The new dry dock at Belfast

K. ROSS, W. J. H. RENNIE & P. A. COX

Mr Ross

There may be some people who think that there has been duplication of effort in providing two large docks at Belfast for the shipbuilding industry. While the new building dock provides for the float out of the near finished product, the dry dock is primarily designed for the ship repair side of the industry and for those ships still launched by conventional means at the Musgrave Shipyard.

130. When the new workshops are in full production four tankers of the 300 000 ton class will be built in the dock each year as well as two bulk carriers of the 100 000 ton class at the Musgrave Shipyard.

131. The throughput of the building dock will be such that it will not be possible to use the dock for ship repair work.

132. The sill level is such that there is a restriction on deep draughted vessels from entering the dock. There is 8·38 m of water over the sill at MHWS at the building dock compared with 11·6 m at the dry dock.

Mr Rennie

Six contractors were invited to submit tenders and my firm was fortunate in being awarded the Contract—this expression of confidence by the Belfast Harbour Commissioners was particularly welcome to Charles Brand, who were building quays in Belfast Harbour for the Commissioners in the mid-1800s.

134. It was a personal pleasure to me as I had been working closely with the General Manager and the Chief Engineer and his staff on numerous contracts in the Belfast Harbour for very many years, and I was also renewing an old association with the Consultants, Rendel Palmer and Tritton.

Mr J. A. Williams, Wilton and Bell

Figure 2 impresses me as being an extremely satisfactory design for a dry dock and one which takes full account of the practical construction problems and methods. With regard to the anchor piles, was the use of stressed anchors to be taken down into the rock considered in the design? I think this might have been more positive and cheaper.

136. The job was designed in the early 1960s. If it were being repeated in 1972 would diaphragm walling be preferable to sheet piling, either technically and/or from the point of view of cost?

137. In Fig. 2, there is a gap between the bottom of the bearing piles and the rock. Does this mean anything, or were the piles carried down to the rock? Was there any trouble with boulders among the other pile driving problems?

138. I have experience of Peine piles in countries outside the UK and think they are extremely useful from the design aspect. On one occasion in difficult ground half-inch jetting pipes were introduced into the leading interlocks to assist the driving.

139. Referring to § 18, is it wise to take adhesion into account in resisting uplift? In similar designs I have always ignored this adhesion in order to keep something in hand. If there is risk of flotation, there is a chance of lubrication between the clay and the piles, and the use of adhesion in design appears doubtful. What proportion of the overall factor of safety is contributed by the adhesion?

140. Is there any positive anchorage between the concrete floor and the piling in the form of shelf angles or other connexions welded to the piling?

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141. In § 32, why was it necessary for the central part of the sill to be a suspended span carried on cantilevers? If the stability of the sill structure was in doubt, could not this also have been anchored down by rock anchors?

142. With reference to § 36, 'box' should have a capital B. It tends to be forgotten that this type of gate was just designed by a Mr Box, a civil engineer on Tyneside.

143. I have had experience of two flap gates both much smaller than the one on this project, but one of which had a similar winch set up on one side and the other of which had two synchronized winches, one on each side. It is appreciated that the winch on one side pulls the gate up quite steadily, but with the two-winch installation all the equipment is much smaller and I am sure has advantages. Were two winches considered in this design?

144. In the meeting face, why was the timber proud of the rubber? If the rubber had been slightly proud of the timber, when the faces came together the rubber would have squeezed and made a positive seal.

145. I should like to programme a dry dock so that the entrance works, the roundhead and the sill were done early, with the main construction following and the gate being built in situ, immediately mounted on its bearings, so that the workmanship and installation of the gate could be positive. It would be done in the dry and would avoid the hazard of towing and stepping the gate. In some docks the gates have had to be towed across the world, while on one occasion during stepping, a flap gate nearly turned over because air was pumped into the wrong compartment. If erected in the dry these hazards would be avoided while a comparatively small area between the cofferdam and the gate could be flooded and the gate given a 100% water test before the dock was opened.

146. As a further development, consider that a cofferdam is an expensive part of a dry dock project. The dock gate is there permanently to keep the water out. Would it not be possible to build two roundheads in small cofferdams and then bring the gate in, if not into its permanent position then into a temporary position, and use the gate as a cofferdam? The gate would have to be much in advance of the rest of the works but appreciable cofferdam savings would ensue.

147. Taking the civil works, the gate and the pumps, the tender costs are 47½ p per cubic foot of dock. In the 1950s dry docks of traditional design cost 10 shillings per cubic foot. That is now worth £1 or more. This design is clearly economic, but is it really as cheap as 47½ p? Do the quoted figures include allowances for contingencies, preliminaries, claims and so on?

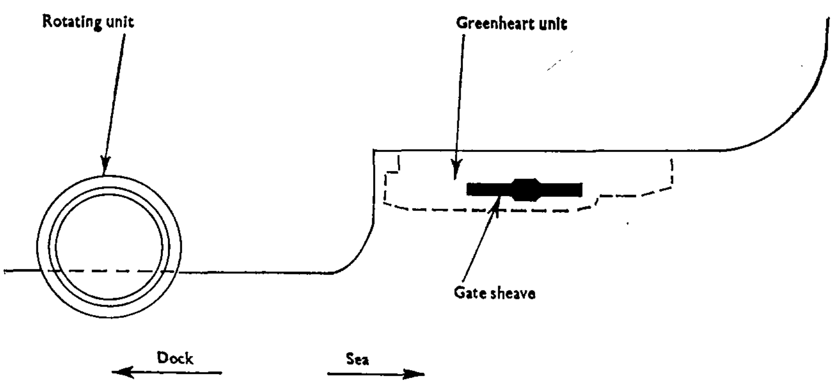

Fig. 14

Mr N. Morrow, Belfast Harbour Commissioners

One of the most vulnerable parts of the dock when the dock gate is in the open position is the rope sheave. If this gets damaged, the gate will not close properly, in which case the dock could not be dewatered and the ship which was to be docked would have to go out again.

149. Figure 14 shows the fendering system in the entrance. Inside the dock there is a Firestone Burleigh rotating unit and just outside the entrance is a composite greenheart unit built over and around the rope sheave. The bow section of a modern tanker at the critical height of the rope sheave is remarkably blunt and the bulbous nose extends beyond it. Incoming ships can strike this greenheart unit before the Firestone Burleigh has had time to take control. The greenheart unit is removable for maintenance purposes, and it has had to be removed three times at a cost of over £1000. Once an incoming ship was so damaged by one of the metal fixings on the greenheart unit that a shaped plate of special steel had to be renewed. So far the sheave itself has escaped damage. The leading edge of the greenheart unit has been modified and given a more oblique angle, but it has not yet been tested in practice. Firestone Burleigh submitted a scheme for an additional rotating unit to augment the greenheart unit, but for the rotating wheel to clear the gate when it is being opened, it must be at least $1\frac{1}{2}$ m above the deck level of the roundhead. It must also be about the same distance from the face of the roundhead. To fit one of these on each side of the dock would cost about £20 000. The roundhead itself is cluttered with bollards and capstans, and to make room for this unit would necessitate the removal of two useful bollards.

150. In the early planning stages of the dock Belfast pilots said they would like to have a lead-in jetty so that they could line up ships before docking. Unfortunately this was not possible because the cost could not be justified and because the jetty itself would tend to obstruct ships in the main shipping channel and also in the turning circle.

151. In the light of the operational experience and the changes in tanker design, if Mr Cox were starting the design now, would he consider that a lead-in jetty was worth the expense, or would he compromise with a more sophisticated form of patent fender?

Mr J. Brown, Belfast Harbour Commissioners

Since the first ship entered the dock in 1968, 27 have made use of it, the largest being 200 000 t and the smallest 4000 t, approximately 2 000 000 t of shipping, with a total occupancy of one third of 42 months. The longest time occupied was 112 days and the shortest 6 days.

153. Minimum docking charge is £450 per tide and, since the dock has been financed by a Government loan, Harland & Wolff have to share the operating costs, plus all loan charges, insurance premiums and so on.

154. Electrical power to the dock is supplied by the Belfast Corporation Electricity Department, and there is a reserve capacity of 4·25 MW. The highest maximum demand recorded to date is 3·5 MW and in 1971 the dock consumed 2 000 000 kW of electrical energy.

155. The intention to install pneumatic bilge blocks was correct, but in practice their operation has not been so successful. The air lines serving the blocks floated, and became an embarrassment to divers inspecting the undersides of ships and had to be weighted to prevent them floating.

156. The chains and hose pipes associated with the pneumatic blocks on the dock floor gave the shipbuilders problems when moving large mobile stagings along the length of a ship. The shipyard employees have to demount each time staging encounters these obstructions on the floor.

157. After each pump-out of the dock, and before another ship is docked, the blocks require servicing to remove sea water from their sealed drive units.

158. At minimum travel from the centre-line of the dock, the caps of the pneumatic blocks are higher than the keel blocks.

159. The pneumatic blocks were designed to support 400 t on a 0·65 m^2 cap of timber, i.e. 6116·10 kN/m^2 of ship resting on each block. Since the design and manufacture stage, classification societies and shipowners have produced figures of 2360, 1930 and 1395 kN/m^2.

160. Supporting a 200 000 t tanker necessitates the support of 50 000 t of steel, half of which is borne by the keel blocks and the remainder by the pneumatic bilge blocks. At 1930 kN/m^2, this will require 130 m^2 of blocks. The 38 blocks at Belfast have only 24·71 m^2 of bearing surface. Consequently, Harland & Wolff have provided 106 concrete blocks with a total bearing surface of 147 m^2.

161. During a recent docking of a bulk carrier, the ship sat down on the keel blocks with a 50 mm hog, 145 m of the mid-ship section being unsupported by the keel blocks. When the mishap was discovered, the dock was flooded and the ship removed from the dock. Inspection of the pneumatic blocks revealed that 17 of the 30 blocks in use had suffered damage by overloading, and were not capable of being operated by their air motor mechanism. The blocks were designed to support 400 t each, and the loading in this case must have been in excess of this to cause the blocks to fail.

162. In future dock construction, consultants will have to provide a greater number of blocks to meet the requirements of classification societies and shipowners.

Mr A. L. Little, Consulting Engineer

In 1940 I was in charge of a design team preparing designs for two docks. One was a cruiser dock for Singapore, and was about 800 ft long, 100 ft wide and 30 ft deep. The designs were finished, the contract placed and work started one week before Singapore fell. The second dock was a battleship dock, and this would have been 1200 ft long and 150 ft wide. The Admiralty governed the depth by the damaged draught of a battleship, and it had to be possible to bring the ship in at lowest high water, giving a depth below mean high water springs of 50 ft. This dock was to have been sited on the site of the East Twin and would have been 25% bigger than the new dry dock. This was solely because of the depth, and its depth was its own undoing because to get into a dock of that depth would have necessitated dredging the approach channel over a length of many miles.

164. On pile driving, I am surprised that the heavy hammer was not an improvement on the Delmag. On a current job in similar conditions steel piles are being driven with a Diesel hammer which weighs 2 tons and drops 8 ft. I thought a heavier hammer would have been preferable but this did not prove to be the case in Belfast. I am surprised too that prestressed concrete piles could be driven with a Delmag hammer of such a large drop. In Portsmouth in similar conditions 16×16 prestressed concrete piles could not be driven into the clay with a 4 ton semi-acting hammer without their being broken, but could when a 6 ton hammer was used. Was that experience borne out at Belfast?

165. On pile loading, I am surprised that the designers took a design working load of 80–100 ton in tension.

166. No reference is made to the horizontal load on the steel sheet piling. For the dock in 1940 the density of sleech was 100 lb/cu. ft and by applying a reduction factor of 90% a florid pressure of 90 lb/cu. ft was adopted.

167. If this weak clay behaves in that way, then dewatering the site would not make any difference to the load and there would be as much load on the steel sheet piling during construction as when the job was finished. Was this so on site?

168. Were the concrete blocks for stops reinforced? Were they anchored into the main body of the concrete? All Admiralty blocks, whether granite or concrete, are anchored into the concrete.

169. The control of measurement in setting the blocks at Belfast was obtained by

readings on piano wires. At Devonport they were set as accurately as possible with a theodolite and piano wire was erected for the final dressing.

Mr F. A. Page, Port of London Authority

The Authors state that they first attempted to drive the Peine piles in panels and eventually resorted to driving them in pairs. I have been told by a Dutch contractor that he drives them singly using a particularly strong template to maintain them in position. Did the Authors consider this method?

171. With regard to the driving resistance of paired piles, obviously the void fills up as they are driven and to some extent the same trouble occurs with the combined section pile. Clay and perhaps gravel balls up between the piles as they are driven and I should have thought that in this case the strong clay would soon block the end of the paired piles and that continued hammering would build a horizontal hydraulic pressure on the toe which would tend to burst the clutch. Was there any trouble of this sort? Leaks were mentioned in the Paper and it is possible that this hydraulic force on the clutch combined with the other forces could cause a problem.

172. At the Port of London Authority fabricated combined piling section was used at Tilbury in 1968 using surplus Frodingham piles. These were reasonably trouble free although there were some burst clutches. I believe this was the first time a combined section was used in the UK. The current price quoted for Peine piles makes them more expensive than the alternative combined sections available and I should have thought that the latter, which are easier to drive and cheaper, were preferable. Would the Authors agree?

173. The construction sequence employed was the reverse of that normally used in which the wall is built first and excavation is done afterwards. It was said to be essential to ensure that there was a sound superstructure and that loads on the piles were correctly distributed. It it not clear why this should be so. Were the tension piles and the Peine piles expected to move under load during excavation, and if so was there significant movement and was it measured? There would appear to be a penalty with this sequence: the horizontal support from the outer raking piles is lacking and the stresses during the temporary stage will be higher than for the final construction.

174. The Authors state they did not achieve the penetration desired for the sheet piles and presumably soil pressures were increased at the toe. An over-consolidated clay tends to relax under load over a long period to a residual strength which can be calculated. Did the Authors consider this relaxation problem in this case and was it necessary to take it into account?

175. Axial flow pumps are susceptible to uneven flow at the impeller to such an extent that the sump needs to be designed with the pump as a combined hydrodynamic unit. In this installation the pumps seemed to be very close to the wall of the sump. To what extent was the sump hydraulically tested and was it water or air tested? There is at least one case where a water test was not sufficiently decisive and the pumps subsequently caused trouble and had to be taken out of service. As dry dock pumps are not required to operate for long periods the design of the sump may not have been so critical in this case.

176. With regard to the crane rail track it is debatable whether it is necessary to make allowance for thermal movements in the track. In my view the best thing is to fix them firmly in the concrete to prevent movement. At Tilbury crane track was concreted in over continuous lengths of 3000–4000 ft with no expansion joints and fixed firmly into the concrete. It has given no significant trouble. Did the Authors treat their crane rails in a similar fashion?

Mr J. P. North-Lewis, Soil Mechanics

The Paper describes the boulder clay as generally one deposit. In fact, it is two deposits: the upper and lower boulder clay. The upper boulder clay varies from 10–20 m thick and consists only partly of typical boulder clay. It includes a proportion of thick beds of silty clay, laminated clays and silts and some permeable sands and gravels, all of them being types of deposits generally associated with glacier-lake and fluvio-glacial deposition. These clays were often only firm to stiff or just stiff. The lower boulder clay is more typical of boulder clay: it is very stony and it has many cobbles and boulders. However, it was not always present on this site, and was nowhere more than 7 m thick. This may have affected the length of piles in pile driving.

178. In the installation of the anchor holes, the intention was for a 14 in. temporary casing to be taken down through the sleech and the boulder clay to the top of the rock and then a drilling rig to take over and drill 10½ in. into the rock. In fact, it was not always practicable to get the temporary casing with a tripod rig down to the rock head, and the rotary drill had to take over on occasions and drill, with mud to support the sides of the hole.

179. The installation of the wells was carried out using reverse circulation, the diameter of the boreholes being 21 in. It was a water lift reverse circulation rig, and was one of the first made and designed in the UK. Generally the wells were bored to a depth of 120 ft. In general the systems adopted for drilling the wells and the anchors went according to plan.

Mr G. P. Martin, Partner, T. F. Burns & Partners

In § 9 the Authors say that with the completion of this dock and the large shipbuilding dock of Messrs Harland & Wolff, the Port of Belfast is well placed to cater for the future needs of the shipbuilding industry. It occurs to me that this may not be strictly accurate for it can be argued that the dock may be just too small to cater for these needs.

181. One should consider the present order book of the world for large oil tankers, i.e. ships with a deadweight tonnage exceeding 150 000 tons. According to the latest records, there are 380 such ships on order which have an average tonnage of 255 000 and of these, only about 27 are below the 206 000 mentioned and only about 56 would squeeze in with the minimum possible clearance.

182. The quarter million ton tankers recently built and now under construction in Belfast, Wallsend and on the Clyde are all too wide to enter this dock or any repair dock in Britain and those which are launched (as opposed to being floated off) have to travel to the Continent to have their launching poppets removed. It would seem wrong for this to continue. Britain should be able to repair the ships she builds. Bearing in mind the number of docks in Britain which have been enlarged, it would appear that the situation is not uncommon.

183. The Authors have used the circular arch as the head wall of the dock—I might warn them that on two recent docks with which my firm has been concerned using this shape, the dock owners have asked for a notch to be cut in the crown of the arch to accommodate the bows of an oversize ship. On one occasion a request was made for a notch to be cut out of the centre of the steel flap gate to accommodate the stern but it was suggested that it might be cheaper to cut a notch out of the ship, which was in fact done.

Mr D. G. Gray

In § 40 I was interested in the use of the finite element method of analysis in the design of the flap gate.

185. I am studying computer aided design of such cellular box structures and have the problem of determining the stress distribution in this type of structure with sufficient accuracy to provide a basis for checking more approximate 'iterative design type' methods of analysis.

186. Could the Authors give guidance on this problem in the light of the experience gained in using the finite element method in the design of the Belfast flap gate? How was the idealization into finite elements made?

Mr Cox

Mr Williams, and other speakers, asked a number of questions about the piling and foundations. The use of stressed anchors taken to rock for the sheet pile walls was not considered. As Fig. 4 shows, the rock was well below the toe level of all the piles and stressed anchors would have had to be very long. To be economic, the load per anchor would have had to be high and this would have increased the problems of distributing the anchor load along the piling during the construction stage.

188. If the work were being done now, the Consultants—in the light of the extensive experience of diaphragm walling which they now have—definitely would have considered its use for the walls of the dock and to form the pumphouse structure.

189. In calculating the overall stability against flotation, the adhesion of the sheet piling in the clay was taken into account but this only formed a relatively small part of the downward forces and even if the value had been substantially reduced, there would have been no risk. (The whole stability of the walls is, of course, dependent on the adhesion value of the raking piles and so there is ample justification to use this factor in the flotation calculations.) The design values used were based on previous experience in Belfast and were checked by the pile testing referred to in § 21.

190. The tension anchor piles moved forward as the main excavation was being carried out, the maximum value recorded being $1\frac{1}{4}$ in. It was because of this movement that the raking piles under the rear wall of the relieving platform were not connected to the Peine piling until later in the construction sequence. Connected earlier, they would have carried a disproportionately high part of the horizontal loading. The main bearing piles were not taken down to rock. Adequate end bearing resistance was obtained in the sands and boulders in the layers immediately above the rock. **Mr North-Lewis** referred to this aspect in his contribution.

191. **Mr Little** drew attention to some of the characteristics of the sleech. The well pointing was not expected to reduce the loading from the sleech during construction; it was to reduce uplift from the water pressure in the underlying strata.

192. **Mr Page** and Mr Williams commented on the choice of Peine piling for the dock walls and on the driving problems associated with it. At the time the design was prepared, the Peine piling was the only piling available with the required section bending modulus for which there was adequate driving experience. A suitable combined section was available in the UK but the Consultants doubted its behaviour during driving, it being thought that there would be a build-up of pressure between the joists which would cause the section to twist. There was, of course, a build-up of pressure in the closed cells of the Peine piling which caused driving problems and probably contributed towards restricting the penetration but it did not cause distortion. With the experience now available, a combined section would be considered as an alternative to the Peine piling. It is believed that only in one case was there a burst clutch due to the build-up of internal pressure during driving. The Contractors tried a number of ways of overcoming the driving difficulties, including shaped shoe plates and the grabbing out of the material in the cells, with limited success.

193. Mr Little expressed surprise that the heavier single acting hammer was not an improvement over the Delmag hammer. The Contractors had had previous experience of working in Belfast and after many experiments had found the Delmag to be the most satisfactory. They had visited Germany to see similar piles driven there and had found that they were usually driven in pairs with heavy plant. The Contractor demonstrated that no benefit was gained by driving Peine piles singly. In reply to Mr Little's query concerning damage to the prestressed piles during driving, the Authors confirm that no problems occurred.

194. Mr Williams asked if two winches for the gate haulage had been considered. It was decided that operation and maintenance would be simplified with one winch.

195. With regard to the timber being proud of the rubber of the gate seal, this was done to prevent any risk of the rubber getting turned over and carried into the space between the timber and seal. It has been found, and certainly the tightness of the

gate shows, that the rubber easily moved over under the water pressure once the dewatering starts. Mr Williams suggested that the gate could have been built much earlier in the programme and used to close off the entrance between the round heads in place of the cofferdam. The Authors doubt whether this would have achieved any economy because a cofferdam would in any case have been needed to enable the sill to be constructed before the gate could have been installed. In this case, the towing of the gate did not involve any real risk as it was built in the adjacent Harland and Wolff Yard. The stepping operation demonstrated to the Belfast Harbour Engineer that the gate could be stepped and unstepped if necessary for subsequent maintenance.

196. **Mr Morrow** made a useful contribution in referring to the vulnerability of the rope sheaves at the entrance and the problems caused by the bulbous bows of the large ships. These bows are becoming quite a problem and it is something to which designers will have to give more consideration. On another project—a very large tanker jetty—a tanker, out of control, struck one of the mooring dolphins set well back behind the berthing line, and sheared the piles off at bed level: about 90 ft below surface. Therefore the navigators must take more care in handling ships with bulbous bows, and the civil engineering designers will have to consider what can be done to make structures less subject to damage by them. The provision of a lead-in jetty was considered for this dock. There was some difference of opinion with the tug pilots on the manoeuvering of a ship into and out of the dock with a lead-in jetty there, and some considered that it might be more difficult with a lead-in jetty. Such a structure would certainly provide additional protection to the rope sheaves at the entrance. If a lead-in structure had been constructed, dolphins would have been the correct technical solution but one has to set the quite considerable capital cost of providing these structures against the relatively small amounts that have to be spent on maintenance from time to time if the protective fenders provided are damaged.

197. **Mr Brown** raised a very interesting question: if we were to do the job again, would we provide pneumatic bilge blocks? The Consultants consider that the answer is 'No'. During the last 20 years, most big dry docks have been provided with these, usually at the request of the company responsible for the repair work on the vessels, the intention being that they would be able to operate the docks economically by undocking one ship on a tide and re-docking another ship on the tide. In fact, due to the risk of damage to a vessel from blocks which have not been physically checked in the dry and because docks are seldom continuously occupied, this is not often required to be done. It is unlikely that there will be many dry docks built in the future in which mechanical bilge blocks will be provided. Large concrete blocks designed to be handled by forklift trucks are the likely future choice and will better meet requirements of classification societies regarding bearing pressures against the hull.

198. Mr Page mentioned problems which can arise in the design of sumps for large dry dock pump sections. The Belfast pumphouse layout was tested in a water model at a scale of 1 to 12 in the laboratory of Drysdale & Co. Ltd, the pump suppliers. As a result, the design of the sump was modified and no trouble has been experienced in pump operation. Expansion joints were provided in the crane rails, to match the joints in the concrete structure, but the Consultants agree with Mr Page that if they had been omitted or reduced, little trouble would have resulted.

199. **Mr Gray** asked for more information on the design of the flap gate. While it is difficult to give guidance on the application of finite element techniques to unspecified cellular box structures, we can elaborate to some extent on the methods used for this structure. As in-plane forces were not being considered, use was made of a specialized computer program developed in the firm, is based on the work of Mohamed Ali El-Gaaly.[3] Briefly, the elements at the solution stage comprise dual bending stiffness elements but include shear lag properties, the final stresses being produced through a back substitution of the rotations into the individual element stiffness matrices.

Reference

3. MOHAMED ALI EL-GAALY. *Jnl Struct. Div. Am. Soc. Civ. Engrs*, 1965, June.