CHAPTER 132

SCRAP TYRE BREAKWATERS IN COASTAL ENGINEERING

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1. INTRODUCTION

The problem of the protection of shorelines and coastal structures from wave action is one of long standing. More recently it has become necessary to examine the feasibility of providing the same sort of wave attenuation for locations further offshore. Where the need for protection is in shallow water, close to the shoreline, bed-based breakwaters are possible and floating breakwaters may only be desirable on the basis of one or more of the following grounds:

a) cost,
b) requirement for protection being of short duration,
c) reduced interference with currents,
d) adaptability to changing performance criteria,
e) poor foundations.

As the water depth becomes larger, the costs of a fixed structure become prohibitive whereas only the anchoring fraction escalates for a floating breakwater.

There is an extensive literature extending from 1842 on the floating breakwater concept. Most of the references, however, are postwar following the wartime stimulation of interest in aid of assault landings. Recent sources of state-of-art information are Kowalski (1974) and Adee (1976). The use of scrap automobile tyres has been discussed by Candle (1974), Kowalski (1974, 1976), Noble (1976) and Harms (1978). Candle was proposing what may be called near rigid mats of tyres where neighbouring tyres move relatively little with respect to one another, whereas the Noble, Harms and Kowalski designs use the breakwater flexibility. In the Kowalski breakwater**, the tyres are formed into groups which are known as modules which allow the breakwater to "breathe" and so dissipate more energy by internal movement as well as making construction easier. Several breakwaters of a fairly simple form have been built using this concept. These have been operational in the U.S.A. for several years and have successfully protected at least one marina through hurricane conditions.

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** The design of breakwaters which make use of the innovations of Professor Kowalski is proprietary.

The use of worn tyres in seawater is a safe way of reducing an increasingly important pollution problem. In Britain alone, about 25 million tyres are discarded annually and only a fraction of these are recycled at present. In many other countries, environmental regulations are more restrictive and old tyres become a liability and an eyesore. Tyres are completely non-toxic in seawater and do, in fact, attract marine life. (Tyres have been used as submerged reefs, where they are quickly covered by marine growth, and also as fishing islands, where anglers make use of the tyre's attractiveness to fish, by virtue of providing both a haven and a source of food.) The tyre's geometry is particularly convenient because while it can be constrained to float vertically it is bistable and will, if released, topple over in time and sink without causing any damage or becoming a hazard.

2. BACKGROUND

2.1 CONSTRUCTION

The construction of the Kowalski breakwater is in the form of modules (or groups) of tyres which may be tied together and used as prefabricated blocks in the on-site construction of the breakwater as a whole. The basic unit, which is shown in fig. 1 and 2, comprises of 18 tyres which are tied together so that they float with all tyres in a vertical plane. The air trapped in the crown of each car tyre which floats in this way gives a buoyancy force of about forty newtons (40N) giving a module sufficient buoyancy to support the weight of an average man. The heaving motion of the tyres during wave action is sufficient to allow the replenishment of air in the crowns but in some exceptional circumstances where the trapped air may be dissolved during prolonged calms urethane foam or other buoyancy material may be inserted in a fraction of the tyres. Buoyancy may also be reduced by air leaking from the crowns of lacerated tyres or by the growth of mussel spat or weeds.

The modules are fastened together using a minimum number of ties to permit tyres slight movement relative to each other. The choice of tying material depends on the application, environment and required life of the breakwater. It is possible to use nylon, dacron, polypropylene or stainless steel wire rope or chain, but each suffers from some disadvantage with respect to sea water corrosion or abrasion caused by the constant agitation of the tyres. Wire rope and chain have an additional disadvantage because of the weight involved. Since there is a need for structural integrity the use of reinforced rubber belting secured by nylon bolts is to be preferred for situations where durability over long periods is required.

In order to increase the attenuation of higher waves, a deeper module may be created from the basic one with the addition of six more tyres. The unit is three tyres deep.

Both sets of units may be connected into strings, and later mats, by the use of link tyres. This is shown in fig. 3 and, in the case of the basic modules, allows the breakwater great flexibility. This property is beneficial both in wave energy dissipation (the Cockerell raft wave energy device) and in the sharing of loads throughout the breakwater in heavy seas.

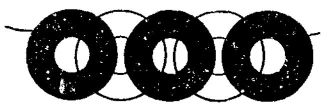

fig 1: Module - Side View

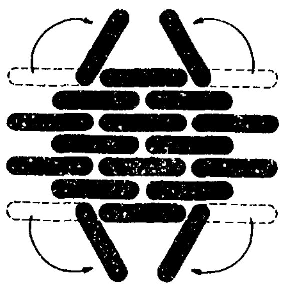

fig 2: Module - Plan View

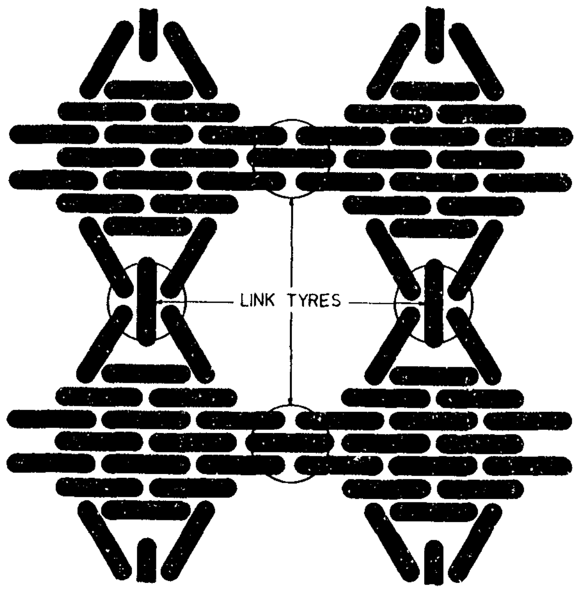

fig 3: Breakwater Mat

2.2 PERFORMANCE

A floating breakwater redistributes the waves energy approaching it in five ways. These are:

1) reflections from the forward face(s) of the breakwater,
2) dissipation of wave energy within the structure of the breakwater,
3) transmission of unsuppressed wave energy,
4) diffraction of the waves passing by the ends of the breakwater, into the protected region in the lee of the breakwater, and
5) generation of waves by the movement of the breakwater itself on the water behind the breakwater.

Different breakwater concepts give different relative importance to these effects. For example, a fixed concrete breakwater will have nearly total reflection, dissipate only a little as noise and spray, transmit a little by overtopping on occasions and generate none. On the other hand, a tyre breakwater reflects very little energy (depending to some degree on the modules which make up the leading edge), generates a little (depending on the trailing edge), leaving the balance to be shared, between dissipation through its flexibility, internal friction and fluid particle path interference and the unwanted transmission. All breakwaters which terminate at sea will diffract waves in some way and this is frequently an important design consideration since it means that the breakwater shadow zone is encroached on by waves travelling in new directions. These waves may interfere to the detriment of conditions in the protected area.

The measure of performance of a breakwater as a whole must be in terms of energy giving

$$\eta_E = 1 - \frac{\text{energy of waves to leeward}}{\text{energy of incoming waves to seaward}}$$

which is easily calculable in terms of the energy spectra in the two situations. Thus

$$\eta_E = 1 - \left(\frac{H_{SA}}{H_{SF}}\right)^2$$

It is desirable from the design point of view to know the transmission coefficient C_T which in the case of a regular wave train is simply

$$C_T = \frac{H_A}{H_F}$$

In the case of a mixed wave spectrum C_T is given by a ratio of Fourier components averaged from a sufficiently long stationary data record. The transmission coefficient is a function of wavelengths (or frequency since these are uniquely related for water of a given depth).

3. EXPERIMENT

3.1 ARRANGEMENT

The experiments were conducted using 1/4 scale car tyres in the Hydrodynamics Laboratory of the Department of Navel Architecture and Ocean Engineering at Glasgow University. This tank is 77m long, 4.6m wide and 2.4m deep and has a parabolic plunger wavemaker at one end which can be programmed to produce a pseudo-random sea made up nominally of 25 different frequency components with a return cycle of 100 time steps. Wave heights up to 0.4m can be produced.

Twenty-five breakwaters fabricated of basic and deep modules were constructed from the 1,300 tyres available and were tested for wave attenuation and mooring loads. The experimental layout is shown in fig. 4.

Previous breakwater tests (Kowalski 1976) had used several runs at discrete frequencies to analyse a particular breakwater, but on this occasion, because of the large amount of test work to be carried out, a broad spectrum was used and the results for a band of frequencies were analysed simultaneously, using F.F.T.'s. This approach is very efficient for a phenomenon of this type, provided adequate attention is paid to the amplitude errors and the coherence between the two wavetrains. In this experiment, the percentage error, which may be written as

$$\frac{100\%}{\sqrt{N_R N_F}}$$

where N_R is the number of runs and N_F is the number of frequencies averaged, was reduced to about 4%.

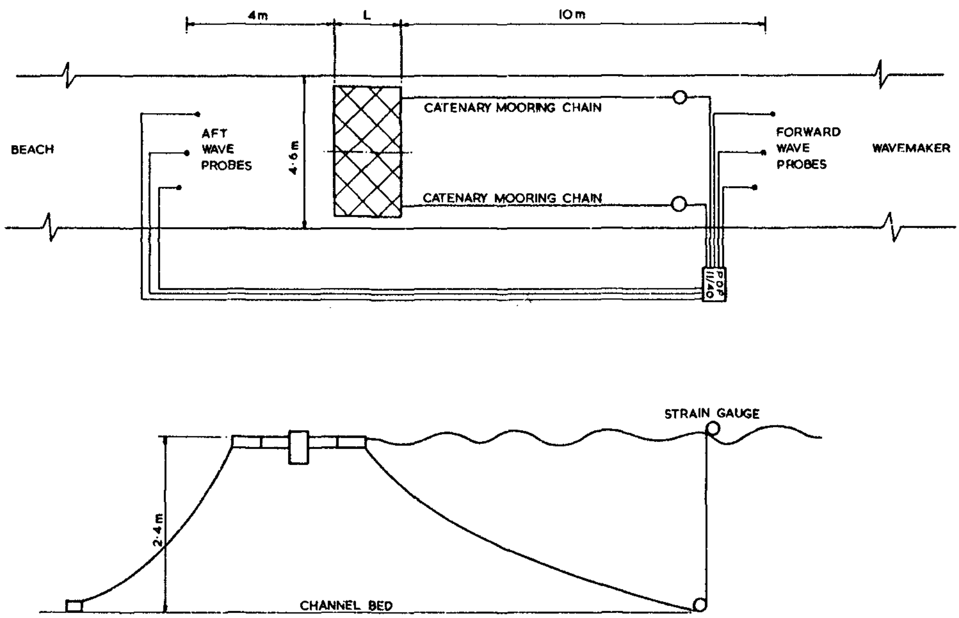

fig 4: Experimental Arrangement

3.2 WAVE PERFORMANCE

The analysis converts the digital record into an incoming wave spectrum $S_F(f)$, a transmitted wave spectrum $S_A(f)$ and a transmission coefficient $C_T(f)$. These are related by

$$\left[C_T(f)\right]^2 = \frac{S_A(f)}{S_F(f)}$$

An example of the computer output is shown in fig. 5 with some extra annotation to explain features.

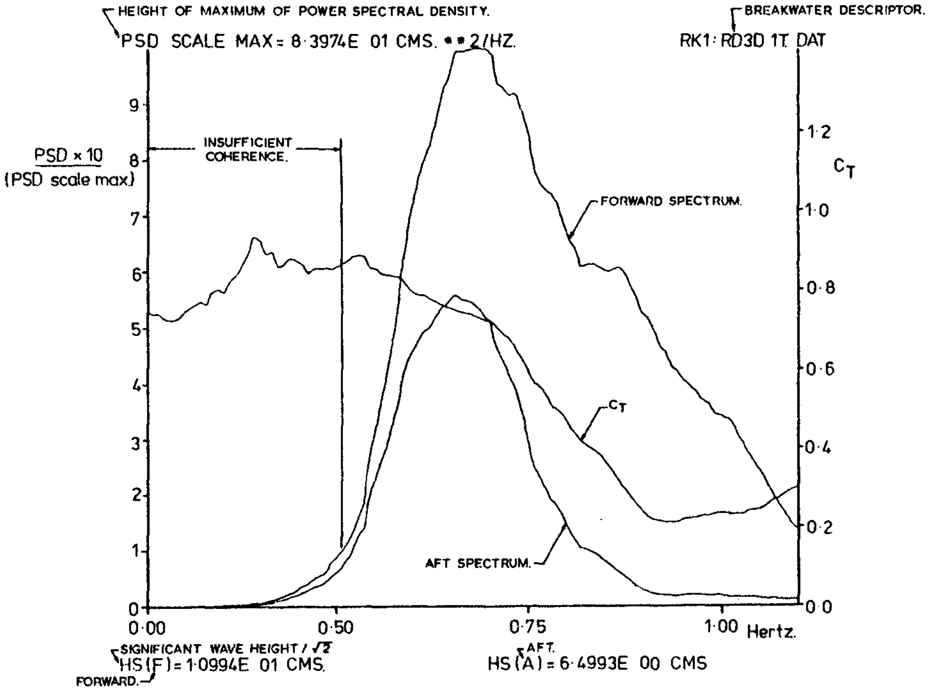

fig 5: Sample of presentation of experimental data as provided by PDP 11/40 Computer

To compare breakwaters it is necessary to use the frequency averaged transmission coefficient, given by

$$\overline{C_T} = \frac{H_{SA}}{H_{SF}} = \left[\frac{\int_0^\infty S_A(f)\,df}{\int_0^\infty S_F(f)\,df}\right]^{\frac{1}{2}}$$

plotted against a breakwater length which has been non-dimensionalised by a wavelength which is representative of the incoming wave spectrum $S_F(f)$.

When $\overline{C_T}$ was plotted against a breakwater length which was non-dimensionalised by a wavelength representative of the wave spectrum, then each of the breakwater 'families' (i.e. those made up of basic modules only, those with one row of deep modules, etc.) produced a discrete curve (McGregor (1978)). For the spectra used in the experiments, the curves for breakwater 'families' using single depth modules only was curved indicating that energy was passing under the breakwater whereas the curves for breakwaters incorporating the deeper modules were straight lines. If wave heights had been larger then these breakwaters would also have given curved lines but as it was, the depth of the breakwater was sufficient to impede the passage of the depth distributed energy. When the plot is made against a non-dimensional breakwater area (fig. 6) then the curves merge and a single straight line is an adequate representation. Although this suggests a law of dependence for scrap tyre breakwaters, such a conclusion would be premature in view of the non parallel trends discernable for individual 'families.'

3.3 MOORING LOADS

The mooring forces were analysed into histograms which were then compared with the Rayleigh probability distribution.

$$p(F) = \frac{2F}{E(F^2)} \exp\left[\frac{-F^2}{E(F^2)}\right]$$

where F is the force per cable and $E(F^2)$ is the expectation of F. For situations where the Rayleigh curve is a reasonable representation of the histogram the cumulative probability distribution

$$P\ (F > F_1) = \exp\left[\frac{-F_1{}^2}{E(F^2)}\right]$$

allows a predication of extreme forces to be made.

The closeness of the fit between the cable tensions and the Rayleigh distribution with the same expectation is illustrated in fig. 7. In each of the families the probability curve skews further towards the higher values for longer breakwaters. Close comparison of data with the Rayleigh distribution indicated that the data is below the Rayleigh distribution in the tail. This discrepancy is sufficiently small to permit Rayleigh probability to be used for high force statistics at least in the first instance.

If the experimental spectrum were to persist on a breakwater for which the expectation was $300N^2$ then a total mooring load of 75N (approximately 5 times the mean) would be expected to occur once per year but the load could well exceed 64N daily. These are quite low loads on what would be one of the largest model breakwaters.

Further examination of the mooring indicates an apparent dependence on wetted surface area. This parameter often has significance in ship hydrodynamics and suggests the dominance of skin friction in producing drag forces. Further, it can be seen that the amount of energy dissipation is increased only at the expense of an increase in mooring loads. It is inevitable that some of the work done on the breakwater is transmitted to the moorings and it also demonstrates the value of internal friction in wave attenuation.

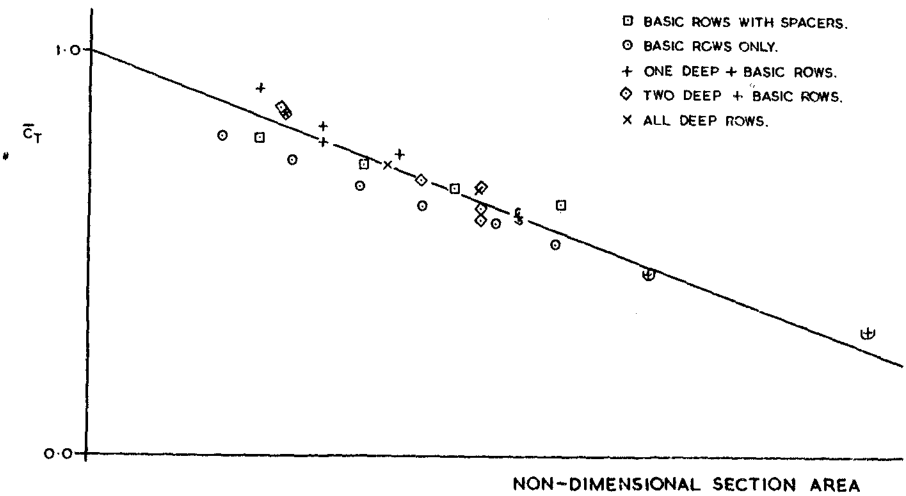

fig 6: Dependence of overall performance coefficient against a non-dimensional side section area (from McGregor 1978)

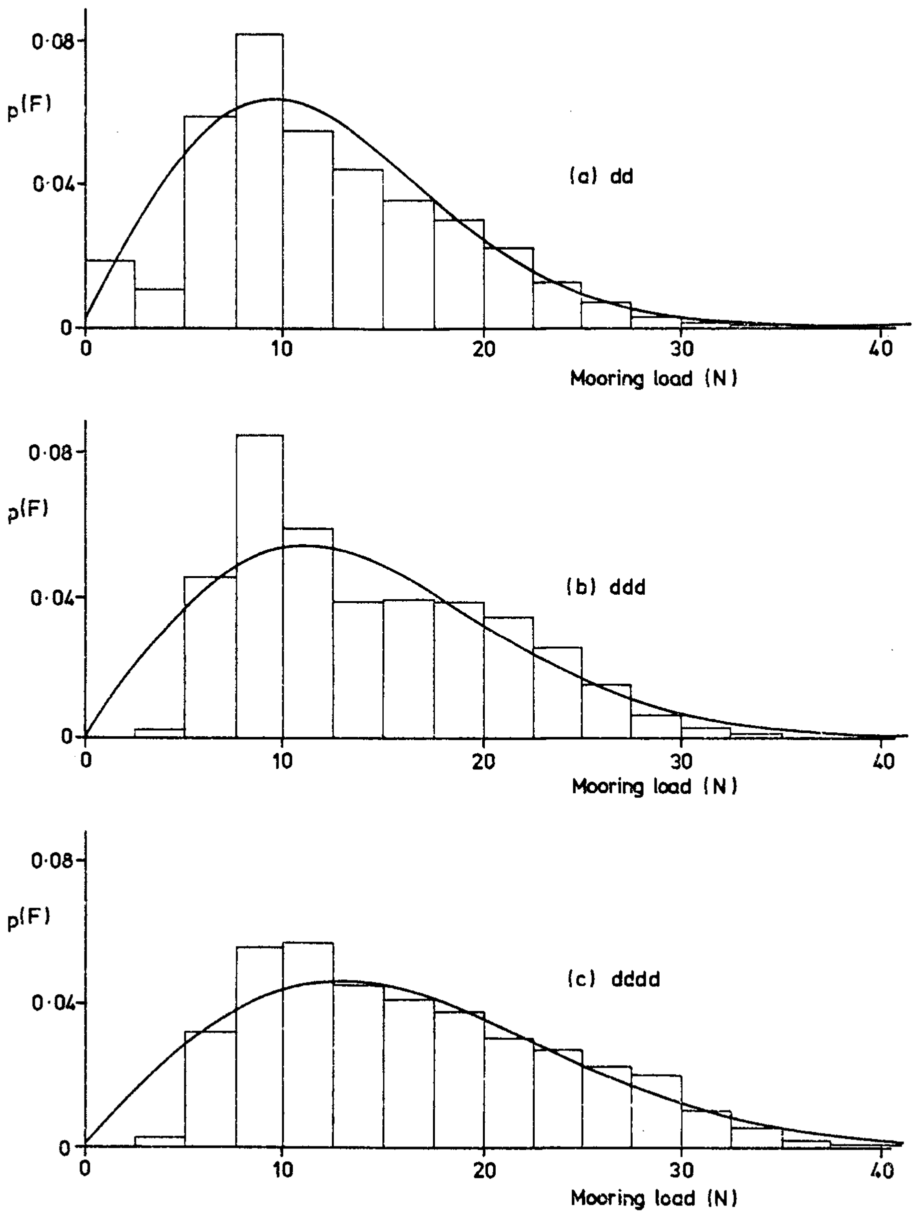

fig 7: Comparison of Mooring Load Histogram with Rayleigh Distribution

4. APPLICATIONS

4.1 RANGE

Tyre breakwaters can be used for a wide variety of applications namely

a) inshore boat marinas,
b) harbour entrances,
c) creating safe natural anchorages,
d) extending existing berths, quays or permanent breakwaters,
e) temporary protection for work areas,
f) fish farms,
g) offshore operations, diving, pipelaying, pollution control,
h) shoreline erosion.

Each of these requires that a breakwater should be adapted to the local situation using available information on fetch lengths, sea depths, prevalence of wind speeds and directions, tidal ranges, and currents and sea bed conditions. The application to fish farms is discussed in McGregor (1977). This paper will discuss design studies* relating to (c), (b) and (g).

4.2 CREATION OF SAFE ANCHORAGE ON ISLE OF GIGHA

The location of Gigha relative to other land masses is shown in fig. 8. The island lacks a natural anchorage which is secure from all directions. A site survey indicated that the anchorage which could most easily be rendered safe was a channel of about 60m width running from 10^{o} to 190^{o} on the south east of the island (fig. 9).

The northern end of the channel is dry at low tide and is sufficiently shallow to dissipate wave energy at high tide even if there were no bend to the east which has the effect of greatly reducing the fetch in the most vulnerable direction. The southern end of the channel is open to an arc around south. The fetch along the channel's axis is interrupted by Gigalum Island (1000m away) and so the most vulnerable direction is due south. The distance to the nearest land along a line of sight is about 20 MM (Mull of Kintyre) but if the line is taken a few degrees to the west the fetch would double (Northern Ireland). The entrance to this anchorage is just deep enough but it is necessary to detour round a submerged rock which may be thought of as an extension to Sgeir Liath and also to avoid fouling with weed on the western side.

Since the most severe weather in this area is likely to be associated with westerly winds, the design condition was reduced to producing tolerable conditions in a sea corresponding to a wind speed of $23ms^{-1}$ (wind force 9). The waves, in this case, would have a significant wave height, H_s, of 2.2m (giving H_{max} ~4m)

**The breakwaters described have not been constructed at the time of writing.*

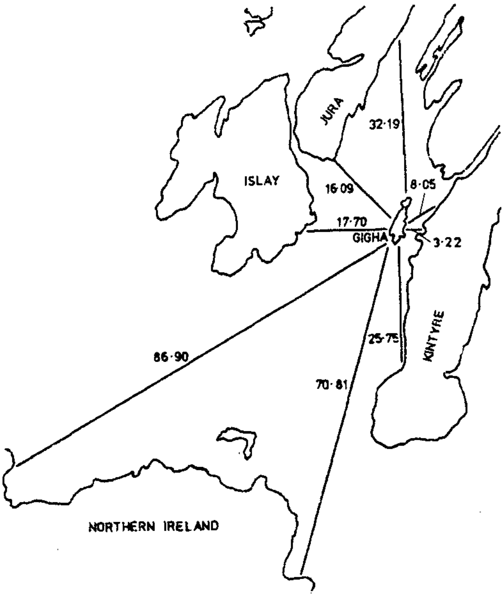

fig 8: Fetches to Gigha (km)

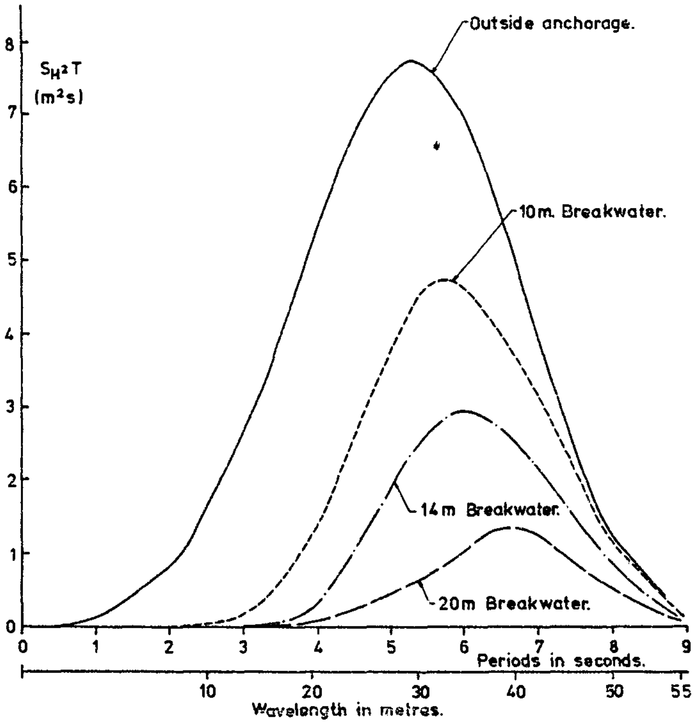

fig 10: Performances for three possible breakwaters at Gigha

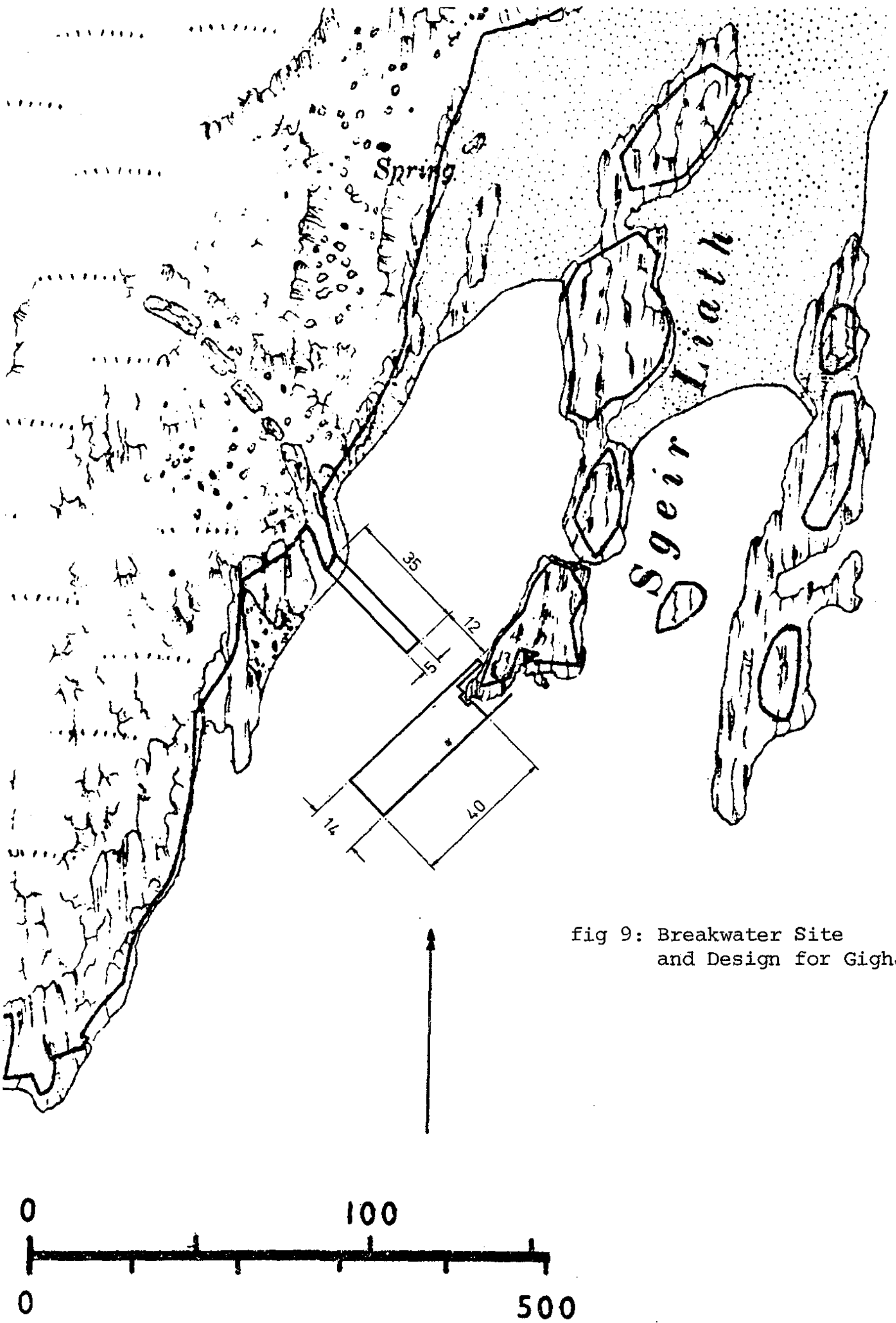

fig 9: Breakwater Site
and Design for Gigha

and a significant period, T_s of 5.3s. However, since the channel is shallow and tides are small the wavelengths would be up to about 50m. The energy distribution curve is shown in fig. 10.

The requirement for access limits the breakwater length to about 40m and its width determines its efficiency (see fig. 10). The intermediate breakwater, which consisted of two rows of deep modules and nine rows of basic modules made from car tyres, was predicted to reduce H_s by 50% and would provide adequate protection. This breakwater and a smaller subsidiary one designed to inhibit diffracted and reflected waves are shown in fig. 9.

The maximum mooring load would be below 40 tonnes allowing manageable sizes of anchors to be used.

4.3 IMPROVEMENT OF HARBOUR ENTRANCE CONDITIONS AT WICK

Wick Harbour has been the subject of several studies in recent years because of its location close to the oil fields and potential as a supply base. The 'topography' of the harbour is illustrated in fig. 11. There are two main engineering problems preventing these developments at present, namely

1) wave funelling within the bay coupled with reflexions from the river harbour and northern shore make the area close to the end of the south pier difficult to negotiate in easterly storms, and

2) sediment is carried into the area adjacent to the outer harbour.

These features inhibit reliability of supply and make harbour maintenance expensive. Solutions which have been proposed using conventional breakwaters, are very costly in an area where the sea is famed for its destruction of the Stevenson breakwater.

The scrap tyre breakwater designed for this situation (and shown in fig. 11) was based on one of the less ambitious proposals for a more normal breakwater. The south pier would be extended by about 80m by the floating breakwater which is also used to "armour" the south pier itself (to decrease overtopping). This breakwater, which would be 52m wide, would reduce H_s from 4m to 1.85m (fig. 12) and because of its relative transparency to the waves reflected from the river harbour it would not aggravate the production of standing wave conditions as a solid breakwater would. The extreme mooring loads would be less than 200 tonnes.

In conjunction with the major breakwater a smaller breakwater between the river and outer harbours would act as a spending beach by reducing the sediment carrying capacity of the waves behind it and stimulating the growth of a beach in this area. This breakwater would also ameliorate the standing wave situation close into the outer harbour entrance.

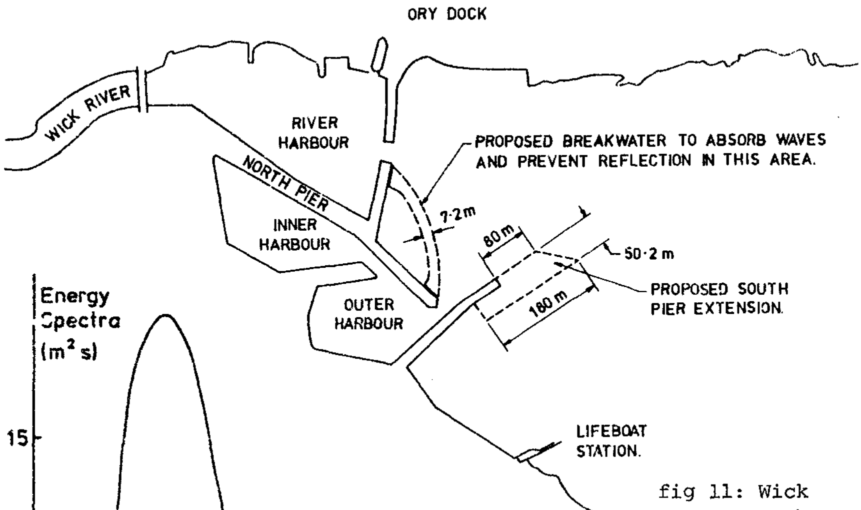

fig 11: Wick Harbour & Breakwaters

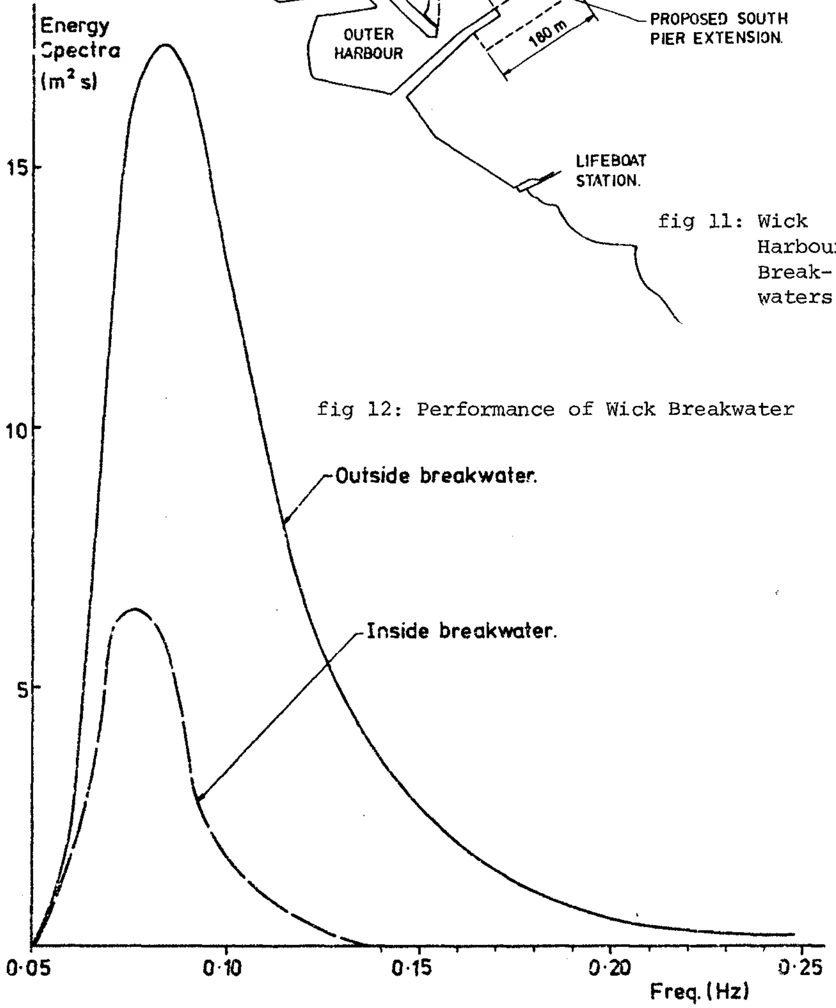

fig 12: Performance of Wick Breakwater

4.4 ASSISTANCE IN OIL CONTAINMENT

In the case of an oil field close to the shore, as in the Moray Firth, there is an increased danger that any spillage will cause widespread pollution along the coast. This danger may be reduced by an oil boom but these cease to be reliable for $H_s > 1.2$m or so. These conditions are exceeded in the Moray Firth for roughly the equivalent of one day a week. This is too high a risk.

The reduction of the risk with a floating breakwater involves a rather different concept to that in either of the previous two examples, since it is now necessary to prevent waves exceeding a specified height from passing out across the perimeter of a large enclosed area.

From directional wind data (Plant 1968) cumulative probabilities of exceedence of wind speeds were drawn and curves of predicted wave heights against wind speed can be superimposed so allowing the probability of wave heights exceeding 1.2m from that direction to be deduced. The modification to this figure by the crescent breakwater required to give protection from this angle can be found by adding in the H_s v U curve when a breakwater is present. Samples of these curves are shown in fig. 13.

The total breakwater is created by taking the maximum of the crescent dimensions at each bearing. Two examples are shown in fig. 14. These reduce the risk of oil crossing the barrier to the equivalent of one day and 18 hours per month respectively. The percentage exceedences can be seen, inside and outside respectively, at the angle of the wave approach.

The total mooring load on such a breakwater would be of the order of 4000 tonnes. For mooring purposes the breakwater would be divided into sections to ensure that the loads were spread and facilitate any maintenance or replacement that may be necessary. A breakwater of this size would also afford a considerable measure of protection to the oil rig in stabilisation from passing ships being off course.

5. CONCLUSION

Scrap tyre floating breakwaters provide a practical, safe and economic option for many wave attenuation problems. There are also occasions when a floating breakwater is the only option.

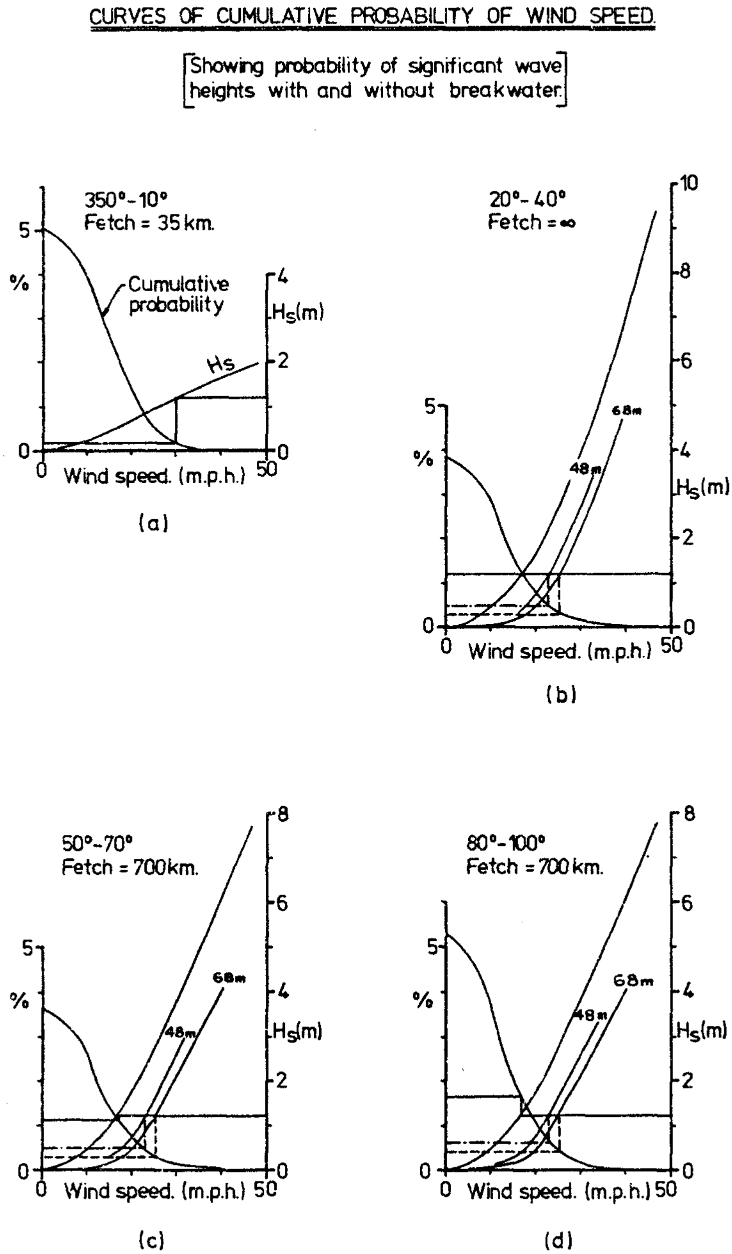

fig 13: Sample of Wind and Wave Probability Curves for Moray Firth with and without Breakwater

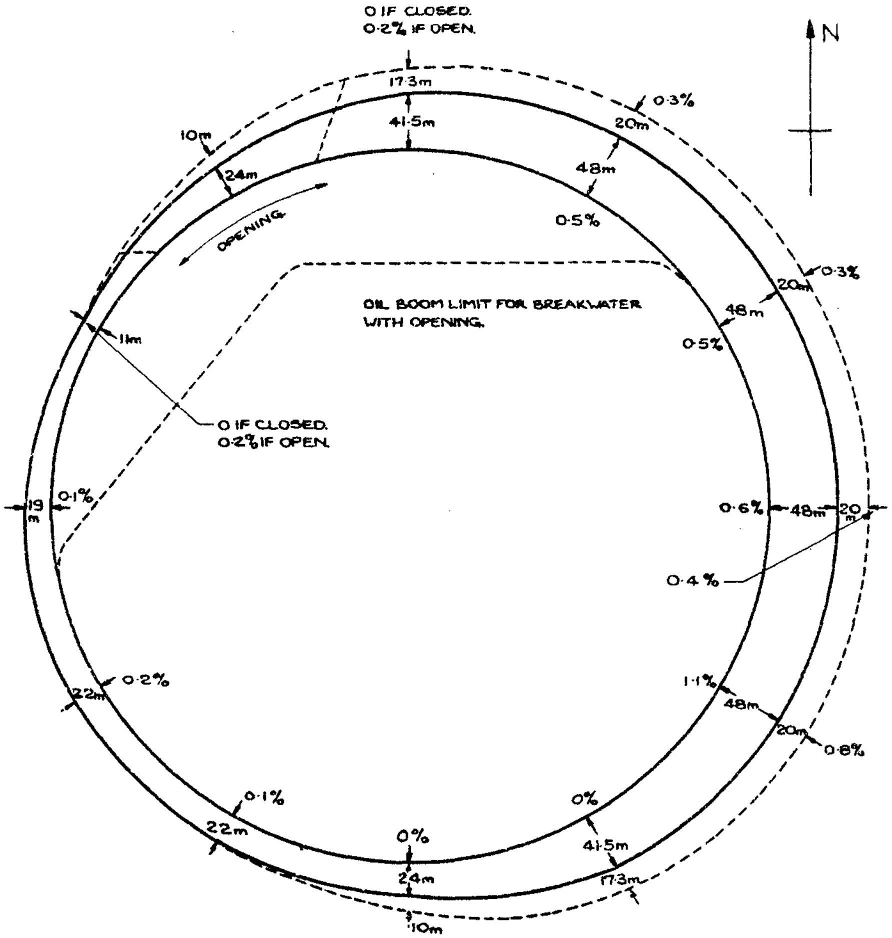

fig 14: Breakwaters for the Moray Firth showing risk of
oil escape

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