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7728 DISCUSSION

Underwater drilling and blasting for rock dredging

J. L. ABRAHAMS

Mr C. C. Marshall, Sir Alexander Gibb & Partners

Reference is made to the effect on cost of blasting restrictions to protect property. In the Author's experience are such restrictions usually included in the terms of contract, or does the contractor have an opportunity of agreeing safe levels once work begins?

Mr P. Jubb, British Transport Docks Board, Swansea and Port Talbot

In the summer of 1967 I was working on the Resident Engineer's staff at Milford Haven upon phase I of the entrance channel improvements. Underwater drilling and blasting such as has been described in the Paper was carried out from a floating pontoon.[11]

76. Up to this time in most harbours, drilling had only been necessary in sheltered and comparatively shallow water. Crude carriers had only just exceeded 150 000 dwt and the problems facing most authorities were ones of deepening berths and enlarging turning circles. These works adjacent to marine structures lost very little constructional time due to wave action or high currents. Shotholes could be safely drilled at relatively close centres and limitations on the size of the charge meant frequent blasting. This allowed the contractor if necessary to recommence drilling closer to the last shothole line, thereby achieving good fragmentation. In only 10 m of water, drilling and blasting with good rates of production was considered an achievement in 1965.

77. When it became obvious that 300 000 dwt carriers with laden draughts up to 20 m were a realistic prospect, much more attention was focused upon the entrance channel at Milford Haven and on its associated navigational problems. Working at those depths and in less sheltered conditions meant that sometimes only one day in seven might be suitable for drilling from a floating drilling pontoon. Tidal and wave influences on pontoons add to increasing problems of bending casings, and shothole centres must be larger for safety. To achieve the necessary degree of fragmentation depth, the shothole must also be deepened, adding to the drilling time. This, in an already restricted time schedule, can prove expensive.

78. At Milford Haven when phase II of the entrance channel improvements was put in hand, the contractors elected to use a fixed structure with spuds to improve the performance at the most exposed locations off St Ann's Head and the mid-channel rocks, in preference to a floating pontoon. I suggest therefore that drilling pontoons, whilst valuable, are limited in their use, and generally in deeper waters fixed structures with spuds are still the answer. Perhaps the Author could give some guidance on the choice between the two alternatives.

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79. Milford Haven presented a further difficulty, this one geological. The ria of Milford Haven and the surrounding coastline of Old Red Sandstones and marls form many striking geological formations. The folding of these sedimentary rocks often means that bedding planes dip at 45° or more. Cleavage associated with the folding is also very marked. The result is that the rock bottom to the channel off St Ann's head is of a saw tooth nature. A great deal of trouble arose from the fact that casings slid down the bedding or cleavage planes, rather than biting into the rock in position. Casings were often bent irreparably, causing delays, the shothole grid pattern became more random and a distinct reduction in the degree of fragmentation was noticed.

80. Once a rock bottom has been blasted, redrilling at some future date, either to improve local spots for dredging or for an overall channel deepening, is likely to prove very difficult in certain types of rock, as fragments will fall into the new shothole. In the Author's experience, how much site investigation or trials prior to works are done, and how far should port authorities drill and blast to depths beyond their present needs to cater for future programmes?

Mr R. F. McCormick, Imperial Chemical Industries Ltd, NEC

I was particularly interested to see the improvements that have taken place in drilling practice and also in the procedure adopted for retrieving the Cordtex leads. Years ago the Cordtex was attached to a cork float and, after removal of the drill pipe, one hoped that the cork would reappear in a suitable place for ready retrieval, but there were times when it was traced inconveniently to beneath the barge itself.

82. I should like to ask a question on the subject of vibration. I was surprised by the limitations which were set in respect of the operation in the south of France at maximum particle velocities of 40 and 60 mm/s for a quay, when Table 3 indicates that velocities of 100–150 mm/s might result in only minor damage being sustained by residential structures. Were these restrictions realistic or were the French engineers a little demanding in the standards which they stipulated? Further I should like to ask the Author what are the typical complaints that he receives from conservationists and people who are against the noise often associated with blasting operations?

Mr D. Shennan, Haswell & Partners

Towards the end of the war in Europe the Royal Engineers had the task of clearing away sufficient of the wreckage of the many bridges in the British sector of the Rhine to enable civilian barge traffic to resume. The only floating cranes were upstream in the American zone or downstream in Holland and none was available.

84. A navigation gap some 80 m wide was cleared at each bridge site by the use of ex-German naval depth charges, each containing about 50 kg of explosive. These were dropped from a converted infantry landing craft in groups of 8 or 10, only one being primed. They were fired electrically, when the craft had moved upstream to a safe distance.

85. Results were very satisfactory and I wondered why the Author had such a strong preference for Cordtex. Is this because of a greater depth of water?

86. I would also like to refer to the problem of driving piles into rock at Milford Haven. Before piling commenced the area affected was drilled and blasted to a depth of some 5 m and left in its loosened state. Driving of both vertical and raking piles up to about 1 m in diameter and 20 t in weight was carried out subsequently with complete success.

Dr J. Markland, Ove Arup & Partners

There has been much interest recently in the influence of natural discontinuities upon the blasting operation. In particular, I have been involved in an underwater blasting problem where they may have been important.

88. It is generally understood that, under water, more explosive is needed per cubic metre of rock than on the surface. Does the Author think that the presence of water is a problem because it is in the natural discontinuities, or is it because it increases the total stress level where blasting is taking place? Is the inertia of the water a problem in that it reduces the throw obtained with a certain amount of explosive?

Mr J. Errington, Chairman of the Association of Underwater Contractors

Many of the members of my Association are smaller diving contractors or civil engineering contractors who often have a problem of the removal of small amounts of rock for local harbour authorities. The amounts are of course much smaller than those the Author mentions. In many cases they have used—not very satisfactorily—the plaster shoot method as mentioned in the Paper. It would be interesting to hear from the Author his experience with shaped charges, as we have done experimental work with these.

Mr R. W. Flint, British Petroleum Company

I should particularly like to ask whether the Author is prepared to give details of the detonators used, together with the precise means of initiation employed. The detonators appeared to be initiated on the open deck of the barge and not 2 or 3 metres under the water to prevent fragmentation, as is the usual practice in all such works carried out offshore for British Petroleum.

91. I should also like to know the percentage of misfires which have occurred using the particular type of detonators employed and how these have been made safe.

92. Further I should be most interested to learn of the safety requirements which the Author and his company impose on the works with respect to the handling, storage and transportation of explosives offshore, bearing in mind the limitations of the present Explosives Act, and having regard to the new legislation which will be coming into force under the provisions of the Mineral Workings (Offshore Installation) Act.

Mr D. L. Martin, British Petroleum Company

I am particularly interested in the passages of the Paper dealing with water-borne shock waves and the damage that can be caused. Two different effects may be distinguished; first the local ones of the shock-wave on individual members, and secondly the vibration induced in a complete structure.

94. For a structure with tubular members, such as a piled jetty or an offshore platform, it would seem that when the hollow members are filled with water, shock-waves pressures are unlikely to cause implosion; however, there is a possibility of undesirable vibration in the structure as a whole. When the hollow members are sealed, with merely air inside, the possibility of implosion also arises. These different problems have been demonstrated in trials.

95. As an example of vibration of a complete structure, on one particular job involving surface blasting of the seabed near a piled dolphin, the vibration recorded on the dolphin deck was attributed mainly to the water-borne shock wave. The associated frequencies were surprisingly low, less than from typical ground vibration, and although the amplitudes were perhaps rather high by normal criteria the particle velocities were safe.

96. Perhaps the Author could give some more information on the further studies mentioned in § 61, concerning secondary effects.

97. Where explosives have been used in offshore applications in deep water it is normal practice only to move a work-barge away from over the top of a shot for heavy charges, for instance, perhaps for 10 kg in 100 m of water. The effect of moving the barge appears to reduce the damaging effect of shock waves, not so much by virtue of distance but because the shock waves strike the bottom of the barge obliquely. Table 4 presumably gives true distances with the pontoons moved away before shoot-

ing. Under what conditions of charge weight and depth would the Author permit a pontoon to remain over the shot position?

Mr J. F. C. Swansbourne, Posford Pavry & Partners

I should like to make some comments on jack-up platforms. I am speaking primarily of jack-up platforms used in unsheltered water where the sea state is likely to be too onerous for floating craft. On the credit side the platform offers a stable base from which a more accurate drilling pattern can be maintained. It permits operations throughout a period of normal rough sea, but only for so long as it takes to complete the area of its field of drilling.

99. On the debit side, it is more unwieldy and more costly to mobilize and to hire than a floating barge, and from experience its daily output is less during periods of weather in which a floating barge can operate. Time is lost in jacking-down for detonation and subsequently in jacking-up. Time can be lost during a storm if the platform has not been removed for work in calmer water. Also, if it is not jacked down and the explosive charge detonated at the beginning of a rising storm, there may be some doubt as to subsequent and possible dangerous behaviour of the already placed charges.

100. Still on the debit side of operation, a platform covers a rectangular drilling field which is not fully utilized when working round the perimeter of an irregularly shaped area. A platform needs to comply with the requirements of Lloyds or other certifying agencies. A structure would not be permitted to jack down in seas greater than 2 m, and circumstances may easily occur where equipment must ride out a rising storm. To meet this condition it may be required to withstand a maximum likely 50 year wave for the area.

101. I now refer to the operation of a platform in an unsheltered environment on the Milford Haven project where some of the rock shoals were possibly too rough and irregular for the operation of drills from a floating barge and, as the job was urgent, where the contractors felt the need to mobilize plant which would guarantee their progress through periods of bad weather.

102. The platform they mobilized had a drilling field of 400 m^2 and was mounted with six drilling rigs which in normal conditions should enable a cycle of jacking and drilling to be repeated every two days. The platform was mobilized in the autumn and started work over the most difficult area, on the east side of the entrance to the Haven, where it had 3000 m^2 to cover. Owing to the irregular shape of the shoal, fourteen movements were required and the work took ten weeks to complete, including the time for tooling up and getting accustomed to the difficult conditions. In the following spring it covered 3000 m^2 on the western entrance shoal and made better progress with nine moves in seven weeks.

103. On these occasions it was achieving a cycle of six days and five days respectively, which indicates that the imperfect working conditions caused a reduction of at least 50% in its expected output.

104. During the intervening period the platform operated in semi-sheltered conditions alongside a floating drill pontoon where its output in terms of holes per day compared unfavourably with that of the floating craft.

Mr B. O. Skipp, Soil Mechanics Ltd

I was interested in the comments made earlier by Mr McCormick of ICI, regarding the levels of vibration to which the Author's company had been constrained to keep on the continent. I noted the difference between the levels which the Author thought would be acceptable, and those to which he ultimately had to work.

106. There is an enormous discrepancy between the standards which have been normally worked in quarrying in the USA and mining operations in Britain, and those favoured for some years in Germany and France. So far I do not think there has

been an adequate reconciliation of these two quite disparate levels. The tendency on the continent—and increasingly in Britain—is to look upon vibration acceptability not in terms of damage, but in terms of a kind of threshold of intrusion.

107. To some extent it can go to ridiculous extremes, and in normal circumstances industrial buildings in the environment of a marine blasting job would tolerate somewhat higher levels than those which have been quoted so far. But undoubtedly the lower level figure is receiving a certain amount of support in other areas as that at which there is a possibility of a minor blemish developing in a non-structural element.

Mr W. R. Miller, Edmund Nuttall Ltd

I would like to refer to two jobs, Great Harbour at Greenock and at St Helier in Jersey, where damage occurred to permanent structures. In both cases the permanent works were constructed considerably above the dredged level. I think in Jersey the dredged level was some 4–5 m below the level of a very old gravity wall. The technique used was to presplit, and then to creep gradually back to the line, but the material beneath the wall collapsed. In other words, the presplit was ineffective.

109. This problem is not so much a question of limiting vibration. I think it can be assumed that the Author's company—perhaps the most experienced in this field—took all the care that one could take, and monitored all blasts. It probably means that in a case like this, other measures have to be taken first; the rock from beneath that wall should have been retained in another manner before the blasting actually took place.

110. I am particularly interested to hear the Author's comments. Fundamental design is the most important consideration in such cases, but there is this alternative problem that the technique of breaking rock back to a presplit line cannot be relied on. This has been experienced on land but at least with land it is possible to see that the presplitting is not working.

111. Presplitting is a very useful tool, but it does not always work. I would be interested to hear the Author's views on the use of air bubble curtains in such cases. Does he think they would be useful, or would they make very little difference?

Mr F. A. Askew, Westminster Dredging Company Ltd

In the conclusions the Author states that consultants may be surprised at the considerable difference in price between drilling and blasting under water and on land. The same sort of difference exists regarding site investigation costs and this may account for the limited site investigation information given on marine works. For a motorway there would be ample information on boreholes, soil tests etc. For dredging 500 000 m^3 probably 20 boreholes would be the most available. The cost of site investigation on marine works is high; therefore it is limited in scope. This places the onus on the dredging contractor to obtain further information, and the same problem may exist for the blasting contractor in assessing any variations that may occur on site.

113. Does the Author usually have sufficient information at the time of tendering? If not, does he feel that extra investigation costs are justified? Is there time to carry out the additional investigation and what factual information would he want from such an investigation?

The Chairman, Mr H. R. Oakley

As a supplementary I would like to ask the Author whether he is prepared to quote a fixed price, and under what conditions?

Mr B. Clark, Bernard L. Clark & Partners

I should like to ask if the Author has experimented with an inflated tube over the line of shot blasting? My firm used this some years ago in dealing with a bridge near

Weybridge. There was no permission for blasting, so I carried out some experiments beforehand, using 225 mm dia. deflated plastic tubing, weighted down and then inflated over the line of blasting. Operations started one morning before anyone was up. We were reprimanded by the local police a few days later for not getting permission. The tube made a considerable difference: effects of the explosion above the waterline and shock effects were almost negligible.

116. One great advantage with underwater work is that nobody can see the end result. There may be a complete mess, but providing everything has been removed according to contract, nobody will question the appearance!

Mr J. O'May, Seadrec Ltd

Presumably once a drill pattern has been fixed after site investigation, the rig is then set to the drilling patterns. The drill rigs seem to be mounted across the well, and do not seem to have a great deal of transverse mobility. Are these rigs specifically designed for a particular job: that is, if the job requires a 2, 3 or $1\frac{1}{2}$ m pitch, are the rigs specifically designed for these limits? Have raked drilling rigs been used offshore, and if so what problems have arisen?

Mr Abrahams, Dr Westwater and Mr Morrison*

In reply to **Mr Marshall**'s question of cost vis à vis permitted level of vibration it can be said in very general terms that if permitted levels of vibration are reduced by half then the explosives which can be used are reduced by one half squared, i.e. to a quarter of the original value. Consequently, the effect on costs can be very marked.

119. In particular, if restriction in permitted levels of vibration are such that the full depth of rock to be blasted cannot be taken in one pass and has to be taken in two passes, then costs can soar to 60% more than what would normally be expected. However, if it is only a question of reducing from firing eight holes at one time to firing two holes at one time the increase in cost is less marked—probably of the order of 10–15%.

120. In reply to **Mr Jubb**, Rock Fall came to the conclusion that except in very specific cases, jack-up platforms for drilling and blasting are not the answer. There are problems. They are wonderful to work on when up, but introduce a tremendous number of complications. It is necessary to jack up the platform perhaps 70 ft above low water, and if working in 100 ft of water, there is immediately an extra 70 ft of Cordtex. If the weather changes, and if there is more than 7 ft of wave, again it is impossible to jack up or down. Being caught out with perhaps a hundred Cordtex leads and a platform which cannot be got down for ten days, produces a marvellous spaghetti pattern and the Cordtex is damaged. It is a great job to find the holes afterwards. Platforms are also very expensive compared with the ordinary flat top very heavy duty barge.

121. On the question of irregular geological formations which have saw-tooth configurations, this does cause problems in respect of collaring drill holes correctly. Previous treatment by shaped charges or surface charges to level the particular area out to some extent would be of help in ensuring that the holes can be collared correctly.

122. In reply to **Mr Swansbourne**, there has been much further development and there is no doubt that the modern type of heavy flat top barge under ideal calm conditions outstrips the jack-up platform except in very specific instances.

123. In response to **Mr McCormick**, Rock Fall uses a phenomenal amount of Cordtex, about half a million feet a year; but, although the price is high, it is an excellent method of detonation and very safe.

124. **Mr Flint** asked about safety regulations. These are basically the Company's

* Dr Westwater is the explosives expert and Mr Morrison the Director for marine matters at Rock Fall Co. Ltd, and assisted Mr Abrahams in the reply.

own as there is no detailed legislation under which to act as far as the use of explosives on board the barges is concerned. For storage and transport the requirements of the Explosives Regulations are met: usually the Company provides its own magazines and sometimes its own explosives transport. It has produced a safety and instruction manual and these rules and regulations are strictly adhered to. Taking 24 h/day, 6 days/week for 50 weeks/year, the Company uses between 400 and 500 lb of explosive every hour, and you can never afford to take any chances. Safety regulations must be absolutely perfect.

125. On misfires, it is rare to get a complete failure but partial failures must occur from time to time. Cordtex is occasionally seen in the dredged material, probably due to holes detonating sympathetically and cutting off the Cordtex lead. The finding of whole or part cartridges of explosives is almost unknown.

126. In reply to **Mr Martin**, the barge is always pulled back 100 m whether it is a ton or 50 kg of explosive.

127. It is good to hear from **Mr Shennan** that, after all these years, the job at Milford Haven was very successful.

128. There is a place for plaster shooting and shaped charges. The Company uses them from time to time and, providing the rock is not too hard, they are economical up to a depth of $1\frac{1}{2}$ m. With the softer rocks shaped charges can be used. What must be avoided at all times is the risk of leaving undetonated explosives under water. This is one of the reasons everything is fired by Cordtex because then there is no detonator in the hole. All detonators are attached to Cordtex for both instantaneous and delay firing: they are lowered into the water just below the surface.

129. In reply to **Mr O'May**, although it would appear that these barges have fixed centres in one direction, the drill pattern is established early in the contract. Initially limited charges are used and built up to what the contract will stand, and vibration is monitored throughout the contract. But there are all sorts of methods of varying the drill pattern throughout the entire period of the contract. The pattern is varied continuously to get control of fragmentation and to save costs.

130. The question of Jersey is *sub judice*, but the facts given are not right. After ten years of this work in all parts of the world, it is the first contract on which the Company has ever had trouble. **Mr Miller** also mentioned another at Greenock but Rock Fall was not the contractor; we went in afterwards to complete the job!

131. Regarding air curtains, these have their uses and they do reduce the waterborne shock waves as shown in Table 5.

132. **Mr Jubb** and **Mr Askew** raised the important question of site investigation. We agree that site investigation would pay a client well. There is never enough time for it. The time in which to tender for a contract is always limited and there is no time to do coring. Where other structures are involved, the more information the more success can be ensured and the more accurate the pricing.

133. In reply to **Mr Oakley**, our organization would normally be prepared to quote a fixed price if the client guaranteed the quantity, quality and depth of rock but in the current climate there would need to be some protection against inflation.

134. **Dr Markland** raised the question of charging ratios. The ratios used under water are fairly widely scattered, but they are not more scattered than in some of the hydro schemes' tunnels. The reason for blasting heavily under water is, first of all, the weight of water, which is considerable. Secondly, blasting is almost always off the solid and not, as in most surface blasting, blasting to a free face. Thirdly, the rock has to be bulked or the dredger will have a difficult task in picking it up. The better the initial blasting the greater the dredging performance and the less frequently is reblasting required. The same applies to drilling below grade. It is most important that the dredger is not left with a foot or six inches to pick up which it cannot get down to grade.

135. Mr McCormick asked about the vibration restrictions in France. Initially Rock Fall was asked to work to a maximum velocity of 20 mm/s, and it was only after

considerable discussion and bringing in the test group that it was possible to have the maximum velocity increased to 60 mm/s. The Paper gives some of the results obtained. The client was concerned about settlement. This jetty was constructed of circular casings which were floated in and then sunk. About 600 rounds of shots were to be fired, and the fear was that every time a shot was fired the casings would settle a little. This is unlikely, and the literature suggests that several million vibrations would be necessary before settlement would be noticeable.

136. Referring to **Dr Skipp**'s remarks in the discussions with the French authorities, they gave us two velocity levels—one below 10 cycles and the other above. The French studies are reported to have found that where very low frequencies occur damage may be caused by relatively low velocities, but they agreed to one important thing: that there is an appreciable scatter of the readings and in fixing working limits it is preferable to state an average and a maximum velocity level, otherwise the restrictions on the charges used will be more severe than necessary.

137. On the questions of the water-borne shock waves asked by Mr Martin, the distances given in Tables 4 and 5 were the horizontal measurements between the shot points and the barges in Table 4, and the instruments in Table 5. Golfe de Fos was the first occasion on which there were actual pressure measurements made to compare with the values calculated from the tables given in refs 7 and 8.

138. It should be possible to estimate the risk of implosion of a hollow tube by using these tables to calculate the peak pressure and impulse of the water-borne shock waves for different charges, weights and distances. Experience in the Tees tunnel showed that dilation of the lining did occur when the charges were detonated. In this case the tunnel was below the charges so the shock waves were through the ground rather than the water. In jetties, there are two waves, the first arrival being through the ground and the second through the water. The explosive is mostly in shot holes so the water-borne shock waves are appreciably reduced.

139. Until two years ago it was not possible to get suitable field instruments for direct velocity measurement and the velocity had to be calculated from the amplitude and frequency recorded by the Cambridge and Combigraph instruments. It is now possible to measure velocity directly and take the recordings on top of the quays. When a suitable opportunity arises it is hoped to measure also at the base of the quay wall.

Reference

11. Swansbourne J. F. C. and Dudley G. The development of Milford Haven. *Proc. Instn Civ. Engrs*, 1971, Suppl. 307–332.