks. There were, however, many dry docks which had ample width of ground at the sides and in those cases the protective fence should be erected at a reasonable distance from the edge, where it would not interfere so much with the work, and where there was less likelihood of it being removed. He supported Mr Jellett's view[6] that people working near the edge of a dry dock should realize that it was a dangerous place, and not be lulled into a sense of false security by relying on a fence which might not be there at the crucial time.

**Mr E. C. Houghton** (Vickers-Armstrongs (Engineers) Ltd) remarked that in normal circumstances there would be a head of water keeping the gate tightly closed against the meeting-faces on the dock, but it was possible to imagine circumstances in which there might be a temporary preponderance of head inside the dock, possibly due to a delay in undocking on a falling tide. Also, some minor emergency might occur, such as the fouling of one of the gate ropes, which would render it desirable to slacken the ropes, or otherwise operate the gate winch without actually opening the gate. Were latches or some form of mechanical locking device provided to hold the gate in such circumstances independently of the holding ropes?

131. In some Box-type gates push-off rams had been provided to initiate the downward movement of the gate. In other cases reliance had been placed on a slight preponderance of head in the dock. Was either of those methods used at Falmouth, or was the gate so designed that there was always a moment available tending to open the gate when it was in the fully closed position?

**Mr R. W. Bishop** (Navy Works Department, Admiralty) referred to Mr Daniell's remarks about the mechanically operated bilge blocks. Blocks of that type were normally moved into position after the ship had partly settled on the centre-line blocks, and were intended primarily as a means of preventing heeling; in that function they replaced or supplemented the side shores.

133. If, however, there were three lines of blocks, all underneath the bottom and correctly lined up, the side blocks would undoubtedly carry a good proportion of the load. The rectangular portion of many large ships extended over at least one-third of the length of mid-ships and trials recently carried out by the Admiralty, by fitting load-measuring wafers in the stacks of blocks, had indicated that 60% of the total load was carried by the centre-line blocks and 20% by each of the two rows of side blocks. In the case of tankers, the rectangular portion could rise to half the length of the ship and, provided there was no great concentration of weight, the centre-line blocks would carry 50% of the load and each of the two rows of side blocks 25%. In other words, the load would be uniformly distributed.

134. Mr Bishop noted that plate bearing tests had been carried out on the dock foundation. What settlement had indicated that the rock would carry a safe load of 40 tons/sq. ft?

**The Authors,** in reply to Mr Cornfield, stated that weep-holes, which were provided on the inner skin of the cofferdam, were drained into a channel constructed along the inner face of the sheet-piling. The channel discharged into a sump, which was emptied over the top of the cofferdam by means of a pump.

136. It was true that it had been hoped to fill the cofferdam with material obtained within the harbour, but in practice this material had proved to be unsuitable. Suitable material having a density of 110 lb/cu. ft had been found on the coast approximately 10 miles west of Falmouth. The main reason for using this material and not the material excavated from the dock was an economic one: it had proved cheaper to hire a suction

dredger and to use the derrick equipped with a 5-ton grab than to transport the excavated material. Also, the excavated material was irregular in size, all of it having been removed by blasting. Had this material been used, it was likely that serious damage to the tie rods would have resulted. Theodolite readings of the horizontal movement had been taken, and a deflexion of only 1¼ in. had been recorded.

137. The 9B3 McKiernan Terry hammer used for driving the piling had proved satisfactory. No significant damage to the heads of the piles had been experienced, and a rate of driving of fifteen piles per day had been achieved.

138. Alternative types of cofferdam had been considered, and in particular an arch dam. This had been rejected because the available abutments had proved inadequate for the thrust which would have developed.

139. Mr Neilson had expressed interest in the pumping station. The air-conditioning plant had proved adequate to prevent condensation in the pumping station except on one or two days a year when exceptional conditions prevailed. This, however, had been realized at the design stage, and it had been considered uneconomic to provide a plant that would prevent condensation in all circumstances. The saving of 25 h.p. by use of siphons for the discharge from the main pumps resulted solely from a reduction in friction head. This was due to the absence of a self-closing hydraulic sluice valve which would produce a head loss in the order of 1 ft. Some authorities had referred to this system as the "anti-siphon system", and that was probably a better description.

140. The precast concrete sill blocks had been cast in machined cast-iron moulds to an accuracy of 0·002 in. on a 3-ft face, this being the length of an individual block. No further dressing had been necessary. The aggregate used was blue elvan, the mix being 1:1½:3.

141. Replying to Mr Williams, the Authors said that a depth of 38 ft over the sill had been considered in the preliminary stages, but had been rejected mainly because of the level of rock in the tidal basin.

142. The height of the centre keel blocks was 4 ft 9 in. to the top of the capping timbers. These blocks were constructed on the usual folding-wedge principle, and had a cast-iron base 3 ft 1 in. high and a capping 17 in. × 14 in. of English oak surmounted by a pine capping 3 in. high.

143. Careful consideration had been given to the choice of site, and a detailed report with alternative plans had been prepared. The site chosen enabled the largest dock to be constructed with a minimum of excavation, and proved to be the most satisfactory in relation to the layout of the existing docks. The geographical layout of Falmouth Docks was unsuitable for the construction of a double-ended dock.

144. Both Box and mitre gates had been considered in the preliminary design. It was difficult to compare actual costs because as a result of the major alteration in design made during construction the final cost of the gate bore no relation to the original figures quoted for mitre gates. The original quotations received had not been substantially different. At Falmouth both mitre gates and Box gates were operated, and experience had proved that Box gates were much more satisfactory in operation. The operating time of 6 min. for a Box gate was more than adequate for use in dry-docking operations.

145. Mild-steel zinc-sprayed billets were used for the meeting faces above low-water level to withstand the high loading from the transverse beam at the top of the gate. The meeting face was perhaps a little nearer the edge of the sea wall than was desirable. That had been brought about by the decision to make the largest possible dock that the site could accommodate. In the original scheme the dock gates had been well back from the sea wall. They were not, however, unprotected. A concrete cope 4 ft 6 in. wide protected the meeting face, and rubber fenders protected the entrance. The T-section stainless-steel meeting face previously used at Falmouth and mentioned by Mr Loewy was not used in the Queen Elizabeth Dock. In previous circumstances they had not been found particularly satisfactory, owing to the galvanic action set up between the stainless steel and the mild steel of the gate.

146. In reply to Mr Houghton, a locking device had been provided on each side of

the dock gate, and this had to be released by hand before the gate could be operated. In practice, however, there was sufficient head at low water to hold the gate in position, and the locks were provided purely as a safety measure. When the dock was flooded there was always a moment tending to open the gate, and the use of push-off devices had not been found necessary. In this connexion, the two 8-ft-dia. equilibrium valves enabled the water level in the dock to be equalized with that in the tidal basin without delay.

147. The maximum plate thickness used in the gate was $1\frac{1}{2}$ in., and all plating both inside and out had been treated by Messrs Wailes Dove's bitumastic process. This process had been found to give protection for at least 10 years on previous gates in use at Falmouth.

148. Mr Arch had asked why the gate had not been designed to permit impounding. The question of impounding had not seriously been considered since the ship-repairing organization at Falmouth did not think this to be of any practical value to them.

149. Replying to Mr Daniel, the Authors stated that the fencing provided around the dock had proved to be a satisfactory compromise. The height of 18 in. had not proved to be an unwarranted obstruction during docking, and the railing above was so easy to remove and replace that no difficulties had been experienced. It was felt that with a permanent wall 3 ft high the handling of ropes at the bollards would be difficult.

150. The Authors had not intended to imply that the Shipbuilding and Ship-repairing Regulations required a solid cope wall, as Mr Wilson had suggested. When the dock was designed it was realized that fencing would have to be provided to comply with those Regulations. The design adopted was considered the most suitable for conditions at Falmouth, although in practice the system chosen might be in excess of any required under the Regulations.

151. Both Mr Daniel and Mr Loewy had referred to the distance between the Queen Elizabeth Dock entrance and the Northern Jetty. This distance, approximately 1,175 ft, was perhaps less than might be thought desirable. Nevertheless, much careful thought had been given to this factor in choosing the site of the dock, and it had been considered that ships could be safely handled. In practice, ships of 50,000 tons dead weight had been handled without difficulty, and in view of this experience no difficulty was anticipated with the larger ships for which the dock was designed. It would not be a practical proposition to turn the axis of the dock.

152. In § 11 it was stated that the use of bilge blocks was required because of the necessity of handling ships of widely differing sizes, not because a rectangular cross-section had been chosen. The dock-bottom drainage-trench system had been chosen particularly to provide an uninterrupted floor to facilitate the movement of wheeled stages without the necessity of gratings, and also to ensure that the floor dried out with the minimum of delay. It had not been considered desirable to construct a horizontal floor, owing to the docking trim with which vessels normally entered the dock. In any event a horizontal floor would not have resulted in a reduction of excavation. The method of venting the floor had proved successful and no nuisance had been experienced from the leakage flow.

153. The collector trench provided for the cranes on both sides of the dock had been designed locally, but the moulded rubber strip had been provided in conjunction with Messrs Stothert & Pitt, who had constructed the cranes. This system had proved satisfactory in practice.

154. The approximate cost of the project was £2 million.

155. Mr Finlinson had raised the question of pressure on the dock floor. If at any time all centre and wing tanks between any two transverse bulkheads of a tanker were fully ballasted in the docking condition, loading on the dock floor might reach a figure approaching 100 tons/sq. ft in the case of a 85,000-ton vessel. The Authors agreed that the greatest loading imposed on the keel blocks of a tanker was likely to arise when the tanks were being tested.

156. The bilge blocks were operated in the manner outlined by Mr Bishop, and experience at Falmouth was generally in agreement with his remarks.

157. The results of plate bearing tests on rock had indicated very small settlements in the range of 0·083–0·184 in. under applied loads of 62½–68 tons/sq. ft. All the tests showed that the ultimate bearing capacity of the sound rock was at least 62½ tons/sq. ft, and it was therefore considered that a safe load figure of 40 tons/sq. ft could be used for design purposes.

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