FLOATING TYRE BREAKWATERS - A CASE HISTORY

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1. INTRODUCTION

The problem of achieving a system of coastal protection which is cheap, effective and reliable has stimulated the minds of researchers and innovators for many years.

Although floating breakwaters have been written about since the 1840s, interest in them has increased rapidly in recent years. Over the last decade or so floating tyre breakwaters (FTBs) have received considerable attention. Several different designs have been proposed. Candle (1974) proposed what may be considered a nearly rigid mat of tyres where neighbouring tyres move relatively little with respect to one another whereas Noble (1976), Harms (1978) and Kowalski (1974,76) use breakwater flexibility in their wave-maze, PT and modular designs respectively. The breakwater described in this case history used the Kowalski or Goodyear design, which is made up of modules of eighteen tyres which are connected up to form a flexible mat (See Fig.1).

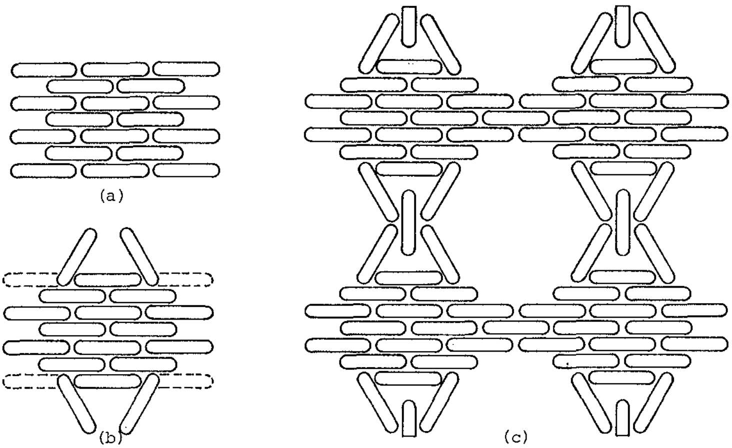

Fig. 1 - Floating Tyre Breakwaters
a) module as constructed on land
b) module ready for linking to others
c) four modules linked together

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There is now an intense demand for increased recreational boating and the numbers of fish farms are growing rapidly. In both cases suitable sheltered water is scare and the mooring pontoons or fish cages require some protection to make marginal areas usable.

The FTB is a contender in these cases. An assessment needs to be made as to whether its advantages, or plus points, namely,

1. lower capital cost - since the main item the tyres themselves are scrap they are widely available in large numbers (e.g. in Britain alone 25 million tyres are discarded annually and only a small fraction are recycled) at very low unit cost,
2. simple and quick to build using unskilled labour (except for supervision) and a minimum of mechanical equipment - similarly mooring and any repairs are easily achieved with minimum interruption to the protection afforded,
3. adaptable to changing needs - the breakwater may be lengthened or broadened to provide more protection over a greater area if the needs of the site change, in addition the breakwater could be towed to another site and reformed to meet the different conditions,
4. ecologically safe with respect to
   i) toxicity - tyres are completely non-toxic in seawater and do in fact attract marine life to the extent that they have been used as submerged reefs and fishing islands,
   ii) impedance of of tidal currents which control sedimentation patterns and the regime of estuaries etc.
5. minimal hazards to boats because tyres are relatively soft in a collision,
6. not liable to catastrophic failure - failures within the module do not free part of the structure to float off to wreck boats or cages since the tyre, while it can be constrained to float vertically is bistable and will, if released, topple over and sink without causing damage or becoming a hazard; failures of moorings will lead to the situation where the breakwater wraps itself like a blanket around pontoons or cages and continues to afford some protection, and finally,
7. little wave reflection - the breakwater works by dissipating energy rather than by redirecting it and consequently undesirable standing wave conditions are not created in the access to the harbour,

outweigh the disadvantages of

1. higher maintenance cost - the breakwater is a dynamic structure and its composite parts are subject to abrasion and wear and so attention must be paid to the state of ties, moorings, buoyancy etc. at frequent intervals (to be discussed more fully later),

2. wave attenuation is partial - floating breakwaters act like filters absorbing the high frequency waves more efficiently than the larger ones but some wave energy will be transmitted or generated by the movement of the breakwater itself,

3. occupies more space - wave attenuation is linked to size of the breakwater, in particular the beam of the breakwater should be a substantial fraction of the wavelength of the waves which must be reduced,

4. relatively short service life - the materials used in the original construction will deteriorate over a few years and a point will be reached where maintenance is better achieved by a reconstruction, and

5. vulnerability to ice on lee side - this is a problem encountered mainly in fresh water sites in high latitudes but can be serious because the moorings may be overloaded.

The object of the design is to develop the situation where the disadvantages are reduced relative to the advantages. Essentially the breakwater is designed to have an adequate level of wave attenuation such that the risk of the damage is reduced to an acceptable level. If this can be achieved within the space limitations (and ice is not present) then the financial balance is the main consideration. Typically the annual maintenance cost is of the order of one third of the first cost. This is a high percentage but the first cost could be as low as 3% to 5% of that of a conventional breakwater, so the maintenance cost is less than servicing the capital involved in such a breakwater. Even with a reconstruction (costing 60% to 80% of the first cost) every three years (which is pessimistic) the life cycle costs compare favourably.

In the case under consideration there was plenty of room and wave conditions were such that an adequate design was possible within the bounds of existing FTB experience. However it is this experience which is rarely published, even though it may be communicated privately, that is presented here to justify the claim that FTBs are not only cheap and effective but can with proper handling be reliable.

2. BACKGROUND

Lothian Regional Council took over the former Royal Navy minesweeper base at Port Edgar on the south side of the Firth of Forth, Scotland.* The harbour at Port Edgar was well designed for its original purpose. Minesweepers are not troubled by waves of 0.6m or so. However yachts are. Consequently Lothian Region engaged Land Reclamation and Development Consultants (LRDC), a subsidiary of Grontmij, to review possible floating breakwaters with a view to establishing a marina as quickly as possible. LRDC recommended a floating breakwater and in association with the Department of Naval Architecture and Ocean Engineering at University of Glasgow** designed a breakwater which would provide

*The site lies in the shadow of the Forth Road Bridge and the Forth Rail Bridge is close by.

**This design service is now a function of Ostec Ltd.

adequate wave attenuation, planned its moorings, prepared detailed design documents and drawings and supervised the construction. The breakwater was made up from 3000 truck tyres and was completed in April 1979 within 5 weeks of the decision to proceed.

3. DESIGN

3.1 Site Assessment

The location of Port Edgar may be seen in Fig. 1. Fetches were measured for each of the relevant bearings and corrected for the effects of width of fetch. A shallow water correction was not considered appropriate.

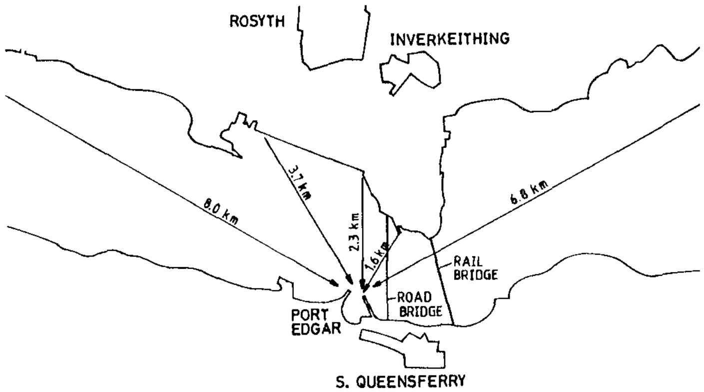

Fig. 2 - Firth of Forth near Port Edgar

Wind data was available from the Meteorological Office for a 20 year period and the mean hourly wind speeds which would have a return period of 10 years from each bearing were predicted.

Over short fetches the sea is quickly aroused to its full potential and the significant wave heights and periods were evaluated using a Bretschneider Chart (US Army, CERC, 1977). (Other methods were examined.) This predicted the sea conditions outside the harbour but in some cases diffraction by the piers of the existing harbour significantly reduces the height of the waves which would penetrate to the breakwater site. This leaves the bearings of 330^{o} and 0^{o} as those producing the only waves of sufficient height to justify attenuation. (In addition wave conditions from other headings are greatly ameliorated.)

This assessment is summarised in Table 1.

TABLE 1: Fetches, Wind and Wave Conditions near Entrance to Existing Harbour.

Bearing (Degrees)	275	285	330	0	30	60
Fetch (km)	7.4	16.7	3.7	2.3	1.5	6.8
Fetch (km)	5.0	7.4	3.7	2.3	1.5	5.1*
Wind Speed (ms^{-1})	26.8	17.4	14.3	14.3	14.3	14.3
Significant Wave Height (m)	1.60	1.15	0.70	0.55	0.45	0.75
Period(s)	4.4	4.0	3.0	2.7	2.4	3.3
Post Diffraction Height (m)	0.25	0.30	0.70	0.55	0.25	0.20

*Further reduced by effect of bridges.

3.2 Wave Attenuation

Extensive data on the performance of FTBs had been collected from experiments conducted on quarter scale car tyres in the Hydrodynamics Laboratory of the Department of Naval Architecture and Ocean Engineering at the University of Glasgow. This tank is 77m long, 4.6m wide and 2.4m deep and has a parabolic plunger wavemaker at one end which at that time could be programmed to generate a pseudo-random sea with wave heights up to 0.4m.

Twenty-five breakwaters fabricated of basic (Fig. 1) and deep modules were constructed and tested for wave attenuation and catenary mooring loads (McGregor 1978, McGregor and Miller 1978). In contrast with other tests on FTBs the breakwaters were tested in a broad band spectrum and analysis was by means of FFTs to generate the transmission function

$$C_T(f) = \left[\frac{S_A(f)}{S_F(f)}\right]^{\frac{1}{2}}$$

where $S_A(f)$ and $S_F(f)$ are the measured wave spectra aft and forward of the breakwater respectively. Sufficient runs were made to reduce the error in the spectral values to 4%.

Other tests described in Giles and Sorenson (1978), Harms and Bender (1978) and Kowalski (1976) have used monochromatic waves and achieved a transmission factor

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

which is <u>not</u> useful in design.)

This different method of experimentation lead to different methods of design. The monochromatic approach by establishing dependence on steepness implies the wave attenuation is non-linear which means that the storm sea spectrum must be idealised to a design wave. The spectral approach assumes wave attenuation can be approximated by a linear system employing a transfer function but can realistically represent the sea in spectral form.

Clearly neither of these approaches has a monopoly of truth but the authors believe that more useful information is ahcieved from a design calculation based on spectral methods. (This discussion is a superficial summary of a complex situation which merits further investigation.)

In this design study it was assumed that the sea could be represented by an ISSC spectrum. (The use of another form such as a modified JONSWAP would change the calculated values but not sufficiently to alter the design.) The evidence of the model tests was that the primary characteristic of a wave was its wavelength and so the transmission function was applied in the form $C_T(\lambda)$ (or even $C_T(^B/\lambda)$).

3.3 Breakwater Design

Figs. 3 and 4 show the predicted performance of a 3 row breakwater of truck tyres aligned east-west encountering waves from bearings of 330^o and 0^o respectively showing the difference in performance at high and low water.

From analysis of several beams and orientations this size of breakwater and orientation was judged to be satisfactory and is shown in Fig. 5. The orientation is a compromise between the extra wave attentuation available if the breakwaters western end is moved northwards and the shorter breakwater length achieved if it were moved south.

The breakwater length is determined by

a) the clearance between the breakwater and the boat moorings,
b) diffraction effects and the area to be protected, and
c) siltation problems.

The clearance was chosen to be 40m but the length is not sensitive to this value and after trying to avoid siltation problems near the east pier by as small a margin as possible it was seen that the diffraction considerations were most significant. The breakwater was designed to be 180m long.

3.4 Moorings

The peak pull on the moorings was calculated from a design wave analysis and was confirmed from extreme value statistics of the model mooring experiments (McGregor 1978) with appropriate scaling for tyre size and wave dimensions. The two methods were substantially in agreement in suggesting a probable maximum of 44 tonnes. The mooring arrangement is shown in Fig. 6.

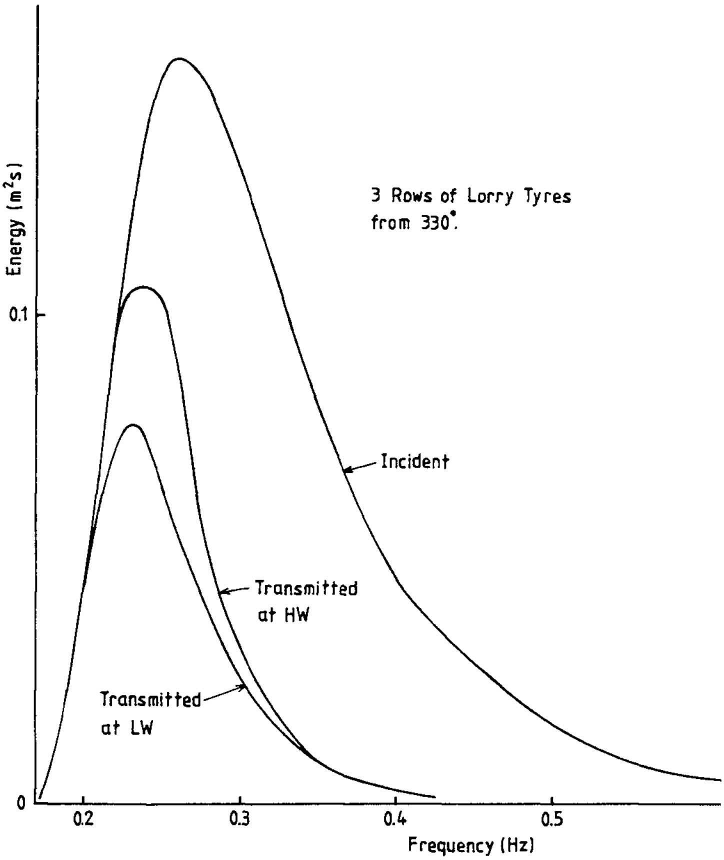

Fig. 3 - Breakwater Performance for 3 rows of lorry tyres with waves from 330°

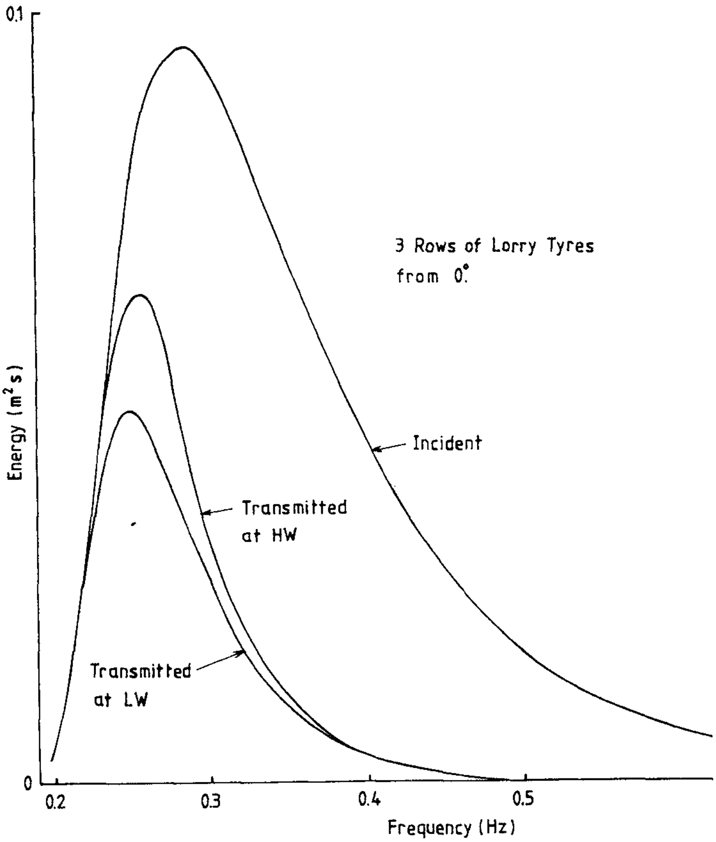

Fig. 4 - Breakwater Performance for 3 rows of lorry tyres with waves from 0°

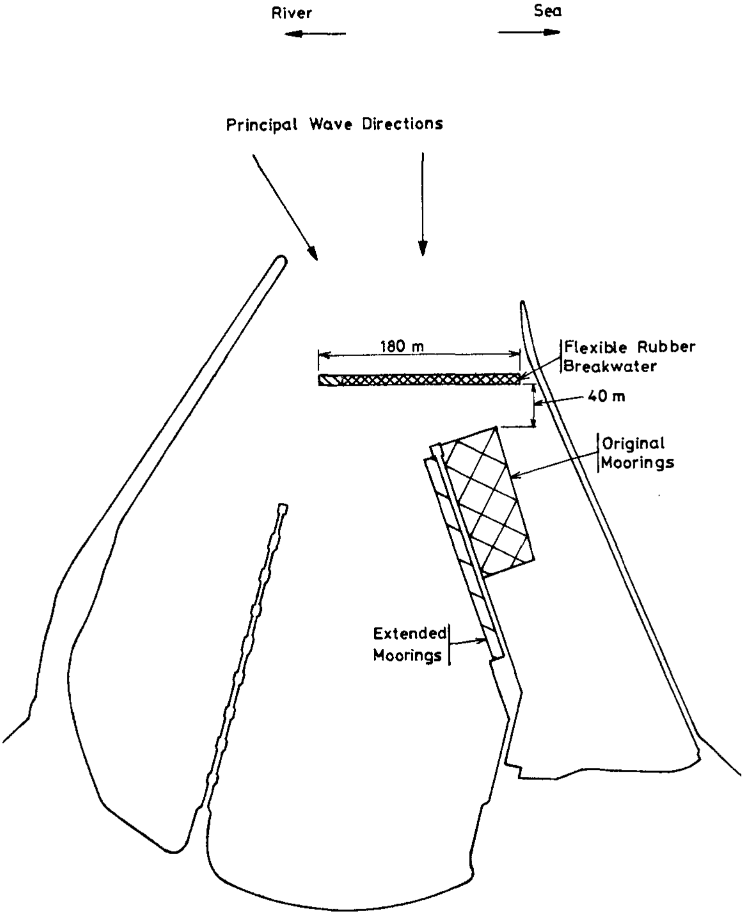

Fig. 5 - Breakwater location at Port Edgar Marina

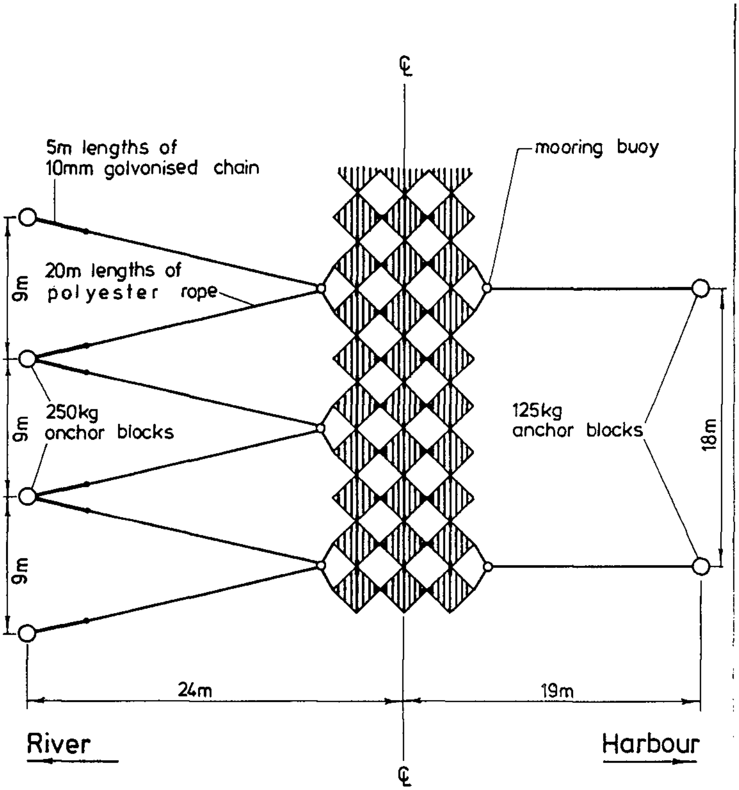

Fig. 6 - Mooring arrangement for floating tyre breakwater at Port Edgar

4. CONSTRUCTION

4.1 Timescale

One of the most attractive features of FTBs is that they can be assembled and installed very quickly. In this case following the initial order in February 1979 the breakwater was tendered for during March and the initial building phase took three weeks. An extension to the originally ordered length to provide protection for an increased area took a further two weeks and the breakwater was completed and operational by mid-April in good time for the marina to be in service and earning during that year's boating season.

Although there were some problems (see maintenance) the breakwater was a successful wave attenuator and the expected life was revised to five years. This coupled with growing suspicion of the status of many of the ties and the level of regular maintenance entailed by the decision that the original breakwater was constructed without additional buoyancy* led to a reconstruction in February and March 1980 carried out on a section by section basis thus maintaining complete protection.

A summary of key dates in the history of the Port Edgar Marina Breakwater are given in Table 2.

TABLE 2: History of Breakwater

1978 December	FTB proposal and design quotation.
1979 January	Report evaluating wave conditions and designing the breakwater was commissioned.
February	Breakwater ordered as a temporary solution with an expected life of two years.
March	Request for, assessment of and acceptance of tender Breakwater built to original specification within 3 weeks and then extended.
April	Breakwater completed and marina becomes operable Some modules ground on silt and are held down.
October	Breakwater partially sinks because of lack of maintenance but is refloated within 24 hours.
1980 Feb. & March	Breakwater is overhauled and fitted buoyancy since the expected life is increased to 5 years.
1982 November	Further FTB under consideration as means of enlarging marina.

* This was done to minimise first cost in the belief that maintenance over the 2 years of expected life would give a smaller life cost.

4.2 Materials

The main construction material is of course tyres. The choice lay between car and truck/tractor tyres. In this case truck tyres were chosen for the reasons below.

a) Scaling - although appreciable quantities of experimental data exist for tyres of different sizes the precise mechanism of wave attenuation is not certain and consequently appreciable uncertainty exists on the scaling laws. For the environment at Port Edgar truck tyres scaled relative to the model tyres in much the same way as the waves thus giving the two scaling factors a similar value and facilitating the scaling problem.
b) Constructional - the number of truck tyre modules required for comparable wave attenuation was very much less than would have been needed with car tyres.
c) Size - The truck tyre breakwater was less beamy than a car tyre design.

A significant price was paid for these advantages.

d) Buoyancy - most truck tyres are tubed and lack the butyl or chlorobutyl lining which is built into car tyres. This means air can leak through the tyre causing the tyre to sink lower in the water. Fig. 7 shows how this effects the breakwater.
e) Handling - truck tyres and truck tyre modules are appreciably heavier than their car tyre counterparts and this increases handling problems. This is offset to a degree by having fewer module connections to make in the water.
f) Abrasion - the extra steel in the beading of truck tyres makes them more abrasive to conveyor belting.

Although the tyre composition factors (d) and (f) were not appreciated prior to the original construction the choice of truck tyres was sound.

Plausible tying materials include nylon, dacron, polypropelene and (stainless steel) wire ropes, open or closed link chain and conveyor belting. All the ropes have overwhelming disadvantages and the choice lies between chain which is heavy and will wear inside the links and conveyor belting which is made of a material similar to the tyres and may be obtained as scrap. Conveyor belting was recommended by Davis (1977) and was chosen for the original breakwater. Belting was cut from used conveyor belts which were scrapped rather than edging of new belting which appears to have been available in America. Three makes of belting were used and two of them exhibited failures within six months. The remaining type appeared unscathed but in the reconstruction a complete transition to chain was made.

The choice of fastenings is determined by the typing material e.g. knots, splices or crimps for ropes, shackles or closing links for chain and stainless steel or black nylon bolts for conveyor belting. Initially stainless steel bolts were used with the belting and these were satisfactory. Later high tensile shackles were used in the reconstruction. A waterproof salt resistant grease is invaluable for use with the shackles when maintenance is necessary.

Fig. 7a - New section (with buoyancy) ready for installation

Fig. 7b - Modules with and without buoyance during
refurbishing of breakwater

Rope, chain and belting have all been used alone or in combination for moorings. In this case nylon rope with spliced hard eyes and black chain were used.

The mooring loads are not in general very high and depending on the bed composition and the anchor handling capability available either small(ish) anchors or concrete blocks may be used. With a silt bed concrete blocks cast in half 50 gallon oil drums were used. The blocks buried well and gave no problems.

It is useful to provide a large number of buoys around the breakwater to provide mooring attachment points which have significant buoyancy to help support the mooring and mark the breakwater. The breakwater was also provided with low intensity intermittent battery powered lights.

(The materials available including floatation aids are discussed at length by Bishop (1980)).

5. MAINTENANCE

5.1 Basic Need

It is important in the context of FTB to appreciate that maintenance is an essential feature of the operation. The very low initial cost is to an extent offset by maintenance costs which will be high relative to the first cost, although only moderate in absolute terms.

Being a dynamic structure the FTB will inevitably be subject to wear and deterioration. It must therefore be inspected regularly and frequently as well as after each storm. It is recommended that at the time of initial construction the appointment of a maintenance contractor, with clearly defined responsibilities, should be considered. Any such contractor should attend to unscheduled maintenance or damage repair without delay. All maintenance should be carefully recorded.

5.2 Maintenance Problems

Several problems were experienced with the initial design which as has already been stated involved no additional buoyancy and relied on maintenance to ensure it floated with a reasonable freeboard. These problems are listed below.

a) Loss of buoyancy from tyres which was not replaced naturally by storms - buoyancy may be lost because of

  i) air dissolving - but seawater is fully saturated with gases and will dissolve no more,
  ii) air leaking through rubber (See 4.2),
  iii) air leaking through tyre faults - any local lightening will migrate to the top,
  iv) marine growth - weeds and crustacians,
  v) flotsam - small weight addition when beached on breakwater.

Once buoyancy is being lost reasons for lack of replenishment become important. These may include

i) shape of the tyre beading,
ii) tightness of the module - in a loosely fastened module individual tyres could heave sufficiently but loose modules are undesirable for other reasons,
iii) inertia of module to wave action - truck tyres with their higher virtual mass are less likely than car tyres to be lifted sufficiently,
iv) lack of freeboard caused by loss of buoyancy makes replenishment progressively more difficult.

Initially this difficulty was to have been tackled with an air line (operated from a boat) which although quite feasible is labour intensive. In addition during a period when there was a temporary lack of maintenance through staff leave an appreciable part of the breakwater sank. A wind of force 5 or 6 blew while the breakwater was down and some considerable damage was experienced. The breakwater was refloated within 24 hours by divers with an air hose. This led to the assessment of permanent floatation. The choice lay between sealed plastic containers for which various sources give evidence of cracking, crushing, escaping or leaking (Bushell (1978)) and foams. The foam may be moulded, rods or mixed in the tyre. The foam should be high density, resistant to crushing, abrasion and pollutants. Although polystyrene cannot be recommended both polyurethane and polyethylene appear to have been used successfull. In this case polyethylene rod was chosen.

Problems created by the belting chafing on the tyre beading were solved as stated by changing to chain.

Port Edgar proved to be an area with three other potential problems.

i) Silt - early in the breakwater's life modules near the east pier grounded at low spring tides and were held down by suction. They were refloated and the breakwater moved a little to the west.
ii) Biological and Zoological Growth - a prodigous growth of kelps (laminaria saccherina and laminaria digitata) which are indigenous to the area developed. These fruit in the coldest months i.e. December and January and should be cleared just before that period removing even the roots to avoid their own ecosystems being established. Mussels were the other major growth. These settle in April and should be cleared then.
iii) Accidental and malicious damage - although this could be serious observation, maintenance and responsible boat owners kept it to a minimum.

6. CONCLUSION

The breakwater has proved hydrodynamically successful in that no damage to boats at the moorings was experienced even when the winds reached force 11 and waves up to 1.25m high were encountered. Without the breakwater, moorings could be untenable at wind forces as low as force 5 or 6. Early constructional problems have been overcome and develop ing biological problems contained by improved understanding of their causes. This has enabled the maintenance programme to be made more timely and more cost effective.

Overall acceptance is illustrated by the consideration of another FTB to provide further protection to the marina which is being extended.

7. ACKNOWLEDGEMENT

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