

Graving dock at Scaramanga, Greece

G. P. MARTIN and K. D. IRVINE

Messrs Martin and Irvine

Because of restriction in the length of the Paper it possibly did not convey a clear impression of the frustrations, the legal, financial and technical difficulties which all occurred during the course of the project.

115. It could perhaps be said that, as supervising engineers, we were acting simply as detached observers of the difficulties in which the Contractors and Employers found themselves. This was, in fact, never true as it was impossible for us not to become deeply involved and the Paper was in part written as a tribute to both the Contractors and the Employers for the way in which they finally resolved their difficulties. Before resolution, the argument might easily have been taken to the International Courts, in which case it would probably still have been there.

116. We feel that a project which could not be constructed in the manner in which the designers had evolved it should be recorded and, if possible, discussed.

117. We should like to pay tribute to the excellent working relationship established on site with the Contractors which made a significant contribution towards the final success of the project.

Mr D. D. Land, Edmund Nuttall Ltd

After the unfortunate events described by the Authors, my firm was asked to tender for a dry dock by a Greek organization. The preliminary documents sent to us included modified International Conditions of Contract in which nearly all the clauses which might protect a contractor had been deleted. Needless to say, we refused to tender. I believe that what remained was better from the Contractor's point of view than the Conditions used for the work under discussion. Much as one sympathizes with those concerned, the results of such a contract were surely inevitable.

119. I was surprised that after having attempted to draw down the water level by pumping without success, the Contractor promptly negotiated an extension to the Contract at what appears to be a rate *pro rata* to the original price. It is not clear who paid for what, but the Client got his job finished nine years after commissioning the design and six years after starting work on site. Had the Authors' firm been appointed as Engineers from the outset and a normal contract been awarded, much time could have been saved. If the Authors had been appointed from the beginning, do they think that the kind of site investigation they would have recommended would have revealed the conditions subsequently discovered on this site? If not, then with hindsight, what kind of site investigation would they recommend in future if they had to build another dry dock where they might encounter similar conditions? Would the Authors consider one or two large diameter boreholes? These are not expensive with modern equipment, and enable people to be lowered down in a bosun's chair to inspect the ground so that an engineering geologist might be able to give advance warning of trouble.

120. Could the Authors give further information about the way the site investigation was carried out? Were engineering geologists employed; if not, do the Authors think they could have helped?

121. With regard to the Prepekt concrete in the dock floor, the description of the method of grouting the aggregates appears reasonable, but if Fig. 8 accurately represents the actual method used, then I suggest that voids in the floor were predictable. In this kind of work the grout, which is heavier than water, must be introduced at the

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bottom of each pour so that, as it rises, it expels the water from the voids in the aggregate above and with the pipe always buried in the grout to pump against pressure. However, if, as Fig. 8 suggests, the grout pipe is above the bottom of the pour to begin with, the pieces of aggregate below act like slates on a roof and the grout, as it falls, is shed to either side of the individual stones so that voids under them are inevitable. Would the Authors please comment?

122. The Paper describes how a suction dredger was used to clean out the accumulation of silt in the dock. In 1958 my firm intended to use Prepakt concrete to fill a large caisson in the Bristol Channel, but when news was received from the USA of underwater pours failing because of silt deposited in the aggregates before grouting, we changed to tremie concrete. If there was any risk of silt being introduced into the aggregates in this case, I wonder if it was wise to choose a continuous pour right down the length of the dock. If there is a siltation risk in such circumstances and a sound floor is required, I think the only method, although an expensive one, is to divide up the area of the floor into a number of overlapped pours using underwater shutters for half the thickness of the floor at a time and placing the aggregates, pour by pour, as late as possible before grouting. Would the Authors say whether they think the extra cost of such a method would be justified by the avoidance of subsequent pumping cost to the Client and the cost of the remedial works which had to be undertaken?

123. Most of the caissons used for the dock walls were similar to what has become a traditional pattern for harbour works in the Mediterranean but the pumphouse caisson is unusual and much larger. It would be interesting if the Authors could provide a drawing of it, together with some details of the general arrangement of the pumphouse and pumping installation.

Mr M. J. Tomlinson, Wimpey Laboratories

The Paper is a good example of how excavation work can go wrong in spite of a careful and quite detailed site investigation. The yield from many of the bored wells confirmed that the average permeability coefficient of 2.6×10^{-4} m/s, which was obtained in the site investigation, was representative of the conditions where the bored wells were able to lower the groundwater. In fact, in several of the bored wells, when pumping at the planned capacity of 30 m³/h (6600 gal/h), it was possible to lower the water down to the pump intake. However, there were some areas of quite close-spaced wells where the water could not be lowered at all and when the job reached this stage the Contractors asked Wimpey Laboratories to investigate the possibilities of using grouting as a means of reducing the inflow into the dock excavation.

125. Having looked at the available site investigation information, we decided that it would be worth while carrying out trial grouting in view of the soil conditions which were described as gravels overlying rock. If, as appeared likely, the gravels were more permeable than the rock, they could be grouted to cut off the flow. It was appreciated that it would have been too costly to inject beneath the whole of the floor area of the dock to form a watertight box, but, on the basis of the site investigation information, it appeared to be feasible to establish a vertical grout curtain around the perimeter of the dock down to rock level to cut off the more permeable zones in the gravel. Thus the quantity of pumping would be cut down considerably.

126. When I looked at the exposed face of the excavation I felt that that approach was right because the porous zones could be seen clearly in the extensive areas of gravels. In places one could see that the matrix of sand and silt had been washed out in earlier times, to leave an agglomeration of quite open gravel.

127. It was likely that the areas where the pumps were not pulling down the water were represented by flow from the very porous gravels which would accept grout. At that stage little was known about the conditions in the rock. Two trial areas were grouted, making a ring of grout holes, using both cement grout and a

bentonite cement. The pumping tests which were done in a bored well before and after forming the grout curtain showed a reduction of about a half, to a fifth, of the quantity of pumping, and it was possible to draw the water down about 6 m within the grouted area.

128. However, these trials showed difficulty in connecting from our injection holes to these pervious zones. If high pressures were used to force a way through, the grout broke surface through the soft clay overburden more easily than it broke through to the pervious zones in the gravel. In view of these difficulties, it was evident that close-spaced injection holes would have to be made to intersect all the groutable areas. At this stage the observations made by the Contractors of recharge from below had indicated that the problem was as much with the flow from beneath the dock floor as from the gravels surrounding the excavation. It became obvious that a grout curtain could only be made at a high cost and it would only cut off a proportion of the inflow. The idea of grouting was then abandoned in favour of the form of construction which was eventually adopted.

129. If, in the initial site investigations, core drilling had been taken to some depth into the bedrock beneath the site, it would have been fortuitous if the suspected large water-bearing fissures which existed in the rock had been intersected. In the quarry behind the dock excavation there were solution cavities in the limestone which were up to about 0.5 m long and the fissures had been enlarged by solution to as much as 10 cm wide. An engineering geologist might have made this observation and given prior warning but is evident that trouble from a concealed water-bearing cavernous limestone was not anticipated at the time of the original site investigation, no doubt because there was no precedent to this happening in the area. These difficulties could not have been predicted by drilling alone.

130. The remedial grouting in the dock floor met with much more success than the attempts to deal with the excavation problem by grouting. The conditions became considerably wetter when anchorage drilling began because the anchor holes tapped pervious zones at depth in the intrusion-grouted concrete and interconnected them, thus greatly increasing the amount of water which was coming up through the dock floor.

131. For this remedial work the technique used was to isolate the leaking areas by means of grout injections to form cut-off walls. These isolated the areas of major inflow, which was allowed to continue through stand pipes. These heavily flowing areas could be grouted only after flooding the dock, and the stand pipes were connected under water by divers.

132. *The Netherlands Harbour Works Co. were vulnerable in their design and construct form of contract with site investigations done by themselves, which is a difficulty with which firms who undertake this kind of work are always faced. Their design was particularly vulnerable to the groundwater conditions because, even if a cut-off by means of a vertical grout curtain had been successfully made, the formation of the anchored tension piles which were drilled down into the rock or the deeper water-bearing gravels would have been virtually impossible to construct even if the vertical grout curtain had been completely successful. It was a personal disappointment for me that, with all the geotechnical processes available, my firm was unable to suggest any method which would overcome the groundwater problem at a cheaper cost than the wet construction method which was finally adopted.*

Mr J. M. Fenton, F

I may have missed the point in the Paper, but would the Authors comment on the nature of the water in the harbour, that is, its salinity? This is important when concrete is poured in the water.

Mr P. J. Claridge, Senior Contracts Engineer, Sir William Halcrow & Partners

I find it surprising that, after three separate site investigations, the dredging apparently

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ran 12 months over time, owing to material being encountered which was too hard for the dredger. Why had this not been more thoroughly investigated by a fourth site investigation to ensure the matching of the plant to the ground?

135. Did the Contractor ultimately finish later than the revised completion date? If so, was he charged liquidated damages? More important, the word 'frustration' was used by the Authors in the sense of 'trials and tribulations'. I wonder if 'frustration' in the legal sense was ever an issue. Was the original contract ever considered as having been frustrated, and did the Contractor recommence under a new contract or was it the same contract under which he faltered and then carried on after the period of delay?

A speaker

Referring to the terminology in the Paper, did the Authors mean a hard angular rock which was cemented by clay, and not a conglomerate?

Mr T. N. W. Akroyd, M

I wish to refer in particular to the leakages and the lifting of the floor which occurred near the entrance and adjacent to the dock sill. The majority of the leaks occurred within the area of the dock floor where it abutted the entrance sill Prepakt concrete. The leakage positions did not extend for a distance from the dock entrance greater than up to the end of the first caisson. The leaks were thus associated with the junction between the dock floor Prepakt and the entrance sill Prepakt.

138. The Authors suggest that the leakage was caused by problems arising from the grouting techniques and the problem of water pressure.

139. The grouting techniques described in the Paper include that of the cold joints produced by the 36 hour interruption of grouting at the weekends. However, the major cold joint was between the Prepakt concrete to the sill floor with its sloping interface and the Prepakt concrete to the main dock floor. The sill floor was grouted two months before the grouting was started for the dock floor itself and it would not be unreasonable to have expected difficulty with this joint. Unless the bond between the sill floor and the remainder of the dock floor was sufficient to prevent all leakage on that face then it followed inevitably that the sloping form of the joint permitted full sea water pressure to permeate over the joint.

140. In connexion with the lifting of the dock floor the Authors refer to a differential pressure between groundwater and the sea—I think that cannot be right. Not only is there no evidence of a differential pressure between fresh water and sea water but there is no need for the postulation of such a phenomenon.

141. To account for the lifting of the dock floor, consider the facts: the dock could not be constructed in the dry because so permeable is the sea bed that an attempt to lower groundwater level was found to be equivalent to trying to pump the Mediterranean dry.

142. Second, the junction between sill floor and the main dock floor was a long, low, sloping surface.

143. Third, the difficulties of cleaning the surface of the grouted floor in the dry led the Authors to the conclusion that the bond between the sill and the main floor could not be 100%, and finally the normal pressure from the sea water, when the dock was first pumped dry, was sufficient to lift the dock floor. On these facts, a further source of high pressure water, namely the flow of fresh water from the land, need not be postulated.

144. However, in regard to the differential pressure between the groundwater and the sea (§§ 98 and 99), a careful analysis of what this means is that at the time of the grouting there had to be a sufficient differential between the fresh water from the main land and the sea water pressure to cause the fresh water to percolate through the various layers of marine conglomerate, beach gravel and similar materials which formed the sea bed so as to cause the washing out of the grout in the 7 m of stone dumped on

the sea bed. If one visualizes the effect on the advancing face of grout shown in Fig. 8, then one is forced to postulate some continuous channel which is momentarily blocked by the grout but into which presumably the grout did not flow because of the hydrostatic pressure of the fresh water. Why the fresh water should continue to force its way through the grout when one can see from Fig. 8 it would flow through the ungrouted stone, I am not sure, but apparently one has also to postulate that this effect on the grout was not noticed although the Contractors took particular care with at least two methods of sounding to determine the level of the grout during the grouting process. Further, because it was known that a layer of silt over the dredged sea bed had formed as a result of the sea bed, then the existence of flow channels of fresh water would have been noted when the grouting was first started. There is a problem of timing in the grouting technique as to when this fresh water leak occurred.

145. The samples of water found leaking through the dock were not fresh water but a dilution of about 85% sea water and 15% fresh water. For fresh water to mingle with the sea water then the fresh water outlet had to have a substantial connexion with the sea and this would have permitted a substantial reduction in the pressure of the fresh water. However, once one formulates a connexion with the sea water then one brings into account the normal hydrostatic pressure of the sea water itself. Instead of running into difficulties in postulating a differential hydrostatic pressure between sea water and fresh water in which one must hope for reduced barometric pressures, if one assumes that there were some cold joints upon which normal sea water pressure acted and if one considers then the behaviour of the dock floor and the stresses induced upon dewatering, one arrives at a much simpler solution as to the causes of all the leaks.

146. The lifting of the dock floor was associated with the major cold joint and the minor leaks were all in the same area, at the entrance to the dock. An analysis of the stability of the dock floor at the time when it was first dewatered, when the dock wall caissons had been filled but the area behind them had not been backfilled with earth and when sea water pressure was present on the outside of the dock walls, indicates that since unit self-weight of the dock floor was less than the uplift due to sea water pressure, then the stability of the floor depended upon the reverse arch-thrust developed within the thickness of the floor and this in turn depended upon the stability of the dock walls. One finds from such an analysis that the safety factor against movement depended on the density of the grouted concrete.

147. If one analyses the situation when the dock was first dewatered and takes the total depth of grouted floor, but not including the reinforced concrete floor later placed on top, then for a density of concrete of 147 lb/cu. ft one finds the floor is just in a state of balance with a safety factor of 1. This safety factor increases rapidly until a maximum density of 155 lb/cu. ft is reached when the safety factor is 2. The total quantity of grout placed represented a voids ratio of 35-36%, some 4-5% less than the full density which could have been achieved if all the voids had been grouted and the full depth of 6.9 m was grouted. However, 4-5% represents 6-8 lb/cu. ft and, deducting this from 155 lb/cu. ft, brings the probable density depth very near 147 lb/cu. ft and a safety factor of 1. If, in addition, there was some effect due to the silt layer on dredged sea bed reducing the total thickness grouted then it is clear why leaks took place and why they took place near the sill entrance. In that position the hydrostatic effect of the normal sea water level was more likely to communicate directly with the permeable layers beneath the dock floor.

148. If one makes a similar calculation for the dock sill with its Prepakt concrete then one finds that the dock sill Prepakt concrete was not critically dependent on the thickness of the material grouted or on the density achieved; this is simply because of the dimensions of the concrete in the sill and the sizes of the caisson walls. Analysis of the predictable effect of the uplift force beneath the dock floor accounts for the uplift of the floor and the leaks.

149. If I appear critical of a particular part of the Paper it is because I think that

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the Authors are putting forward theories which, in geotechnical terms, are very difficult if not impossible to substantiate, while ignoring the reason expected to cause a dock floor to leak where it is known that the underside of that dock floor is subject to full hydrostatic pressure of the sea water when the dock is first pumped dry. Finally, I would like to pay tribute to the Royal Netherlands Harbour Works Co., whom I believe carried out a first class job and I am full of admiration for some of the techniques they adopted on a very difficult site.

Mr I. M. Varley, Partner, T. F. Burns & Partners

As one responsible for the checking of the Contractor's calculations, I would like to comment. The dock floor with the triangular cross-section behind the sill was naturally not stable in itself if subject to water pressure over its lower surface. For one reason or another water pressure had developed over this area and the upward movement had taken place mainly at the apex of the triangle as would be expected. The design had made an assumption, which had been confirmed by site tests, that there would be adhesion between the triangular portion and the concrete below; this unfortunately proved not to exist. There appeared to be no evidence that the whole floor had lifted appreciably as inferred by Mr Akroyd.

Mr L. P. Hill, F

Many interesting contractual and legal problems must have been engendered by the breakdown of the original Contract. These might have taken years to resolve, but they appear to have been settled amicably and expeditiously, probably due to the relationships peculiar to a design and construct contract.

152. It is interesting to note that in one sense the Client benefited from the delays, in that he was able to alter the design criteria to accommodate the rapid escalation of shipping sizes taking place at the time.

153. Would the Authors give some further information about the method used for plumbing the caissons with a light source and ring?

154. With regard to the dredging and the attempts to break up the material, had a mechanical rock breaker been tried or contemplated? Air/steam or diesel operated piling hammers fitted with rock breaking shoes and mounted on a floating rig had been used successfully elsewhere.

155. It was not clear if the bedding under the caissons was grouted. Partial intrusion of grout from both the floor and the spaces between caissons could lead to subsequent uneven settlement of the caissons.

156. The over-height portions of the caissons were demolished before final dewatering. Was any structural provision made to assist this? Could temporary or demountable bulkheads have been used to save demolition?

Mr G. H. Cochrane, Taylor Woodrow International

Would the Authors describe the terms of reference of T. F. Burns & Partners when they were appointed as Supervising Engineers? Were they asked to check the Contractor's design and his method, or did they accept the Contractor's specification and design, and ensure that the job was constructed accordingly?

158. In particular, was the procedure for joining the underwater concrete of the floor with the concrete under the intake structure approved by the Supervising Engineers?

159. If the Contract had been designed by consulting engineers in the first place and had been put out to tender on the basis of the site investigation that was performed, do the Authors feel that the standard clauses in the International Conditions of Contract would have covered the Contractor or would the usual clause in the specification, which says that the contractor shall satisfy himself that the ground conditions are exactly in accordance with the boreholes, have been brought into use?

Messrs Martin and Irvine

In reply to **Mr Land**, the site investigation appeared initially to have been carried out with every care and attention and, in fact, subsequent site investigations have shown up no new information on mechanical or physical properties of the subsoil. While **Mr Land's** suggestion is an excellent one for many soil conditions it seems doubtful if any further data on mechanical properties could have been obtained in this case. However, since it would have been necessary to undertake a small dewatering operation to allow the geologist to enter the large diameter hole it is quite possible that the dewatering problem would have been brought to light. The method of grouting the **Prepakt** concrete in the dock floor was initially tested and shown to be satisfactory. Of the various cores taken in the **Prepakt** after the completion, the voids which **Mr Land** predicts were not evident. The porosity of the **Prepakt** appears to be at random locations which we suggest would not indicate a fundamental fault as **Mr Land** suggests.

161. We agree that the continuous pour did create a number of problems, not least may have been the risk of siltation. However, the extra cost of shuttering is large and it is doubtful if it could be justified by reducing pumping costs due to leaks. The cost of remedial works can be high but generalization is difficult. If shuttering is used we do not believe that overlapped pours are necessary or desirable. It is better to create vertical joists and use a water bar; if there is any subsequent leaking the location of the leak is well defined and can be dealt with more easily.

162. The pumphouse caisson was approximately twice the plan area of the normal wall caisson with a permanent central division wall. Other stiffening walls were included but were designed to be removed after the caisson was placed and the internal works built. About 2000 m³ of concrete were placed in the caisson to form suction and filling valve chambers, winch pits and roof, etc., giving the structure negative buoyancy when dried out.

163. We would like to thank **Mr Tomlinson** for his valuable contribution and feel that he has answered better than we could, some of the questions relating to the first and subsequent site investigations.

164. In reply to **Mr Claridge**, the difficulty with the dredger seemed to be a surprise and disappointment to all concerned. It was quite capable of dredging the majority of the material but the cemented bands of gravels in some respects caused more trouble because they were located at random locations and levels. It was when the dredger buckets were caught under the layers without prior warning that much of the damage occurred.

165. The Contractor did finish some weeks later than the revised completion date due to the leakage in the floor and liquidator damages became a matter of discussion between the Contractor and the Employer.

166. The second contract was a new contract in the legal sense but it will be appreciated that the Employer insisted on many of the same rigid terms as were contained in the first contract.

167. We were interested in **Mr Akroyd's** long and detailed explanation of the cause of leakage of the dock floor but we still believe that the problem is not as simple as he suggests. His arguments are based on certain assumptions which we suggest are not quite accurate and thus his theory breaks down at these points. First, the leaks were not all associated with the dock entrance and occurred at various places in the dock at apparently random positions not even in relation to the 36 hour 'cold' joints. Second, **Mr Ackroyd** assumed, in his calculations, that the area behind the caissons had not been backfilled when the dock was dewatered. As will be seen in **Fig. 11**, the backfilling was almost completed before the dock was dewatered and was certainly sufficient to provide all the active and/or passive pressure required by **Mr Akroyd's** analysis.

168. We accept that the possible presence of silt would initially lead one to assume that this may have been the cause of the trouble at the joints. However, it was the

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leaks in the body of the dock remote from the entrance which led us to consider other possible causes, and the differential pressure between the groundwater and the sea appeared to be a cause worth investigation.

169. There was no doubt that such a pressure difference existed at least at certain times since, when the cofferdam was removed, there was an obvious difference in head between the water contained behind the dam and the sea. The significance of this was not noted at the time.

170. We do not postulate that there is an upward flow of water spread over the whole area of the dock bottom but we suggest that it could occur at defined points possibly related to water fissures in the rock below. Our theory does not require that the water need be 100% fresh. It would be expected that with changes in sea level there would be intermingling of sea and land water and an analysis showing any fresh water content would help to confirm the theory.

171. Having established that an upward flow of water at localized points was possible, it follows that this could disrupt a thin layer of grout immediately it is placed. This would continue as further grout is placed thus forming a vertical shaft of poorly cemented aggregate which would ultimately become a leak. As a quite separate condition it follows that such a flow close to the sill could be a contributory factor in causing a leak or bad bonding between the sill floor and the main dock floor. It did not require anything approaching 100% bond between the two layers for stability but once the bond was totally broken the subsequent lifting became inevitable.

172. In reply to **Mr Hill**, no attempt was made to break up the material with a rock breaker. This was contemplated at one stage but we assume that the Contractor decided that the cost of importing this equipment could not be justified.

173. The bedding of the caissons was not specifically grouted but no sign of differential settlement of the caissons has been noted.

174. The demolition of the over-height portion of the caisson was remarkably simple and the debris was allowed to fall through the water into the flooded dock without fear of injury to personnel.

175. In reply to **Mr Cochrane**, the terms of reference of the Supervising Engineers were given in two stages. The Engineers were first appointed at approximately the same time as the Contract was signed so that the initial terms of reference were simply to supervise the job as designed and specified by the Contractor.

176. The Contract having failed, the Supervising Engineers' terms were extended to assist in negotiating a new contract. This included supervision of the preparation of a new design and revised Contract documents. The Employer naturally insisted that the Conditions of Contract be similar to those in the original Contract.

177. The procedure for joining underwater concrete of the sill and main floor was only agreed to after tests had shown that the Contractor's proposals were likely to be satisfactory.

178. Although the question is hypothetical we feel that, had the standard clauses in the International Conditions of Contract applied, the Contractor may well have been successful in a claim for unforeseen conditions.