Hydraulics Research
Wallingford

A REVIEW OF NOVEL SHORE PROTECTION METHODS

Volume 5 - Offshore breakwaters and sills - Text

J Welsby T Eng
J M Motyka BSc (Eng)

Report No SR 34
May 1987

Registered Office: Hydraulics Research Limited,
Wallingford, Oxfordshire OX10 8BA.
Telephone: 0491 35381. Telex: 848552

This report describes work carried out by Hydraulics Research on research into novel forms of shore protection. Prior to April 1985 this research was funded by the Department of the Environment (Water Directorate) under contract number PECD 7/7/055. Since April 1985 it has been funded by the Ministry of Agriculture, Fisheries and Food under contract number CSA 1034, the nominated officer being Mr A Allison. At the time of reporting the Hydraulic Research nominated project officer was Dr S W Huntington.

The report is published on behalf of the Department of the Environment and the Ministry of Agriculture, Fisheries and Food, but any opinions expressed within it are those of the authors only, and are not necessarily those of the ministries who sponsored the research.

ABSTRACT

This is the fifth in a series of reports on low cost or novel forms of shore protection.

It covers the use of breakwater type structures whose aim is to encourage beach stability. The structures that are examined range from large gravity type breakwaters which dissipate and disperse wave energy through the small sills which trip waves at the toe of existing seawalls and revetments.

CONTENTS

CONTENTS CONT'D

FIGURES

PLATES

APPENDIX (see separate volume)

1 INTRODUCTION

This report, commissioned by the Ministry of Agriculture, Fisheries and Food, is the fifth in a series of reviews into novel or low cost methods of shore protection. It examines the potential of breakwaters and similar structures as a means of coastal defence in a UK wave and tidal environment. The structures examined here are designed to either absorb, reflect or diffract waves and by doing so improve beach conditions in their lee. They include offshore free-standing breakwaters which are built on the sea bed, and are detached from the coastline and those which float on the sea surface. Also included are structures known as nearshore breakwaters and sills which are essentially low crested breakwaters built on the lower part of the foreshore and used to retain beach fill.

Interest in novel or low cost methods of shore protection has come about largely as the result of the increased cost of constructing traditional forms of coastal defence. In America the need for designs which are within the means of private property owners promoted a major appraisal of shore protection methods and devices which was carried out by the US Corps of Engineers. The American "Shoreline Erosion Control Demonstration Program "(referred to hereafter as the American programme) examined a wide range of structures. Many of the designs reviewed here are based on American experience but it cannot be stressed too strongly that they were often tested in conditions of small tidal range (typically of the order of 1-1.5m) and of low to moderate wave activity (wave heights typically less than 1.5m). Similarly, breakwaters in Mediterranean countries, eg Italy and Israel, have also been examined. These too are built in areas of low tidal range but with moderate to severe wave activity.

At the other end of the spectrum we have also looked at massive, costly breakwaters which have been built in this country in recent years. There is however a large gap in our knowledge as to the behaviour of medium sized structures and hence our assessment of the type of installations that could be used in a UK coastal climate is therefore largely subjective.

In Chapter 2 we describe the performance of fixed offshore breakwaters either built on the sea bed or connected to it by piling. In this type of structure, the static forces such as mass and the dynamic forces such as wave action, are transmitted directly to the sea bed. The loads thus transmitted are largely compressive ones and hence structures in this category require careful foundation design.

The role of the floating breakwater and its ability to suppress wave activity is examined in Chapter 3. In these structures high tensile forces are transmitted through the anchorage to the sea bed.

Nearshore structures such as low crested sills and other devices which dissipate wave energy at or near breaking or during uprush are covered in Chapter 4. Sills are often used in conjunction with beach nourishment schemes. However since essentially they are designed to retain beach levels, no distinction is drawn between those structures which trap littoral drift and those which retain beach material placed artificially.

Environmental aspects are discussed in Chapter 5. Although breakwaters can be designed to withstand the most severe wave conditions, their effectiveness in protecting the coastline is as yet imperfectly understood. The effect of such structures on adjacent coastlines can be damaging in that they can interrupt or cut off the natural supply of beach material. Amenity problems, such as reduced water exchange and additional pollution due to the collection of trash etc, may also be encountered with this type of structure.

Chapter 6, the final chapter, is devoted to assessing the need for monitoring existing structures in a more positive fashion. Conclusions and recommendations about potential breakwater types are also included here.

Finally, we are once again grateful to the publishers of the "Shoreline Erosion Control Demonstration Program", Moffat and Nichol, Engineers of Long Beach, California for their permission to publish excerpts from the report.

1.1 Purpose

The purpose of this review is to explain the function of breakwater structures, the types and materials most often used, where they are currently in use, and which of these come in to the "low cost shore protection" bracket.

Breakwaters are reviewed in this report under three headings; offshore, floating and inshore structures. The offshore types are usually of rubble mound construction although steel, timber, concrete caissons and even sunken ships have been used. They are constructed normally parallel to the shoreline either singly or in series with a gap between each breakwater. Their main function is to dissipate wave energy by turbulence, friction or by inducing the waves to break on their seaward face. If the breakwater has a high degree of porosity a certain amount of wave transmission may take place. This is by no means always a bad thing and when such structures are placed off bathing beaches they can give protection against waves while maintaining the exchange of clean water between the offshore area and the inter-tidal zone.

Floating breakwaters act quite differently having little effect on damping large waves. They are mainly used in sheltered waters to smooth out short period choppy waves. Fairly popular in parts of Canada, for instance, they can be found in ports or marinas sheltering small craft from choppy seas or boat wash. However, they tend to collect trash and are thus not suitable for amenity beaches. Even the most substantial of such structures do not reduce wave transmission to a degree, in our opinion, to significantly effect beach changes.

The third type, which is rather cheaper than a gravity type offshore structure, is the sill. Placed in the inter-tidal zone it acts in many ways similarly to the offshore breakwater. At low water the sill is exposed on the lower foreshore and has little effect other than to deflect tidal drainage. Towards high tide the sill begins to trip the incoming waves and cause stilling in its lee. At high tide a sill is likely to be submerged hence its capacity to build up the upper beach is somewhat limited. If placed too far up the beach it acts more as a retaining wall or a revetment. The dimensions, layout etc of sills therefore need very careful testing to produce an efficient design. In the USA sills appear to have been used with some success. However, we believe that this is related to the fact that the small tidal range largely reduces an error of correct placement, ie the sill is either within the intertidal zone or outside it. Many of the sills which have American patents (Sandgrabbers, Beach Prisms, Surgebreakers etc) are prefabricated concrete structures which have sufficient porosity to allow water to transport sand through them. The sand then tends to settle out in their lee causing some accretion. With a low tidal range these structures can have relatively small dimensions and be reasonably low cost. If "scaled up" to be effective in tidal ranges and wave heights of several metres, however, such structures are likely to be costly.

Perched beaches are often associated with the construction of sills especially in areas of low littoral drift. Artificial feeding, ie replenishing the beach sand landward of the sill from an outside source has the added benefit of not depriving the adjacent beaches of their littoral supply. To date all the perched beaches have been associated with sills of modest proportions. We do not think that their behaviour is well enough understood to scale up their performance to UK conditions. (In the one case where attempts have been made in this country to create a perched beach the attempt has not been entirely successful).

2 OFFSHORE GRAVITY BREAKWATERS

These are usually constructed parallel to the shoreline, their primary function being to dissipate the energy of incident waves. Indeed, one problem with large breakwaters is that providing there is a plentiful supply of beach material, tombolos can form in their lee. Tombolos often act like long groynes cutting of the natural supply of littoral drift which may in turn cause erosion of the downdrift beaches. Alternatively tombolos can be created deliberately. On the Adriatic coast of Italy for example an offshore submerged structure was constructed using sand filled bags together with groynes on the foreshore. Synthetic fabric bags filled with sand were then laid underwater from the seaward end of the groynes to the breakwater. These enclosed areas were then artificially re-nourished. The function was to arrest erosion with the sand filled diaphragms and trap littoral drift with the short rock groynes.

The ability of a breakwater to trap sand is a function of the wave and tidal conditions, its distance offshore, its length parallel to the shore, its porosity and, if more than one breakwater is to be constructed, their spacing. Thus the height length, wave transmission characteristics etc, need to be examined carefully if breakwaters are to be used as part of a coastal defence system.

There are good reasons for constructing offshore breakwaters with a low crest. This fundamental principle is in direct contrast to the one used in designing breakwaters to prevent harbour disturbance, where every effort is made to ensure a sufficiently high crest elevation to prevent wave transmission. However submerged breakwaters have several obvious constructional disadvantages and may also be unacceptable from an amenity viewpoint. Offshore breakwaters are just as hazardous as natural reefs and need to be marked for navigation purposes.

While breakwaters have not been widely used in the UK, a complex system of groynes and offshore breakwaters has recently been constructed in the Wirral. One such system was constructed at King's Parade, New Brighton in 1985. The breakwaters are submerged to a depth of about 1 metre at mean high water. All consist of a sand core covered by a layer of rock. The crest is armoured with pre-cast concrete units known as reef blocks. The system is designed to increase beach levels in front of the high vertical wall at King's Parade. The shoreline response is to be monitored over a number of years and presently it is too early for any comments to be made about their likely success.

Submerged breakwaters are, of course, less expensive to build than the emergent type. Wave forces on the seaward face are smaller because more wave energy is transmitted over such structures. The tripping of waves by the crest of such structures does mean that greater forces will be imposed upon the landward face. Therefore, submerged breakwaters need as careful testing and design as the emergent ones.

In areas with a large tidal range a submerged breakwater may be relatively ineffective at high tide. This is at the time when incident wave activity is greatest and when the maximum of protection to the coastline is desired. It is therefore thought, that for maximum effectiveness these types should be restricted to areas of low tidal range (Ref 7). Although little is known about the effectiveness of this type of breakwater in the field, much useful information can be gained from the research which has been carried out in recent times (see Refs 2, 7 & 14).

The choice of crest level will hinge upon a variety of factors including protection required, tidal range, storm levels etc. Loveless (Ref 36) suggests that from available evidence it can be argued that a crest level around one metre below MHWS would be sufficient in many cases of beach and coast protection.

The crest width of a submerged offshore breakwater should be a function of the design wavelength while the gaps between a series of breakwaters will depend mainly on the wave climate and the diffraction patterns produced.

The most common form of breakwater is the rubble mound structure. Providing the material is freely available it is a relatively simple operation to tip rock directly into position to form such a structure. Unsophisticated breakwater types also have the advantage of being easily modified as construction progresses or as hydrodynamic conditions change.

For economic reasons breakwaters are often constructed with a steep seaward face and hence wave energy is also reflected seawards. Structures with a relatively flat seaward face together with a rough armour layer at the surface, allow wave energy to be dissipated over a large area and this deters scour at the toe by minimising wave backrush. It is sometimes more cost effective to build such structures as a series of segmented units. This allows some wave energy to be transmitted shorewards, helping to maintain sediment transport and retard the formulation of tombolo's. The water interchange helps to maintain environmental quality in their lee.

Fixed offshore breakwaters have been used widely in countries such as Italy, Israel, Japan and the USA, generally in conditions of low tidal range. They are mostly of the gravity type and of rubble mound construction. Normally used to protect sand beaches fronted by a shallow sea bed, they are generally constructed parallel to the shoreline. A series of offshore breakwaters in Singapore for example were specifically designed with their orientation parallel to the dominant wave crests (Ref 50). The project was designed to protect reclaimed land and the concept was to install offshore breakwaters or headlands at intervals allowing crenulate shaped bays to form between them. Two types of rockfill structure were utilised on this "low energy" coastline, gabions and soil mounds faced with layers of rock. Where the dominant direction of wave action is quite different to the beach alignment, placing them at an angle in this way can help to develop a stable beach plan shape more quickly between each breakwater unit. Spacing of the headlands in this situation is of course of prime importance.

The UK coastline is subjected to a severe wave climate and a large tidal range. To contend with this, structures in this country have therefore been large and expensive to construct by comparison with their foreign counterparts. Also, partly due to the high costs and the widely varying hydrodynamic conditions from site to site, no two breakwater structures have been designed in the same manner.

One of the relatively few breakwaters to be found off the UK coast is at Rhos on Sea, North Wales. This rock breakwater whose general layout is shown in Figure 3, built up a two to three metre wide sand berm on the seaward face of the structure. On the landward side shingle beach levels increased by two metres within four years of construction. Since the structure is essentially there to provide additional protection against wave attack, it is clear that such a system, forming only part of the defence, cannot be classified in the low cost category.

A similar situation exists on the Wirral coast, where some innovative breakwater designs are undergoing trial. At Leasowe Bay, an area with a high tidal range and strong inshore tidal currents, wave action and tidal scour was eroding the beach and it was decided to try to re-align the wave approach and thus to reduce wave and tidal action. Two rubble mound breakwaters (Ref 4) were built in 1982 in an area of sand foreshore, one shore connected and one detached. 80,000 t of rock were used on each breakwater. Beach levels in the breakwater lee have built up. Here also the breakwaters provide only part of the defence system since the shoreline is also protected by a rock revetment. Taking the system as a whole, the price of protecting this frontage must be considered to be high.

One of the most innovative systems tried in the UK to date is at Dengie in Essex. This did not involve a high technology approach but rather a pragmatic use of available materials. A number of disused lighters (barges) were bought by Anglian Water, half filled with silt, and topped off with gravel and towed out and sunk parallel to the shoreline. There were 16 lighters in all, 19.2m long and sunk in a line parallel to the coast with 10m gaps between each, giving a total breakwater length of almost 460m. At present 2.5m above the bed they may well sink into the muddy sea bed making them less effective in time. However, at an estimated cost (in 1983) of £48,000 this is a low cost scheme when related to the cost of refurbishing or replacing the embankments on-shore. Essentially used to protect an area of saltings on a low flat coast, the system is seen as an experimental one. The performance of the system is being monitored. Plate 1 shows an oblique aerial view of the system and the intention is to take similar photographs at intervals to assess the effect of the scheme in halting saltmarsh erosion.

Breakwaters of a roughly similar design were tested in the American programme (Ref 55) but with rather more limited success. The summary sheet describes the construction and performance of a concrete box system built at Kitts Hummock in Delaware Bay. The breakwater, constructed of pre-cast concrete boxes filled with sand, was 100m long and situated some 230m from the shoreline at a depth of 0.3m below MLW. Not surprisingly the sand in the boxes was quickly washed out. Had they been filled with concrete or large aggregate they might have fared better. Purpose made concrete caissons are to be placed offshore of the Essex coast at Sales Point. These will be filled with silt from the foreshore and capped with concrete.

The cost of breakwater construction on an open coastline is likely to be very high. In this context sand asphalt shows some promise. This material, usually used as a core, can be laid rapidly and can be placed underwater without losing its strength. It has some resistance to wave attack and has the advantage of being permeable. Use of sand asphalt fill could improve the speed of construction but is unlikely to put it into the low cost category.

The "lighter" breakwater system used by Anglian Water may prove useful as coast protection in sheltered areas. However it is unlikely to be acceptable in a harsh wave environment on open coast beaches. The draught of the lighters used at Dengie was small, of the order of 2.5m with the crests at mean water level. To protect an open coastline with relatively deep water close inshore would require vessels with considerably more draught.

The design of an offshore breakwater can be complex and before developing an effective solution, the hydrodynamic regime of the area must be understood, ie waves, tides and sediment transport.

Waves

Waves generated by winds or moving vessels are always present on an open coast and represent the major cause of erosion.

Reflection may occur on the seaward side of a breakwater, the degree depending upon the angle of the incoming wave crest and the porosity of the structure. If its seaward face is smooth and vertical, near perfect reflection will result. This would create standing waves which could cause considerable bottom scour. Waves approaching at an angle would generate choppy short crested seas which could also cause bottom scour.

Diffraction occurs when the incoming waves pass around the breakwater and energy is transferred along their crests to the quiet area in the structure's lee. The degree of diffraction determines whether tombolos are likely to form.

Tides

Tidal currents can be another cause of beach erosion. Breakwaters often include shore connections which help to reduce tidal scour. Erosion on the seaward face of the breakwater can be minimised by suitable toe armouring.

Sediment

Waves breaking at an angle to the beach contours carry sediment along the shore in the direction of wave advance. This is termed littoral transport or drift.

The ability of the waves to transport sediment is a function of the wave height to the power of 5/2 so a modest decrease in wave height in the lee of a breakwater can have a major effect on sediment movement. It should be obvious that accretion will depend on the amount of material available, and that trapping of sediment at one point can lead to depletion further downdrift.

The distance between the breakwater and the shore can have a significant effect on its efficiency. Model tests in a wave flume can determine this optimal distance. Minikin (Ref 38) suggests that the toe of the breakwater should be located at the seaward limit of the surf zone.

2.1 Breakwater materials

A number of materials have been used in breakwater construction, the most common being rock or concrete armour units. Bitumen may play an increasingly important role in future years. At present its use is largely as a grouting medium but with its ease of handling and its malleability, bitumen could be very useful, for instance in the construction of breakwater cores.

Steel, concrete, timber, rubber tyres and synthetic materials have all been tested in breakwater construction. Details of some of these design materials and how and where they have been put to use can be found among the summary sheets in the Appendix. In the following sub-sections we have described these materials although not all can be used in an open coast situation.

2.1.1 Asphaltic breakwaters

The combination of stone and asphalt has been used extensively in Holland and Belgium for the construction of harbour walls and can be seen in various works in the 'Delta Project'. Asphaltic grouted rock breakwaters are impermeable structures and details of two such installations, at Ijmuiden and Hoek van Holland can be found among the summary sheets in the Appendix. Grouted structures have the advantage of allowing smaller rocks to be used than would normally be the case with 'free standing' rock armouring. Details of the advantages and disadvantages of bituminous construction can be found in a site visit report to Holland and Belgium (Ref 39) and in volume 4 in this series (Ref 57).

Among other types of asphaltic materials is 'Fixtone' a patented mix of gap graded rock and bitumen. This form of permeable construction seems to be working well as breakwater material for example inside the developing harbour of Zeebrugge, Belgium. Here it has been used as an armour layer, laid over a lean mix of sand-asphalt (bitumen and sand) which forms a filter over the sand core of the breakwater. Laboratory tests at Delft, (Report No M1942) using regular waves have shown that 'Fixtone', laid as a revetment on a 1 in 3 slope, can withstand wave heights of up to 2.65m (with a periodicity of 3 to 5 seconds) without damage.

Other asphaltic materials (such as grouted stone) can also withstand quite severe wave attack. The cost of asphaltic construction can be high, but it has potential as can be seen in many coastal defences on the Continent. It is thought that costs could be reduced once the engineer becomes more experienced and less reliant on the contractor for the design of mixes etc.

A useful report on most aspects of the use of asphaltic products in hydraulic structures has been written by the Technical Advisory Committee on Water Defences in Holland, see Ref 53.

2.1.2 Concrete

The American test programme included a patented concrete panel design called a Z-wall, consisting of rectangular, reinforced slabs held vertically and bolted to each other in zig-zag fashion. A 30m long Z-wall was built in the Great Lakes at Geneva State Park, Ohio at a distance of 30 metres from the shore (see summary sheet no 4). It consisted of 14 panels, each 1.8 metres high and 4.7 metres long and each weighing 6600 kg. The toe of the structure was in about 0.9 m depth of water. The panels were lifted into position by crawler crane and bolted to each other. No special preparation was made to the Lake bed before placing. A partial tombolo was formed and the structure maintained a fairly large accretion in its lee, despite loss of end panels. The easternmost panel broke off shortly after construction and when it was replaced further damage occurred. Uneven panel settlement damaged the edges of the panels causing exposure of the reinforcement. The stability of this massive structure left much to be desired, especially when one considers the small water depth in which it was placed.

A similar system of Z-wall breakwaters was built at Perre Marquette township, L Michigan as part of another demonstration programme. Here three breakwaters were built some 15 metres from the shoreline. The panels were 1.8 metres high and 4.3 metres long, weighing 5440 kg. A storm, with up to 3 metre breaking waves, caused severe damage. Analysis indicated that the necessary design changes would remove such structures from the low cost category.

On an open coastline concrete panels would not resist wave impact well and would tend to overturn, particularly the end panels. Erosion on the seaward would also be a major problem. A system of zig-zag timber breastworks has been used to protect the seaward face of a shingle spit in the United Kingdom at Hurst Castle. These, despite their permeability suffered a similar fate to the American structures. Their seaward faces were undermined and the panels rotated in a seaward direction. We would therefore, not generally recommend the use of free-standing structures with vertical faces, due to the very high forces imposed upon them by wave action.

2.1.3 Rock breakwaters

Dumped rock is useful as a means of constructing low crested breakwaters. Providing the wave climate is not severe they can be of relatively simple construction. Even so problems can be encountered if the hydraulic characteristics and the likely rate of settlement are not assessed. In some situations the latter need not be a serious problem, if the structure has not been designed to fine limits. Settlement can normally be tolerated provided it takes place soon after construction and before the structure is subject to severe wave attack.

As mentioned earlier an offshore rubble mound breakwater was constructed at Rhos on Sea in 1981 to alleviate overtopping of the sea wall and flooding of the low lying residential area beyond. A detached offshore breakwater was opted for in preference to raising the sea wall for several reasons: (a) a higher sea wall on the promenade would have been visually intrusive, (b) the breakwater would build up the beach in its lee, and (c) it would also allow boats and fishing vessels shelter. The structure was positioned at the low water mark and orientated as shown in Figure 3. It was designed to prevent overtopping by waves of up to 3m. While constructing this 240m long breakwater it was noticed that waves were entering the lee side from the north and a rubble groyne (debris from the structure) was built on the beach to prevent the beach material being washed through. The structure (see Plate 2) has been in existence for about five years and a substantial amount of shingle has accumulated in the lee of the groyne. A reasonable amount of fine sediment has also collected in the lee of the breakwater; beach levels too have increased on its seaward side. Fears have been expressed that the breakwater may now be exacerbating the erosion downdrift in Colwyn Bay.

Another such structure was tested in the American programme, at Kitts Hummocks in Delaware Bay. Constructed of 250 to 550kg quarry stone it was sited 180m offshore at a depth of 2m at low water. 2.67m high the structure was built, half on filter cloth and half on matstone. Founded on a soft mud bottom the half on a matstone foundation (0.3m thick) sank by about 0.15m while the other half showed no appreciable change. With no obvious displacement of the armouring during the monitoring period about 0.3m of accretion took place in its lee. Apparently the structure functioned effectively, but at a cost (in 1979) of nearly $700 per metre it could not be considered low cost. This project demonstrates that not only the stability of the armouring needs careful design but that an assessment of the foundation material is equally important. At present, design formation is based largely on the result of hydraulic model tests of structures subjected to regular waves. Wave conditions can vary widely from site to site and clearly the energy distribution needs to be reproduced correctly. The use of model random waves, representing realistically, the sea conditions at a specific site, can give much more accuracy in the test results. In a paper on random wave physical model studies of low crest breakwaters, Allsop (Ref 1) makes the following conclusions. The rate of overtopping is strongly dependent upon the significant wave height at the site, less so on the height of the breakwater above static water level. The degree of wave transmission is strongly dependent on the incident wave conditions, particularly the mean sea steepness. It is thus very important to model wave conditions very carefully when designing shore protective breakwaters.

3 FLOATING BREAKWATERS

It has been demonstrated that offshore breakwaters in the UK are likely to be substantial structures. A cheaper way of reducing wave activity in special circumstances is by the use of floating breakwaters. These are tethered to the sea bed but are allowed to rise and fall with the tide. However, unless they are extremely large, floating breakwaters will only filter out high frequency waves, ie those that have the least amount of energy.

Floating breakwaters or pontoons are used primarily to protect small craft in harbours or other enclosed bodies of water, where the wind fetch and hence wave activity is small. They can however be economical when water depths are large but where wave action is limited, ie sea lochs, deep estuaries, etc.

There are limits at which wave attenuation becomes insignificant and at which point the structure begins to ride the waves. This is to some extent dependent on the size of the structure and a consensus of opinion suggests that a wave period of about 5 seconds is the upper limit for existing designs.

Although this type of breakwater is used to suppress wave action in a mild sea, it will still have to be able to withstand the worst conditions that are likely to occur, hence the anchorage and structural strength must be designed accordingly. It is therefore inevitable that such a breakwater would be structurally overdesigned under normal working conditions. As with all breakwaters the design of a floating breakwater is "site-specific". Hales (Ref 19) suggests that waves attenuated by a floating structure do not usually exceed 1.2m with wave periods of 4 seconds or less.

In order to achieve significant wave attenuation, a floating breakwater will need to have a beam width of the same magnitude as the incident wave length and will need to have a submerged depth of the same magnitude as the incident wave height. This means that for a storm with significant wave heights of say 3 metres and zero crossing periods of 10 seconds the structure may have to be 3 metres deep and up to 100 metres wide if placed in 10 metres of water. To be efficient it would be massive and inordinately expensive to install while the mooring forces would probably be so large as to pose serious design problems. It would also be well outside the low cost category.

Floating breakwaters can be constructed out of many forms of buoyant material such as polystyrene foam,

foam filled rubber tyres, oil drums, hollow steel or concrete modules. With proper anchorage they can be used in deep or shallow water, in areas of silty, sandy or rocky sea bed topography. Their greatest disadvantage is the gradual loss of buoyancy with time as a result of siltation, marine growth, structural damage etc. They also tend to collect debris which also leads to a loss of buoyancy as well as making them generally unsightly. Their greatest use is as protection in marinas and harbours where there are facilities to inspect, remove and repair them as and when necessary. A wide variety of floating breakwaters constructed of scrap tyres were reviewed in the first of this series of reports (Ref 40). For this reason only a small selection of these are included in the summary sheets found in Appendix 1. Included here also are floating caisson breakwaters, a few of which have been tested in the UK.

It has to be stated at the outset that we consider such structures as an unproven means of coastal defence. Their hydraulic performance has been very variable. When structural failure begins it tends to be progressive and usually leads to the complete destruction of the system. In only a few of the case histories has there been assessment of their effect on adjacent beaches, usually because such changes were too small to be measurable.

Anchorage is probably the most important aspect with all types of floating structure and will depend on the peak mooring conditions, water depth and type of sea bed encountered at the site. The breakwater is usually connected by wire cable or link chain to the anchor. Two of the most common are the deadweight anchor (usually a large concrete block) and the pile anchor (which can be expensive). Ordinary ship anchors and screw anchors are sometimes used although they are limited to shallow depths and are difficult to install effectively in a firm sea bed.

Whichever type of anchorage system is used it must be substantial enough to prevent drag and can cost more than the structure it is anchoring.

A case in point was a floating tyre breakwater installed at Guilford, Connecticut. The maximum fetch here was some 56km and the site conditions obviously proved to be too exposed for the anchoring system. This project highlights the difficulties that could be encountered if such a structure was sited on the open coast of the UK.

3.1 Structure type

The types and designs of floating breakwaters vary widely as do the materials used. Below is a selection of types presently in use or at the design stage.

3.1.1 A-frame type

This concept comes from Canada where an abundance of timber has prompted research into designs using this locally available material (Ref 59).

(a) Twin cylinder. Essentially an inverted triangle suspended by pontoons fixed at each end of the baseline (see Figure 4). The frame itself is aluminium with hollow aluminium cylinders connected rigidly at either end. Sitting vertically through the middle of the triangle is a rigid timber wall. A floating breakwater such as this has been in service at Lund, British Columbia for several years.

(b) Four cylinder. A variation of the above design was investigated by Brebner and Ofuya (Ref 9) in 1968. In their experiment they used two pairs of cylinders, (presumably for added buoyancy) one pair on each side connected either rigidly or by chain.

3.1.2 Flexible membrane

A number of laboratory tests have been conducted on various types of floating membranes or fluid filled bags but relatively few field tests have been carried out in sheltered water and it is thought that this type of floating breakwater would have limited application on the open coast.

3.1.3 Hydraulic

This system attenuates the waves by discharging water under pressure through a submerged manifold in the direction of the incoming waves. This creates a horizontal current and ensures partial or complete breaking of the waves, dissipating a large part of their energy. Rao (Ref 45) suggests that this type of breakwater could have important application in deep water waves. It is also thought, Herbich, Ziegler and Bowers (Ref 25), that it would be useful in attenuating waves near the coast. There is at the moment too little field information to assess this type of structure for use in open coast situations. However, the siting of such structures, even if they could be shown to perform well, would pose severe practical problems on the open coastline.

3.1.4 Pneumatic

Somewhat similar to the hydraulic type, this concept was patented in 1907. Wave attenuation in this case is by the release of compressed air through a submerged perforated pipe vertically. Described by Brasher (Ref 8) in 1915 it was re-analysed at the request of the Admiralty by Taylor (Ref 51) in 1943. Taylor (Ref 52) modified the theory in 1955 and his work was verified by Kurihara (Ref 32) in 1958. Sherk (Ref 49) conducted further large scale experiments in 1960 and indicated that a multiple manifold system may be more effective. One problem however could be that excessively large power requirements may be necessary. Again there is too little field information to assess this system for open coast situations.

3.1.5 <u>Pontoon type</u>

This is possibly the simplest form of floating breakwater and can consist of one or more, usually rectangular, pontoons floated onto the water, ballasted, joined together and anchored. There are several different configurations including:

(a) Single type:
where several are joined end to end.

(b) Double type:
rows of caissons connected to float side by side, joined rigidly to form two lines.

(c) Catamaran:
this design consists of rectangular wooden modules (circa 13m long, 3m wide and 2m deep) fastened together to the required length and ballasted with concrete beams. Wooden decking is usually fitted and the pontoon normally anchored by chain to concrete blocks on the sea bed.

(d) Alaska type:
so called because it was developed by the Alaskan Department of Public Works, it is constructed of twin pontoons built with light concrete (0.1m thick walls). The pontoons are connected with cross pontoon sections to form an open framework (circa 18m long, 6.5m wide and 1.5m deep). The hollows are filled with polystyrene foam for buoyancy. The pontoon breakwater at Sitka, Alaska is anchored by a combination of piles and concrete block connected by galvanised link chain.

(e) Sloping float type:
this form of breakwater consists of a row of moored flat interconnected pontoons. Partial flooding allows their sterns to sink to the sea bed where they are anchored. Freeboard and angle of inclination is controlled by flooding a specified number of units. A modification to this design is the addition of legs at the base to

increase the depth range by lifting the pontoons off the sea bed.

Some of the above structures, notably the Alaska type, have been used with some degree of success in partly sheltered waters, in areas of low to moderate tidal range.

3.1.6 Porous wall type

A perforated portable structure was tested by Jarlan (Ref 27) in 1960. This idea which has only been tested, as far as is known, in the laboratory, consists of a rigid steel plate fronted by a perforated plate. The incoming waves impinge on the front wall reflecting part of their energy and allowing the remainder to pass through the perforations. The breakwater being specifically designed to both dissipate and reflect incident wave energy.

A variation of this concept is a floating breakwater consisting of a horizontal array of open tubes.

3.1.7 Scrap Tyres

In general, structures incorporating scrap tyres can be used successfully to form floating breakwaters where their low cost is a positive asset. Where they are used in structures connected to the seabed or to the beach the flexing of individual tyres and the deformation of the structure as a whole can cause problems with tyre to tyre connections and with anchorage. Such problems will be greatly magnified if the structures are built within the zone of wave breaking.

A number of fixed breakwaters were tested in the American programme, use being made of car and lorry tyres strung onto horizontal poles or stacked vertically over piles, see summary sheets. They performed reasonably well resulting in some accretion in their lee. At Fontainbleau State Park, Lake Pontchartrain, Louisiana the tyre/timber pile breakwater was located only 15 metres from the shoreline at a depth of 0.3 metres below mean tide level. An incipient tombolo began to develop and it was considered that further accretion could interrupt littoral transport, to the detriment of the downdrift shoreline. This like other similar structures had problems with tyre movement despite the sheltered nature of the site. Only one month after construction the tyres began to sink into the sandy bed of the lake. The design wave height for this type of structure has been estimated at being less than 0.6 metres.

There appears to be little scope for using discarded tyres as offshore breakwaters in a harsh wave environment. Such structures have great permeability and very large mounds of tyres would be needed to achieve a significant degree of wave damping. If the tyres were subjected to breaking wave forces then the tyre to tyre connections would have to be made such as to prevent parting while at the same time the problems of chafing would also need to be resolved. Since the tyres are practically neutrally buoyant, very strong anchorage would also be needed to keep the structure firmly fixed to the seabed.

A pilot scheme for reducing cliff and foreshore erosion is taking place currently on the Holderness coastline. This involves the use of scrap tyres filled with concrete and laid up to three tiers deep. While we have reservations about schemes using tyres for halting or reducing shoreline recession we will be taking a great interest in its performance.

Although there are many combinations of tyre breakwater design they fall into four main categories:

(a) Goodyear type (Figure 5). The Goodyear Tyre and Rubber Company initiated research in 1974 into using old tyres as floating breakwaters. This research, Candle and Fischer (Ref 10), led to them patenting a modular building block design. This structure consists of a number of modules, each of 18 tyres, bound or bolted together to form an interlocked structure (circa 2m by 2m and 0.75m deep). Transported like this to site they are then assembled as necessary into a pre-arranged pattern. Unwelded open link 13mm chain has been found to be best suited to this type of construction while connecting materials vary as widely as heavy steel chain and conveyor belting. Prototype scale mooring line forces were tested by Giles and Sorensen (Ref 17) in 1978 and Harms (Ref 20) in 1979.

(b) Kowalski type. A simple mat-type floating breakwater was tested by Kowalski (Ref 31) in 1974, to determine the effectiveness of the breakwater in suppressing waves and to investigate the construction problems and durability of such a structure. The experiments concluded that a three-tyre deep mat had a wave suppression efficiency of 70%. However, this was in waves with a significant height of 0.76m and a spectral peak density of the order of 2 seconds, not the conditions one would encounter on the open coast even in relatively calm weather.

(c) Wave guard type (Fig 7). Developed by Harms and Bender (Ref 21) in 1978 this wave guard or pipe-tyre structure consists of large logs such as telephone poles, and steel or reinforced concrete beams, onto which the scrap tyres are threaded. Each beam or log is interconnected longitudinally by strips of conveyor belting and the tyres are closely spaced to ensure a high spatial density, thus resulting in a smaller structure in plan to attain similar attenuation as the previous devices. Model tests in fact showed that this type of structure offers a significantly greater degree of wave attenuation than the more "porous" Goodyear concept. Anchorage, according to Harms and Bender, should include a tyre mooring damper (at least 5 tyres) at the breakwater end with an open link, low carbon, 13mm dia anchor chain near the bottom.

(d) Wave-maze type (Figure 6). Patented by Stiff and Noble in the early 1960's this design is usually made up of lorry tyres filled with polystyrene to increase buoyancy. Design is as shown in Figure 6 with a top and bottom layer of horizontal tyres enclosing a layer of vertical tyres in the centre in triangular fashion. Noble (Ref 42) suggests that the width of the breakwater should be at least half of the length of the waves to be attenuated. If wave heights exceed about 1.2m then additional tiers should be added so that breakwater depth exceeds the wave height. The tyres are bolted together using conveyor belting as reinforcing washers.

Conveyor belting is used extensively in this type of breakwater construction. It is highly abrasion resistant and inert in sea water.

3.1.8 Tethered float type

Conceived initially, it is thought, at the Scripps Institute of Oceanography, this design consists of spherical floats connected to triangular modules of reinforced concrete (equilateral 6m sided triangles) which are joined together with flexible connectors at their apices to form mats about 30m wide. Several mats can be joined together to form the breakwater. These modules, some 0.5m thick, are tethered to a framework resting on the sea bed which can be ballasted to prevent movement.

Hales (Ref 19) presents this and many other forms of floating breakwaters in more detail in his 1981 review.

3.1.9 Turbulence generator

This type of floating breakwater of which there are several designs, takes the form of a flat relatively thin surface floating framework.

(a) Seabreaker. Described by Hasler (Ref 24) it is a long (40m) rigid pontoon of specialised design. Tested in Stokes Bay in the Solent in 1971 it remained on station for 2 years. Hasler contends that the structure attained up to 60% reduction at maximum design wave height within a maximum fetch of 5km.

(b) Harris type. Developed for use at the Port of Le Havre and described by Harris and Webber (Ref 23) the prototype breakwater was required to be effective in seas of up to 10m. A scale model one tenth of the size of the prototype was built and installed in Stokes Bay (around 1970) where wave heights of 1m can be expected. Design consisted of two flat booms connected at intervals with cross members to form a rectangular surface floating plate with slots. Five of these 9.6 by 10m units were joined end-to-end to form what looked like a giant ladder in plan. Mooring was by chain at each corner of the ladder, supplemented by nylon lines to nullify shock loads. Each 50m long chain was connected to an anchor on the sea bed.

Performance, described by Harris and Thomas (Ref 22) in 1974, was measured in terms of percentage energy reduction. The primary function of the breakwater was to inhibit the vertical component of orbital motion with wave breaking and eddy formation and its secondary purpose.

Breakwaters of this type have been used in the UK with varying degrees of success. It would seem that the structural problems associated with this type of design have not as yet been entirely eliminated.

3.1.10 Twin cylinder type

This type of breakwater falls into two categories.

(a) Twin-log type. In 1964, Jackson (Ref 26) conducted a series of experiments to determine the most economical system to attenuate 0.6m waves to a height of about 0.15m. The tests were conducted in water depths ranging from 0.6m to 8m, with a maximum tidal range of 6.5m. Several tests were done and the effect of changing the angle of wave attack, water depth and wave period were checked in a concrete flume. The model structure simulated a twin-log floating breakwater made up of 1.2m diameter logs spaced at 1.7m centres. The flotation depth of the structure was 1.05m. The tests concluded that for an incident wave height of 0.6m and a period of 2 seconds the structure would provide sufficient protection for a small boat basin.

(b) Twin cylinder type. A variation on the above theme using two hollow cylinders (1.83m dia) connected rigidly at intervals by structural supports was tested by Ofuya (Ref 43) in 1968 in the laboratory. Flotation effects were varied by filling or partially filling the cylinders with water.

3.1.11 Wave barrier

Essentially a series of upright cylinders with counter weights beneath to hold them at the surface. Developed by Bowley (Ref 6) in 1974 laboratory tests showed that buoy type systems such as this can be deployed to attenuate waves.

Summary: As can be seen from the above the number and types of floating breakwaters are many and varied. They all however have the same objective, that is to obtain damping of high frequency waves. None of the designs would appear to have potential as a means of coastal defence, due to anchorage problems and low wave attenuation at high water heights.

It is fairly obvious that with the possible exception of the "Harris type" turbulence generator, none of these floating breakwaters would last very long in the harsh environment of the open coast of the UK. In the case of the "Harris type" turbulence generator it is not known whether the structure was actually sited at Le Havre or, if it was, how it fared.

Floating breakwaters are by no means maintenance free and can quickly collect flotsam. Therefore unless they are accessible as they would be in sheltered waters they could become a maintenance liability.

Finally, adequate anchorage as mentioned above can be a problem and in open waters could be insurmountable.

4 SILLS AND PERCHED BEACHES

Sills are essentially low crested breakwaters constructed in the inter-tidal zone. Usually placed parallel to the shoreline they are used to protect the upper part of the beach, their function being to dissipate wave energy either by tripping the waves or through turbulence, and to promote the accretion of beach material. They have to be carefully designed so as not to cause scour of both the beach to seaward, by wave reflection, and to landward as a result of wave overtopping. These problems also occur with breakwaters, but to a lesser degree since they are situated in deeper water. Sills are generally free standing structures although this is not always the case. A wave tripping device has been incorporated in the toe beam of a sea wall in East Wear Bay, Kent. Shown in Plate 3, the idea is for the sill to trap sand at the toe of the wall, and build up the beach. In actual fact although beach scour here has not been entirely eliminated it is clearly less serious than if the sills had not been used.

Sills are commonly used to protect an existing beach or one that has been built up by artificial re-nourishment. In the latter case, the sill and raised beach is called a "perched beach system". The sill can be constructed from a variety of materials but to hold a perched beach it has to be impermeable to prevent the washing out of the fill material. Materials such as quarry stone can be used but would require a filter cloth to be laid between the landward face of the sill and the beach fill.

At low water the sills are stranded on the foreshore and retain the material on the upper beach, preventing it from being carried seaward in suspension via the drainage runnels. It is not advisable to construct high sills, this could result in ponding in their lee, giving rise to stagnant water conditions.

Screens or sills need to be designed carefully with regard to their position within the inter-tidal zone. If they are too successful in trapping material they can build up an are of beach which can act as a barrier to littoral drift. The alternative is that too often sills are placed too far offshore with the result that they produce no significant effect. More often than not in the American programme sills were built so low that they had little trapping capacity and thus could not raise the beach sufficiently to reduce wave action at the back of the beach at high tide.

The design of sills varies greatly, ranging from simple brushwood screens to complex pre-cast concrete units. The latter are patented structures with seemingly somewhat exaggerated claims made as to their ability to build up beaches. In the American programme, a number of these pre-cast units have been installed in areas of low tidal range and with moderate to low water activity. They performed with some degree of success but rarely up to their specifications.

In the American programme (Ref 55) the height of the sills was one metre or so, not much less than the tidal range in some instances. When the sills were backfilled with sand because of their modest height the cost of nourishment did not prove to be prohibitive. Sills in conjunction with sand fill (perched beaches) can certainly improve the amenity value of the beach although because of their low height rarely did they give protection to the defences at the top of the beach. They have not been tested in the conditions typical of the UK coastline. Because of the large tidal range here the cost of such structures would be prohibitive. For example, a structure built in a tidal range of 5m would require to be massive to produce wave attenuation at high water. Clearly model testing is required to optimise dimensions and determine its efficiency with respect to its position on the foreshore.

The American programme of low cost demonstration devices was designed to a large extent with the private property owner in mind. They therefore would not expect a large degree of vandalism. This must be borne in mind especially with sills, which are usually placed in the inter-tidal zone and thus well within reach of vandals.

4.1 Structure type

4.1.1 Beach Prisms

These are pre-cast reinforced concrete blocks triangular in cross-section and formed with recesses to allow water to pass through vertical slots. A line of prisms is held together with pre-stressed tie bars running through the apices of the structure.

Claims about their likely performance can be found in the design brochure produced by the manufacturers. This states that under the right hydrodynamic conditions the system can rapidly build up a beach and cover itself (with sand) in one or two months. This breakwater design was not tested in the American programme. The manufacturers' evaluation would appear to be somewhat optimistic in view of the performance of devices such as the surgebreaker which work on much the same design principle.

Because the cross-sectional shape is an equilateral triangle the unit is inherently stable. The reinforcement running through the system would make it difficult for the structure to twist or undergo differential settlement. The design sizes vary, but units can be up to 1.5 metres high with a weight of 435kg. At this size some 8 units would be needed for a structure 3 metres long.

Transport of the pre-assembled prisms by land or sea is usually by enclosing the two upper faces and ends with airtight rubberised fabric. This is then connected to a mobile air compressor which pressurises the cavities and the whole assembly moves like a hovercraft. Alternatively they can be placed by tractor (at low water) or flat barge (at high water).

This type of unit may also be useful in front of seawalls. Due to the action of storm or steep waves, beaches fronting seawalls often recede. After storms sand which has been moved offshore returns to the beach areas. In calmer weather these concrete prisms, placed in a suitable position might well help in restoring the upper beach.

4.1.2 Sandisle (a sand filled membrane) structure

A fairly new concept in offshore protection, a sand isle is basically a water tight membrane which is taken to the site and firstly filled with water to give it shape. A layer of coarse gravel is next laid in the bottom and the bag filled with sand. Well casings are lowered to the bottom and submersible pumps installed at the bottom of each. As the sand is pumped in, the submersible pumps draw out the water simultaneously. These structures have been tested on the south coast of the UK in water 14.3m deep.

Research is also going on to test low cost methods of cementing the sand during or after construction, to convert it into moderate strength "sandstone" which does not rely on hydrostatic pressures on the wall casing for stability. Sand isles can also be connected together by walkways to provide a multi-cell structure.

The particular structure mentioned above and tested in Christchurch Bay suffered an imperfect fabric seal and a series of storms led to its destruction after one month.

4.1.3 Caisson structures

One caisson structure reviewed in this report was at Kitts Hummock, Delaware Bay. A line of concrete boxes were laid on the seabed about 180m seawards of low water. Each concrete box was then filled with sand. Not surprisingly sand was washed out of the boxes by wave action. Some settlement of individual units also took place.

Capping the boxes with a lean sand-cement mix might help such structures to survive the mild hydrodynamic environment in which they are placed. This type of construction would stand very little chance of success on the open coastline, where any fill, whether it be sand or shingle would be quickly washed out. Wave reflection from the vertical concrete faces would induce scour and breaking waves could overturn the boxes unless they were of very large dimensions.

On the East coast of England at Dengie in Essex, plans are going ahead to install concrete caissons seaward of an eroding saltings area. These purpose-made units will be placed at 20m spacing and filled with silt. The tops will then be capped with weak concrete.

4.1.4 Fagotting

Brushwood fagotting has been used extensively, and with considerable success to reduce erosion of estuary banks. It has also been used on more open parts of the coastline, for example on the Dengie Peninsula, Essex. The salt marshes on Dengie Flats are eroding and wave energy is no longer dissipated by the marsh vegetation, allowing waves to overtop the embankments breaching them in places. To regenerate the saltings Anglian Water have enclosed areas of the upper foreshore within a system of brushwood enclosures. These have tended to trap silt and mud, but drainage channels have had to be cut to allow sediment borne in suspension to be spread evenly over the area.

Fagotting was also used in the American programme to form an offshore breakwater at Fontainbleau State Park, Lake Pontchartrain, Louisiana. The so called dyke breakwater consisted of two lines of brushwood positioned seawards of the edge of the saltmarsh. The system is said to have performed well until the brushwood was washed out by wave action. This type of protection would have little success on an open coastline and indeed it is not designed for this purpose.

4.1.5 Longard tubes

These are a two-ply form of flexible tube which are filled by pumping in a sand slurry, the water being drained off by means of a valve. The outer casing consists of high density polypropylene woven fabric which is sometimes coated for protection with sand-epoxy resin. The inner tube is an impermeable low density polyethylene film. Longard tubes can be of substantial dimensions, up to 1.75 metres diameter and 60 metres in length. The tubes have been used successfully to build up sand beaches or to retain sand fill and this is probably attributable to their large dimensions.

A 61 metre long Longard tube was placed 61 metres offshore and in about 1 metre water depth at Basin Bayou, Florida, see summary sheet No 7. Before it was vandalised the breakwater caused a sand spit to form in its lee. It was considered to be too close to the shoreline and there were fears that further accretion might result in the formation of a tombolo, thereby starving downdrift beaches of sand. The Longard tube was vandalised some 8 months after installation and was replaced with a new one clad in aluminium sheeting. This proved unsuccessful and the tube and sheeting were removed because they had become a hazard to bathers. This type of structure has an estimated design wave height limit of 1.5m (Ref 55). It is clearly not suited for open coast conditions.

4.1.6 Gabions

These are rectangular or mattress-type baskets filled with rock or large pebbles. The most common type, Maccaferri gabions, consist of PVC coated galvanised wire which is woven into a hexagonal mesh. There are also gabions on the market which are constructed of galvanised wires electrically welded into a rectangular mesh. Gabions made of tough plastic mesh are also available.

Revetments made of gabions have been widely used in this country to protect the upper parts of beaches. They are particularly effective on sandy upper foreshores where they tend to become covered with wind blown sand. When placed on the upper part of the tidal zone they are less affected by waves which would otherwise cause movement of the fill, settlement and abrasion of the wires.

Where they have been used on the lower foreshore they have been subject to a high degree of wear and tear as well as corrosion (Ref 58). Plastic gabions have not as far as we know been used in the inter-tidal zone and are clearly not suited for situations where they are exposed to direct wave attack. All the gabions can become damaged and the plastic gabions are very easily vandalised.

A gabion breakwater was tested in the American programme at Geneva State Park, Lake Erie. Built some 18 metres from the shoreline, it was approximately

1.8m high and stood in about 0.8m of water, see summary sheet No 5. In this area wave heights of 1.3m are given as the maximum with a 0.5m wind set up occurring annually and increasing the depth of water in storm conditions. During the first year the structure trapped material in its lee, despite extensive damage. However, four months later the east end had become very badly damaged and much of the accretion behind it had disappeared. Waves up to 1.3m high were severe enough to have broken most of the baskets at the toe of the structure and the stone fill was then washed away. Scour also resulted in some deformation of the structure.

A Guide for Engineers and Contractors has been produced by the US Army Corps of Engineers, summarising the information gained from the American programme. In this report that the "wave height range" for this type of structure is less than 1.5m (Ref 55). Clearly gabions are not suited as offshore breakwaters because of their short design life in a marine environment.

4.1.7 Sand bags

Sand-filled bags of various types and sizes have been tested as coastal defences in the American programme. Summary sheets (in Appendix 1) describe their performance at two such sites. The bags make for easy construction as offshore breakwaters but are not very resistant to damage by wave borne debris and are easily vandalised. The design wave height for such structures has been estimated as being less than 1.5 metres and thus they can only be of use in sheltered waters.

Hessian or woven nylon bags can also be used, being filled with either sand or a sand/cement mortar and stacked in pyramid fashion, with rows of bags staggered for added stability. Typically, sills consist of three tiers of bags with three forming the base, two the middle layer and one bag forming the crest.

From a structural viewpoint both sand and mortar filled bags act in much the same manner. They need to abut well to each other to prevent wave penetration and scour of the beach. Light bags (weighing up to about 45kg) are easily displaced by wave action and hence larger bags are generally recommended in the American programme though these may be harder to fill and place. Being relatively impermeable such structures are subject to scour. The summary sheets in Appendix 1 show that even where they build up beach levels or manage to retain an artificially nourished beach the degree of protection is insufficient to prevent erosion of the upper beach.

Nylon sand bags are flimsy and are liable to chemical degradation under the action of UV light. Even when they are not vandalised their design life is not likely to exceed one or two years. If this type of bag is envisaged then a sand-cement mix should be used as fill, then if the bag deteriorates the fill will stand on its own. It has been estimated that the maximum design wave height for sand bag sills is 1.5 metres or less.

Their performance has been described in an earlier report (Ref 41). Suffice it to say that we consider they have little potential as a means of coastal defence in the UK though they may be useful as short term protection. They are easy to install and quick to fill so they are useful for plugging temporary breaches, gaps in sand dunes etc.

4.1.8 Sheet pile

Sills can be constructed by simply driving in rows of timber, concrete or sheet steel piles parallel to the shoreline. Such systems however, have distinct drawbacks when subjected to wave action. The scour is likely to be of the same order of magnitude as the maximum incident wave height (Ref 55). Such structures would also be extremely dangerous from an amenity point of view. The following example of a wooden sheet pile sill used in the American programme illustrates that this form of protection can nevertheless be effective in mild hydrodynamic conditions.

At Slaughter Beach, Delaware a 100 metre long sill was formed of treated timber planking (see summary sheet No 22). The planks were connected in tongue and groove fashion and each driven into the estuary bed to a depth of 2 metres. In the mild estuarial wave conditions the timber piling retained the perched beach during the 9 month monitoring period. There was no scour in front of the piling and there was no tendency for the wood to "float out". The performance was assessed as being excellent "for low sills in mild wave climates".

Conditions in the United Kingdom are rarely conducive to the use of vertical faced structures situated in shallow water and subject to breaking waves. Toe problems (scour, structural abrasion, loss of fill through undermining etc) are only too often encountered when seawalls are placed in shallow water and subject to wave attack. The use of vertical sills under such conditions should be avoided.

4.1.9 Sandgrabbers

These are patented prefabricated concrete units composed of hollow rectangular concrete blocks, somewhat similar to but larger than cellular building blocks. They are placed in brickwork fashion with the hollows horizontal and are then tied together with U shaped steel rods threaded through the hollows. In principle, waves carrying their load of entrained sand pass through the blocks and in doing so lose sufficient energy to deposit sand in their lee. As the openings in the lower courses are filled in, waves deposit sand on the seaward side.

The structures are certainly able to trap sand and enhance accretion, as can be seen from the field installations described in summary sheet No 26. At Basin Bayon, Florida, for example a 1.6m wide, 0.9m high, 73m long sandgrabber was constructed in shallow water with its crest just above high water level. In the first few months after construction it built up sand by jetting it through the rectangular holes. Sand also accreted on the seaward side and then littoral transport seaward of the structure was re-established. In other field installations saturation conditions were not reached and the structures began to cause downdrift erosion problems.

The current design does not incorporate any toe protection and as a result there is likely to be uneven settlement. In a number of the installations, movement was sufficiently large to pull the cable ties against the blocks hard enough to damage them. Progressive damage of this kind can ultimately lead to complete collapse of the structure. It has been estimated that the design wave height is less then 1.5 metres. Scaling up such structures by simply adding further tiers of units is not feasible. The stresses imposed upon individual blocks would be greater than in the present design and hence the strength of the structure would be considerably reduced. The present unit size is therefore not suitable for UK wave and tidal conditions. Increasing the size of individual blocks would allow a more robust design, especially as the concrete compressive strength could be improved. The stability of an increased structure size under severe wave action would need to be tested for structural strength and hydraulic performance.

4.1.10 Sta-pods

These are pre-cast concrete units (see Fig 2) which consist of four inclined legs supporting a cylindrical trunk. They are about 1.7m high with a leg "spread" of 2.7m, and weigh about 2000kg. They have not been tested in this country.

A 29 metre long Sta-pod breakwater was built at Geneva State Park, Ohio as part of the American programme. The units were placed in position by crane, about 18 metres from the shore and in about 0.9m of water, see summary sheet No 11. Although the units were laid out so as to overlap slightly the 0.6m diameter trunks could not be placed closer than at 1.2m centres. Because of the high degree of permeability they were not effective in screening out wave energy. The Sta-pods remained stable and undamaged during the monitoring period despite some severe wave activity.

The units would require some radical design changes to make them more effective. They could perhaps be laid out in parallel lines in order to reduce permeability. At present however they appear to have little potential for use in UK wave and tidal conditions.

4.1.11 Surgebreakers

These are patented reinforced concrete modules which are triangular in section. They have large vent holes to prevent the build up of wave pressures. Each unit weighs about 1700kg, is 2.1m long, 2.4m wide at the base and 1.2m high. These systems were not monitored over a long enough period in the American programme to evaluate their performance. During the six month period of monitoring following its construction the adjacent beach showed little change.

At Basin Bayon where these were installed, the structures remained intact with no observable change in alignment or any leaning of the units due to toe scour being apparent. It has been estimated that the maximum design wave height is in excess of 1.5 metres. However, the structures were not tested to the limit so the actual design wave height may be considerably larger. The units were installed at some distance from the shoreline and because of their weight had to be airlifted into place. Increasing the size of the units to accommodate UK wave conditions and the larger tidal range would pose problems in terms of installation. The cost of construction and installation would also be very high. With a question mark as to their likely performance even in sheltered waters it is difficult to see their potential in UK conditions.

4.1.12 Timber

At Penhryn Bay on the North Wales coast an open timber revetment was installed in 1980 some 30m offshore and parallel to the existing stepped mass concrete sea wall. It was shore connected at each side by conventional permeable vertical groynes, making it in effect a perched beach system. A wedge of rockfill, of 250mm minimum size was placed against the timber structure on its landward side to absorb most of the incoming wave energy. Inside this enclosure the upper beach was filled with smaller, well-graded granular material. The top of the timber revetment is at MHWN, thus the structure is immersed at high tide. A visit in July 1986 showed that the beach level within the perched system had fallen sufficiently to expose the sheet steel pile at the toe of the sea wall. It would appear that the permeable revetment has allowed the finer material to leach out while retaining the majority of the larger boulders.

5 ENVIRONMENTAL ASPECTS OF DESIGN

The hydraulic and structural aspects of design of breakwaters has been well documented and we would refer the reader to a recent report by Brampton and Smallman (Ref 7).

Rather surprisingly it has been found that breakwaters can accumulate beach material on the seaward side as well as in their lee. The amount of accretion is generally limited but it does add to the stability of both the beach and the structure itself. The Rhos on Sea breakwater described earlier, accumulated a 3 to 4 metre sand berm along its seaward toe within months of its construction. On the landward side the shingle beach increased by about 2 metres over a period of 4 years following construction. The amount of landward accumulation is now becoming a problem in that boats can no longer moor so easily within its shelter. A form of shingle tombolo has now formed between the west end of the breakwater and the shoreline. It is likely, therefore that in the long term downdrift beaches will be starved of their littoral supply of shingle. This in fact may already be taking place with erosion appearing to be on the increase in Colwyn Bay to the east of this breakwater.

Sills have been widely used in the USA with some degree of success on semi sheltered shorelines. Their purpose can be either to retain an artificially nourished beach or as a wave tripping device designed to trap suspended sediment. Usually no greater than 1-2 metres high, the expected increase in beach levels to landward would under ideal conditions be of the same order of magnitude providing an adequate supply of littoral material was available. However, judgement needs to be made as to where on the beach a sill is placed. Too high up and it is only reached by the tide for a limited period, too far offshore and it will give little accretion at the high water mark. Positioning is very dependent on the conditions at a particular site and beach monitoring or model studies are a necessary part of the design.

Because of the severe wave climate and large tidal range experienced around most of the UK coastline, sills are rarely used. It is really only in sheltered waters where waves are small that one can build a structure that can be cost effective. Mud flats and saltings have been successfully protected in this way by brushwood fencing but on the open coast the same degree of protection would require very large structures which would effectively be offshore breakwaters.

Reference 55 gives the following recommendations for sheltered waters:

(a) use fixed breakwaters for shore protection only where the offshore slope is relatively flat and tidal range is small. If the water is too deep at a distance of 60m or more offshore, consider using a revetment at the shoreline or a floating breakwater instead;

(b) where the depth 60m offshore exceeds about 1m and wave periods are short, a floating tyre breakwater may be more economical than a fixed one;

(c) use fixed or floating breakwaters where vegetation is to be cultivated as a shore stabilisation measure. Design the structure adequately to allow the vegetation to become well established;

6 CONCLUSIONS AND RECOMMENDATIONS

1. This report reviews the performance of structures whose primary purpose is to reduce wave energy at the shoreline and whose secondary purpose is to build up beach levels in their lee. Most of the breakwaters and sills which have been reviewed were built in semi sheltered waters and in areas of low tidal range. They were all of modest proportions being typically 1-2 metres high and placed in about 1 metre of water at high tide. Extrapolation of such designs to UK coastal conditions, ie a high wave energy climate and a large tidal range, is therefore subjective.

2. The majority of fixed gravity breakwaters around our coasts are very large and expensive and even so they provide only partial protection. For example, on the Wirral coast an offshore breakwater which is some 50 metres wide at the base and 6 metres or so high provides protection, in conjunction with on-shore defences, against wave attack. Similarly at Rhos-on-Sea an offshore breakwater protects an existing sea wall against flooding. It is our opinion that cost will inhibit the building of such structures to provide protection for open beaches although they will probably continue to be used as additional defence in problem areas. To provide protection through the tidal cycle they have to be quite massive. The longitudinal breakwater, a common sight off the Spanish and Italian coasts, can really only be economically viable in areas of low tidal range. Offshore breakwaters are normally constructed seawards of the low water line and reduce wave energy by breaking and by reflection. The energy which is transmitted shorewards is redistributed by diffraction. Experience has shown that a certain degree of wave transmission helps to maintain an exchange of water between the beach and offshore. This is particularly important in the case of amenity beaches and in such cases design requires some form of hydraulic modelling.

   Tombolos can and often do develop in the wave diffraction zone. The siting of such structures therefore requires site specific studies to ensure that accretion is not excessive and does not result in unacceptable erosion of the downdrift coast.

3. In recent years some very large breakwaters have been constructed in the UK. While many do not fit into the low cost category their performance is a guide as to how structures of more modest proportions are likely to behave. It has been found that even with the most sophisticated designs the amount of beach build up is modest and none of

the structures examined give "total protection" to the coast. Clearly, structures which are modest in size and which might fit into the low cost category are likely to provide a smaller degree of protection and should be considered as a means of beach stabilisation, not as replacement for existing coastal defences.

4. A number of unusual breakwaters have been tested off the Dengie Peninsula, Essex. This is an area of salt marshland subject to low wave conditions and a moderate tidal range. A series of barges have been placed in a line on the lower foreshore and infilled. The breakwater system is designed to halt the erosion of the edges of the salt marsh. The design is certainly in the low cost category and initial results are favourable. The adjacent coastline is being monitored regularly to see how effective the system is in damping wave attack. While the design is unlikely to be suitable for open coast conditions, it appears to have potential for semi-sheltered conditions.

5. Sills are low crested breakwater type structures which are normally constructed within the intertidal zone. Their function is to trip incident waves, whose energy has already been reduced as a result of wave attenuation over the inshore sea bed. They are sited within the zone of wave breaking hence the water which passes over them usually contains a large suspended sediment load. Effective sill designs allow the suspended sediment to settle out and build up inshore beach levels. Sills constructed of artificial armour units have been tested in a recent field study in the USA. Under conditions of low tidal range and low wave activity they have proved to be capable of building up nearshore bed levels and causing some beach accretion. Scaling up of such units to cope with the much larger tidal range in the United Kingdom would pose design problems and the structures would probably not be low cost. Their effectiveness in tripping waves and causing local accretion does however, suggest several possible uses. Many sea walls in this country are suffering from falling beach levels and undermining of foundations. Sills of a modest size could be used to protect the toe of the walls without necessarily changing the hydrodynamic conditions except very locally. On a recent visit to the south-east coast of the United Kingdom it was noted (see Plate 3), that wave tripping devices have actually been incorporated in the toe beam of a sea wall in East Wear Bay, Kent. The beach scour in front of the sea wall has not been entirely eliminated but it is

clearly far less serious than if sills had not been used.

6. The use of more natural materials is also being examined in the field, though in the context of groyne design. In Christchurch Bay a series of groyne systems have been constructed using rock tipped directly onto the foreshore. A low technology approach was considered to be appropriate and no attempts were made to grade the rock, provide filter layers etc. Monitoring of the groynes has been carried out at several sites by the Coast Protection Authority, Christchurch Borough Council, with the co-operation of Hydraulics Research Limited. The groynes were found to absorb wave energy and helped stabilise an artificially placed shingle beach. Settlement of these simply constructed groynes has not been a problem, with the crest being maintained by tipping small additional quantities of rock as and when required. We consider that a similar 'low tech' approach may also prove to be possible for breakwaters and sills though these may be subject to greater wave forces and may suffer greater settlement. Breakwaters or sills constructed of rock would be most appropriate in areas when a local supply of material is freely available. We consider that this form of structure may have considerable potential for halting or slowing down foreshore erosion by reducing inshore wave activity. They could therefore be used in areas where the beach in front of sea walls has been eroded to such a degree that groyning is insufficient to remedy the situation (ie due to lack of littoral drift).

7. Floating breakwaters are not suited for open coast protection. They obviously need to be positioned outside the breaker zone to attenuate incoming waves, since within the breaker line energy is in any case rapidly dissipated by turbulence and bed friction. Their location and dimensions would have to be carefully determined to be effective. Beam width for instance would have to be of the same magnitude as the incident wave length, which for anything other than short waves would be inordinately large. Water depth too is a limiting factor in attenuating longer period waves, for example a structure situated in 10 metres of water and subject to a 10 second period wave would require a beam width of 90-100 metres. If in much deeper water the wave length is proportionally greater and hence the beam width would need to be in the region of 150-160 metres to obtain the same degree of attenuation.

Tidal range poses logistical problems with respect to anchorage. With a large tidal range the floating breakwater requires a large amount of chain or cable to hold it at the surface at high water. At low tide this could result in the structure moving off station taking up the slack in the anchoring cables.

7 REFERENCES

1. Allsop N W H. "Low crest breakwaters, studies in random waves." Proc Coastal Structures Conf, Virginia, USA, 1983.

2. Aminti P, Lamberti A and Liberatore G. "Experimental studies on submerged barriers as shore protection structures." Coastal and Port Eng Conf in Developing Countries, Colombo, March 1983.

3. Anon. "Beach prisms - a shore erosion protection system embodying an artificial stabiliser." Payne Inc 1933 Lincoln Drive, Annapolis, Maryland 21401, USA.

4. Barber P C and Davies C D. "Offshore breakwaters - Leasowe Bay." Proc ICE, Part 1, 77, Feb 1985.

5. Bishop C T. "Research into floating tyre breakwaters and the headland defence of coasts." Proc 3rd workshop on Great Lakes, Coastal Erosion and Sedimentation.

6. Bowley W W. "A wave-barrier concept." Proc of the Floating Breakwater Conf, Univ of Rhode Island, Kingston, Rhode Island, USA, 1974.

7. Brampton A H and Smallman J V. "Shore protection by offshore breakwaters." Hydraulics Research Limited, Report No SR8, July 1985.

8. Brasher P. "The Brasher air breakwater." Compressed Air Magazine, USA, Vol 20, 1915.

9. Brebner A and Ofuya A O. "Floating breakwaters." Proc 11th Conf on Coastal Engineering, ASCE, Vol 2, 1968.

10. Candle R D and Fischer W J. "Scrap tyre shore protection structure." Goodyear Tyre and Rubber Co, Akron, Ohio, 1976.

11. Colquhoun R S. "Dune erosion and protective works at Pendine, Carmarthenshire, 1961-68." 11th Coastal Engineering Conference, 1968.

12. Cortemiglia G C, Lamberti A, Liberatore G, Stura S and Tomasicchio U. "Effects of harbour structures on shoreline variations along the coast of Italy." Bulletin PIANC, Vol II, No 39, 1981.

13. Davies C D. "Offshore breakwaters at Wirral." Municipal Engineering (2), August 1985.

14. Dick T M and Brebner A. "Solid and permeable submerged breakwaters." Coastal Eng Conf, Vol II, 1968, p1141-1158.

15. Diez J J. "The performance of different shore protection systems in the east Spanish Mediterranean coasts." Int Symp on Maritime Structures in the Mediterranean, Athens, 1984.

16. Fried I. "Protection by means of offshore breakwaters." Coastal Eng Conf, 1976, p1407-1424.

17. Giles M L and Sorensen R M. "Prototype scale mooring load and transmission tests for a floating tyre breakwater." TP 78-3, US Army Corps of Engineers, Coastal Engineering Research Centre, Fort Belvoir, Virginia, April 1978.

18. Greensmith J and Tucker E. "Salt marsh erosion in Essex." Nature, Vol 206, 1965, p607.

19. Hales L Z. "Floating breakwaters: State of the art literature review." US Army Corps of Engineers, CERC, Fort Belvoir, Va, Technical Report No 81-1, October 1981.

20. Harms V W. "Data and procedures for the design of floating tyre breakwaters." Water Resources and Environmental Engineering Research Report No 79-1, State University of New York, Buffalo NY, Jan 1979.

21. Harms V W and Bender T J. "Preliminary report on the application of floating tyre breakwater design data." Water Resources and Environmental Engineering Research Report No 78-1, State University of New York, Buffalo, NY, April 1978.

22. Harris A J and Thomas J M. "The Harris floating breakwater." Proc Floating Breakwater Conf, Univ of Rhode Island, Kingston, R I, USA, 1974.

23. Harris A J and Webber N B. "A floating breakwater." Proc of the 11th Conf on Coastal Engineering ASCE, Vol 2, 1968.

24. Hasler H G. "The 'Seabreaker' floating breakwater." Proc Floating Breakwater Conf, Univ of Rhode Island, Kingston, RI, USA, 1974.

25. Herbich J B, Ziegler J and Bowers E C. "Experimental studies of hydraulic breakwaters." Project Report No 51, St Anthony Falls Hydraulic Laboratory, Univ of Minnesota, Minneapolis, Minn, June 1956.

? C.E Bowers.

26. Jackson R A. "Twin-log floating breakwater, small boat basin no 2, Juneau, Alaska." Misc Paper 2-648, US Army Waterways Experiment Station, Vicksburg, USA, May 1964.

27. Jarlan G E. "Note on the possible use of a perforated vertical-wall breakwater." Unnumbered report, Canadian National Research Council, Ottawa, Canada, August 1960.

28. Johnson J W, Fuchs R A and Morison J R. "The damping action of submerged breakwaters." Trans American Geophysical Union, Vol 32, No 5, October 1951.

29. Jones D B. "Sloping float breakwater: Interim data summary." Technical Note No N-1568, US Navy Civil Engineering Laboratory, Port Huenerne, California, Jan 1980.

30. Jones D B, Lee J J and Raichlen F. "A transportable breakwater for nearshore applications." Proc Conf of Civil Engineering in the Oceans, ASCE, Vol 1, 1979.

31. Kowalski T. "Scrap tyre floating breakwaters." Proc of the Floating Breakwaters Conf, Univ of Rhode Island, Kingston, RI, USA, 1974.

32. Kurihara M. "Pneumatic breakwater III. Field test at Ha-Jima. A translation by K Horikawa." Research Report 104, Univ of California, Berkeley, California, USA, 1958.

33. Leach P A. "Ship deployable hinged, floating breakwater." Thesis for Master of Ocean Engineering, Oregon State University, 1983.

34. Leach P A, McDougal W G and Sollitt C K. "Ship deployable floating breakwaters." Proc Conf on Coastal Structures, Virginia, USA, 1983.

35. Ligteringen H and Heydra G. "Recent progress in breakwater design." Dock and Harbour Authority, July 1984.

36. Loveless J H. "Offshore breakwaters: some new design considerations." Inst Water Engrs and Scientists Presented to the AGM, Leamington Spa, March 1986.

37. Miller D S. "Practical applications of floating breakwaters for small craft harbours." Proc of the floating breakwater Conf, Kingston, Rhode Island, USA, 1974.

38. Minikin R R. "Winds, waves and maritime structures." Publ by Griffin, London, 1963.

39. Motyka J M and Welsby J. "Inspection of sea defences in Holland and Belgium." Hydraulics Research Limited, Report No SR 6, December 1984.

40. Motyka J M and Welsby J. "A review of novel shore protection methods, Vol 1. Use of scrap tyres." Hydraulics Research Limited, Report No IT 249, July 1983.

41. Motyka J M and Welsby J. "A review of novel shore protection methods, Vol 2. Sand or mortar filled fabric bags." Hydraulics Research Limited, Report No IT 253, June 1984.

42. Noble H M. "Use of wave-maze flexible floating breakwater to protect offshore structures and landings." Proc of Offshore Technology Conf, Vol 2, 1976.

43. Ofuya A O. "On floating breakwaters." Research Report No CE-60, Queens University, Kingston, Ontario, Canada, Nov 1968.

44. Patrick D A. "Model study of amphibious breakwaters." Issue 332, Series 3, University of California, Berkeley, California, October 1951.

45. Rao V S. "Experimental studies on hydraulic breakwaters." MS Thesis, Univ of Washington, Seattle, Washington, USA, 1968.

46. Sato S and Tanaka N. "Artificial resort beach protected by offshore breakwaters and groynes." Coastal Eng Conf, 1980, Vol II, p2003-2022.

47. Seelig W N. "Effect of breakwaters on waves: Laboratory tests of wave transmission by overtopping." Coastal Structures Conf, 1979, p941-961.

48. Seelig W N. "Prediction of beach erosion and accretion." US Army Corps of Engineers, 1983.

49. Sherk S N. "Offshore discharge, Pneumatic wave attenuation full scale tank tests." Tech Report TREC 60-26, US Army Translation Research Command Fort Eustis, Va USA, Dec 1960.

50. Silvester R and Ho S K. "Use of crenulated shaped bays to stabilise coasts." 13th Coastal Eng Conf, Vol 2, 1972, pp1347-1365.

51. Taylor G I. "Note on possibility of stopping sea waves by means of a curtain of bubbles." Admiralty Scientific Research Dept, Report No ATR-Misc-1259, London, 1943.

52. Taylor G I. "The action of a surface current used as a breakwater." Proc Royal Society of London, Series A, Vol 231, 1955.

53. Technishe Adviescommissie voor de Waterkeringen. "The use of asphalt in hydraulic engineering." Rijkswaterstaat communication 37/1985.

54. Toyoshima O. "Design of a detached breakwater system." Coastal Eng Conf, 1974, p1419.

55. US Army Corps of Engineers. "Final report on shoreline erosion control demonstration program (section 54)." Published by Moffatt and Nichol, Engineers, Long Beach, California.

56. US Army Corps of Engineers. "Shore protection manual, Vols I and II, 1984." Publ by US Army Corps of Engineers, Vicksburg, USA, 1984.

57. Welsby J and Motyka J M. "A review of novel shore protection methods, Vol 4. Revetments." Hydraulics Research Limited, Report No SR 12, April 1986.

58. Welsby J and Motyka J M. "A review of novel shore protection methods, Vol 3. Gabions." Hydraulics Research Limited, Report No SR 5, November 1984.

59. Western Canada Hydraulics Laboratories Limited. "Report on hydraulic model studies of wave damping characteristics of "A" frame pontoon-type floating breakwater." Unnumbered Report, Port Coquitlam, British Columbia, Canada, Nov 1966.

60. Wong P P. "Beach evolution between headland breakwaters." Shore and Beach, July 1981.

61. Zwamborn J A, Fromme G A W and Fitzpatrick J B. "Underwater mound for the protection of Durban's beaches." Coastal Eng Conf, Vol II, 1970, p975.

8 GLOSSARY

Alongshore -	Parallel to and close to the shoreline
Beach -	The area of sand or shingle from the mean low water line stretching landward to the coast (usually the limit of storm waves)
Coast -	A strip of land extending inland from the shoreline to the first major change in the terrain
Dune -	A hill bank ridge or mound of loose wind blown material, usually sand
Erosion -	The removal of beach materials by wind wave or tidal action
Fetch -	The area of water in which waves are generated by the wind
Filter cloth -	A synthetic textile with openings that allow the passage of water but which prevents the passage of soil particles
Foreshore -	The intertidal area
Gabion -	A wire basket, usually PVC coated for marine use, filled with stone
Groyne -	A shore protection structure usually constructed perpendicular to the shoreline to trap littoral drift or retard erosion of the shore
High water -	The maximum elevation reached by each rising tide
Impermeable -	Doesn't allow passage of appreciable quantities of sand or water
Intertidal zone -	Usually from mean low water to extreme high water

Leo - Littoral environmental observations. Usually daily observations on wind wave and current conditions at a site. An American term, shown on the summary sheets

Littoral drift - The sedimentary material moved in the shore zone under the influence of waves and currents

Littoral transport - The movement of littoral drift either parallel (alongshore) to the shore or perpendicular (onshore-offshore) to it

Littoral zone - An indefinite zone extending seaward from the shoreline to just beyond the breaker zone

Longard tube - A patented two-ply flexible tube. The outer ply is high density polypropylene woven fabric and the inner ply is an impermeable low density polyethylene film. The tube is filled with sand and comes in 0.25, 1.02 and 1.75m diameters

Mastic - Asphalt applied hot to seal voids in a rubble mound

Nourishment - The process of replenishing a beach either by natural or artificial means

Perched beach - A beach or fillet of sand retained above the normal profile by a submerged dyke or sill

Permeable - Having openings large enough to permit the passage of appreciable quantities of sand or water

Pile - A long section of timber metal or concrete driven or jetted into the sea bed to serve as a support or protection

Revetment - A facing of stone concrete etc built to protect an embankment or shore structure against erosion by waves or currents. Usually sloping

Riprap -	A layer of stones, randomly placed, to prevent erosion or scour of a structure. Also the stone so used
Rubble -	Loose angular waterworn stones on a beach or rough irregular rock or concrete fragments
Rubble mound structure -	A mound of random-shaped or random-placed stones or concrete rubble protected with a cover layer of selected stones or armour units
Sandgrabber -	A patented permeable structure of hollow concrete blocks similar to but larger than commercial building blocks. Tied together with U-shaped rods the structure is placed on the beach face and waves wash sand through the hollow to build up on its landward side
Screw-anchor -	A type of metal anchor, sometimes used with floating breakwaters, that screws into the sea bed
Sheet pile -	A pile, generally with a flat cross section, driven into the ground and meshed with like members to form a diaphragm or wall
Sill -	A low offshore barrier type structure, designed to retain sand on its landward side
Sta-pod -	A concrete module with a vertical cylindrical body and four legs. Placed close together they form a permeable wave barrier
Surgebreaker -	A patented breakwater system comprising triangular shaped concrete modules, 122m high with a base of 2.44m and 2.13m long. Set end to end in shallow water, openings in the blocks dissipate wave energy in a profusion of water jets

Tombolo -	A bar or spit that connects or "ties" an island or breakwater to shore
Wave-maze system -	A patented floating tyre breakwater system
Z-wall -	A patented concrete breakwater system comprising concrete slabs 1.83m high and 4.27m long set on edge in zig-zag fashion and joined with large hinge bolts

Figures

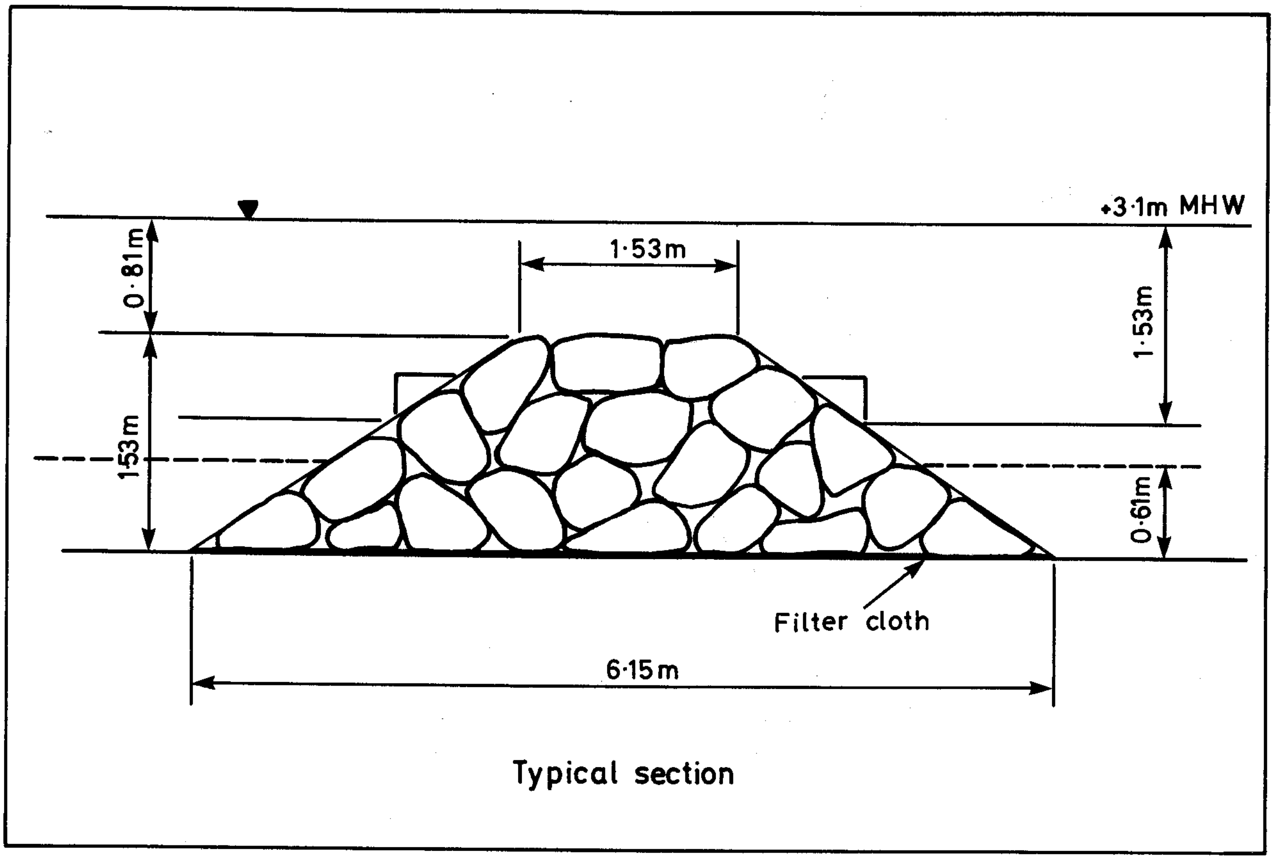


Fig 1 Rubble-mound breakwater

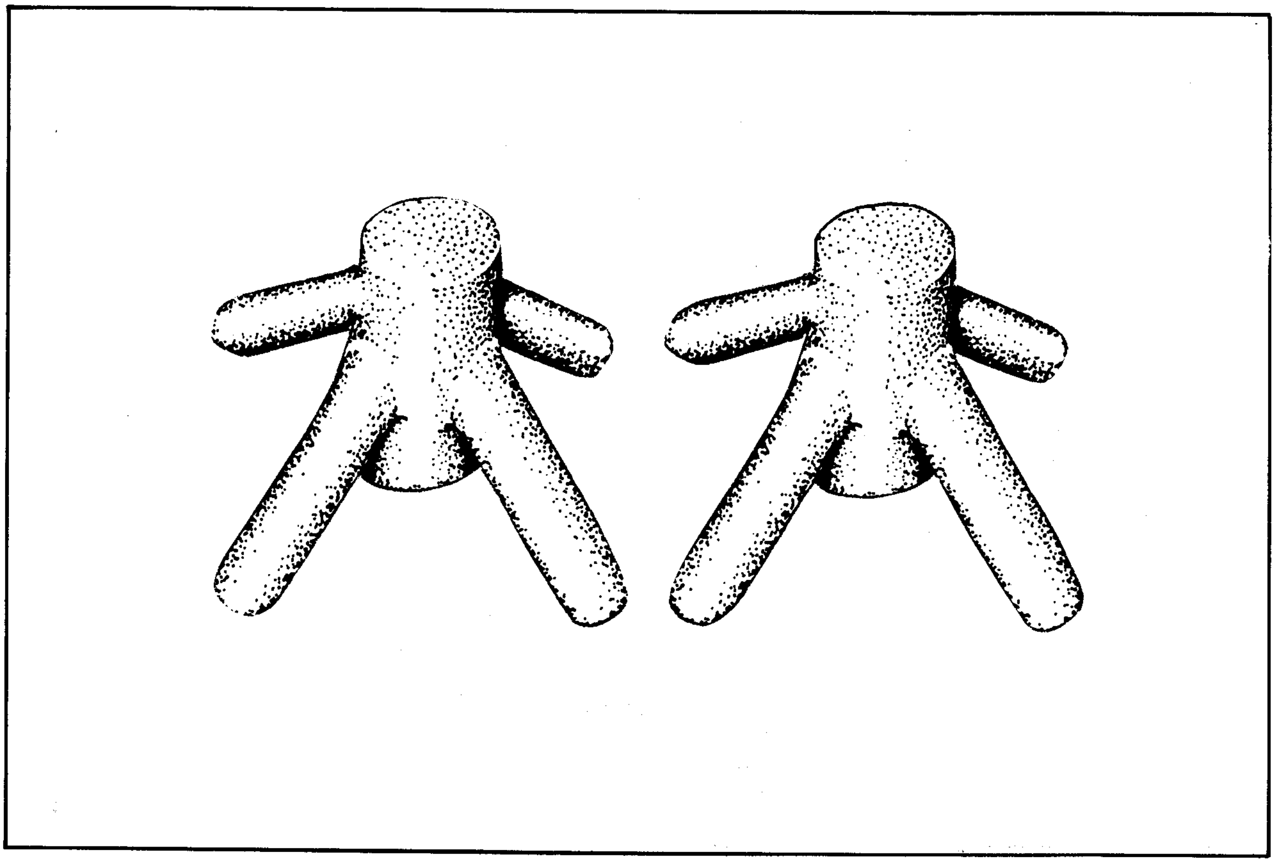


Fig 2 Sta-pod breakwater units

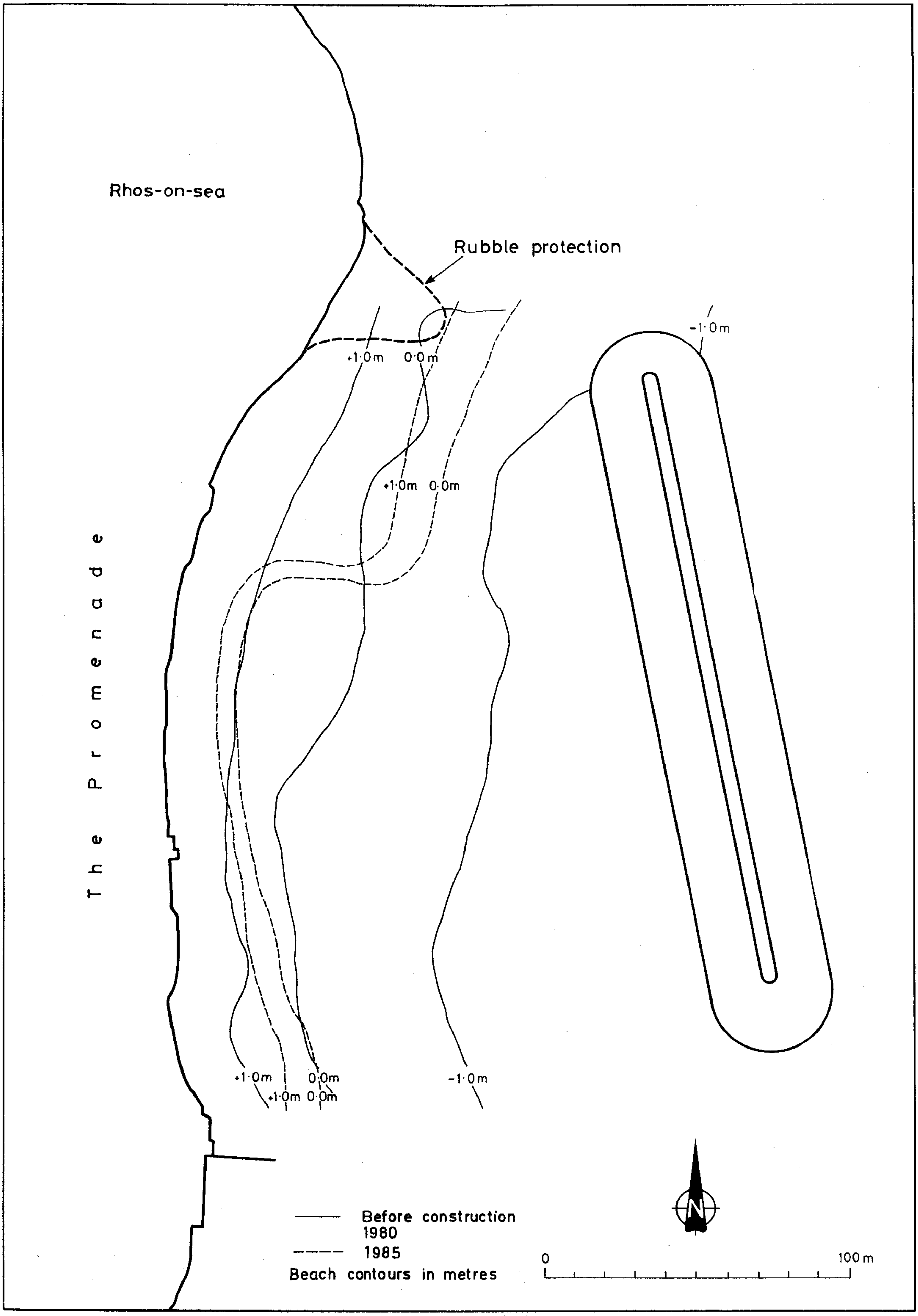


Fig 3 Rock breakwater, Rhos-on-Sea, North Wales

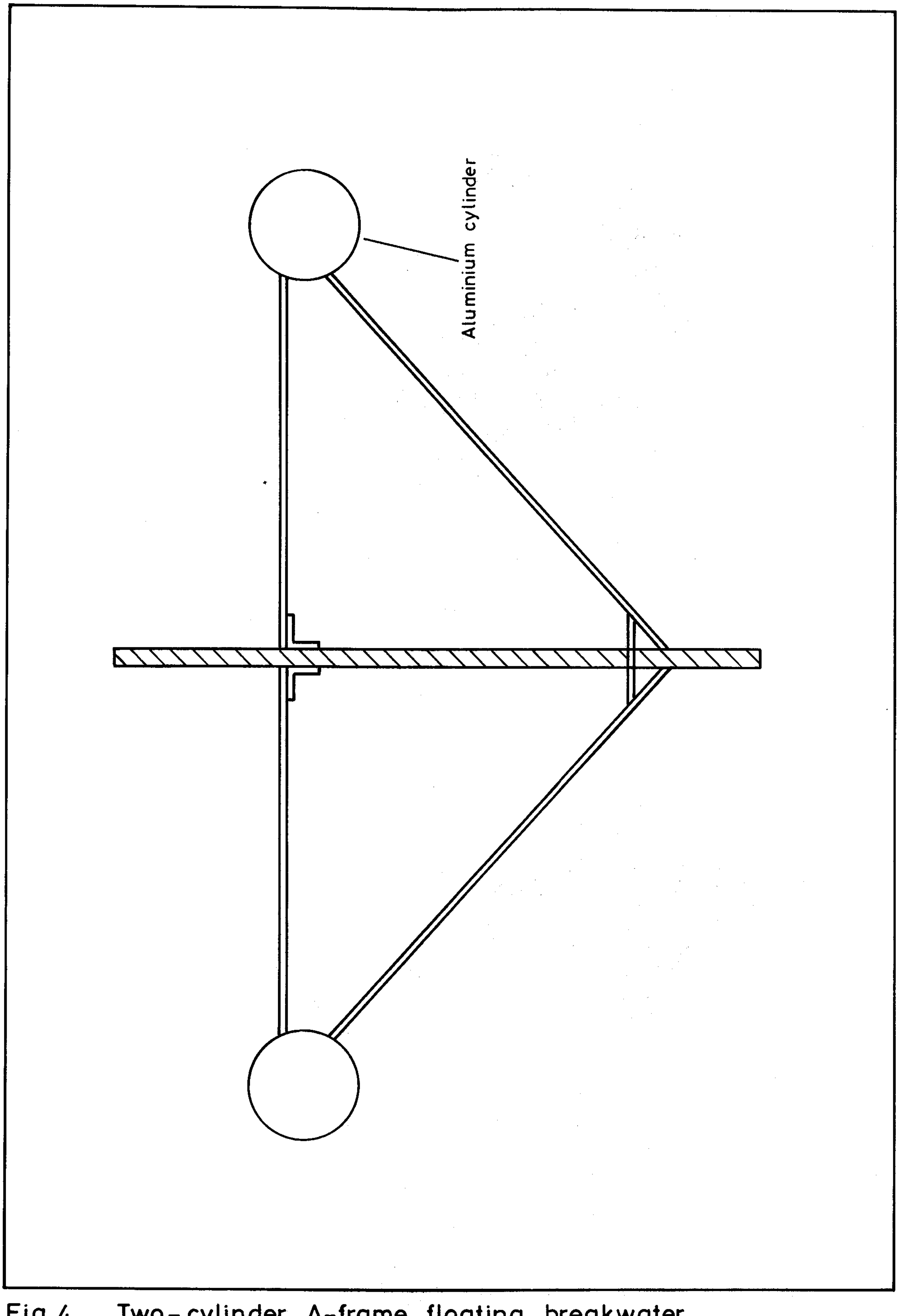


Fig 4 Two-cylinder A-frame floating breakwater

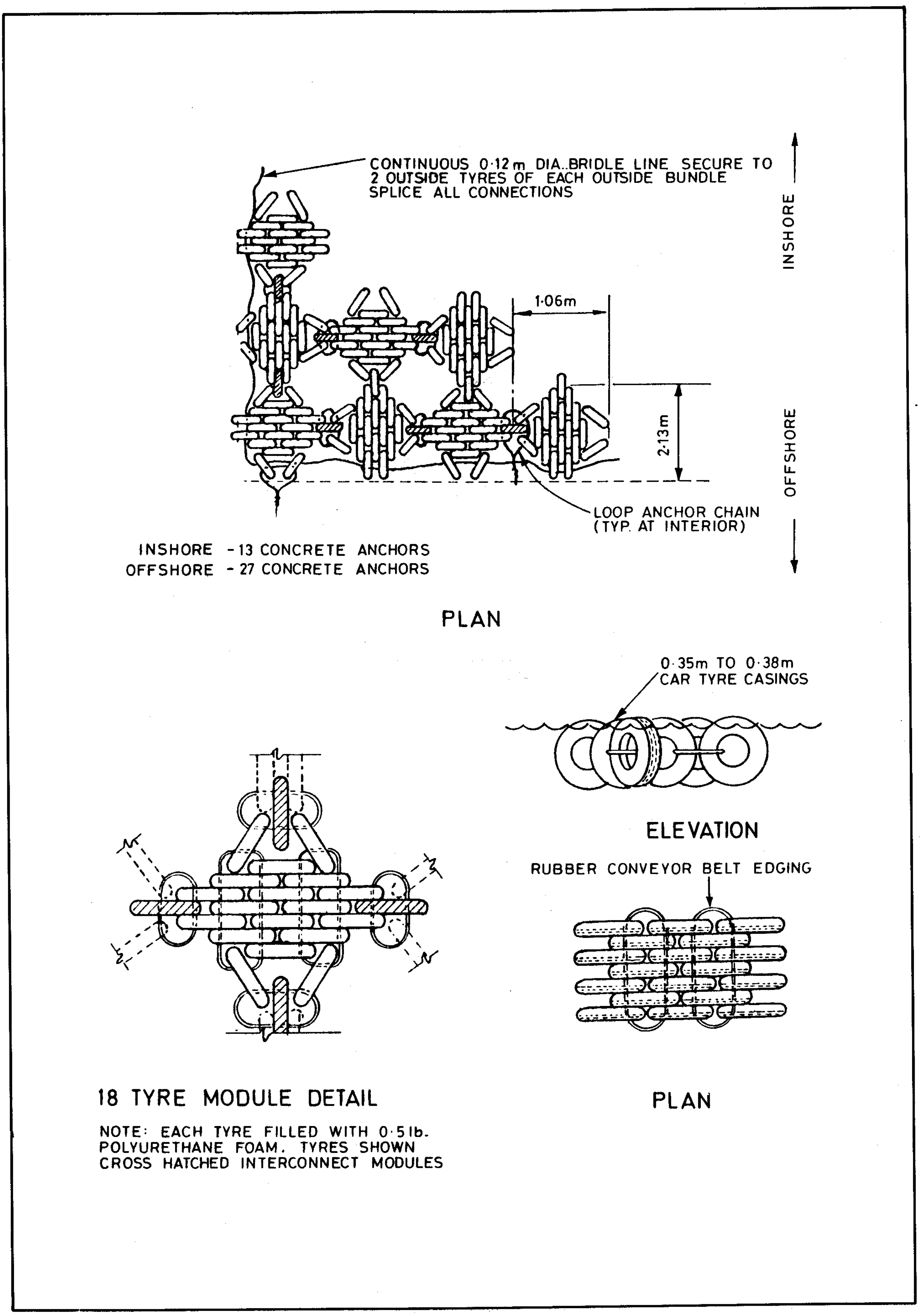


Fig 5 'Goodyear' type floating tyre breakwater

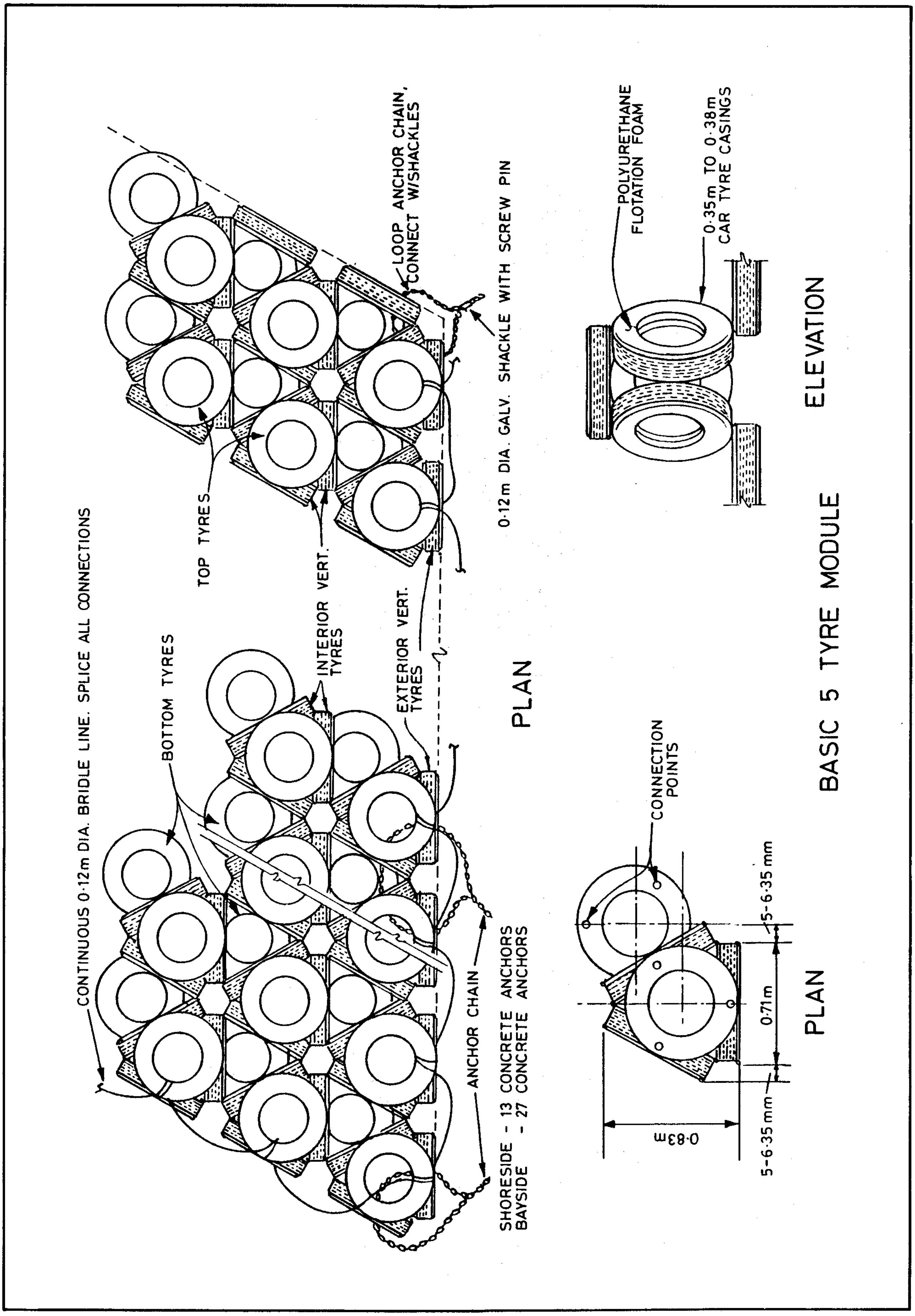


Fig 6 'Wave maze' type floating tyre breakwater

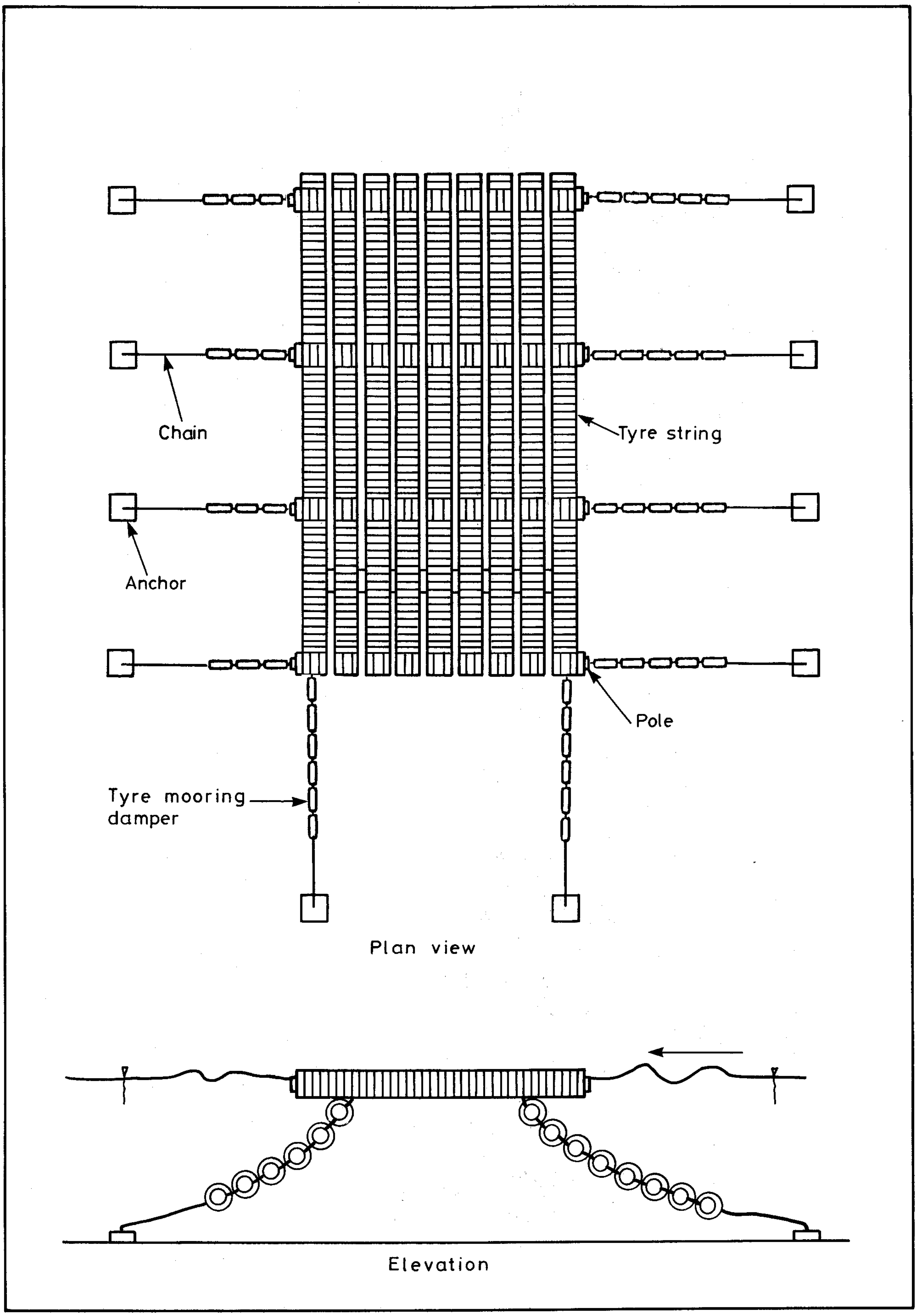
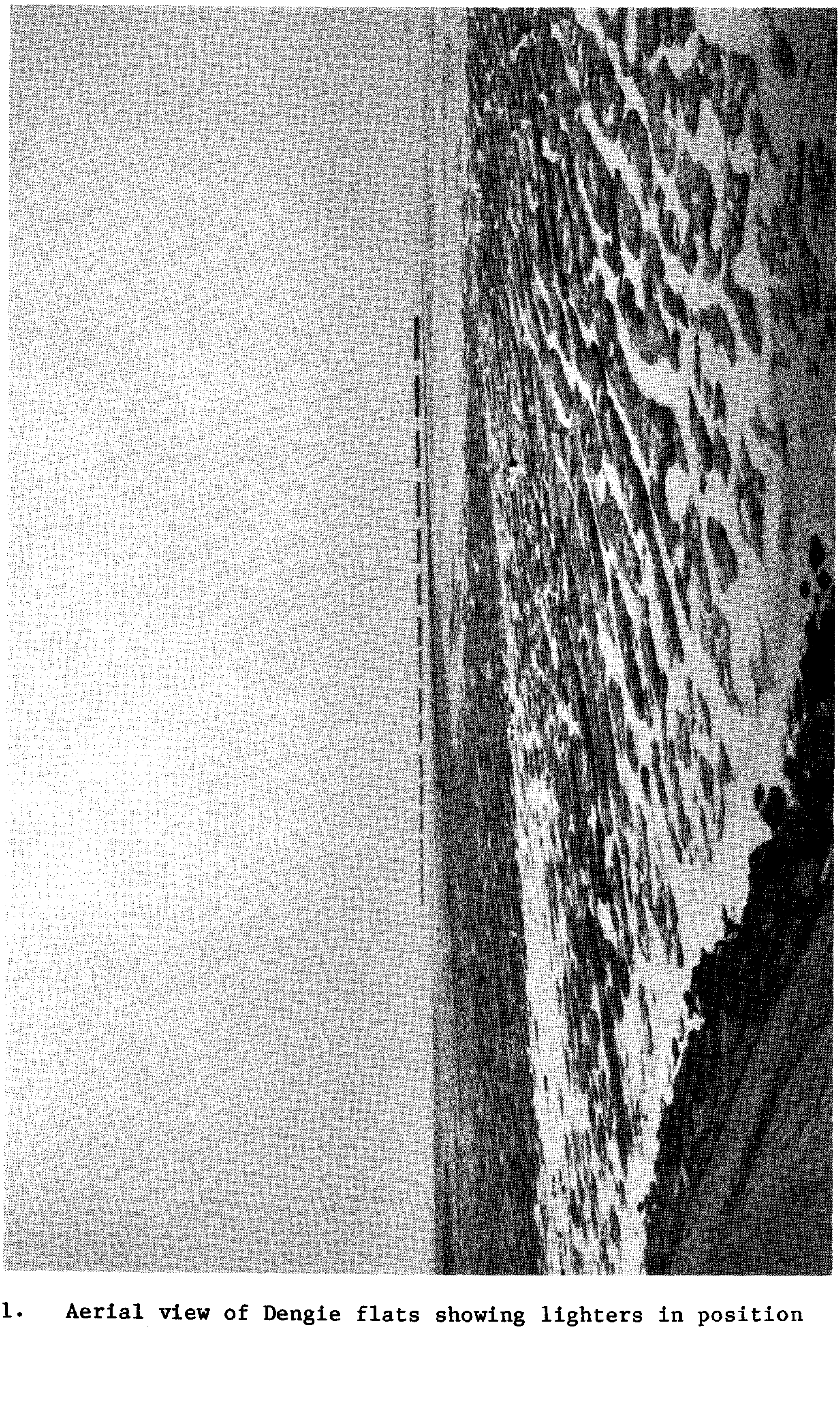


Fig 7 Schematic 'Wave-guard' floating tyre breakwater after Harms (Ref 20) 1979

Plates



1. Aerial view of Dengie flats showing lighters in position

2. Rock breakwater, Rhos on Sea, North Wales

3. Sill incorporated in sea wall design, East Wear Bay, Kent