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A Review of Novel Shore Protection Methods

Vol 6 - Final Report

by

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ABSTRACT

This is the last of the series of reports on low cost or novel methods of shore protection. It summarises the findings of the earlier reports, indicating which of the coast protection methods examined are suited to UK coastal conditions. Recommendations are also made for further research since our reports indicate a lack of design information for such structures.

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1 INTRODUCTION

In 1981 the Water Directorate of the Department of Environment commissioned Hydraulic Research Limited to review various novel or low cost methods of shore protection and assess their potential for use on the open coastline of the United Kingdom. Since that date five volumes on various types of structure have been published, plus an inspection report on sea defences in Holland and Belgium (Refs 1 to 6). This, the final report presents the principal findings of this review.

Chapter 2 covers the use of scrap tyres as floating breakwaters and revetments. (Their use as groynes has not been considered due to the lack of prototype information). Detailed findings are in Volume 1 of this series.

Sand or mortar filled bags (Volume 2) have been widely used in low energy conditions. Their performance as offshore breakwaters and sills, groyne systems and revetments is described in Chapter 3.

Gabions (Volume 3) have been in existence for many years but modern methods of manufacture have made them popular in recent times. Their use as groynes, retaining walls, revetments and sea walls is described in Chapter 4.

A wide variety of material types have been used in revetment construction Because of the diversity of material types and generally a lack of detailed information, it was decided to cover their usage within one report (Volume 4). Materials such as asphalt, pre-cast concrete blocks, gabions, fabric, rock and timber were examined and the most promising of these are described in Chapter 5.

Offshore breakwaters and sills (Volume 5) are a fairly recent development in coastal engineering. Their possible use as coast protection in the United Kingdom is described in Chapter 6.

There is a lack of information on novel or low cost sea defences built in this country. We have with the permission of the Coastal Engineering Research Center USA, made extensive use of their report on Low Cost Shore Protection (Ref 7). However, it has to be stressed that the majority of defences monitored in the USA were in areas of low tidal range and in low to moderate wave energy conditions. Use has also been made of reports on structures built in the Mediterranean, also an area of low tidal range but having more a severe wave climate.

Due to lack of information on UK structures it was also felt necessary to examine some sea defences abroad. The North Sea coasts of Holland and Belgium were therefore inspected since they were relatively close and are subject to a roughly similar wave climate to that in the UK. A great deal of useful information was obtained from this visit, especially with regard to the use of bituminous materials. Our findings, are published in more detail in a separate report (Ref 6).

In the final chapter, a number of recommendations and suggestions for further work are outlined. Clearly with the rising cost of traditional forms of coast protection, a watching brief is required to keep abreast with new developments in coastal engineering design. It is also necessary to assess the performance of newly built, innovative schemes. We feel it would be very worthwhile to produce regular, say yearly, reports to update the state of knowledge. These would be made available to coastal engineers etc, with whom an interchange of information would also be sought.

2 SCRAP TYRES

To date tyres have been used primarily in floating breakwaters, to protect harbour moorings against short period, small amplitude waves. Since tyres are cheap and plentiful and are a resilient and durable material, there is an understandable willingness on the part of coastal engineers to extend their use for more exposed locations. Thus several attempts have also been made to construct revetments and sea walls out of tyres. However, most of these proved abortive, the structures tested being unable to withstand intensive wave action. If tyres are to be used successfully on the open coastline of the United Kingdom then a number of major problems will need to be overcome (anchorage, excessive tyre flexing, etc).

2.1 Revetments and sea walls

To date rubber tyres have not been used extensively as a means of direct protection to the shoreline. However, a number of scrap tyre revetments were tested in the USA as part of the Shoreline Erosion Control Demonstration Program (Ref 7), all being installed in fairly low energy environments. The monitoring period of these structures was short, being generally less than two years, nevertheless many of the structures failed within this timespan.

Construction of flexible revetments on beaches, where they will be subject to breaking wave conditions, poses serious design problems. Tyres connected to the beach face cannot be allowed to move en masse as they do when used in a floating structure. The flexing of individual tyres would lead to disturbance of the backfill and make it more susceptible to erosion by wave action. Because of their very high porosity it is difficult to design tyre revetments of sufficient thickness to prevent washing out of backfill.

None of the beach installations tested to date have shown promise, due to major structural defects and/or through their inability to halt shoreline erosion.

At Michiana, USA, a rubber tyre revetment was installed in the latter half of 1975. It was designed to lie partly on the sand beach but with the seaward edge afloat so as to dampen incident wave energy. Before construction was completed, work was interrupted by a storm. Because the seaward anchorage had not been completed the structure was washed ashore and never repositioned.

Such structures might, with modification, perform adequately in a low wave energy environment. It is unlikely however, that they would work effectively on the UK coast. They are also not aesthetically pleasing, and are not likely to be an appropriate form of protection for amenity areas in that the gaps between and within the tyres may be a hazard to beach users.

Because of the low cost of rubber scrap tyres one is reluctant to reject totally, the possibility of using them. We would recommend, however, that new designs should first be tested rigorously in the controlled conditions of a laboratory study.

2.2 Floating breakwaters

When scrap tyres were first used as floating breakwaters many problems were encountered, including loss of buoyancy, insufficiently strong tyre to tyre connections, poor anchorage, and marine growth and other debris in the tyre casings. Many of these problems, especially tyre to tyre connections and anchorage to the beach, will be magnified if such structures are built in the wave breaker zone.

Designing a sufficiently strong but not prohibitively expensive anchorage has posed serious design problems even in semi-sheltered waters. There have been many instances where floating tyre breakwaters have remained intact but have dragged anchor under wave attack or strong tidal flow. At Guildford, Connecticut a "Goodyear" floating breakwater installed in 1977 was severely damaged in 1978, reconstructed in 1979 and destroyed in the same year. The maximum fetch here is some 56km and the conditions proved to be too severe for any of the anchorage systems used (maximum wave heights of up to 2.4m during Hurricane Frederic caused the destruction of the breakwater). A massive and costly anchorage would have been needed to survive the conditions to which the structure was subjected. This project highlights the difficulties that will be encountered if such a structure were sited on the open coastline of the UK where it would come under attack by shoaling and breaking waves.

Few floating tyre breakwaters are to be seen in the UK and only then in very sheltered conditions. One such structure was built inside a harbour at Port Edgar in Scotland (Plate 1). Completed in 1980 at a total cost of £29,000, this "Kowalski" type breakwater has so far been successful in attenuating waves of up to 3 second periods. One drawback is the high cost of maintenance of which 50% may be for anti fouling measures (removal of silt, seaweed, barnacles, etc.). However, the low capital outlay needed for these schemes and the rapid installation gives them positive advantage in comparison with more conventional works.

The systems tested to date indicate that floating breakwaters cannot be used as a means of shore protection, except in very sheltered areas, where the fetch is 10km or less. Even then the wave suppression characteristics under extreme conditions are not very good.

3 SAND OR MORTAR-FILLED FABRIC BAGS

Mortar-filled hessian bags have been used for river bank protection and have in the past also played a significant role in protecting the coastline from wave activity, particularly in semi-sheltered waters.

In recent years natural fabrics such as Hessian have been replaced by man-made fibres. Also modern manufacturing techniques have led to the development of a number of patented bag designs. While mortar-filled bags have generally been used to construct groynes, breakwaters and revetments, sand bags have been used to form offshore sills as part of beach improvement schemes. Such structures, particularly the sand filled bag type are vulnerable to damage and their success has been rather variable.

3.1 Revetments and sea walls

The comments made above apply equally well to revetments and to sea walls made of sand or mortar-filled bags. However, if such structures are situated out of reach of most wave activity they can be used as a means of giving temporary protection at low cost. At Ashland, Winconsin, three sea walls were constructed from Longard tubing (a type of fabric bag). The exposed surfaces were sprayed with a sand-epoxy coating for extra protection. Unfortunately this flaked off in a relatively short period of time. If this happens on an underwater part of the structure then the coating obviously cannot be replaced.

Because of their shape Longard tubes do not resist earth pressures very well and should not be used as protection to the toe of slumping clay or sand cliffs.

They could, perhaps, be used with advantage to 'plug' dune blow outs etc, at a beach level where wave action is slight.

Revetments made of mortar-filled containers have been used with success in this country as well as abroad. Mortar-filled bags can develop a certain degree of cohesion. Normally this is insufficient to prevent failure if toe scour or settlement of the backfill takes place on more than a very local scale. They are not used widely now because of the labour intensive nature of construction. For example, the sand dunes at Eccles on the East Anglian coastline were until quite recently protected by a sea wall consisting of mortar-filled hessian bags which had been in place for many years (see Plate 2). They are now being replaced by a conventional concrete wall, since the original was damaged due to undermining during a period of lowered beach levels.

Although the revetment at Eccles has had a long design life, adverse conditions can lead to rapid failure. For example, at Alameda a sand-cement bag revetment was constructed at a slope of 60° to the horizontal, with the toe taken down to 0.6 metres below beach level. In March 1979, only three months or so after construction, the embankment had slumped badly and there appears to have been very little left in the way of bonding between adjacent bags. The failure of this project highlights the fact that such structures, if lacking in tensile strength, are all too easily destroyed when there is movement of the bedding layer.

3.2 Offshore breakwaters and sills

Breakwaters made of sand bags, Longard tubes, etc, have been used in the United States of America, under conditions of low tidal range and low wave activity. In gentle wave climates they may attenuate waves and encourage accretion of sediment. Even relatively fragile nylon containers filled with sand have proved to be effective under such conditions.

One of the problems is that such structures can 'work' themselves into the underlying sediment and the amount of settlement may be high. At Kitts Hummock, Delaware Bay, large sand bags were placed on a silt bed and despite the use of filter cloth they eventually settled 0.3 to 0.6 metres. Despite the reduction in crest height the offshore sand bag breakwater still caused accretion in its lee.

Offshore sills or breakwaters have proved to be particularly effective in combination with beach nourishment schemes. A 'perched beach' built up landward of the sill not only helps to reduce wave attack but is clearly beneficial from an amenity point of view. At Basin Bayou, Florida, a 61 metre long Longard tube was laid on a filter cloth some 60 metres offshore. The crest level of the breakwater was about 0.1 metres above mean low water, being submerged about 0.4 metres at high water. The Longard tube was very effective over a 9 month period by which time a sand spit had formed in its lee. In fact it was considered that the breakwater may have been sited too close to the shore and that continued extension of the spit in the long term would have eventually cut off sand to the downdrift beaches.

Offshore breakwaters and sills made of sand-filled bags are perhaps less effective than structures made of Longard tubing. However, the main problem with all types of fabric bag is their vulnerability to damage. They deteriorate progressively if ruptured, while degradation by ultra-violet light can reduce the life of the fabric to as little as one year.

Sand-filled fabric containers have been used effectively as offshore breakwaters or sills, but even under these conditions they are by no means vandal proof. They are best suited for use in areas, where they are relatively inaccessible. Their life can be increased by using a mortar fill, but clearly at substantially increased cost. Along the coastline of the United Kingdom very large structures of this type would be needed to withstand impact by wave action, and the outer skin would have to be strongly reinforced to resist damage by wave borne debris. Abrasion by beach material would seriously reduce the lifespan of sand-filled containers, possibly to a matter of months. The very much larger containers required to withstand wave action preclude the use of mortar, since filling and handling would then be extremely laborious and costly.

3.3 Groyne systems

Most of the above comments apply equally well to fabric containers used as groynes. Light-weight sand bags have little value in groyne systems. They are not only easily displaced by wave action but are also subject to rapid wear and tear by beach material. Longard tubes are more resistant to damage (they are of two-ply fabric, the outer membrane being fairly robust). The following example demonstrates, however, that these types also are prone to vandalism

At Ashland, Wisconsin, six 30 metre long, 1.75m dia groynes were built along the shoreline bordering Lake Superior. The downdrift (most westerly) groyne stayed intact from the date of installation in June 1978 to September 1979. Some damage occurred during October 1979, but despite this, it continued to trap sand up to the end of the period of monitoring in May 1980. However, the adjacent groyne was damaged very soon after construction and the outer fabric then unbraided progressively. In 1980 the whole tube had become so deflated as to be totally ineffective. The performance of the third groyne was similar to that of the westernmost one and in May 1980 it was still intact and trapping sand effectively. Groynes 4 and 5, like groyne 2 had become completely deflated by the end of the two year period of monitoring. Groyne 6 was also severely damaged, being initially vandalised by a shotgun blast!

Nylon bags filled with mortar have been used as groynes under mild wave conditions. Although most of the fabrics available do have a short life, if they are sufficiently porous to allow some leaching to take place the units may bond together before the fabric deteriorates. The bonding strength of the mortar is generally insufficient to hold large units intact under differential settlement. Mortar-filled bags have occassionally been used as groynes but they are likely to be damaged if built on beaches which fluctuate in level (as can be expected on beaches subject to seasonal change in wave climate)

In conclusion, we consider that neither mortar nor sand-bags are particularly suited for use as groynes, given the harsh wave environment of the coastline of the United Kingdom.

4 GABIONS

Gabions have been used as a form of sea defence for many years and can be traced back to the fifteenth century when they were used as a military engineering device for fortification as well as for river protection in Italy. The modern gabion is basically a rectangular, box shaped cage filled with large stones, rockfill or large shingle. There are three main types in common use today:

1. Maccaferri - Woven galvanised steel wire which can be coated with PVC for added protection in salt water conditions.

2. Weldmesh or Gridweld - High tensile galvanised steel wire mesh, electrically welded at each intersection. The mesh can be PVC coated.

3. Netlon - Corrosion resistant heavy duty plastic mesh.

Gabions have been used in a variety of coastal defence works including groynes, revetments, sea walls and retaining walls. The type most widely used is probably the "Maccaferri" gabion and the "Reno" mattresses, the latter being a Maccaferri gabion whose depth, compared to width and length, is small.

Gabions are most often used on sand beaches but can also be effective on shingle beaches, providing they are only subjected to occasional wave action. If they are placed within the intertidal zone, movement of either the beach or the fill material can rapidly abrade the plastic coating and accelerate corrosion. However, there are a number of sites on the north-west coast of England where gabions are being used on shingle beaches, although with a limited life expectancy. In these areas the gabions require regular inspection and maintenance.

Gabions depend for their strength on the retention of a large number of small rocks within an enclosing mesh. If the fill is not tightly packed, wave action causes excessive flexing of the mesh which in turn leads to breaking of the plastic coating and damage to the galvanised surface, and the ensuing corrosion can cause breaking of the wire.

Regular monitoring and repair is essential, especially where gabions are subjected to beach movement or wave activity. It is usually possible to repair the mesh type gabion quickly by rewiring if the damage is localised. Unless baskets are repaired quickly, however, broken wires can unravel and become an amenity hazard.

"Maccaferri" gabions are flexible and therefore can adjust to moderate beach profile changes without structural damage. The more rigid galvanised wire gabions, such as "Gridweld" and "Weldmesh" have been used less extensively in the foreshore zone. For this reason one can be less certain about their performance in this environment. It is likely, however, that with these types only minor beach changes could be accommodated without structural damage.

4.1 Revetments and sea walls

Revetments usually consist of an armoured facing laid on a prepared slope. They can be designed to dissipate wave energy gradually so that relatively light units can be used to withstand wave impact forces. For reasons of stability, gabion mattresses are usually laid on slopes no steeper than 1:1 and generally far flatter ie 1:3 to 1:4. Adequate toe protection and anchorage must also be provided because of the danger of uplift of the armour layer and scour at the toe. Another factor to be borne in mind is that gabions are less stable on steep shingle and coarse sand beaches than on flat sand beaches. On steep beaches wave energy is absorbed over a relatively narrow breakwater zone, hence the beach material will be more agitated and the gabions subject to more attrition. At many UK sites revetments on shingle beaches have become severely damaged in one or two years. Once serious damage begins to take place attempts are often made to protect damaged lids by patching with concrete or grouting with bitumen. On most sites visited where bitumen was used for repair, penetration of the grout was poor and the bitumen tended to spall of under hydrostatic pressure, more often than not tearing the gabion wire in the process.

At the east end of Chesil Beach, a system of gabion mattresses (both Maccaferri and Weldmesh type) were installed in 1981 as a three layer blanket over the beach crest (see Plate 4). Both local beach pebbles and Portland "capstone" rock were used as fill material while some of the Maccafferi gabions had a lining of Netlon plastic mesh to prevent undersized fill from being drawn out by wave action. The mattresses are situated on the beach crest above the level of wave activity during normal tides. The baskets are still in good condition 5 years after construction although some local damage has occurred to the Netlon lining.

At Brancaster on the Norfolk coast (see Plate 5), a sloping revetment consisting of a "Netlon" mattress and incorporating "Tensar" short stub groynes (Tensar is another type of plastic mesh manufactured by "Netlon"), was built in 1981 to protect the seaward face of eroding sand dunes. This was an experiment to determine the usefulness of plastic as compared with the "Maccaferri" type gabion. When the baskets were being filled from the top by machine the fabric became stretched and holes were punched through the cages. The baskets therefore had to be hand filled to ensure that they kept their shape. Hence, although cheaper, this type of revetment requires more attention than one made of plastic coated metal gabions.

Few of the gabion sea walls built to date are subjected to high levels of wave activity. Those that are have shown a high level of damage due to wire corrosion, etc. Instability is often a serious problem, especially on steep shingle beaches, where gabion baskets tend to overturn in a seaward direction as a result of falling beach levels. As with revetments, the effective use of gabions for sea wall construction, even in moderate levels of wave activity is not easily achieved. Despite the short life of these structures, gabions are sometimes used in preference to conventional sea walls because of their low capital cost. It is difficult to assess the cost benefit of these structures because of their "uncertain" design life. Generally, they appear to be most effective as short term (5 years or less) protection.

4.2 Groynes

There are several advantages when using gabions as groynes. They are flexible and so conform to minor settlement. They are also permeable and thus wave energy absorbing. Individual gabion boxes can be installed fairly quickly between tides. At Old Hunstanton, Norfolk, (Plate 3) Anglian Water have installed "Maccaferri" groynes to trap wind blown sand. They have also incorporated a low gabion sea wall to stabilise sand dunes at the rear. The system, built on a wide sandy shore on the eastern edge of the Wash, was installed in stages starting about 15 years ago Initially it comprised 21 gabion groynes 24 metres long and 25 metres apart together with 500 metres of revetment. This system has proved successful and was extended south-westward in 1975, and again in 1978.

Disadvantages, some of which have been stated earlier, are basket deterioration due to abrasion of the PVC coating, vandalism and the need for good compaction of the rockfill. Gabions are flexible so in a wave environment they may work their way into the beach unless suitable foundation is provided.

4.3 Retaining walls

Both the flexible "Maccaferri" type PVC coated gabion and the rigid "Weldmesh" or "Gridweld" type can be built with sloping, vertical or stepped faces. Since these structures are permeable, problems with water run off for example are considerably reduced. At Overstrand in Norfolk for example, "Weldmesh" gabions (see Plate 6), were used to stabilise a cliff slip and regrade its seaward face. The cliff face was protected with 12 rows of gabions laid at an angle of 45 degrees. Built in 1966, the 245 gabion wall continues to be effective. An inspection in 1983 showed only minor corrosion had taken place and the baskets were generally in good condition although one or two were half empty, possibly the result of the rockfill splitting into smaller pieces and being washed out by run off.

5 REVETMENTS

This chapter marks a change in presentation from a description of one particular type of material to a more general resumé of various innovative forms of revetment armouring.

Lightweight revetments are now being widely used instead of the more traditional forms of shore protection. Coastal defences such as massive sea walls will continue to be used to protect urban frontages, but in rural areas, particularly where the coastline is not subject to severe wave activity, significant savings can be made by using alternative forms of protection.

Many new revetment designs have been developed in recent years using materials as widely different as asphalt and scrap tyres. Probably the most innovative and one of the more promising types now in use is the pre-cast integrated concrete block system (Plates 7, 8 and 9). With this system individual blocks are connected by cable or wire to form a mat. The cables not only allow large mats, say 6m x 2m, to be laid quickly but also form an integral part of the structure by spreading wave induced forces or indeed settlement loads over a wide area. Cabling allows relatively light blocks to withstand wave forces since uplift pressures are distributed by tension forces over a wide area of mat. One disadvantage of these systems is that cables need to have a high tensile strength and also have to withstand wear and tear caused by block movements or vandalism. Some nylon ropes are also prone to degradation by UV light. Also one serious maintenance problem is that of repair to the sublayer if any settlement or leaching takes place.

The quality of the concrete in some of the mattress types has been poor, leading to abrasion and chipping and hence loss of block size. Despite such drawbacks this type of revetment has the advantage of being relatively cheap and it can be installed rapidly.

There are also many new interlocking block systems both of impermeable or permeable design. One such type, the Sebloc is shown in Plate 11. Many have only been tested under low to moderate wave energy conditions. Many concrete block units rely on friction, interlocking, or inter-connection between adjacent modules for stability. Design is often based on experience with other similar blocks or on extrapolation of existing formulae such as the Hudson equation.

At present, therefore, we have insufficient information to judge the relative merits of one type of concrete block system against another. We would refer the reader to Volume 4 in this series, which includes a description of many of the designs on the market today.

In general there are clear advantages in using revetment systems which are flexible, move en masse under wave impact and are designed to spread loading over a wide area. Interlocking units such as the Wallingford block, for example, are so shaped that displacement of an individual block is counter-acted by the restraining weight of surrounding ones. The degree of interlocking is such that even if one unit is broken and displaced the revetment remains 'knitted' together.

Shiplap type interlocking blocks (Plate 10) are widely used in estuaries where they can be very effective. However, most only have overlaps on two adjoining edges, hence there is a tendency for them to rotate diagonally. Once a small degree of displacement has taken place, fine material will tend to infill the gaps. Permanent separation of the overlap then tends to make the blocks less stable. This type of revetment will not necessarily follow changes in the level of the sub-layer and spanning of cavities can occur. Despite such drawbacks we have seen many structures of this type in estuarial conditions where they have had a long design life.

Tongue and groove blocks usually have connections on opposite sides. With some designs the short sides interlock while the long sides just butt against each other. Because the blocks are normally laid in strips from the revetment toe upwards, differential movement between adjoining strips can cause stresses on the underlying filter which may then result in loss of fill. This type of blockwork also tends to bridge cavities or holes and makes the armour surface appear more rigid than it is. Thus damage to the sublayer is not always evident by inspection of the revetment face. Tongue and groove Shiplap type blocks are effective in low to moderate wave energy conditions.

Stability of most types of block can be improved by asphalt grouting (see Plate 12). When cooled, the grout has a high elastic modulus, hence under short period loading it is able to withstand wave impact forces. It also has a very high viscosity, allowing the revetment to adjust to sublayer settlement. In the Netherlands, asphalt grouting is a widely used technique for reducing the maintenance of stone pitched revetments. However, most of the revetments using grouted blockwork have been constructed in areas of low to moderate wave activity. (Alternatively a revetment can be constructed of loose stone which can be allowed to adjust to changes in wave activity, see Plate 17.)

Asphaltic mixtures have been used much more widely in the Netherlands than in the United Kingdom. Details of a wide variety of structures using asphalt mixes can be found in a report (Ref 6) on a visit to Holland and Belgium. For example, Fixtone, a patented name for a gap graded stone asphaltic mix has been found to form a good revetment material due to its ease of construction and its hydraulic characteristics (good wave run up dissipation, etc).

Dense gap-graded stone asphalt has also been used in the Netherlands. At the port of Ijmuiden it forms a protective layer to the core of two massive breakwaters. Asphalt has also been used as a grout to stabilise and protect stone armouring on the north breakwater at the entrance to the Rotterdam waterway, Hook of Holland. This form of grouting appears suitable for areas subject to continuous wave activity especially as it can be lain below the water line.

Asphaltic concrete when laid as a membrane over rock or sand fill also appears to have potential as a revetment material. In Holland, it is widely used for dam or dyke protection above the water line, while grouted stone aprons give a higher level of protection against wave action.

A revetment incorporating a gap graded stone toe and an asphaltic concrete upper apron has been recently constructed at Prestatyn, North Wales (Plate 13). There is an asphaltic concrete sloping revetment (Plate 14) at Porthcawl, South Wales. No serious construction problems were encountered with either design and both structures are performing well to date. The revetment at Porthcawl is subject to Atlantic waves. It protects a vertical concrete sea wall which was formerly being abraded very rapidly by beach pebbles. The asphaltic concrete surface by contrast is resilient to some degree. It has also been designed with a relatively flat slope so as to minimise wave impact forces. We consider that it should be carefully monitored to ascertain its design life under what are extremely harsh environmental conditions.

Sand-asphalt is a mixture of sand with some 3 to 5% of bitumen. Its use should perhaps be restricted to areas of low wave activity. It is a relatively "weak" mix, but can provide an effective and rapid method of stabilising the core of sand or earth embankments. It can also be used as a filter layer to heavier armouring.

Over-filling the voids in a sand filler results in what is commonly referred to as sand mastic. The composition of sand mastic can vary within wide limits and hence the material can be put to various uses. It has been used as a grout or laid in mattress form for toe protection under water. We feel that the range of uses for this material has not perhaps been fully explored.

In summary therefore the following revetment types appear to have potential as open coast defence:

1. Asphaltic revetments - This form of protection has already proved a versatile defence. Mixes, including large aggregate, can be used in open coast situations as primary armouring. Those with a high proportion of fine aggregate or sand are more appropriate as secondary armouring or a filter material. There are many designs including:

    (a) a patented mix of gap graded stone keyed together with asphalt. This form of protection has however yet to be fully proven on the open coast;

(b) stone asphalt, a dense gap graded mix containing stone, sand, fines and bitumen. This can be used as primary protection to revetments utilising an aggretate which would unstable without the asphaltic binding medium; and

(c) asphaltic concrete using a mixture of stone, sand fines and bitumen with a voids ratio of 3 to 6% after compaction;

(d) sand asphalt, a mix of 6% bitumen and the rest sand, is useful as a filter.

2. Cable linked concrete blocks constructed as mattresses also have a place in areas of moderate wave activity. They are relatively cheap to install and follow minor changes in revetment profile. However, existing designs could perhaps be improved by increasing block size and better quality control of the concrete.

3. Timber revetments (Plate 16) are built largely on experience and increased efficiency could undoubtedly be obtained by a more careful design. This is an area which requires further study since there are large stretches of coastline protected by timber revetments which in many cases are not performing to their full potential.

4. Gabions and gabion mattresses have been used successfully on the upper parts of sandy beaches. Regular maintenance of such structures is essential as failure can be rapid.

5. Many of the flexible interlocking block designs which rely on interblock connections have been used successfully in estuaries. Such designs may be applicable to coastal situations by increasing the block dimensions. Upper design limits in terms of wave heights for many of these block types are not yet determined.

6 BREAKWATERS (FLOATING AND OFFSHORE)

Because of the large tidal range and the severe wave conditions that can occur on most parts of the UK coast, emergent breakwaters and submergent breakwaters (sills) are generally costly and have therefore not been widely used. Indeed most of the breakwaters and sills which have been reviewed in our reports were built abroad, 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.

The majority of offshore breakwaters in the UK are very large and expensive and even so provide only partial protection against waves. For example, on the Wirral coast an offshore breakwater which is about 50 metres wide and 6 metres high provides added protection against wave attack (in conjunction with on-shore defences). Similarly at Rhos-on-Sea (Plate 18) 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 may become more widely used as additional defence in particularly severe problem areas.

Offshore breakwaters 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 is required to maintain an exchange of water between the beach and offshore. This is particularly important in the case of amenity beaches. Thus there is therefore some scope for constructing structures which are not surface piercing and hence reducing construction costs e g. still type structures as described later.

A number of unusual breakwaters have been tested off the Dengie Peninsula, Essex. This area is one 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 systems are in damping wave attack. It will also be necessary to determine whether scour becomes a serious problem around the vertical sides of the barges. While such designs are not suitable for open coast conditions, they have considerable potential for semi-sheltered conditions.

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 a moderate amount of beach accretion. Scaling up of such units to cope with a large tidal range and severe wave conditions would pose design problems and the structures would 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 the 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 inspection of the South-East coast it was noted that wave tripping devices have 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 almost certainly less serious than if sills had not been used.

Floating breakwaters have also been examined and found to be unsuited for open coast protection. Their location and dimensions would have to be carefully determined to be effective. Beam width would have to be of the same order of magnitude as the incident wave length, which for anything other than short waves would be inordinately large. Tidal range also poses logistical problems with respect to anchorage. With a large 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 while taking up the slack in the anchoring cables. Perhaps most inhibiting is the need for a very strong anchorage, such as to be able to tolerate wave forces which would be experienced during severe wave activity.

7 GROYNES

The majority of groynes found on the coastline around the UK are of the vertical, smooth-faced timber variety. They are not ideal for all beach types and the material used (usually a hardwood such as Greenheart) is expensive.

In recent years rock (if available locally) has proved itself to be a reasonably low cost material. In Christchurch Bay, for example, a number of groyne systems have been constructed using rock tipped directly onto the foreshore. A low technology approach was considered to be appropriate in this particular case and no attempts were made to grade the rock, provide filter layers etc. Monitoring and analysis of the groynes has been carried out by the Coast Protection Authority and Hydraulics Research Limited. The groynes were found to absorb wave energy well and have helped to stabilise the artificially placed shingle beach. Settlement of these simply constructed groynes has not been a problem, with the crest being maintained by tipping small quantities of additional rock as and when required. We consider that a similar 'low tech' approach may also prove to be possible for low-cost breakwaters and sills built in areas where a local supply of material is freely available.

8 RECOMMENDATIONS FOR FURTHER RESEARCH

The problem with most novel or low cost shore protection schemes is that their performance, because of the lack of well documented information, is generally poorly understood. They are often constructed because they are relatively inexpensive or perhaps because someone else on another piece of coastline has built a similar structure which appears to have been successful.

The lifespan of many of these structures is unknown and their effect on beach behaviour has only been assessed qualitatively. It is essential therefore not to stint in the design stage (each site has its own characteristics) and consider regular monitoring.

With economic considerations uppermost in the minds of most coastal authorities it would seem logical to closely monitor new coastal defence schemes, particularly those which are innovative designs. A number of schemes have recently been completed involving the use of gabions, lightweight concrete blocks and asphaltic mixes, etc. These need to be inspected on a regular basis and information about their performance disseminated widely. This could be carried out as a summary review along the lines of the present report but including more detail about individual designs. We would recommend that such a review should be made annually and reports offered to all interested coastal authorities. The work carried out for MAFF could be publicised in the Hydraulics Research bulletins and symposia and interested parties could be asked to contribute on experience with new designs.

The majority of data included in the reports has been obtained from literature reviews and discussions with local authorities in the UK. Our examination of the sea defences along the coasts of Holland and Belgium proved extremely useful and it is thought that wider exchanges of data with other countries should be sought.

9 ACKNOWLEDGEMENTS

We would like to thank Messrs Moffatt and Nichol of Long Beach, California the publishers of the Low-Cost Shore Protection Report (Ref 7) for their permission to reproduce the data from it.

10 REFERENCES

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

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

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

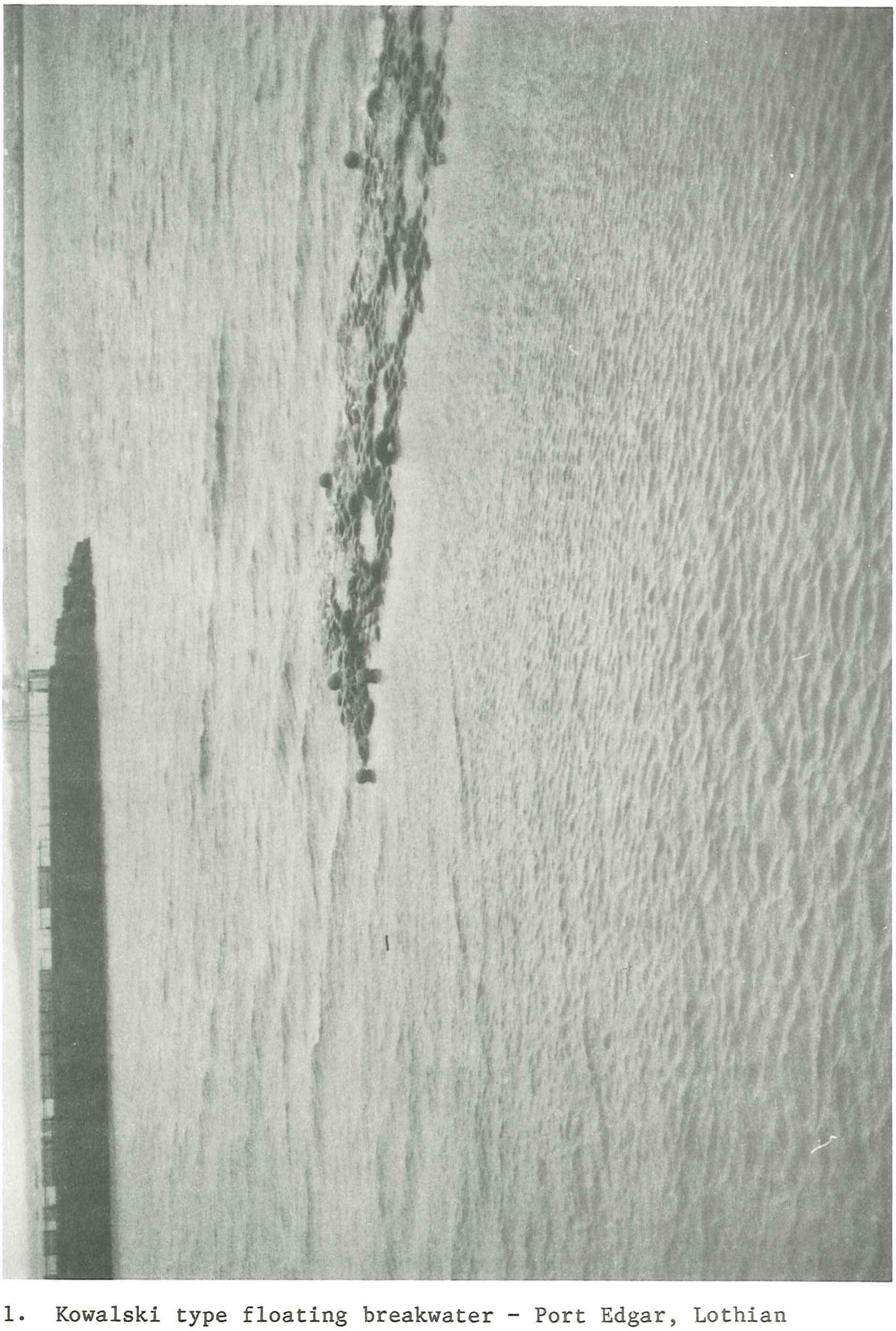
4. Welsby J and Motyka J M. "A review of novel shore protection methods. Volume 4 - Revetments". Hydraulics Research Ltd Report No SR 12, April 1986.

5. Welsby J and Motyka J M. "A review of novel shore protection methods. Volume 6 - Offshore breakwaters and sills". Hydraulics Research Ltd Report No SR 34, May 1986.

6. Motyka J M and Welsby J. "A review of novel shore protection methods. Inspection of sea defences in Holland and Belgium, 17 to 21 September 1984. Hydraulics Research Ltd Report No SR 6, December 1984.

7. US Army Corps of Engineers. "Low-cost Shore Protection. Final report in the Shoreline Erosion Control Demonstration Program (Section 54)". Prepared and Published by Moffatt & Nichol, Engineers, California, USA, August 1981.

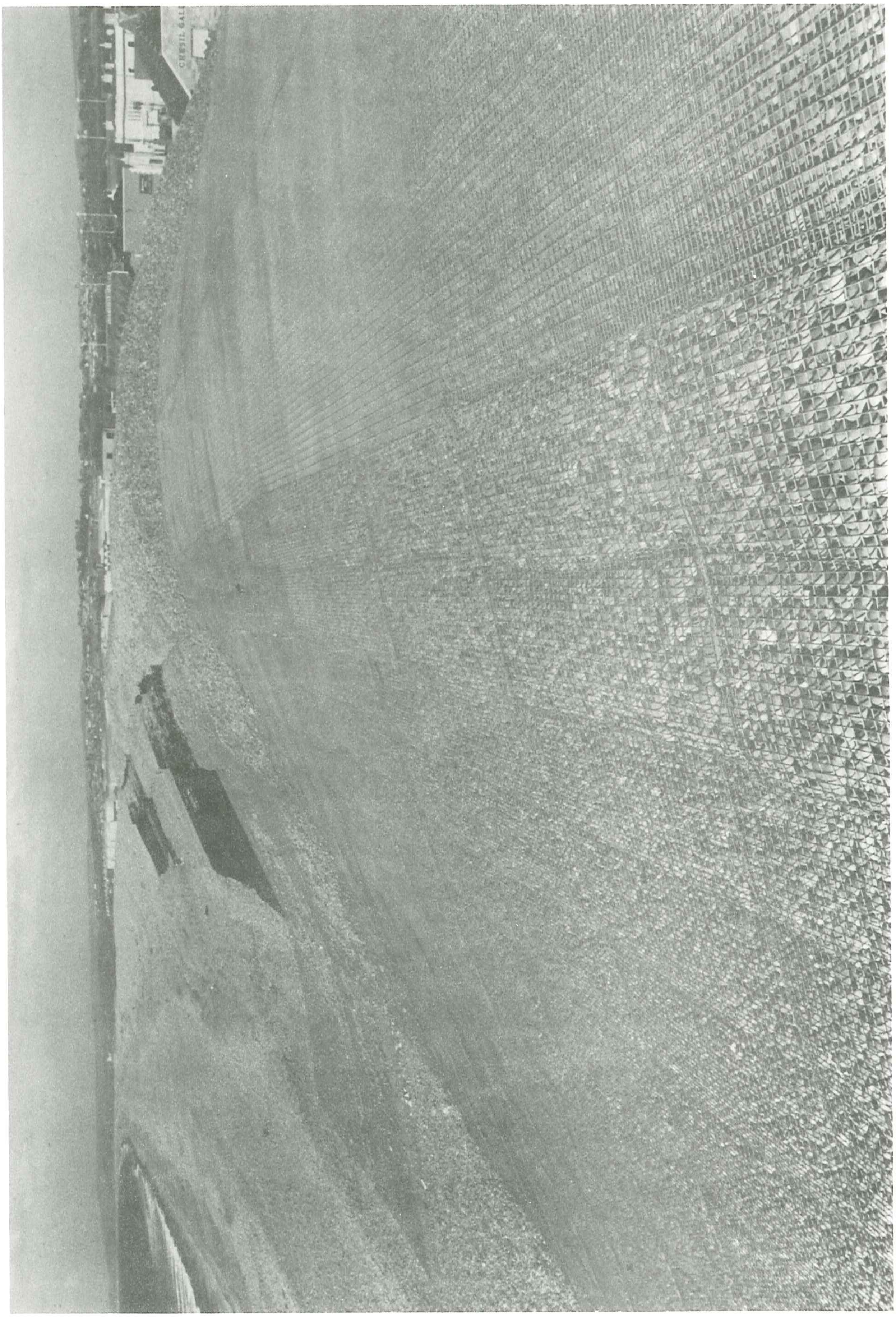
Plates



1. Kowalski type floating breakwater - Port Edgar, Lothian

2. Sand/cement filled bag revetment - Eccles, Norfolk

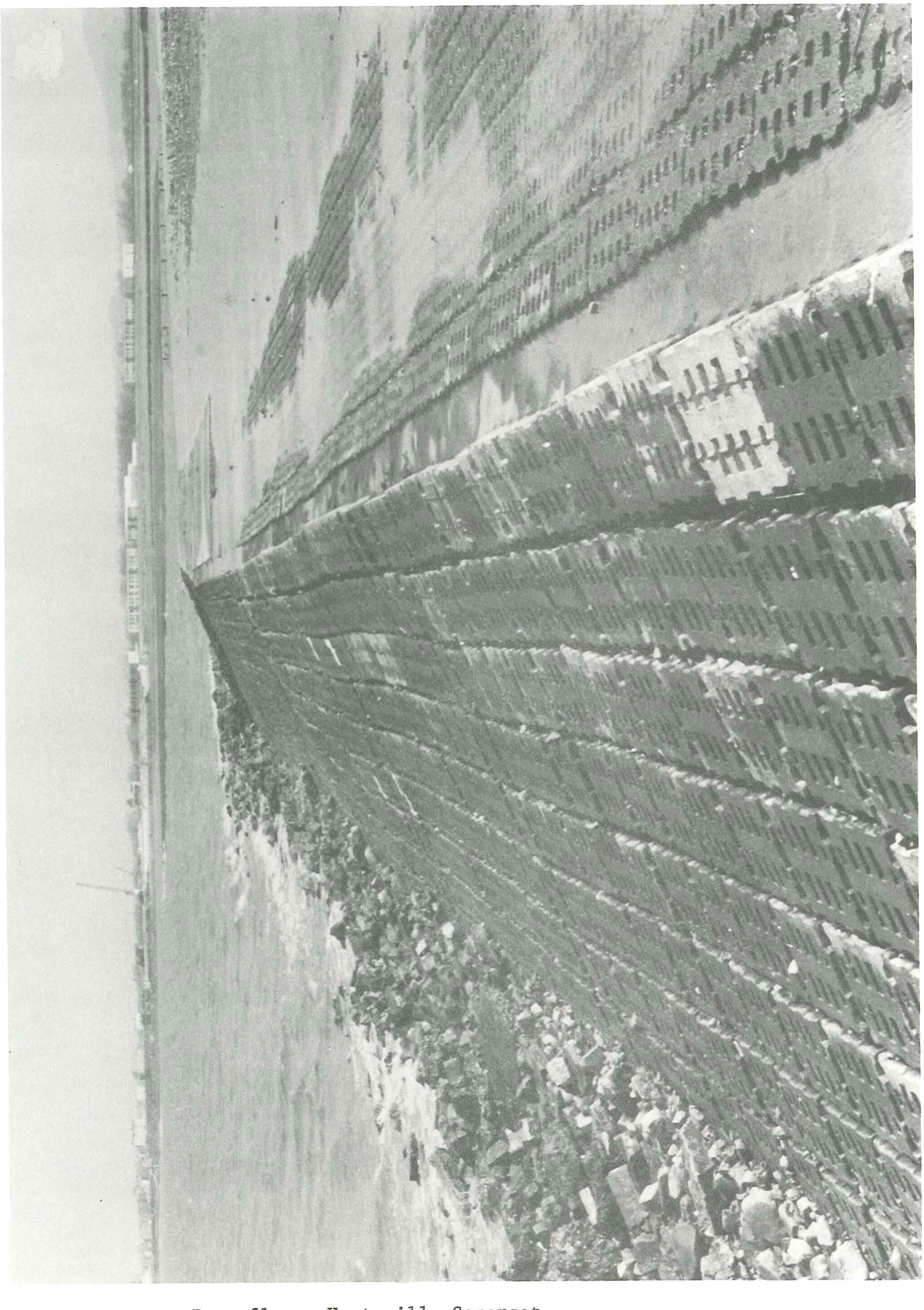
3. 'Maccaferri' gabion groynes - Old Hunstanton, Norfolk



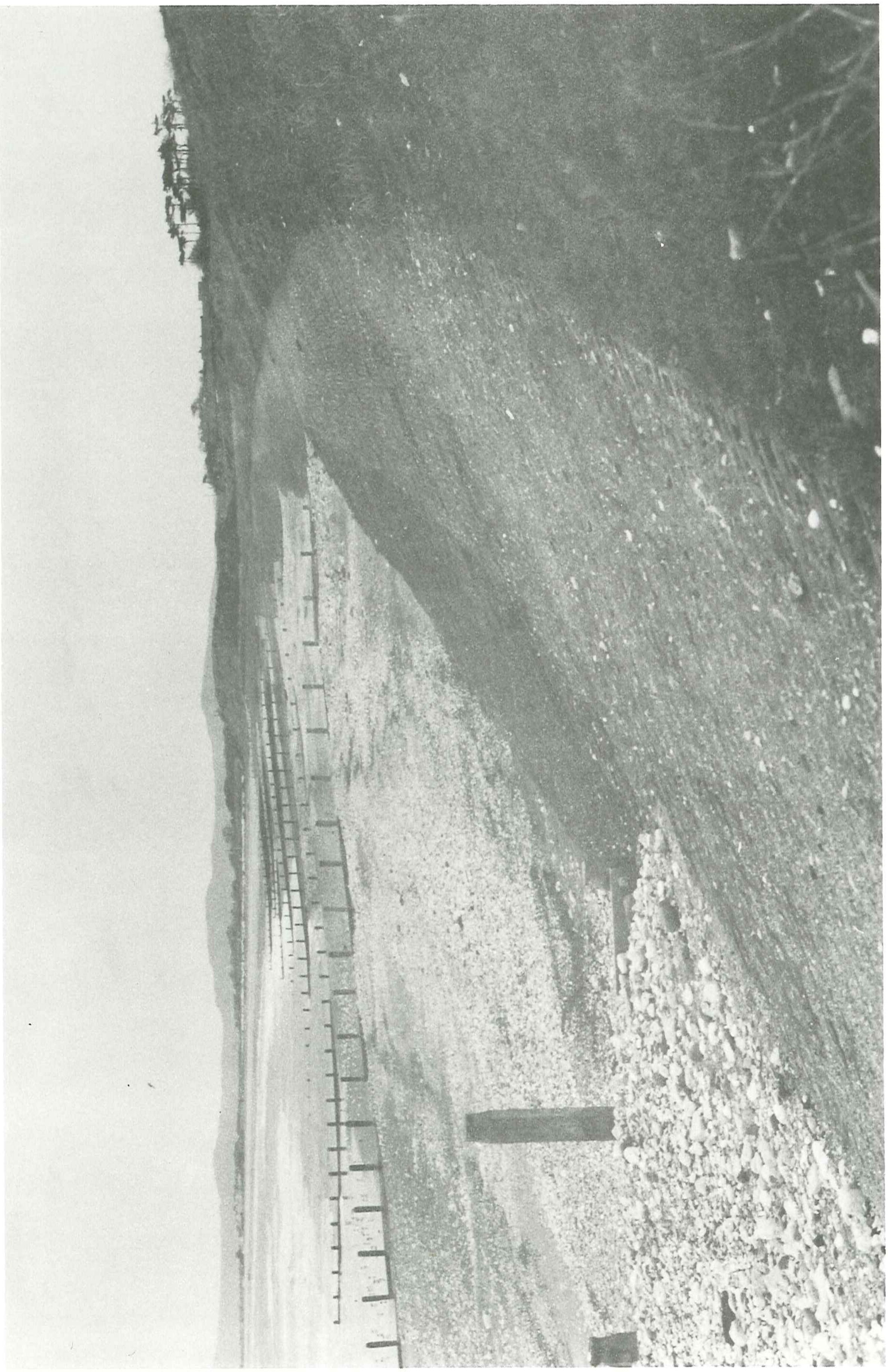
4. Gabions stabilising shingle ridge - Chesil Beach, Dorset

5. 'Netlon' gabion revetment - Brancaster, Norfolk

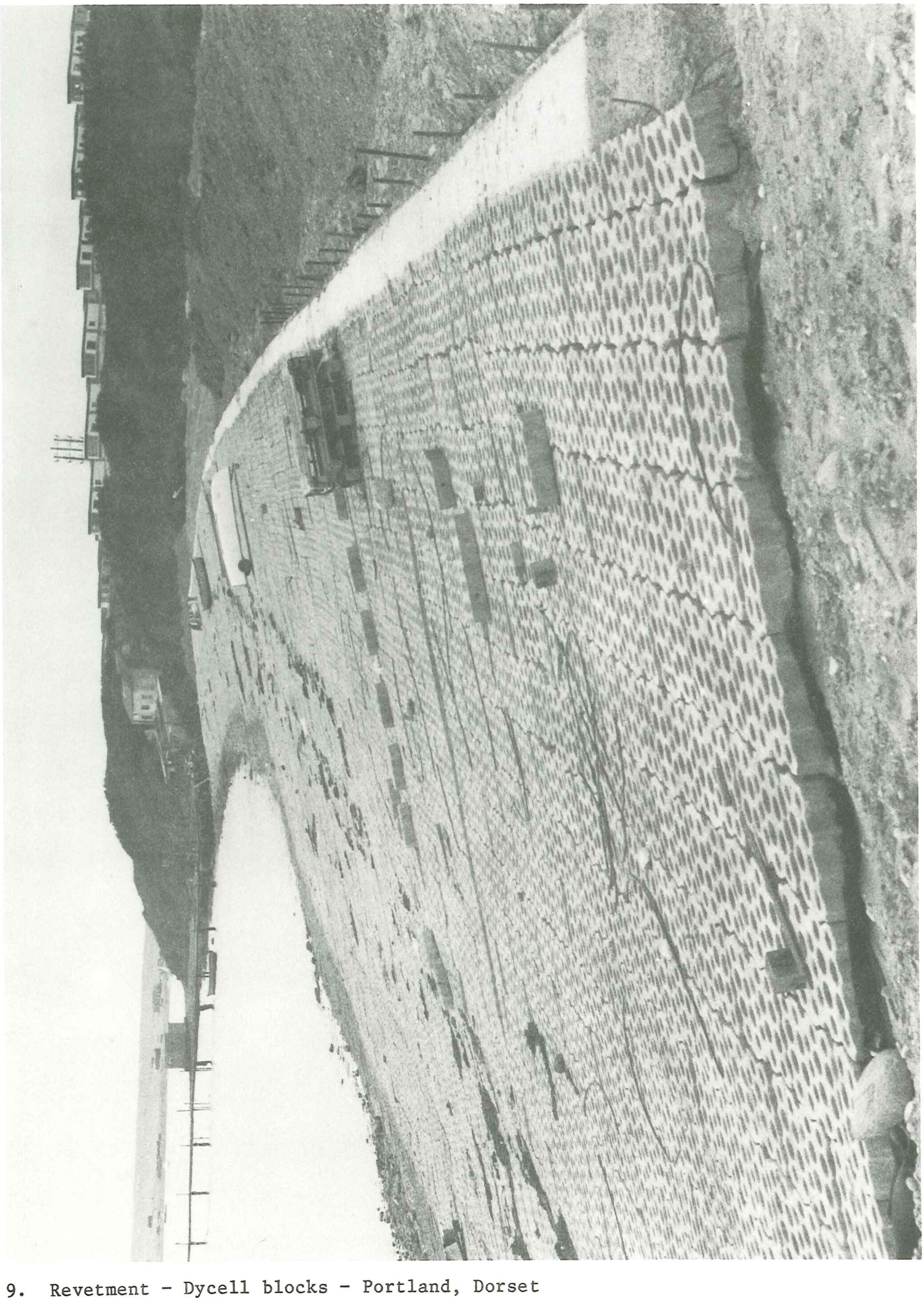
6. 'Weldmesh' gabion retaining wall - Overstrand, Norfolk



7. Revetment - Petraflex - Huntspill, Somerset

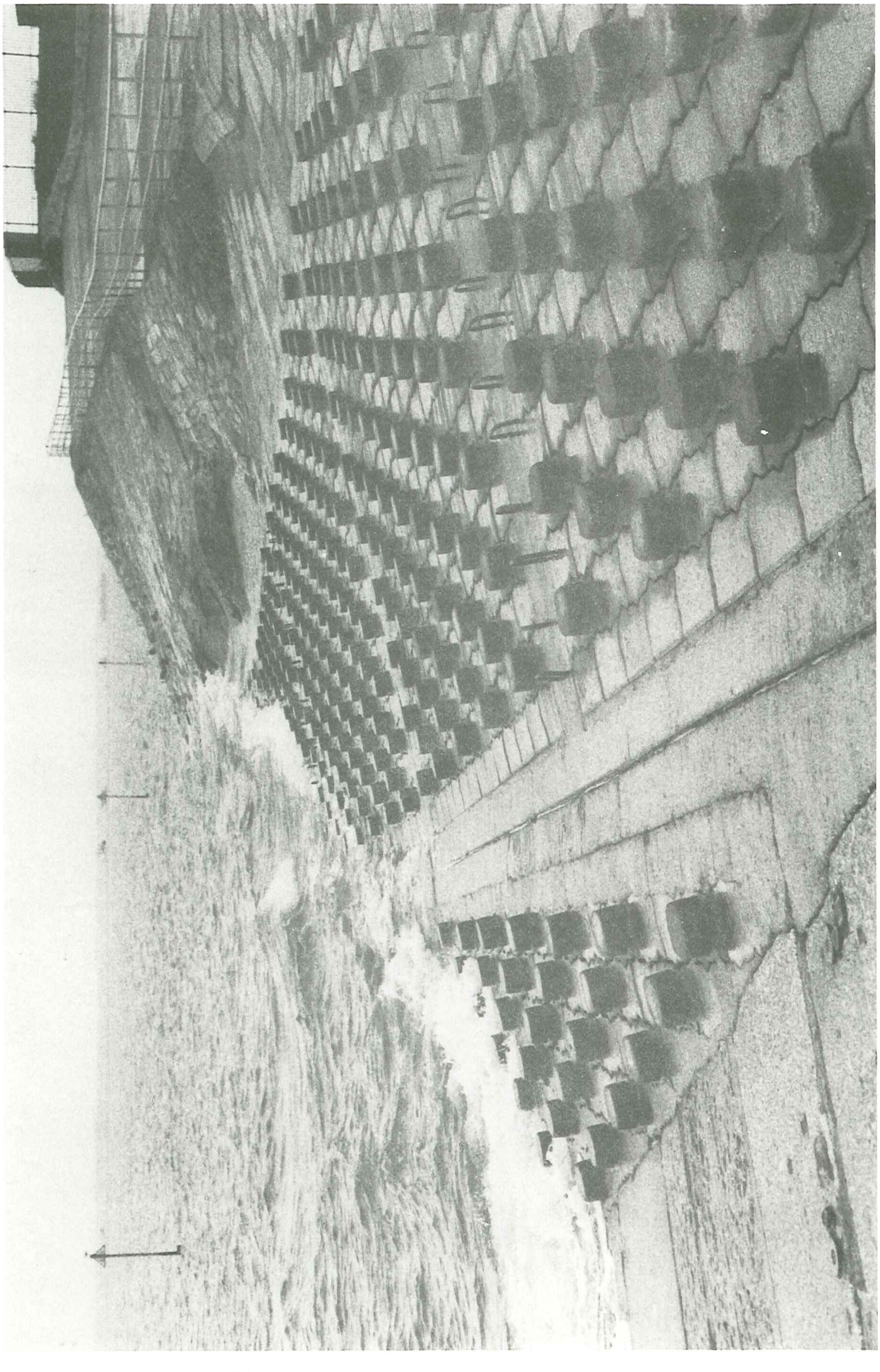


8. Revetment - Armorflex - Llanddulas, Clwyd



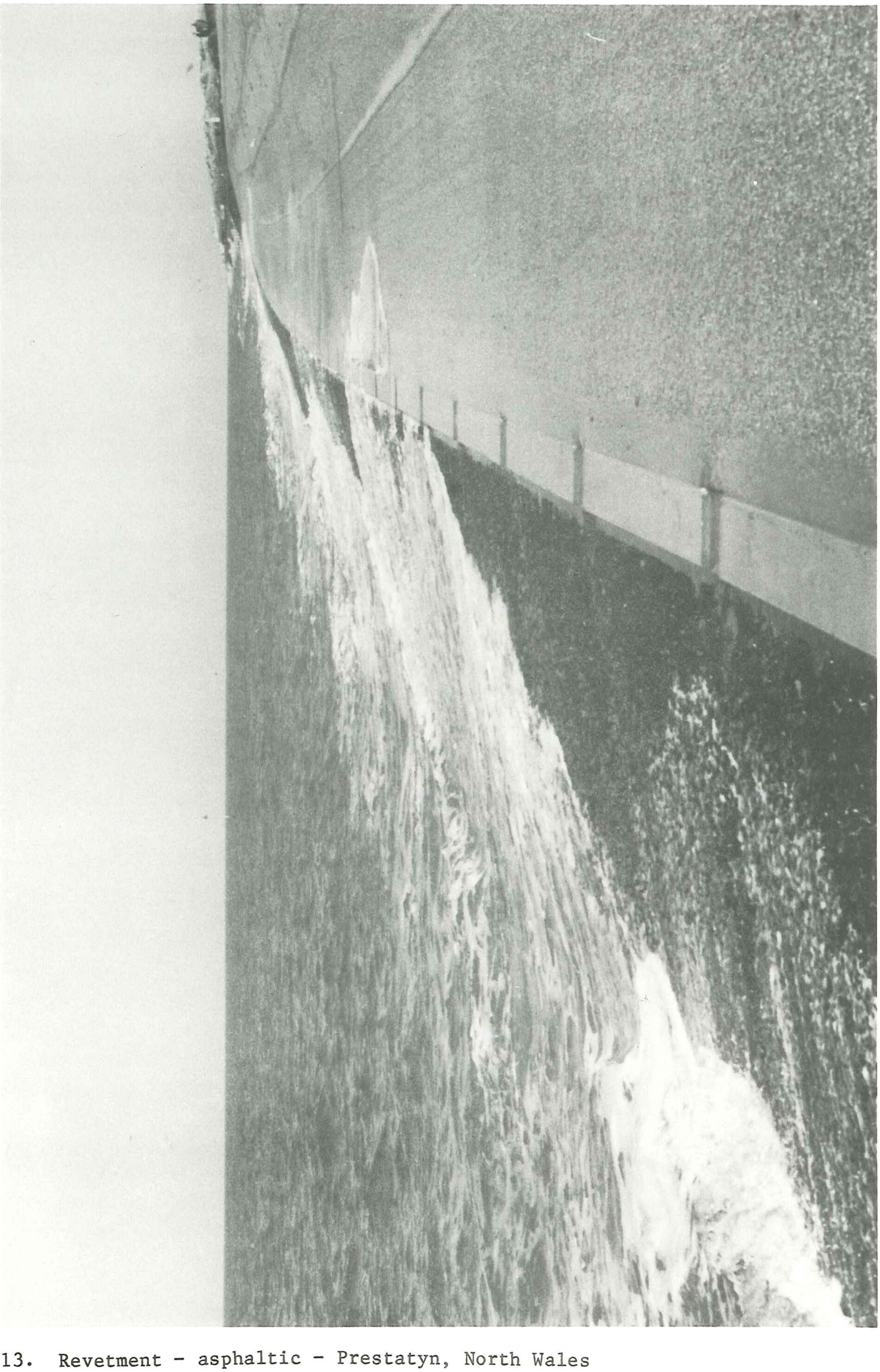
9. Revetment - Dycell blocks - Portland, Dorset

10. Revetment - shiplap blocks - Pett, Sussex

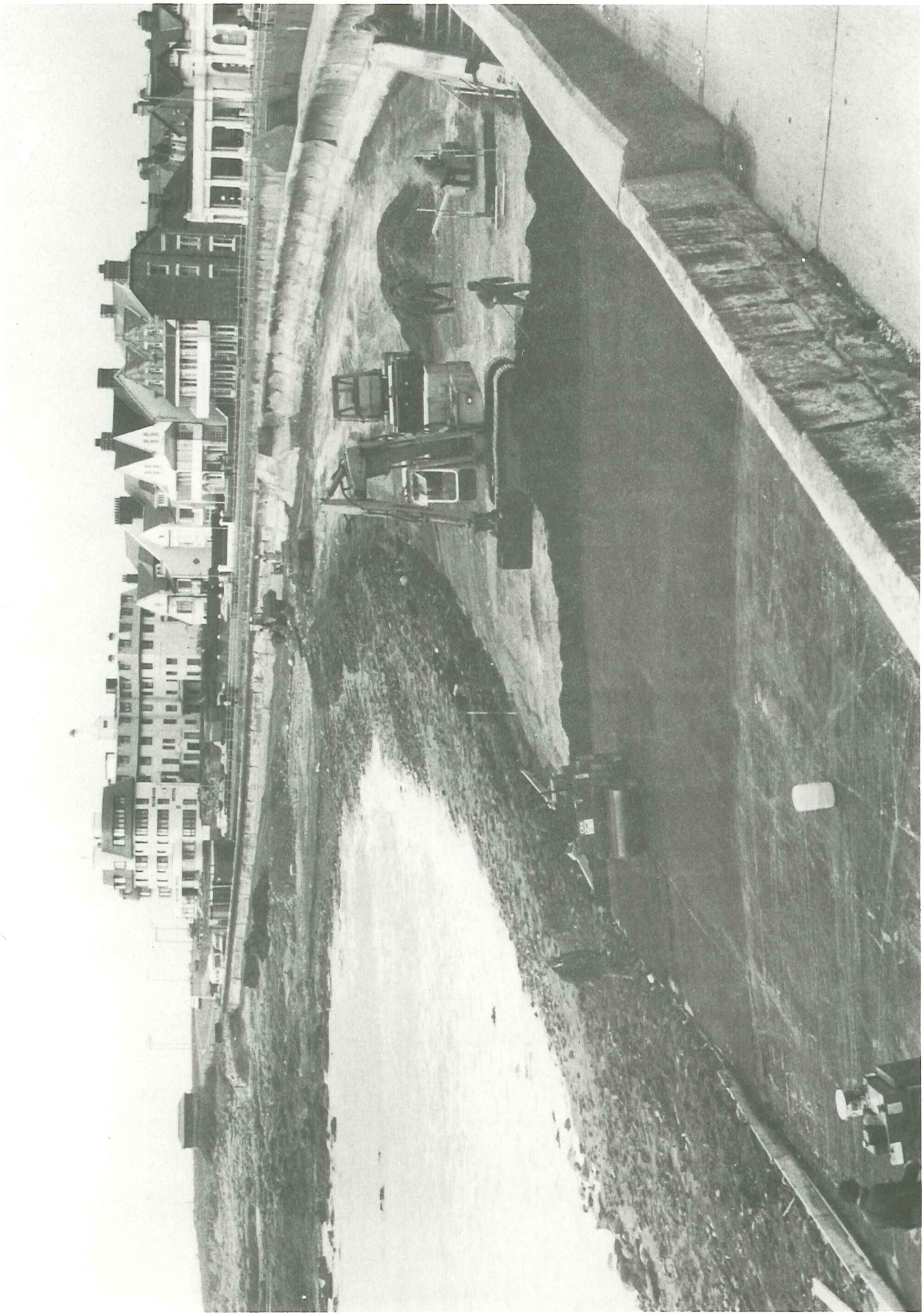


11. Revetment - Sebloc - Southsea, Hants

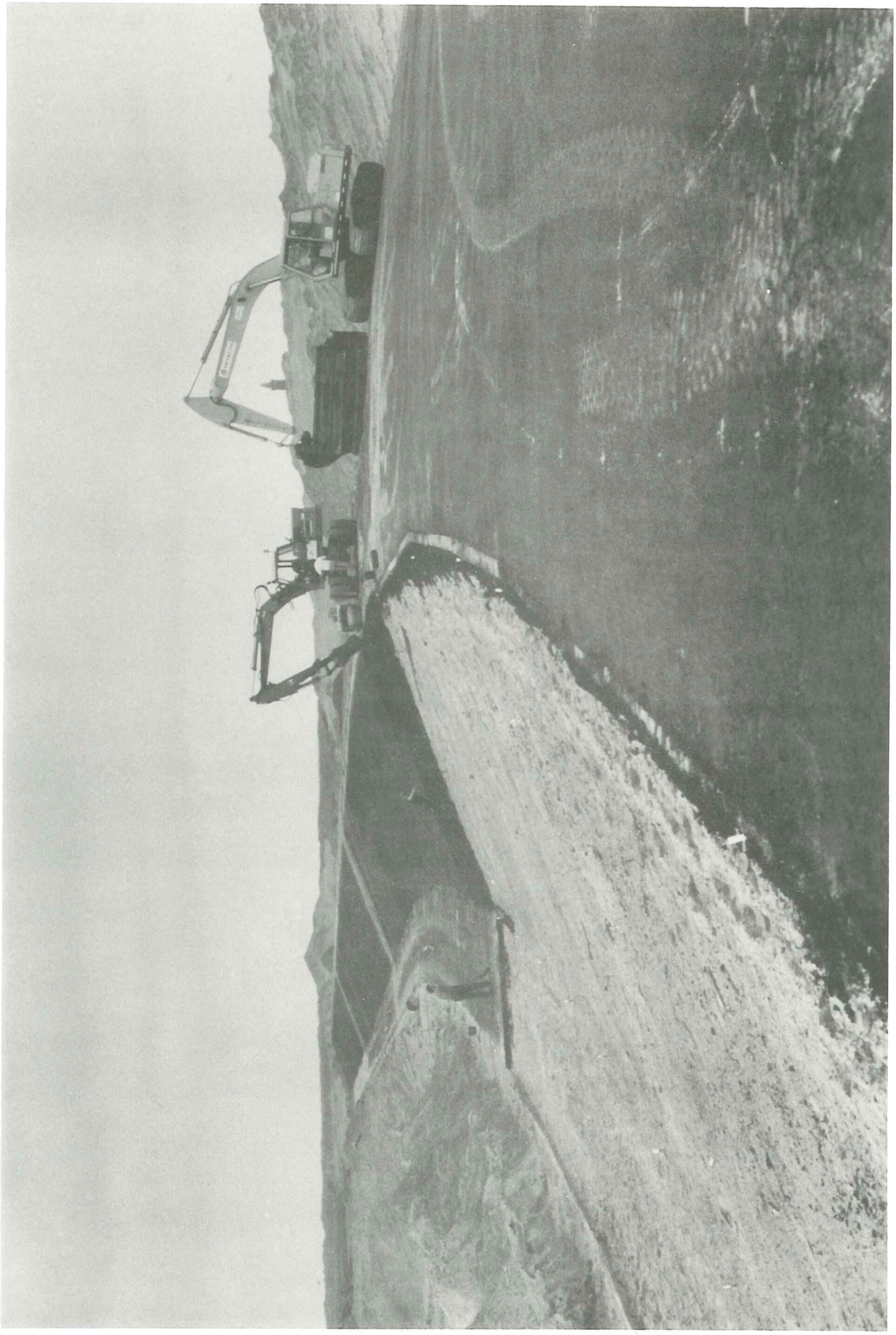
12. Revetment - asphalt grouted blocks - Felixstowe, Suffolk



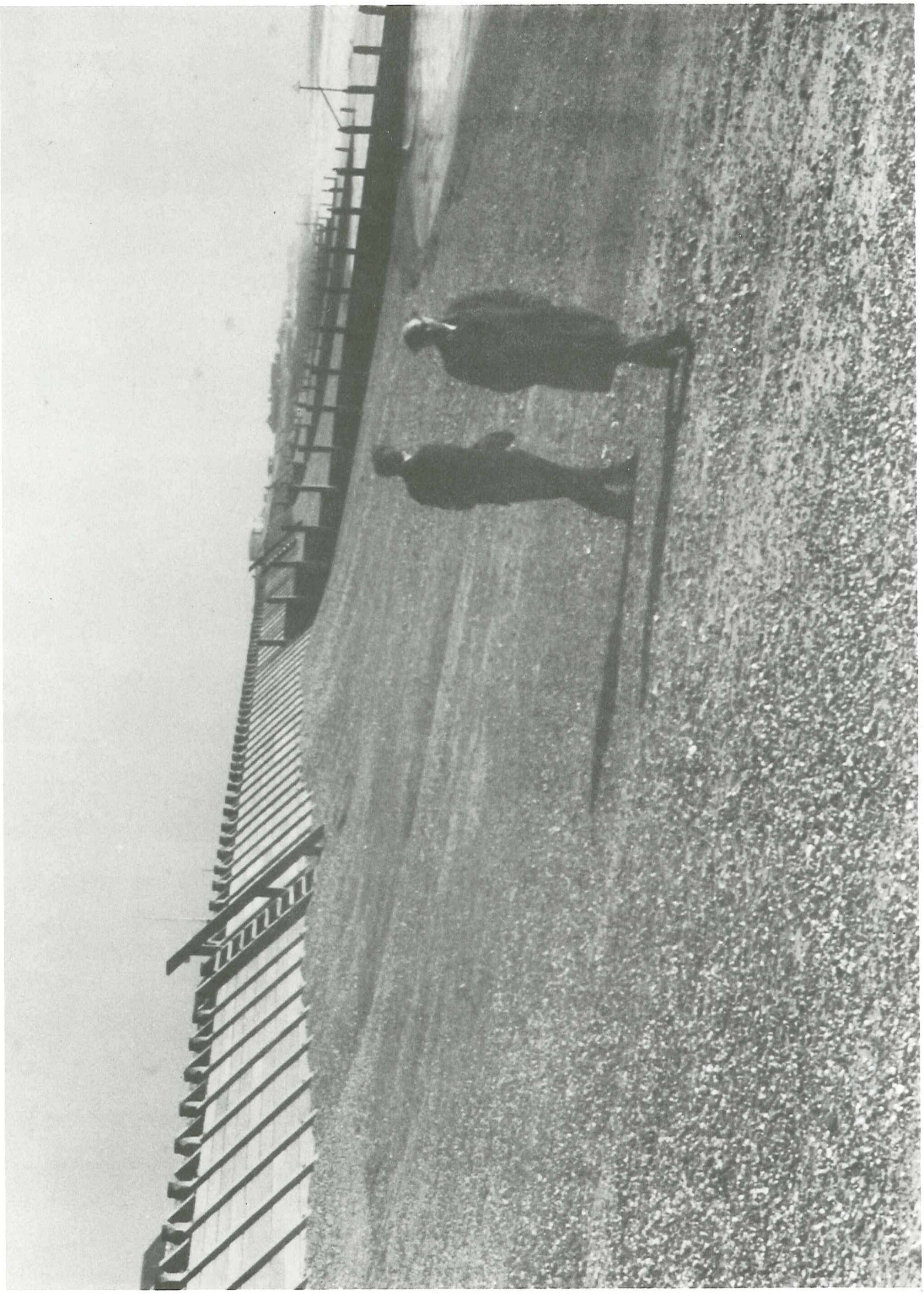
13. Revetment - asphaltic - Prestatyn, North Wales



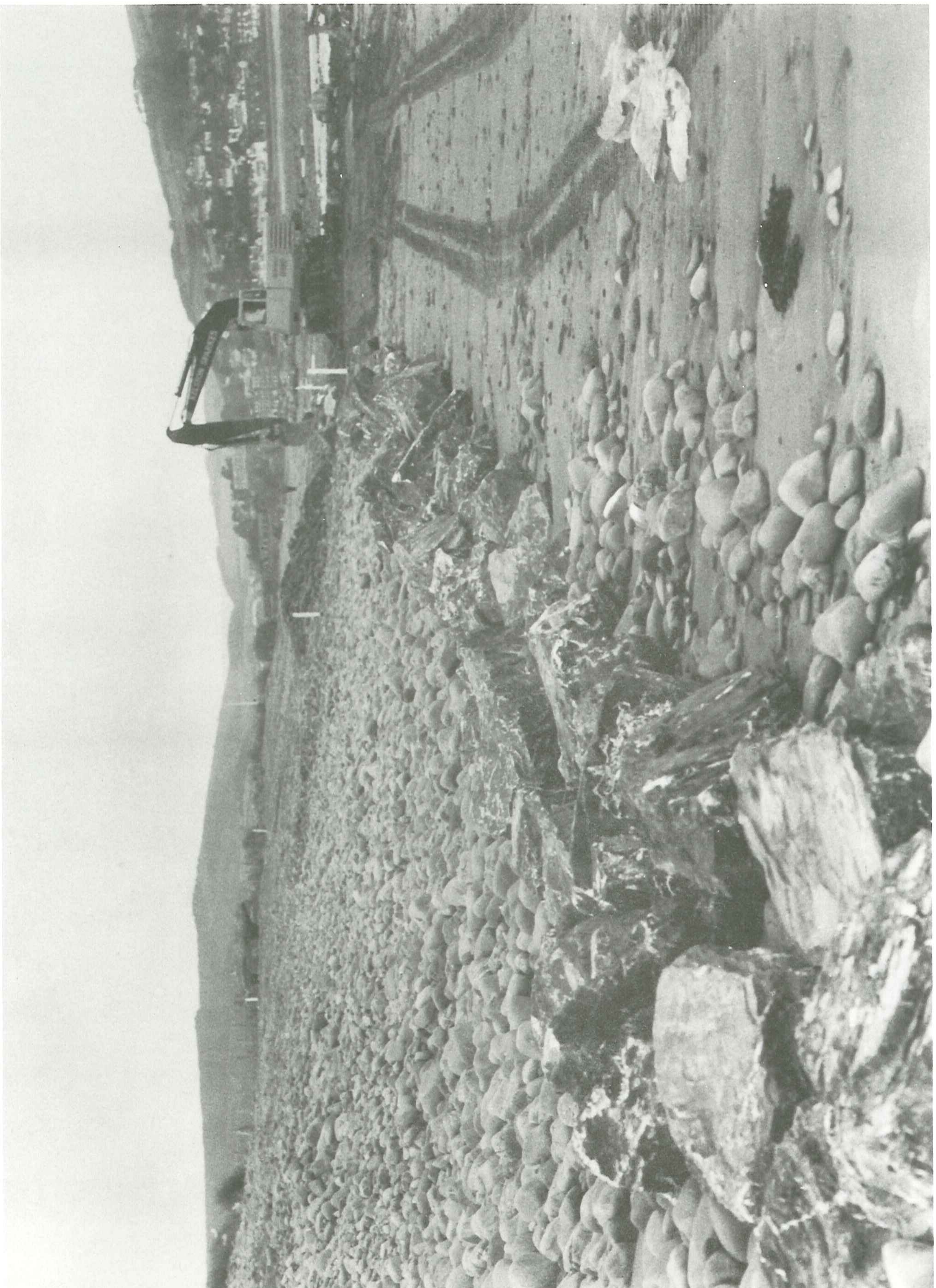
14. Revetment - asphaltic - Porthcawl, Glam



15. Revetment - asphaltic concrete - Ouddorp, Holland

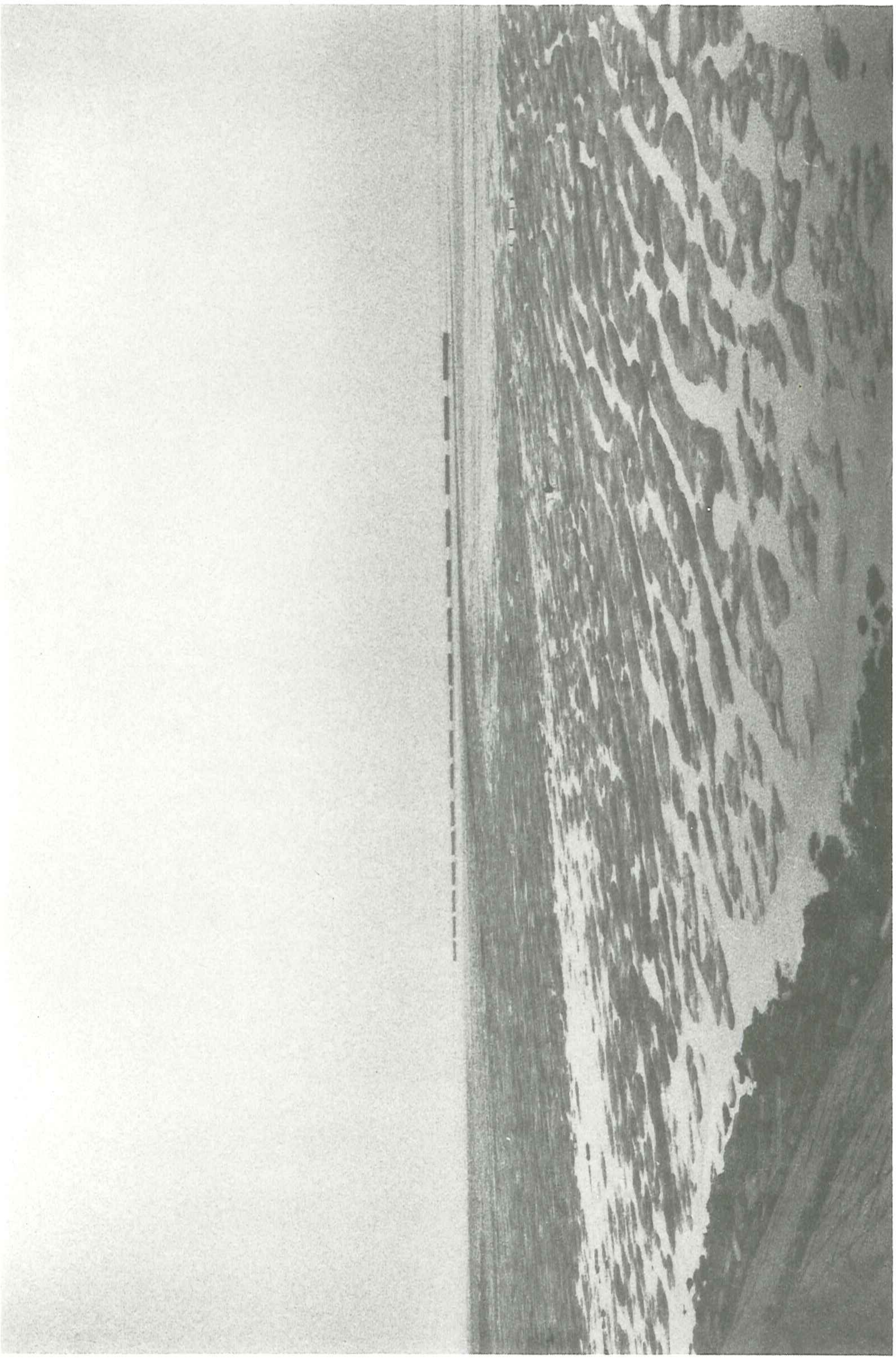


16. Revetment - timber - Hayling Island, Hants



17. Revetment - cobble - Minehead, Somerset

18. Offshore breakwater - rock - Rhos-on-Sea



19. Offshore breakwater - Lighters - Dengie, Essex