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8200 & 8242 DISCUSSION

Harbour works at Brighton Marina:

Investigations and design

F. L. TERRETT, P. GANLY & S. B. STUBBS

Construction

T. J. LLEWELLYN & W. T. MURRAY

Mr Terrett, Mr Ganly and Mr Stubbs

Paper 8200, presented jointly by the Consulting Engineer and the Contractor, results from the very close collaboration between the two since the late 1960s. By this time the earlier investigations and model studies had been completed and the main features of the harbour had been settled, and both Parliamentary powers and outline planning approval had been obtained.

2. In view of the length of time taken by these events the Marina Company was advised to negotiate the construction of the breakwaters so that preparatory work could proceed on site concurrently with design of the breakwaters, to which the Contractor could contribute from his own resources and expertise. It was, in fact, the Contractor who suggested the caisson form of construction and he carried out the design of the breakwater caissons and superstructure to the Engineer's approval and to design parameters specified by the Engineer.

3. Special clauses were written into the contract covering this arrangement and defining responsibility for design and there was a clear line of demarcation between the two. In practice, all stages were studied jointly, the Contractor being intimately concerned with the hydraulic model testing from which the design parameters were derived, and the Consultant being involved in the choice of loading cases and caisson design.

Mr Llewellyn and Mr Murray

The main consideration, both in the construction planning and in the actual execution of the work, was always the fact that we were working on a very exposed part of the coast where the sea conditions could change quickly. If complacency developed it was inevitably short-lived.

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5. One of the main attractions of the caisson method was the fact that we could in four days secure an advance of 13 m and not worry what storms or the sea could do on the fifth day. The problem when pricing the work was to evaluate how many such occasions of four days of calm weather would be available in a typical year. After studying the available records for the area we decided that there were 40 such occasions in a typical year. In practice, this worked out well for the west breakwater but less satisfactorily for the east breakwater, due largely to the untypical weather in 1974. Nevertheless the average length of caisson advance throughout the entire caisson placing period was 8 m/week; which was only slightly less than the planned advance.

Mr D. Hodges, The Louis de Soissons Partnership; Architect for the Brighton Marina Complex

Close collaboration between architects and structural engineers has been established now for a long time, the two parties working as a team from the beginning of any conceptual design. Opportunities for collaboration with civil engineers are more rare. I count myself lucky, therefore, that I had an opportunity at Brighton of such magnitude and one which bore such fruit. I was lucky, too, to be dealing with engineers who so readily understood the importance of their product, not just in itself but as a vital element in a total architectural concept.

7. The choice of structural method for the breakwater construction was one of the first considerations with which I had to come to terms as architect and project controller. I had to come to terms with it not only because I was responsible to the company for general advice on all aspects but because I recognized the importance of the breakwaters as an attraction and an amenity for the general public. The choice of construction clearly was going to affect the aesthetic quality of the breakwaters, and this in turn would much affect their public appeal. The method finally adopted quickly commended itself to me. The degree of on-shore construction did a lot to give credibility to an otherwise much suspect programme. It allowed a higher standard of workmanship, which in a public place is important. The circular form of the caissons gave to the whole structure a unique distinction, and the possibility of combining in the design of the superstructure both hydraulic performance and an attractive series of promenades at various levels for the general public soon became apparent. Unencumbered by inhibiting knowledge of the dangers and the difficulties which might attend this somewhat novel system, I had no difficulty whatsoever in making up my mind, and I made it up long before the engineers!

8. All, however, depended on the crane—the one and only crane, lying on the Hanstholm foreshore after its long tour of duty in the Skaggerak. And so we went to see it, some to make useful observations, others of us to enjoy ourselves in various ways. As a result of this visit the crane was pronounced fit and well. But the option to buy it had not long to run, and this decision was not easy for the company to take at a time when the whole future of the project was, to say the least, uncertain. It was taken courageously, only hours before the option ran out, after which the crane would have been broken up, as indeed it was broken up immediately after it had finished its work at Brighton.

9. Despite my underlying confidence there was one nagging fear which

afflicted me. I did fear the absolute dependence on this one major piece of machinery, irreplaceable except at a cost of time and money which would have been quite unacceptable, and I wondered whether, as project controller and general adviser to the company, I should have allowed the company to run that risk, because loss of the crane would have been totally disastrous. However, it suffered no terrorist attack, and it did not topple over into the English Channel. It did its work without a hitch.

Mr J. P. Wilkins, Assistant Borough Engineer, Brighton Borough

The design paper (§ 1) refers to a Brighton study of a small harbour on the sea front. This was called for by the Brighton Planning Committee following requests from local yachtsmen for the provision of a sheltered slipway from which they could put their boats into the water. To meet this requirement, we in Brighton, assisted by Mr Jack Duvivier, proposed a scheme for enclosing some water between two existing Victorian concrete groynes, between the Palace Pier and Black Rock, but the cost—then estimated to be £400 000—was considered by the committee to be more than they felt able to spend. As things turned out, that sum was less than 1% of the money that has been spent.

11. Discussions continued in the hope of finding a private source of finance, and eventually a local business man formed the Brighton Marina Company. He collected a team of professional advisers and brought a major scheme to a planning inquiry in January 1966. The inquiry Inspector, in his report to the Secretary of State, described the project as bold and imaginative. The Secretary of State gave his approval.

12. Black Rock was chosen as the site because it offered good road access and good scope for land reclamation, and also in general planning terms it was considered that the marina there would provide a strong feature at the end of the Brighton sea front (the eastern end of the built-up area), which otherwise tended to peter out where the cliffs began.

13. Having obtained their first planning consent—only the first of many—the company had to seek Parliamentary approval. An interesting point arose during the examination by the Select Committee of the Commons, because attached to the scheme for the harbour itself were proposals for the road access. It was about twelve years before the grade-separated interchange at Black Rock was due to be built for general traffic reasons, and the lawyers felt that there was some doubt as to whether the highway authority would have the powers to provide access in the meantime. The company therefore sought compulsory powers in their Bill to acquire some cottages which were needed. The Select Committee did not like this. The company's counsel argued that compulsory powers had been given to private companies for railways, docks and harbours, and more recently pipelines. Nevertheless the Select Committee insisted that as the whole of the UK is covered by highway authorities, only a highway authority could be given compulsory powers to carry out roadworks. This was the main reason why the council had to seek yet another Bill in order that they, in their own name, could acquire the necessary powers and tidy up various other legal matters. This was the cause for seeking the Brighton Corporation Act 1970 which is referred to in the Paper.

14. After nearly 20 years now it is natural to ask whether the expenditure of so much time, effort and money has been worthwhile. We in Brighton would

emphatically say that it has and we are very pleased with the marina as we see it today.

15. Looking eastwards from the Black Rock interchange, Fig. 1 shows the marina in use in the summer of 1979. To the left is the navigation channel leading to the eastern end of the marina where the lock is sited. Alongside the water is the old sea wall built by Welsh miners during the depression of the mid 1930s as an unemployment relief scheme. The uniform 70° batter of the 30 m high chalk cliffs was cut by miners slung over the cliff top, working by hand from bosun's chairs, a thing we would not do today!

16. Some of the caissons have now been in the water for nearly seven years. Has any maintenance work, apart from the dredging, yet been needed, and if not, what is the first main job expected? Do the Authors consider that the choice of the caisson method of construction was right? Given a free choice, would they like to use similar caissons again, and if so, how was it that the caisson-placing crane was broken up and sold for scrap?

Mr A. H. Beckett, Sir Bruce White, Wolfe Barry & Partners

It has been said many times, particularly with regard to marine civil engineering, that when a job is properly planned and designed and the right tools are brought to site, it is very nearly finished. We have here a wonderful example which proves that concept to be true. The team went to a lot of trouble getting out the design, and they brought to site a tool which had already been proved as practicable, and it did the job very well.

18. I wonder whether the Authors would like to comment on what seems to me to be a great improvement in weather forecasting in recent years, due to widespread information collection by satellites and the like. Did they have many occasions when the forecasts let them down, when they started work which they could not complete because of bad weather?

Fig. 1

Professor H. Lundgren, Consultant

I always tell students that when selecting a site for a marina, there should be no waves, no currents, no tides and no pontoons, and that this would result in a requirement for no coastal engineer! The UK is a country where a site was selected where not only coastal engineers were needed, but companies, firms and institutions, co-ordinated by the architect, which resulted in the creation of the most beautiful breakwater in the world.

20. In the Paper it is said that in 1972 it was decided to design for stability for the 1000 year event, and the strength of the caissons under shock loads for the 100 year event. The reason for this is that there is a factor of safety in concrete and steel, whereas for stability there is only gravity. This would be very incomplete today; a real reliability analysis would be done, taking into consideration the variation of strength and forces.

21. The question has been asked whether the engineers and the contractor would do this again. It should be pointed out that the conditions at Hanstholm in chalk and Brighton with chalk are special. It is the unevenness of the chalk which necessitated the procedure of suspending the caissons about $\frac{1}{2}$ m above the bed.

22. Most breakwaters are rubble mound breakwaters, but in certain circumstances caisson breakwaters are needed. My feeling is that it might be worthwhile to apply the principles of offshore foundation, with a skirt penetrating into the sand and clay in the sea bed, and perhaps to shape the bottom in such a manner that the chamber can be filled with gravel, allowance being made for the underside pressure through holes.

23. With regard to the horizontal section, the water is compressed between two neighbouring caissons. Because of the tidal range the shock pressures in the corner are very high. I have been thinking whether it would be possible to reduce the shock pressures in those corners: one possibility that has not been tried out is a floating unit consisting of four cells, with a perforated box which will release the enormous concentration of pressures.

Mr W. R. Walker, Terresearch Ltd

The chalk surface under the breakwaters is a wave-cut platform which extends to the back of the foreshore where it is exposed for up to 5 h between the tides.

25. In situ loading tests were made on the chalk on the foreshore between the tides. Block samples of the chalk at the test locations, and others taken by divers from the breakwater areas, were then tested and compared in the laboratory so that the in situ test results on the foreshore could be translated into safe parameters for the design of the breakwater foundations.

26. The first series of tests on the foreshore were plate loading tests. By using plates in pairs it was possible to apply vertical loads against a reaction frame and also horizontal loads by jacking the plates apart. In this way the horizontal resistance to shearing was measured over a range of vertical load. Also the load–settlement relation of each plate under purely vertical loading was measured up to the ultimate bearing capacity of the chalk.

27. The plates were in three sizes between 225 mm and 375 mm dia. Sixteen plates were tested covering three different areas of the foreshore. The ultimate bearing capacities were within a narrow range and averaged just over 6000 kN/m^2.

28. In a second series of tests, pairs of concrete blocks were cast on the chalk on the foreshore. They were then jacked apart horizontally to measure the resistance to sliding under negligible vertical load. The average peak and residual shearing stresses under these conditions were 50 kN/m^2 and 30 kN/m^2.

29. In the laboratory the block samples were cut into cubes and cylinders for strength and elasticity tests.

30. The average crushing strength of 100 mm cubes of the foreshore chalk was 2300 kN/m^2. Translating this cube strength into a cohesion and applying the usual bearing capacity factor very closely predicts the average ultimate bearing capacity measured in the plate bearing tests. This suggests that the simple cube crushing test can be used as a convenient and practical way of assessing the ultimate bearing capacity of massive, unweathered chalk such as was found at Brighton.

31. The chalk from the breakwater areas differed from the foreshore chalk only in the surface being riddled with marine borers. These drilled vertical holes about 15 mm dia. and up to 125 mm deep. The borers reduced the compressive strength of the chalk surface by about 40%, while possibly improving the resistance to sliding.

32. From an evaluation of all such information from the tests (which were undertaken by Terresearch) it was possible to select the parameters for the design of the breakwater foundations.

Mr P. C. Mornement, Bertlin and Partners

During the construction of the lock, for which we were the consulting engineers, it was necessary to excavate a deep pit immediately behind the north wall. A head of water of approximately 10 m had to be resisted and we specified a 40 m long grout curtain to minimize risk. The curtain required 56 t of cement, which indicated the presence of a significant degree of fissuring in the chalk. Measurements show that there has been very little settlement on the breakwaters apart from the one accident, but I wonder if there might also be fissures under the breakwater.

34. I also wonder what consideration was given in the preliminary studies to locating the entrance to the extreme east end of the harbour. There would be problems in devising an entrance to permit a clear run in for the boats while preventing too much wave energy entering the harbour, but the problem of wave reflection from the lee breakwater which caused some difficulty at the entrance would have been avoided.

Captain J. Rohde Nielsen, J. Rohde Nielsen ApS, Denmark

My company did the dredging for the Brighton Marina. Tendering raised some tricky problems. The material to be removed consisted of 400 000 m^3 of hard chalk and an overlying layer of material described as 'sand and gravel'. The area to be dredged was split into six sections, which had to be dredged to different depths ranging from -5 m to $-6{\cdot}5$ m, with a tolerance of $+0$ and -30 cm on the specified levels.

36. Our first thought was to use a very large grab dredger. But we were not happy that a large heavy grab could be operated to the very close tolerance required. And we were not sure that even the heaviest grab would be able to bite into the very hard chalk. So we decided against using a grab.

37. Our next thought was to use a bucket dredger. But any bucket dredger which was heavy and strong enough to dredge the chalk would have been stopped over every low tide, as the ladder angle would have been too near to horizontal. We were also concerned about noise. Brighton is a quiet place, and we thought it quite likely that an injunction would be taken out, stopping a bucket dredger from working at nights and during public holidays. Though the tender documents did not put the financial risk of an injunction on to the contractor, we thought that it would be nearly impossible to complete the work by bucket dredger in 45 weeks—the contract period—without being able to work 168 h a week. So we decided against using a bucket dredger.

38. Our eventual choice was a 'back hoe' excavator, mounted on a pontoon. Though this was a relatively new method of dredging, we knew that contractors had operated these machines successfully in North Germany, and also that a contractor had used them with great success in Sweden, where the material to be dredged was very hard.

39. As our dredger *Progress* was already in the area, we used her to start removing the overlying layer of 'gravel and sand'. But we soon ran into trouble. The 'gravel and sand' was much finer than we had expected. We would call it silt, and this fine material would not settle in the small (150 m^3) hopper well on *Progress.*

40. Our next problems were with the back hoe excavators. The water level at Brighton changes at up to $2\frac{1}{2}$ cm/min. We found it very difficult to get accurate depth control using the normal method of a visual tide gauge. So we installed a laser on shore with a horizontal beam; and mounted a receiver on the pontoon. An electronic system converted the information into a reading on the excavator-driver's control panel. Unfortunately, the electronic system was brand new, and it proved to be unreliable. But we think the idea was right. The manufacturer of the system has now made it reasonably reliable, and the system is used satisfactorily—we understand—by a number of our competitors.

41. Another trouble in depth control was that the depth of excavation depends on the angle at which the back hoe hits the chalk. Tide variation made this angle very hard to control. We have not yet found a solution to this problem.

42. Our third problem was output. Our estimate of time lost due to weather was not far wrong. But back hoes are relatively new in dredging, and the time lost due to breakdown was far greater than we had expected. Instead of getting the output of some 150 m^3/h we were getting an output of not much above 30 m^3/h. As a result we fell behind programme. So we decided to mobilize more equipment for the summer of 1977 so as to take full advantage of the good weather.

43. We considered bringing in another back hoe excavator, plus barges and a tug. But this would not have helped with our problems in depth control. And back hoe excavators cannot dredge fine material.

44. So we decided to mobilize a cutter; and to pump the material into the dumping area immediately to the east of the marina. A cutter works well on removing fine material. And it also is good for removing high spots left by a grab or a back hoe excavator.

45. Our remaining problem was to find a cutter which would work in the shallow depth of water, but was also powerful enough to cut the hard chalk. The hardness of the chalk in Brighton varies considerably within the marina area;

but tests which were done for us by Hamburg University indicated that the cutter EMS which we had in mind was sufficiently powerful to dredge at least the softer parts of the chalk. We mobilized the EMS—and this worked well.

46. Do the Authors think the combination of back hoe and cutter was the right plant for this unique job?

Mr J. G. Perry, University of Manchester Institute of Science and Technology

The Authors have covered many interesting aspects of the design in depth; unfortunately, the same rigour is not accorded to the design of the contract types, which can have a significant effect on the success of a project. Whereas I respect that some of the influencing factors may be regarded as confidential, perhaps the Authors would elaborate on the choice of admeasurement contracts for the breakwaters and north wall, and target modified to cost-reimbursable for the further harbour works. With the benefit of hindsight, do they believe these decisions to have been optimal?

48. Paper 8242 describes the effects of storm damage and severe weather on the construction of breakwaters and the north wall. Presumably this was recognized before contract formulation as posing a significant unquantifiable risk to the Contractor. CIRIA report 56[1] and other documents referenced within that report stress that the conventional admeasurement contract is unsuitable when substantial unquantifiable risks such as these are present, and especially when there is the additional risk of significant design change. Was a target contract considered for these works, and how successful was the admeasurement contract in assisting settlement of the contract price in respect of these circumstances?

49. The further harbour works would appear to have been protected from the weather risk but subject to considerable variations. CIRIA report 56 describes the ability of target contracts to cope with large variations in design and work content. Could the Authors explain more precisely why it was not possible to retain the target mechanism and adjust the target cost for the variations? It would seem that abandoning the target would give no additional flexibility to either the Client's ability to order variations or the Contractor's willingness to comply since the actual cost was being recorded and would be taken into account in the contract price through adjustment of the target. The benefit from reverting to a cost-reimbursable contract would therefore appear to lie solely in removing the need for assessing the value of target adjustment in respect of each variation. Perhaps the extent of variations caused this adjustment to become an intolerable burden—or were some external influences predominant?

Mr A. R. McAvoy, Construction Industry Research and Information Association

As a member of Taylor Woodrow's design team on the project, working on the main breakwater, I remember that one of the caissons was instrumented to measure long term movements. Could the Authors briefly describe the method used and comment on any results obtained to date.

Mr Terrett, Mr Ganly, Mr Stubbs, Mr Llewellyn and Mr Murray

We welcome **Mr Hodges'** remarks and confirm that we did indeed enjoy a very close degree of co-operation with the Architect. Mr Hodges describes his concern about the possible loss of the crane, but a great deal of effort went into the temporary works design, both on the gantries for the north wall and on the temporary works for the breakwaters. Thus we assure Mr Hodges that the temporary works stood up not by chance but by design!

52. The design of the crane itself was checked, and the steps taken to deal with the possibility of brittle fracture are described in Paper 8242. There was some natural apprehension as the crane was moved forward over the first caisson, which had suffered some cracking due to expansion of the tremie plug, and arrangements had been made to check settlement as the load was applied.

53. It is not easy to answer **Mr Wilkins'** question as to whether or not, if faced with the same circumstances, we would use a similar caisson scheme. We were certainly influenced by the fact that the crane was in existence, having just completed a similar operation, and was available relatively cheaply. If faced with such a scheme again we would not have this advantage. On balance the answer would be 'Yes', in the right circumstances; **Professor Lundgren** puts his finger on the point when he says that special circumstances dictate a special answer to the problem. This was an innovative solution to a particular situation and, all things considered, we believe that the caisson scheme was the right choice. The crane was sold for scrap because there was no buyer for it at the time.

54. We agree with Mr Wilkins that the expenditure of so much time, effort and money has been worthwhile. No real maintenance work has yet been necessary; we think that the first significant maintenance job, apart from dredging, will be to make an under-water survey of the scour protection system and carry out any remedial work shown to be required.

55. In reply to **Mr Beckett**'s question on weather forecasting, there was close co-operation with the Southampton Weather Centre, which gave telex forecasts morning and afternoon plus any indication of major storms in between. The reliability improved as the work progressed, possibly because of the development of personal relationships with the forecasters. Although operations were often halted due to forecasts of bad weather, there was no case of having to abandon an operation after passing the point of no return.

56. **Mr Mornement** asks if there might be fissures under the breakwaters. We know that there is some fissuring and jointing in the chalk, and account was taken of this as far as possible in assessing the foundation design. The crane in its operating condition placing caissons (§ 12 of Paper 8200) imposed a sustained foundation load approximately the same as a 1 in 1000 year storm, but over a somewhat greater area. Thus every caisson foundation has been test-loaded to a condition at least as severe as the maximum design loading.

57. **Mr Walker** refers to the plate bearing tests. In considering the results for design, the values of the ultimate bearing capacity were assessed rather more conservatively on minimum values and this indicated a figure of about 5500 kN/m^2. However, the load–deflexion diagrams showed a distinct 'yield' at a lower figure still of approximately 3800 kN/m^2. A reduction to just under 60% of this figure was taken to allow for loss of strength due to marine borers, so giving approximately 2000 kN/m^2, which was then taken as the ultimate bearing capacity for design purposes.

58. Mr Walker mentions the holes formed in the chalk surface by marine borers. His measurements probably refer to laboratory specimens. However, on site, holes were found up to about 20 mm dia. and up to 200 mm deep.

59. In reply to **Mr Mornement**'s question on the siting of the harbour entrance, the first sketch plan of the Brighton Marina had the entrance in the south-east corner of the site. The problems with that layout were that if the south breakwater were extended to give adequate protection to the entrance, boats in their approach would be sailing almost parallel to the coast, with shallow water under their lee, and in south-westerly winds they would be close-hauled.

60. If the entrance in this position is opened up so that it faces more to the south-east, so that the line of approach is north-west as it is at present, it is difficult to find an internal arrangement that will prevent waves reaching the mooring area. Therefore, although this alternative siting of the entrance was considered, the present location is thought to be a better solution.

61. Regarding the dredging, it was a bold decision for **Captain Nielsen** to bring the cutter suction dredger to site because of the large flints known to exist in the chalk; in fact it performed exceedingly well. The back hoe only produced about 35 m^3/h against an expectation of 100 m^3/h and the programme fell very much behind on this account; however, the cutter suction dredger did produce 100 m^3/h and put this subcontract back on programme, so in our view there is no doubt that the cutter suction dredger was the right piece of plant, whereas the back hoe was not. Apart from the poor output of the back hoe excavator it proved difficult to get the bottom to the specified level. Surveying of completed areas frequently showed up ridges in broken chalk which the machine was unable to pick up, and further attempts merely pushed the material about on the bottom.

62. Turning to the forms of contract to which **Mr Perry** refers, in the case of both the breakwaters and north wall contracts normal measured bills of quantities and fixed unit rates were considered appropriate since the design work was largely completed before construction. The breakwater contract was on fixed rates, negotiated before the work started with the ICE conditions, fourth edition, but there was a special clause 44 which carried an extension of time in respect of bad weather. (This is now incorporated in the fifth edition.) The extension of time did not carry any monetary value with it.

63. The north wall contract also used the fourth edition and was priced in competition. In neither case were variations during construction of very great significance.

64. The further harbour works to which Mr Perry refers are covered only in part by the subject of these Papers and the situation was quite different from that of the contracts for the breakwaters and north wall. Many decisions as to what was to be built had not been taken beforehand, and by that time there were four firms of consulting engineers, in addition to the Architect, engaged to deal with different aspects. The contract arrangements for these further harbour works is therefore more complicated and outside the scope of the present discussion.

65. In reply to **Mr McAvoy**, the caisson movement measuring system was not intended for the measurement of long term movements, but more for the movements experienced under storm loading. The measurement system consisted of protected mild steel reference rods drilled and grouted into the chalk at each

end of the caisson diameter. The rods were 'sleeved' through the foundation concrete and were fitted with stainless steel scribers which marked a removable concentric aluminium shell fixed to the caisson roof. The shells were removed after storms or at other suitable times and the 'engravings' were examined. The readings have shown very small or negligible movements under wave action and this can be discounted as a cause for concern. Such movements as have been measured appear generally to be due to temperature variations.

Reference

1. PERRY J. G. and THOMPSON P. A. *Target and cost-reimbursable contracts—a study of their use and implications.* Construction Industry Research and Information Association, London, 1975, report 56.