The Wallasey Embankment

M. N. BELL, P. C. BARBER & D. G. E. SMITH

Mr Bell

The early 19th century was a period of rapid economic expansion throughout Britain, during which many of the most important and durable civil engineering works were executed. Many of these classic structures have to this day continued to perform their original function, and indeed, in some cases, additional and more onerous duties. Such structures, of which the Wallasey Embankment is one example, are now well into their second century of life and the problems of maintenance can become acute.

60. In the reconstruction of the embankment an infinite design life had to be assumed for the structure, coupled with the expectancy of attrition and eventual failure of all elements exposed to sea action. The tapered T unit system described in the Paper has been developed as an optimum solution to this problem, particularly in bad ground.

Mr Barber

I would like to elaborate upon the vulnerability of an existing structure undergoing major construction. The principal source of damage to the old facing was the rubble from old breaks, which accumulated seaward of the toe and battered the facing under storm conditions. This rubble has now been largely removed and with proper maintenance it should never again accumulate in such quantity. The vulnerability of the structure to damage during excavation is greatest in those areas of the old construction without cut-off walls. The major break described in the Paper occurred in such an area.

62. Important changes were made to the apron and the facing on stage II of the reconstruction. An apron sub-base was introduced to increase the working period which was available for concreting during each tide; previously it has been necessary to fill the apron formation before concreting could commence. When the presence of bad ground landward of the toe beam was established during stage I, consideration was given to ensuring the independent stability of the cut-off walls on the facing, which was satisfied by the cruciform units of stage I and the T units of stage II. To permit local settlement without an abrupt change of level, T units were 'hinged' together. A particular advantage of the T units was the elimination of the variety of 'specials', necessary when the basic shape was a cross. Only one basic shape of unit is now necessary, though one modification has now been introduced.

Mr Smith

Of the total cost of the permanent works on these contracts no less than 70% was for concrete. On stage I a normal high-strength concrete was specified with an aggregate of high durability. On stage II a full concrete specification for coastal structures was formulated, applying North Sea research; a reduction in the cement content was achieved as the Contractor successfully designed a mix with the minimum specified

DISCUSSION

cement content of 400 kg/m³. The coarse aggregate was Penmaenmawr stone and the fine a coarse Mersey grit. Both aggregates were prone to gap grading and the coarse aggregate was very flaky; nevertheless the mix proved to be adequately cohesive when tested by the simple but effective segregation test of over-vibrating a cube. It is not however known whether segregation would have occurred had the mix been dropped over an appreciable height.

64. In preparing for stage II various topics were investigated. These were:

- (a) the use of super-plasticizers and other admixtures;
- (b) structural grouts, in particular grouts containing PFA, capable of resisting erosion when used between precast units;
- (c) the reason for various defects in the concrete elements on stage I;
- (d) the success of the various repair techniques.

Mr F. Rodgett, Metropolitan Borough of Wirral

Little did the Local Authority think, when the 1962 Wallasey Embankment Act was passed, what it was letting itself in for. It was right that financial responsibility should be spread over all the Wallasey ratepayers; and just as well as matters have turned out! Now, it is spread over the whole of the Wirral and even over the North West Water Authority (NWWA) area.

66. As the departmental chief officer responsible for persuading my Authority that a major reconstruction could be put off no longer, I would like to comment on the legislative and financial background. When contract 1 was started by the then County Borough of Wallasey, the local authority sought to act under their powers in the 1962 local Act (Table 2) and as Coast Protection Authority under the Coast Protection Act. Coast protection matters (i.e. prevention of physical erosion) are dealt with by the Department of the Environment. Negotiations for grant from that source soon indicated that as the Wallasey Embankment had a dual function of preventing erosion and more important, preventing tidal flooding (§ 1), it would not be appropriate to proceed entirely under Coast Protection Act powers. We thus found ourselves proceeding under the Coast Protection Act for the stage I works with government grant from the Department of the Environment and the local authority element coming from key sector finance. The then Mersey and Weaver River Authority contributed to the new splash wall under their land drainage powers. It was agreed that the remaining reconstruction would be carried out entirely under Land Drainage Act powers, involving a different government department for administration and grant, i.e. Ministry of Agriculture Fisheries and Food (MAFF).

67. Complications now started, allied to local government reorganization. If the new Wirral Authority had proceeded under the 1962 Act and Land Drainage Act powers, finance for land drainage works (in this case prevention of flooding) would have had to come from the locally-determined schemes (LDS) allocation, with a contribution from the NWWA, and MAFF grant only certain on the NWWA element, and no longer from key sector money. This LDS money is fully committed, primarily to a continuing multi-million pound central area redevelopment, so that there would have been difficulty in proceeding with contract 2 without NWWA help. The solution has been for my authority to continue with the work, but now as agents for the NWWA thus getting the benefit of better grant from MAFF, whilst still contributing its share. I must pay credit to the good relations and understanding of our colleagues in the water authority, particularly Mr J. G. Lloyd, previously Engineer to the Mersey and Weaver River Authority, now NWWA Chief Executive. The excellent relations established with NWWA colleagues on agency work must set a pattern which could well be followed around Britain in this delicate current problem arising from local government reorganization.

68. One other recognition I must mention is our working relationship with the Consultants. For over 30 years Sir Cyril Kirkpatrick and Partners, now Scott Wilson Kirkpatrick and Partners, have advised the local authority on coast protection matters. In preparing the reconstruction scheme, my authority accepted that the department

would not have the staff capability to prepare all the drawings and documents required. Thus a partnership arrangement was entered into, though I retained responsibility as Engineer under the Contract. From the local authority viewpoint, this has worked excellently and full co-operation and assistance has always been forthcoming from the Consultants.

69. Credit is also due to the Contractors for the stage I works, Mears Construction Ltd. Bad weather conditions, poor ground and design changes were coped with admirably; I am sure the site staff agree wholeheartedly with the Authors' comments about the site exposure.

70. The Authors refer in § 11 to the cherry branch fascine groynes. I think I am the only one now around who ever saw these. There was only one area where they appeared in the western third of the embankment about 1951 after a severe storm. They soon disappeared, but were dug into a silt layer in a NE alignment, about 10 m apart, with cross members at right angles making about 10 m squares. None of my workmen had seen them before and I think they were soon eroded once they were exposed. It is interesting that the alignment chosen for the 1947 groynes further east is very similar.

71. I would however ask the Authors what type of profile or structure they would choose for protection and for economy of cost, given a similar virgin site.

Mr R. W. Hawkey, Scott Wilson Kirkpatrick and Partners

There is no doubt that the Wallasey embankment is an historical engineering work of considerable importance. It is a pity that it has not been possible to trace the engineer responsible for its design and construction, but it may be that it was largely left to the craftsmen of that era and they were undoubtedly good masons who fashioned and laid the sandstone blocks. I know of no other sea defence work of this magnitude and importance built 140 years ago, and it is a pity that none of the original stone facing will remain for future generations to see when the present repairs are completed. Would it not be possible to cover a section of the original stone facing with armourplate glass or preserve it in some other way?

73. I often wonder how much people who live below sea level, and depend on an embankment or wall for their safety, worry about it. They seem to have great faith in the engineers who are responsible for keeping the sea from their doors. What I saw of the results of the 1953 floods showed that the damage done to the contents of houses and factories was greater than that done to the buildings and I am wondering if the valuation includes the contents. In a factory any electrical motors, switchgear, etc. are usually a write-off if submerged in sea water for one tide, and of course in a house any soft furnishings, carpets and flooring are equally irreparable. It was fortunate that during the war the enemy did not make a concentrated effort to breach the embankment. I don't suppose they appreciated what havoc it would have caused.

74. In the Authors' conclusions in § 56 they recognize that there is no permanence in any sea defence scheme. It seems to me that this was appreciated too by the original constructors of the embankment who limited their initial capital expenditure and provided a full-time construction and maintenance gang to look after the work. This not only gave regular employment but spread the cost over a much longer period. These days the tendency is to design and construct works to be as permanent as possible to reduce maintenance cost. One reason for this is that under the Coast Protection Act, the Coast Protection Authority, having received its capital grant from the government, has to pay the cost of all maintenance out of its own pocket. It will be interesting to see, although I never shall, if the new concrete facing will last as long as the original sandstone blocks. I doubt it.

Mr H. A. Glover, North West Water Authority

The former Mersey and Weaver River Authority, now the NWWA, was interested in the wave wall mentioned in § 12 because of the complicated drainage pattern brought about by the closure of the Wallasey Pool and the construction of the dock system. The

natural drainage is carried past the docks by a 3.2 m dia. culvert 3.7 km long discharging through tidal flaps to the Mersey at Woodside. Most of the urban development has taken place since that time and as a result the culvert is now inadequate for flood flows. The former Cheshire River Board constructed a pumping station at the downstream end to pump when the culvert was tide-locked, but the restriction is the 10.2 cumec capacity of the culvert itself. The alleviation of flooding therefore depends on storage in the old channels at Bidston Golf Club (270 000 m³), and the 65 m³/h per m run of embankment which was the predicted rate of overtopping from the tests carried out at the Hydraulics Research Station, cannot be allowed.

76. A large proportion of the 1800 houses mentioned in Table 1 are therefore at risk from river flooding as well as an embankment collapse, and I strongly suspect that few if any of the occupants are aware of the danger. This brings me to the emergency mentioned so graphically in §§ 44–51. Were the public warned of the danger? Collapse was prevented and a warning to the public would, after the event, have been classed as scaremongering, but during the past year the NWWA has been criticized several times (quite unjustifiably) for not issuing warnings to the public. Perhaps the politicians did not know of the problems or the risk at Wallasey.

77. Going back to § 12, the Hydraulics Research Station report was one of two desk studies carried out for the Mersey and Weaver River Authority, the other being of the Lancashire Coast where Formby Point is eroding rapidly and the dune belt is being lost. One of the recommendations in that report was the 'hardening' of Formby Point, and an embankment like Wallasey would probably be needed. It would undoubtedly be very expensive and the Coast Protection Authority has not yet decided to carry it out. There is no desperate need as at the moment the dune belt is still very deep.

78. The Hydraulics Research Station reports were prepared in 1969 and were studies of all the previous work carried out on Liverpool Bay. Since that time there have been considerable amounts of work carried out which affect the bay (Seaforth Docks, Crosby sea wall, Wirral long sea outfall), and increased dumping of sludge. There is probably the same amount of capital expenditure still to be carried out on Formby Point, Leasowe Bay and Crosby sea wall extension, dealing with inshore crude sewage outfalls. The time has surely come when a full investigation into the whole bay is not only necessary but could be well worthwhile financially.

79. Would the Authors comment on any interrelation which they consider exists between the problems at Formby Point and those on the Wirral coastline?

Mr R. L. Bott, Metropolitan Borough of Wirral

The Authors have referred to the protection from tidal inundation which the Wallasey Embankment offers to the low lying hinterland. I should like to refer to the two structures to the east of the embankment which serve rather different purposes but have closely related problems.

81. On Fig. 3, two nearly equal lengths of coastline can be identified to the east of the embankment. These are stepped where they join and extend almost to the mouth of the River Mersey. The length nearest to the east end of the embankment is known as Leasowe Revetment, the other as King's Parade promenade.

82. Leasowe Revetment was constructed in the 1920s at the foot of the sandhills to arrest their erosion. It is 1760 m long and consists of concrete slabbing at a 1 in 2 slope some 225 mm thick, running between a mass concrete stepped toe and a short cut-off wall at the rear of a 4.6 m access way. There are transverse cut-off walls at 30 m centres along the length of the revetment.

83. This structure has been a source of trouble since its construction. The heart of the structure is of sand which is continually being washed out through the facing slab joints and cracks. This leaves voids in the structure which no amount of filling or grouting can control. Records indicate that most of the structure has been reconstructed at least once, and much of it twice, during its lifetime. This structure, which is 2 m lower than recommended for this coast line, is frequently over-topped by the tide,

which washes through further material from the core in finding its way back to the sea. In the last 12 months a 100 m length has been reconstructed using some of the principles employed on the Wallasey Embankment, i.e. steel sheet piling and a concrete apron in front of the toe, and cut-off walls at more frequent intervals both along and into the structure to contain storm damage. A flexible face of interlocking facing blocks has been used so that any deformation is indicative of movement within the structure. Only the recent development of a suitable filter membrane allows the last principle to be used.

84. King's Parade wall and promenade were constructed between 1931 and 1939 and, being 100 m seaward of the sandhills, reclaimed an extensive area for amenity purposes. The mass concrete wall, 2400 m long, is founded directly on the underlying sandstone or on piles through the clay and sand. Its face is vertical, stepped back at the base and curving outwards to the sea at its crest. The base of the wall is 5 m thick and the toe is protected by steel sheet piles driven to the rock overlying. These piles were the original coffer dam piles cut off where the base of the wall steps back. This wall has suffered virtually no damage from the tidal action.

85. The foreshore fronting both of these structures has been gradually eroding. In the case of King's Parade, it was necessary to erect groynes within 10 years of its construction to try to arrest the loss of sand, and this has proved only partially successful. Fortunately, extensive records exist of foreshore levels over the last 50 years and a study by the local authority has now commenced to try to establish the long-term trends and causes of breach movements. Without in any way trying to anticipate the results of this study, would the Authors care to comment on this erosion problem and its possible relationship to the migration eastwards of the Rock Channel referred to in § 10?

Mr A. Rogan, Mears Construction Ltd

Piling was driven along the total 1200 m length of embankment using a crawler crane, drop hammer and steel gates. This was then followed by toe beam placing. The total length of toe beam was installed to enable the embankment to be constructed at various positions. Three infill panels had been allowed in the contract at various locations so we worked at all three to ensure rapid progress. Piling was subcontracted.

87. The method of breaking out the existing embankment was with a 30 t crawler crane using a 2 t drop ball. This method was used as the crawler was also needed to place the cruciform units. It was not practicable to use an alternative method such as an Arrow breaker for breaking out the existing concrete, as the amount to be broken out was governed by the amount that could be replaced and, therefore, an additional piece of plant would have been an unnecessary expense. The material was then excavated with 360° 1 cu. yd slew excavators. The material was then carted off site using 11 cu. yd dump trucks running along the foreshore at low tide. Three gangs were used to excavate the embankment, each consisting of a 30 t crawler, a 360° excavator, a dump truck and three men.

88. Concrete had its difficulties due to the tidal working. The ready mix supplier was unable to work six tidal periods so we installed an 18 m³/h batching plant. A combination of the two systems was then used. The batching plant was Italian. It had a 3 cu. yd Benford dispatch hopper and two cement silos, one 30 t and one 50 t capacity linked together. A Hydrol additive tank with a measuring system was installed to the system to ensure correct mixing.

89. Placing concrete into the bays was by 1 cu. yd dumpers as RMC trucks were unstable on the 1:6 slope. The concrete was then vibrated with 50 mm pokers and a vibrating screed. Due to the flat foreshore and unpredictable winds, freshly placed concrete often sustained erosion. However, because the embankment had to be kept sealed, this fact had to be lived with as overcautious placing of the concrete would have delayed other operations, such as a cruciform placing, excavation, etc. The access roads and retaining walls were placed on ordinary working days. One of the day gangs

DISCUSSION

on concrete was brought in early one week at 06.00 h and the following week finished work at 20.30 h in order to catch the tide and to give a boost to the concreting operation.

90. Labour worked generally 07.30 h–18.00 h days and 6 h tides for the tidal work. This meant that labour on tidal days had to be accommodated on site, as the average operative needed half an hour each way to and from work plus half an hour to have a meal, which left him $4\frac{1}{2}$ h to sleep, etc. A caravan camp was supplied by Mears and a welfare superintendent was engaged to look after the operatives' welfare. We also had similar problems with the engineering staff who naturally liked to go home to their families. After discussion with the engineering staff they agreed to operate the same system as the production operatives. After working on a tidal system during the week it was found that it was impracticable to work weekends as the staff and labour needed a well earned break.

91. The contract had more than its fair share of difficulties. Exceptionally high tides and winds put a strain on all the people involved but after many set-backs the contract was completed successfully on time.

Mr Bell

With regard to Mr Rodgett's observations on the roles of the local authority and the Consultants, I would like to add that thrashing out problems together in a down-to-earth manner, as it has been our good fortune to do at Wirral, gives considerable personal satisfaction to the participants, and this satisfaction I am sure itself nourishes performance, if, as in this case, the relationship is right.

93. Mr Rodgett's question poses some problems, as there is no complete information on the situation in 1829. It appears that a catastrophe had not quite occurred, although for many years engineers and others had been warning the people and bodies at risk. Every sea defence problem is different. In this case there was a low, flat and fairly stable sandy foreshore with amenity and recreational value, a large tidal range and exposure to frontal wave attack. Dune erosion had been feeding the beach, so clearly there would be foreshore depletion were this supply stopped and the material carried away by the NW drift. To avoid channel formation, it would be advisable to provide a gently sloping revetment from below equilibrium beach level and indeed I personally feel that something like the present profile and construction would have much to commend it as a basis for an optimum solution up to mean high water spring tides (MHWST), although possibly a little steeper than 1 in 6 to reduce first cost.

94. From MHWST upwards the design field is rather more open. A terrace just above this level, functioning as a wave break platform, a promenade and a maintenance roadway would certainly be desirable, as would a wave return wall at the crest to turn back the final run-up. The section between the terrace and the wave wall could be quite steep, possibly in situ steps or precast panels. Its mode of support and that of the wave wall would depend upon the ground conditions and formation prevailing at the time, but in general a flexible solution would be preferable. There would undoubtedly be various possible, and maybe radical, modifications to the general profile, aimed at absorbing wave energy and thus reducing impact forces and the reach of the run-up. A fairly intensive programme of design research, including hydraulic model testing, could be expected to yield substantial savings in total cost for a sea defence work of this magnitude. I know that, on the Wirral at least, my final point is already well appreciated. I must include the tremendous importance of a timely start to site investigations and feasibility studies, particularly in such a case as this which would involve wave and weather recording and model studies, if a truly economic solution is to be achieved.

Mr Barber

I do not consider that the 1 in 6 profile would be the best to adopt on a virgin site, despite its hydraulic advantages. Costs are prohibitive for the advantages gained over the 1 in 4 slope of the apron. Wave attack on both slopes was similar, but in the latter case

the cost was significantly less. The present design is inevitably tailored to suit the existing structure and other alterations, although anticipated to be only minor, would be necessary for the design to be applied elsewhere. Bearing this in mind, however, the advantages of a streamlined version of the design for virgin site application are significant. For instance, the design concept allows construction, even in this severe exposure, to be at least contemplated without costly cofferdam protection. To summarize, the choice of structure would be of changed profile but of the same type with minor modifications to allow a more universal application.

96. In answer to **Mr Glover**, the public were not informed of the danger and neither, as a body, were the politicians. The whole situation was kept under close review and although a full-scale breach was only 'narrowly averted', the mobilization of emergency services was not requested. Whilst a breach would have disastrous effects upon repair work, at this particular location the tide would have had to remove several hundred tons of sand to establish a spillway into low-lying areas behind the embankment. Weighing all matters, it was felt that the actual occurrence of the breach, defined as complete interruption of protection over any length of the structure, was the mobilization point for emergency services. It was assessed that there would be between 12 and 24 hours after such an occurrence before significant numbers of properties would be affected by tidal waters. When to disrupt the affected community in these circumstances is a difficult matter of judgment. I was very relieved that the remedial measures proved successful.

97. With regard to protection at Formby, the answer to Mr Rodgett's question is relevant excepting that the physical parameters affecting the site might dictate changes in design. The interrelation between sand movements at Formby Point and Wirral is a most interesting problem. I believe that sand movements must be considered on larger as well as smaller scales. The Liverpool Bay is a convenient area for sand movement analysis and it has been shown that movements within this area are connected. Certainly it is desirable that problems and solutions within such areas are shared to avoid works producing trends which benefit an area at the expense of its neighbour.

98. In answer to **Mr Bott** and following on from the previous question, the migration of the Rock Channel eastwards was one of the major changes in the Liverpool Bay seabed this century and before. I believe that these major changes started a chain reaction of major and minor disturbances to the various equilibrium systems. The whole scene is interconnected and the difficulties of interpreting events observed is immense. However, I feel that the Rock Channel affected the erosion problem, although its influence was secondary to the construction of the Crosby Channel training walls, begun in the early 1900s and completed in the late 1950s. The particular erosion problem on Wirral appeared, on preliminary investigation, to be initiated locally but was developed by larger scale influences, such as those mentioned.

99. In replying to **Mr Rogan**, I accept the preference of some contractors to defray risk by sub-contracting readily identifiable sections of the works, but feel that this sort of work is better retained by the contractor on site. Here it allowed the economic employment of more labour, available for use in emergencies; secondly, the high standard of precast concrete units required for the work could be better supervised on site; thirdly, flexibility of production of various units was possible; and fourthly, minor repairs were more easily effected. I would like to mention the high standard of unit produced on site, a standard which exceeded by own expectations.

100. In answer to **Mr Hawkey**, I have been contacted by the Institution's organization for works of historical interest and it is hoped to preserve a panel of the sandstone pitching, although the details of how this can be done in conjunction with the reconstruction have not yet been finalized.

Mr K. J. Sommerfeld, Sommerfeld Formwork Ltd

As manufacturer for the moulds used on stage II of the reconstruction, I would like to ask whether engineers should not co-ordinate their schemes so that standard moulds

DISCUSSION

can be employed, with consequent savings in cost? The prepurchasing of moulds by the client enables the contractor to commence casting as soon as a contract is let and I favour an extension of this practice whenever possible.

Mr Barber

I agree in principle with the suggestion but wonder about its practicability. I hope that in the foreseeable future the design used on the embankment will be rationalized to provide a protective system of much wider application. In this event a certain standardization may be possible, but acceptance of such designs, especially in coastal engineering, usually takes several years, during which progress must continue.

Mr Smith

The prepurchasing of the moulds in this instance achieved the objective of enabling the Contractor to commence precasting T units and toe beams as soon as the mix design was agreed. I consider it undesirable that this practice should be generally adopted, as a contractor should have complete freedom in the choice of casting techniques. Tenderers were in fact approached for their views on the proposed moulds prior to the letting of the contract, but this procedure did not produce any significant improvements in the mould design. Nevertheless the timetable gave the successful tenderer the opportunity to modify the mould designs prior to manufacture.

Mr T. A. Stoker, Ward Ashcroft and Partners

I would like to enquire whether water pressure behind the facing was taken into account in the design and whether any problems were experienced due to this pressure. The T units appear rather slender and I question their ability to withstand tide and wave action. I wonder, were these units designed or 'conceived'.

Mr Bell

The level of the ground behind the embankment is generally low. Internal hydrostatic pressures are therefore not excessive. The facing slabs are heavy enough not to be lifted, and venting is provided through the shrinkage gaps at the panel boundaries. At one point, where greater pressure due to a higher adjacent ground level was evident, filter material and weep pipes were installed as an additional safeguard. Undermining of slabs and their consequential failure has been avoided by allowing the slabs to settle freely between the cut-off walls, so maintaining contact with the fill material at all times. In this way the instantaneous build up of pressure beneath slabs due to wave action was avoided.

Mr Barber

The T units were indeed designed. Their shape was developed to provide efficient installation, structural adequacy and satisfactory appearance. The wall thickness was determined by calculation based on consideration of handling and wave forces. The shape was developed with regard to a number of other considerations.

107. The crosses on stage I of the reconstruction were difficult to align and relatively small placing errors could be seen from a distance. The T units which superseded the crosses for use on stage II were easier to level and placing errors were less noticeable. The latter were due to the taper in the stem and arms of each T, which provided maximum root strength for given weight of precast unit. The earliest crosses used on stage I were prone to damage at the roots of each arm, though this was overcome by a local increase in the amount of reinforcement.

108. The joints were carefully designed. Levelling ledges on the end of the positioned unit prevented relative movement of the unit placed against it, whilst relative movement in the opposite direction was prevented by the slope of the Z-joint (Fig. 17).

Fig. 17. Joint between arms of precast T units (not to scale)

The result was a hinge. The Z-joint itself serves three functions; it inhibits the intrusion of soil into the joint before grouting; it protects the grout seal from wave action before backfilling; and in the event of a washout it protects the formation of the neighbouring bay. The grout pocket above the Z-joint is tapered to avoid 'pull-out' from wave action.

Mr T. Whitley Moran, Contractor (retired)

I note that the eastern and western ends of the embankment have not yet been reconstructed. I live immediately behind the western section and have noticed that the structure is suffering from wave attack. I would be grateful for an assurance that this will be attended to in good time, although I wonder whether the accretion and landward movement of the East Hoyle Bank might render the work redundant.

Mr Bell

Treatment of the western section forms the major part of stage III of the reconstruction which is expected to follow after stage II finishes in late 1976. It was mentioned only briefly in the Paper due to space limitations.

Mr Barber

The eastern end, although unprotected, is flanked by the embankment and Leasowe Revetment, which act like headlands protecting the bay. As a consequence, the need for protection is not immediate, although eventually desirable. With regard to the movement of East Hoyle Bank, the likelihood of its progression to the actual embankment is remote. However, such major sand movements call for close observation and this is in hand.

Mr R. P. Whiting, Scott Wilson Kirkpatrick and Partners

I would like to comment on the unusual manner in which the Consultants had been working for the Council. The normal practice when consultants are engaged by a local authority is for the consultants to handle all the design, preparation of contracts

DISCUSSION

and supervision-in-chief. In the case of the works for the Wallasey Embankment, however, staff of the Council (notably Mr Barber) also participated in these activities. It might be thought that this would cause problems of organization and responsibility but this was in no way the case. The principles of the design and the contractual matters were settled in consultation, drawing on the knowledge and experience of both parties. The result, I believe, was probably better than either could have achieved alone.

113. The detailed design and the preparation of the contract documents were carried out largely by the Consultants in conformity with the agreed principles. The Council's Director of Engineering Services was the Engineer under the contracts and the Consultants had no formal relationship with the Contractors. However the Consultants exercised an advisory role over construction methods, and, notably, concrete technology. They also dealt with most of the measurement, a task that was onerous because of the frequently varying materials and cross-section of the old facing construction.

114. I would like to conclude by suggesting that the same sort of utilization of the services of consultants might be adopted elsewhere with advantage.

Mr J. Horrocks, Ministry of Agriculture, Fisheries and Food

I would like to enquire why, in the Wallasey reconstruction, a system of precast concrete beams and blocks as used in the Birchington sea defence scheme (Reculver to Margate on North Kent coast), could not have been adopted?

Mr Barber

I recall that the Birchington wall was constructed on mud flats, where high flexibility was required; also the beams were shallow and more widely spaced than at Wallasey, so that in the event of paving failure, they would be unable to provide so effective a cut-off. The panels were filled with shaped precast concrete cubes of 375 mm side length. Costs of this system appeared high when similar ideas for part of the slabbing on the first stage of the reconstruction were examined. However, in order to match the undoubted aesthetic qualities of such a system, standards of workmanship required for the in situ concrete alternative have to be set high.

117. In general, I feel that high quality in situ concrete pavings permit the attainment of aesthetic acceptability in work of this type. This type of construction then allows higher production rates and cost economies, as concomitant advantages.

Mr D. L. Hockin, North West Water Authority

I would like to enquire why the various resin compounds have failed, and whether consideration had been given to the heavy asphalt carpets used for similar defences in Holland?

Mr Barber

The numerous resin compounds employed have failed due to the ambient conditions concomitant with their application. Damp and contamination were practically impossible to exclude from situations in the tidal zone and no resin was successful here. However, a resin compound was employed for minor repairs to precast units in the Contractor's compound, and these repairs were effective and have withstood the onslaught of the sea to date.

120. With regard to heavy asphalt carpets, these were investigated but discarded. Such materials are not suited to the exposure of the Wirral coast and the risk of puncture from masonry broken away from other defences is quite high. Heavy asphalt carpets do not lend themselves to cell construction, so advantageous for maintenance and for confining damage. In addition, this alternative, along with several others, involves the maintenance of the existing paving.

Mr Smith

The resin repairs on stage I have been sufficiently successful to justify their use on stage

II in preference to normal mortar repairs, though some erosion of these repairs has occurred. This seems to be due to inconsistent abrasion resistance and may be caused by variations in the mix ratios; no bond failures have been discovered. Such repairs to precast units above the tidal range have been completely successful. The resin repairs which have failed were those applied in situ to the facing construction and may be attributed to the poor adhesion of most resins to damp surfaces, though resins are being developed which can be applied in the damp. Resins can be formulated which set under water.

Mr G. A. Noonan, North West Water Authority

What is the particular relevance of the mix design to coastal structures and what aspects of it apply to other hydraulic structures?

Mr Smith

The concrete mixes for coastal structures subject to scouring action of sand and water are designed to provide both durability and low permeability. For other hydraulic structures low permeability is the chief objective. The required properties are provided by preselecting the coarse aggregate, by placing limits on the cement and the water/cement ratio and by tight routine quality control.

124. The durability of concrete is closely associated with the permeability of the surface, which may be measured by the recently developed initial surface absorption test. The permeability depends upon the permeability of both the paste and the coarse aggregate. In marine structures the admissible limit is associated with the tricalcium aluminate content (see §§ 140–143).

125. A coarse aggregate of low permeability may be preselected on the basis of porosity, which is easily measured. This method should be used with caution as it may exclude some satisfactory materials.

126. The permeability of the paste is minimized by minimizing the water content, which is achieved by the use of plasticizers. A lignosulphonate was chosen on stage II as it is relatively insensitive to overdose and is compatible with most other admixtures. In common with most plasticizers it tends to retard the initial set and cannot be used for tidal work in winter, when however it is not necessary.

127. For durability when scour and impact are likely, the aggregates should have high resistance to both abrasion and impact. The impact values of the granites and limestones used on stage II were satisfactory, being for both about half the maximum value permitted for wearing courses. The abrasion values were quite different, and the better durability of coastal structures with granite aggregate is due to this property. The abrasion resistance is severely reduced when the silt content of the sand is high, and fortunately Mersey grits contain little silt.

Mr M. Minter, Chairman

I would like to know if long-term settlement has been allowed for in the design, since it has been established that the Wirral Peninsula has settled 1 m/100 years in the past.

Mr Bell

The embankment at its present height, including the wave wall, allows for settlement of up to 1 m.

Mr R. A. Stephenson, formerly Mersey Docks and Harbour Board

I would like to take up this matter of long-term settlement. Tidal observations over the last 100 years at Liverpool have shown no appreciable change in relative levels of land and sea, although small variations could have occurred. Certainly in my time with the Mersey Docks and Harbour Board there was no need to take heed of any variation.

DISCUSSION

Mr Dent, Mears Construction Ltd

I would like to ask why the wall was not converted to a vertical profile by driving piles along the crest, and also to query the limiting gradient of 1 in 3.6 for casting in situ concrete without a top shutter. I have been engaged in the construction of walls with slopes between 1:2 and 1:3 without top shutters. This was made possible by the use of large quantities of calcium chloride, though the operation was somewhat hazardous as the concrete was liable to set prematurely.

Mr Barber

There are many foreshore problems arising from the use of vertical profile walls and I regret the high incidence of such structures round Britain. The severe erosion problems to the east of the embankment were caused in no small measure by the vertical profile of the sea wall.

133. With regard to the gradient of in situ concrete, the arrangement was tested, and 1 in 3.6 was certainly the limit for 50 mm slump concrete compacted with immersion vibrators. However, these observations are confined to the special mixes designed for the work and different results might well be possible with a varied mix design.

Mr Smith

The limit of 1:3.6 seems a little severe but it has been found necessary in pours as large as those of the apron slabs, each of which was poured in a single operation. The use of calcium chloride is generally deprecated in severe exposures, as it impairs the durability of the concrete. However, calcium chloride does tend to increase the density of the surface and there may be some situations in which this property is useful. On stage II an extra 10–20 kg/m³ of cement is being used in preference to calcium chloride.

135. The use of polypropylene fibres may provide the answer to the construction of slopes of 1:2 without top shutters. At a 20% increase in the cost of the concrete, polypropylene fibres enable wet concrete to stand in a vertical face in excess of 250 mm, though it has not yet been demonstrated that these fibres prevent slumping in a slope of any appreciable size.

Mr C. D. Davies, Metropolitan Borough of Wirral

Would a substantial saving in material have been possible by using a 1 in 3.6 gradient instead of the existing 1 in 6?

Mr Barber

The reconstruction was partial, deliberately assessed to minimize initial capital outlay and to allow maximum use of existing surfacing by programmed replacement over a number of years. A complete reconstruction would have been necessary with a modified gradient. This would involve five files of slabbing instead of the average of just below four achieved by the partial reconstruction. This 20% increase in slabbing costs associated with greater earthworks would have significantly increased the cost of the scheme. Also, of course, from a hydraulic point of view, the embankment is to be preferred at its existing gradient.

Mr P. W. Beard, Sea Platform Constructors (Scotland) Ltd

Passing reference is made in § 28 to the significance of the tricalcium aluminate (C₃A) content of the cement as regards durability of concrete in sea water.

139. I would like to ask the Authors what they consider to be the desirable limits for the C₃A content of cements used in a marine environment? What is the C₃A content of the cement being used in the current stage II contract, and has the cement been specially obtained or is it normally available in the area?

Mr Smith

The approach adopted on the question of the C₃A content of the cement was one of

caution. Until conclusive information is available on this topic it is desirable to impose some limit for that part of a structure subject to repetitive wetting and drying, which is liable to lead to the disintegration of the more porous areas of the concrete surface. The region which is particularly vulnerable is that towards the top of the tidal region and in the splash zone where an accumulation of salts is likely. A limit of 8% on the C_3A content in this region may be considered desirable, but if care is taken to obtain a surface of low permeability, 10% is undoubtedly satisfactory. To achieve low permeability, plasticizers or air entraining agents may be used, but due account should be taken of any retarding side effects common with these admixtures, which may cause problems in cold weather.

141. The desirable C_3A limit in critical regions is associated with the glass content of the cement. The glass tends to absorb the C_3A , rendering it inert from the aspect of chemical attack. Depending on how the cement clinker is cooled, cement may have a high or low glass content. Cement manufacturers prefer a clinker with low glass content as the wear on the crushers is less.

142. Another factor relevant to the C_3A limit is the design life of the structure. In 30 year old structures around the British coast it is reasonably certain that poor design and poor compaction have caused greater deterioration than high C_3A contents, but such observations cannot yet be made concerning structures of comparable age to the design life of the facing on the embankment.

143. For the purposes of the specification on stage II of the embankment no limit on the C_3A content was specified, partly because no supplier would guarantee the C_3A content; one national supplier informed us that in his product it varied from 8% to 12%, but he would not guarantee the content of any given batch of cement as it was beyond his control. Fortunately the cement used on stage I, which was from another national supplier, contained less than 8% of C_3A , and the same cement was used in the trial designs for stage II. This cement had been of consistently high quality throughout stage I (with some deterioration during the 3-day week), with a rapid set which is desirable for tidal working. It is hoped that this consistency will continue throughout stage II. However, as a precaution against the rise in the C_3A content, measurements of surface absorption will be made on precast concrete elements throughout the current contract. It is hoped to introduce initial surface absorption limits into future marine contracts when there is more experience with the apparatus. Regarding North Sea structures, which are obviously the principal concern of Mr Beard, it is worth mentioning that British cements are generally of higher quality than continental cements.

Mr J. Duvivier, Lewis and Duvivier

There is a reference in § 11 to the use of various types of groyne. Perhaps the Authors would enlarge on the subject, indicating whether the fascine types were of any use in gathering and holding a covering of dune sand over the clay and silty foreshore. How long did they last, were permanent piled groynes planned at any time, or were they deemed to be unnecessary, etc?

145. Sir Cyril Kirkpatrick has also referred to the construction of groynes at Wallasey. The description reads as if it refers to the NE corner of the peninsula and not to the embankment section. Nevertheless, as it refers to a massive new concrete sea wall, nearly 2 km long founded on rock or clay and constructed by the Council before the 1939–45 war some 100 m seaward of an old sea wall it could be of interest, while coast protection in Liverpool Bay is under discussion, to hear a few particulars of what appears to have been a major and costly work.

146. I was somewhat horrified to hear that erosion of the foreshore had occurred to a depth of nearly 4 m at one point near the wall, and 2 m at other places. Beach conditions may have been similar to Fleetwood where catastrophic scour and extensive damage to the sea defences occurred in 1955 as a result of the erosion of the silty clay on which the old sea wall was founded.

147. The design of the Wallasey revetment as a flexible precast reinforced concrete

DISCUSSION

honeycomb box with in situ mass concrete infilling, steel sheet piled toe and reinforced concrete bull nose parapet-cum-flood-wall cannot be faulted.

148. I think I can say without exaggeration that I have not designed or built a sloping sea defence subject to tidal wave conditions anywhere in the world since the mid 1930s without transverse or longitudinal bulkheads to control and contain scour during or after construction.

149. It is perhaps surprising to hear that precast units weighing 6 t standing near crest level on the embankment could be moved by the swash from heavy seas. Before one draws any conclusions from the event one would need to know the level of the crest at the time and whether the units were loosely stacked without regard to the possible consequences of the embankment being seriously overtopped.

Mr Smith

Wooden groynes and facine groynes were the two types used and the former are thought to be the earlier. The facine groynes are discussed by Mr Rodgett (§ 70). There is no record that these were ever effective, but their erosion, when uncovered, may be attributable to their deterioration. The age of the wooden groynes is not known, but the fascine groynes were mostly constructed towards the end of the 19th century. The wooden groynes indicate an advanced state of deterioration in a photograph of 1920 and the construction of some type of groyne can be seen in the distance in another photograph of 1916. Groynes were not used over the length of the embankment during the present reconstruction as they would have caused further scour to coast protection systems NE of the embankment.

151. The wall referred to by Sir Cyril Kirkpatrick is the Kings Parade sea wall situated NE of the embankment and towards the corner of the peninsula. This wall is considered in some detail by Mr Bott (§§ 82, 84 and 85). To his observations we may add that the concrete appears to contain the same granite aggregate used on the embankment below MHWST. It is thought that a normal 1:2:4 mix was used and plums may have been dropped into the core of the wall during placing, a practice used in dock construction in the area in this century. The lower part of the wall (that taking the major part of the wave forces) is now protected by an encrustation of sea life and if this is removed the shutter marks are still visible over extensive areas.

Mr Barber

The 6 t unit was in fact a retaining wall unit (shown in Fig. 13) standing in a trench upon its foundation blocks. The unit had a height:breadth ratio of about 2:1 and under the sea action it was displaced by about 200 mm. The wave forces producing this displacement were much less than those lower down the embankment, and the units would undoubtedly have overturned had they been struck by the design wave.