Guidelines for the Effective Use of Floating Tire Breakwaters

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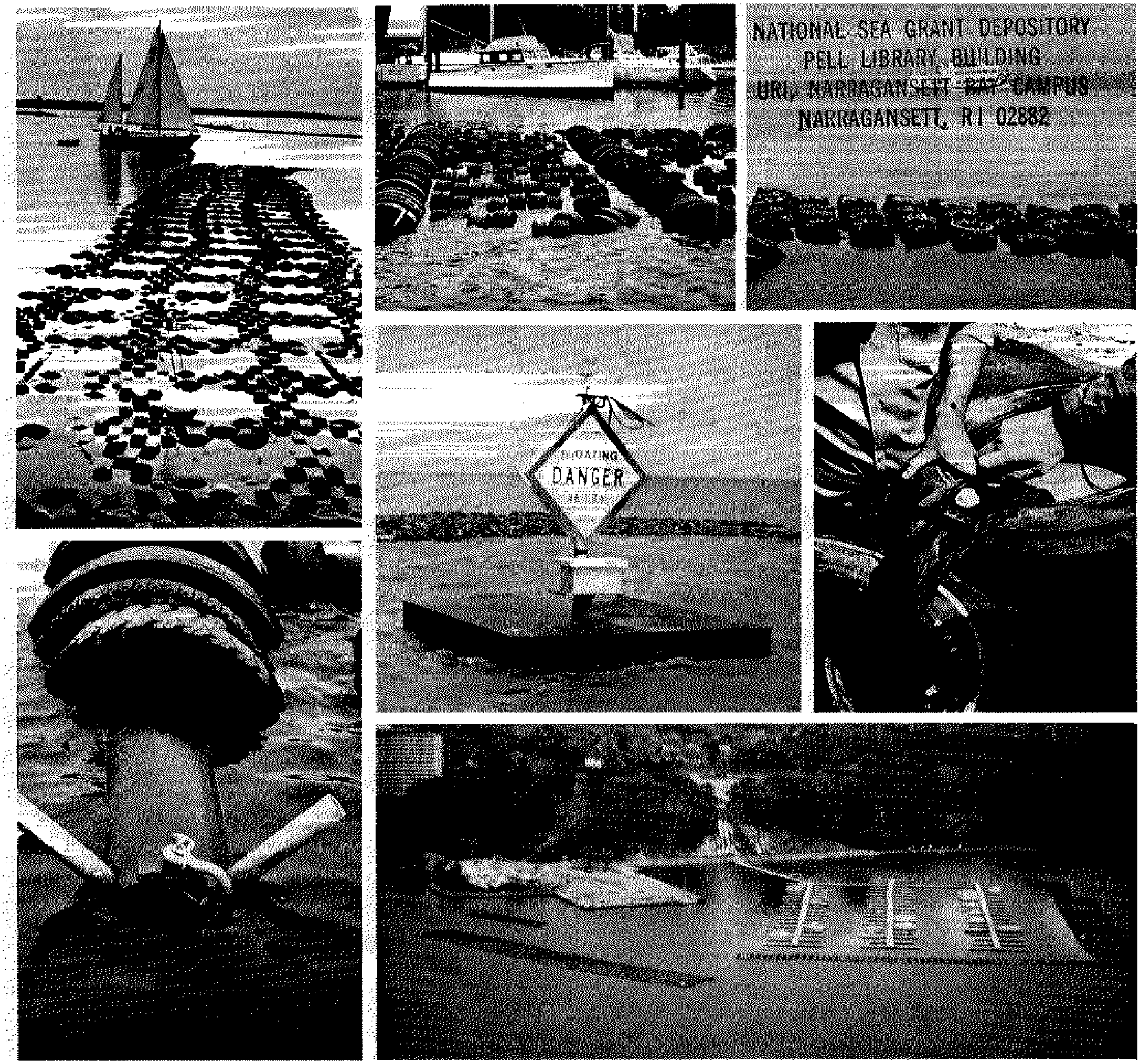

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Introduction

This publication provides current information on the effective use of floating tire breakwater (FTB) technology. The purposes of this publication are to:

- ☐ help managers of coastal facilities assess the feasibility of FTBs;
- ☐ assist regulatory authorities in evaluating FTB applications;
- ☐ inform FTB designers and building contractors of current technology and research information;
- ☐ help university and industry-based investigators identify existing FTB technical information and research needs.

Floating tire breakwater technology has been used at more than 200 sites worldwide. Nevertheless, the authors recognize the limitations of this technology and through this bulletin hope to discourage the use of FTBs in unsuitable areas.

After reading this publication, you will be able to decide if an FTB appears to be appropriate for use in a given area. If it does appear feasible, the reader is urged to consult specific technical references cited at the end of each section and confer with appropriate professionals. Copies of these source materials are available through organizations identified on page 19 of this publication.

To allow for international readership, measurements are given in metric units followed by the English equivalents. When a specific product or company is noted it should not be interpreted as the authors' endorsement. To enhance awareness of floating tire breakwaters, this publication may be produced in whole or in part with a reference citation.

History of Floating Tire Breakwaters

Floating breakwaters have been used to protect coastlines for almost two centuries, but only in the past 20 years has floating-breakwater technology truly flourished.

In 1944, as part of the invasion of Normandy, a 3-kilometer-long floating concrete structure was built to protect Allied landing sites. The breakwater served its purpose, but after a few days it broke apart during a storm which was much more severe than the structure had been built to withstand.

The years immediately following World War II provided little incentive for the development of floating tire breakwater technology. By the 1960s, increased use of coastal areas, especially for recreational boat marinas, filled most naturally protected coves. Demand for safe moorage began to outstrip supply, and new marinas were forced to locate in more exposed sites. Fixed, bottom resting breakwaters for some locations were either unsuitable or prohibitively expensive. Hence demand increased for alternatives, and floating breakwaters were considered.

Floating tire breakwaters are relatively recent innovations, although tires are not strangers to waterways. One could speculate that by the end of the year in which the first rubber tires were discarded, some probably became fenders on tug boats and piers. In 1963 in California, truck tires were assembled into the first workable floating breakwater. The structure, a patented design, was called the Wave Maze. Floating tire breakwaters became more prominent in the 1970s when the Goodyear Tire and Rubber Company field tested its FTB design in Ohio, New York, and Rhode Island. A third FTB design, the Pipe-Tire breakwater, was first installed in New York in 1980.

Floating tire breakwaters have been launched in Scotland, Canada, New Zealand, and France, as well as in the United States. The authors estimate that by the end of 1982 nearly 200 FTBs had been constructed, using the three designs that are discussed in this bulletin. The Goodyear design was used in approximately 95 percent of these installations. The tire has proved to be readily available and an adaptable building block for breakwaters.

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How Breakwaters Work

Most types of rigid breakwaters (floating or bottom-resting) function primarily as wave reflectors: waves are intercepted with some energy dissipated upon the structure, but the largest portion is generally redirected seaward. The converse is true for the typical FTB. This flexible breakwater primarily dissipates the wave energy by transforming it into turbulence within and around the tires. This fundamental difference is important in the analysis and design of such structures. Depending on the characteristics of waves striking a floating tire breakwater, the structure will provide varying degrees of wave protection. The FTB is most effective in reducing wavelengths shorter than twice the beam width of the FTB while longer swells are hardly affected by its presence.

Of the many types of waves present in bodies of water, the most important to consider for floating breakwaters are those generated by the wind and in some cases, by the passage of ships. The size of wind waves is related to wind velocity, the length of time the wind blows, the depth of water, and the area of open water across which the wind blows. In addition, when waves progress into coastal waters, the changing water depth alters the wave's appearance and characteristics. These are the principal factors determining the changing directions of movement, heights, wavelengths, and periods of waves (fig. 1). By determining these characteristics, the most effective size of floating tire breakwater and appropriate moorage location can be assessed.

Crest - high point of a wave

Trough - low point of a wave

H, wave height - vertical distance from trough to crest

L, wave length - horizontal distance between successive crests

T, wave period - amount of time between successive wave crests passing by a fixed object in the water, such as a pile.

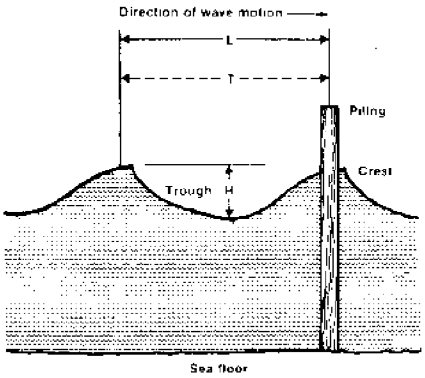

Figure 1. Terms used in describing waves. (DeYoung 1978)

Research and experience have shown that floating breakwaters are effective in improving coastal protection when designed for specific wave conditions. Typically, these structures cost less to construct than conventional fixed structures, but have a shorter lifetime and higher annual maintenance costs. To date, floating breakwaters have been moored predominantly in lakes, bays, and rivers, or within natural harbor areas. In each successful case, the structure's size and mooring design have been carefully planned.

Is an FTB Suitable for Your Needs?

When considering the use of an FTB, three general questions should be asked:

1. Will an FTB provide the desired protection from waves at this specific site?
2. Will an FTB structurally survive extreme events at a specific site (waves, ice, or currents)?
3. Is an FTB the most cost-effective alternative for a specific site?

The reduction of incoming wave energy by an FTB depends mainly on the ratio of wavelength to breakwater beam (fig. 2). Thus, for incoming waves of equal height, the longer the wavelength the larger the breakwater's beam must be to reduce wave heights to the desired height leeward of the FTB. Similarly, for a given wavelength, the breakwater's beam requirement increases as the requirement increases for wave energy reduction. Broadly speaking, FTBs can reduce wave energy effectively when the beam size is greater than twice the wave length.

In practice, the range of feasible beam sizes is limited by space restrictions, economics, or anchor requirements. Floating breakwaters are held in place by various kinds of mooring systems; the forces exerted by waves on the mooring system increase roughly in proportion to the square of the wave height. Also, for

H incident wave height
H_t transmitted wave height
L wavelength
d water depth
MWL mean water level
D tire diameter
B beam size of FTB
H_t/H ratio of transmitted to incident wave height (C_t)

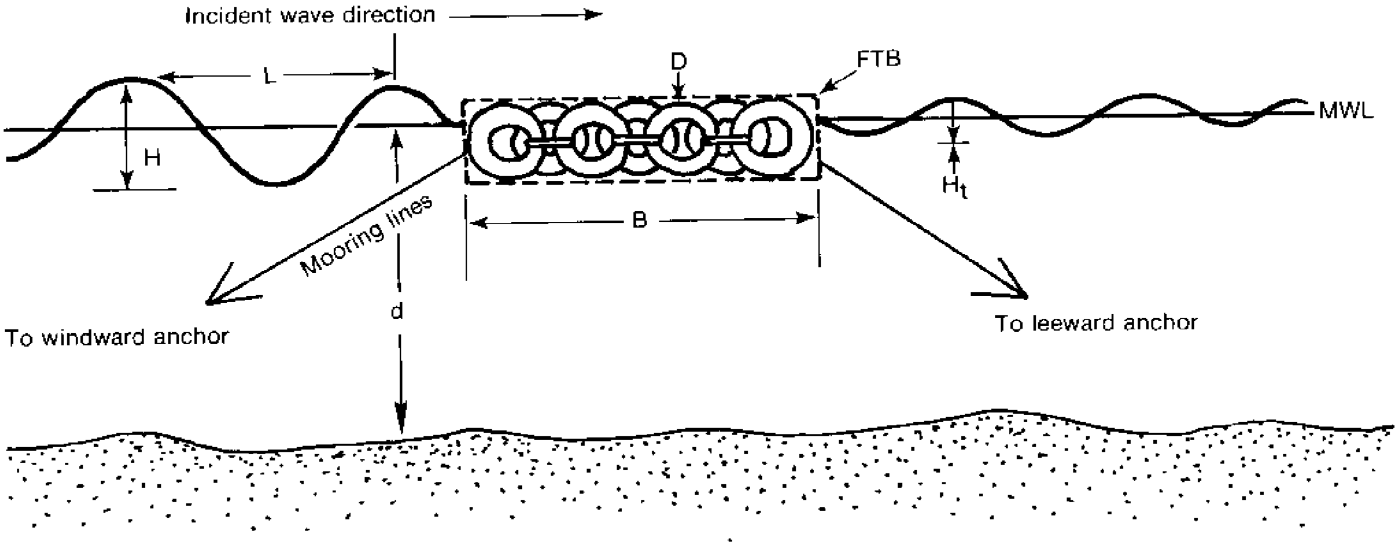

Figure 2. Terms used in describing a FTB.

waves of equal height, the maximum mooring forces are greater for longer wavelengths. With increasing severity of the wave climate, therefore, it becomes increasingly difficult and expensive to anchor a floating breakwater.

It is prohibitively expensive to design an anchoring system to withstand severe forces of moving ice. To avoid the expense, the breakwater could be disconnected from its summer mooring lines and be removed from the water for winter storage, or it could be relocated at a protected site where it would experience only static ice forces (due to thermal expansion and contraction of a fixed ice mass). Floating tire breakwaters have been observed to survive static ice forces with virtually no structural damage.

In terms of structural survival, appropriately designed and constructed FTBs have successfully withstood attack by waves with a significant wave height of 1.5 m (5 ft). (The significant wave height is defined to be the average of the largest one-third of the wave heights in a sample.) It is not yet known at what wave height structural damage begins. In most cases, the mooring system would probably fail before the FTB deteriorated structurally.

It should be remembered that FTBs are just one type of floating breakwater, and, in any given case, other types of floating as well as conventional bottom-resting breakwaters should be considered.

As a general guideline, FTBs can be potentially cost-effective alternatives in the following situations:

1. Primary, ongoing wave protection at sites where the fetch (open water distance over which the wind blows) is less than 10 km (6.2 mi) or supplemental, ongoing wave protection where the FTB is sheltered partially by other wave barriers such as reefs, shoals, islands, or conventional breakwaters.

☐ small harbors and marinas
☐ coastal erosion control
☐ aquaculture

2. Short-term or temporary wave protection

☐ emergencies (marine accident, oil spill, erosion)
☐ marine construction
☐ military applications
☐ special event wave protection (harbor festival, boat show)

At this time, FTBs should not be considered for ongoing use at ocean or other exposed long-fetch sites.

Advantages and Disadvantages

Advantages of floating breakwaters compared with conventional bottom-resting breakwaters:

☐ Lower capital cost.
☐ Shorter construction time.
☐ Suitable for sites with deep water, soft bottoms, or large water-level fluctuations.
☐ Less disruption to water circulation and sediment transport.
☐ Adaptable to various locations—can be moved relatively easily.

Disadvantages compared with bottom-resting breakwaters are:

☐ Feasible only in short-fetch or semiprotected locations, or for temporary use.
☐ A floating breakwater always transmits part of the incoming wave energy, unlike a well-designed conventional breakwater which transmits virtually no wave energy through the breakwater.
☐ Higher annual maintenance costs.
☐ Shorter service life.
☐ Cannot be moored year round at some sites experiencing severe ice conditions.
☐ Space occupied by the breakwater and its mooring system can be large.
☐ Breakwater's low profile in water may be a hazard to navigation if the FTB is not adequately marked.

Compared with other floating breakwaters (concrete caissons, A-frames, and other rigid body types), FTBs have the following advantages:

☐ Lower capital cost.
☐ Tires, the primary construction material, are readily available at most locations.
☐ Wave reflection is generally less because FTBs primarily dissipate rather than reflect incoming wave energy.

☐ Local biological resources may be enhanced by the FTB acting as an artificial reef.
☐ Damage to boats involved in boat-breakwater collisions may be less.

Disadvantages are:

☐ Potentially higher maintenance costs.
☐ Larger amount of physical space required.
☐ Potential public opposition to the use of tires as a construction material, due mainly to aesthetics.
☐ Reputation of FTBs as unreliable, due partly to the failure of some early installations in the pioneer stage of FTB technology and to the recent failure of others. These later failures can generally be attributed to the following:

1. Ignoring state-of-the-art technology in the design stage.
2. Ignoring field-proven experience in the selection of construction materials.
3. Ignoring the important requirement of providing regular maintenance.

There now has been sufficient research and field experience for a qualified person to confidently design and construct an effective floating tire breakwater. However, this must be done recognizing the basic limitations of FTBs as described in this section.

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Legal Obligations

The legal use of floating tire breakwaters in many waterways requires authorization from appropriate government agencies. Regardless of government permit requirements, individual legal liability dictates that prudent practices be followed. This section describes common public and private legal obligations associated with FTBs.

Federal, state, provincial, and local government agencies evaluate the appropriateness of FTBs being installed in waterways. Page 19 identifies appropriate government agencies to be contacted in the United States and Canada. The approval process can take from a few months to more than a year and applications often are required by several government agencies. By submitting all applications at the same time, the time spent in acquiring the necessary approvals can be minimized. It is important to understand, however, that federal agencies are often reluctant to issue permits until the required local approvals are obtained.

When preparing a permit application, specify all areas that are being considered for FTB moorage sites. Because floating tire breakwaters are mobile, the FTB could be used on a trial basis in several locations before choosing the most effective site. Or it may be winter stored in a more protected site than during its seasonal use. For this reason, it is important to clearly indicate the initial site as well as others under consideration. Notifying appropriate permit agencies before a site change will allow them time to contact others who would be affected.

Permit applications usually consist of two or more pages of survey questions and a detailed plan drawing. To help develop a detailed plan for your FTB, a representative plan drawing is provided (fig. 3).

Because of the relatively recent design and use of FTBs, some agency personnel are not familiar with this technology. Their awareness can be increased by submitting a copy of this information bulletin with permit applications. In this way, communications regarding the proposed FTB will take place with a common understanding of terminology.

Limiting Legal Liabilities

When placing an FTB in a waterway, be aware that you assume legal responsibilities. This section, written with the aid of a university-based coastal resources legal specialist, reviews specific legal liabilities and individual responsibilities related to FTB use in the United States. Check with your own attorney for an understanding of your responsibilities.

The following questions are often asked by those building FTBs. The responses reflect legal probabilities, rather than absolute answers:

Q: Is an FTB an attractive nuisance if moored alongside a dock or in the middle of a harbor? If so, how can legal liabilities be minimized?

R: Any structure that is unusual for an area or captures the imagination of people is potentially an attractive nuisance. To limit your liabilities, post a conspicuous sign that states the danger (e.g., Danger—Swimmers may become entangled in breakwater). Because some children cannot read and adults may have impaired vision, try to control access to the structure. This can be done by placing a barrier or fence between the FTB and other structures.

Q: Who is liable if a boat or water skier collides with the structure and injury occurs?

R: If the FTB is well marked and visible, the boater may be held negligent. Remember, also, that the low profile of your FTB and its flexibility help to reduce the probability that significant structural damage will be done to a boat if it should run aground. It would be a good idea to place a notice in local newspapers each season telling where the FTB is located, and giving its size and owner's name. It would be prudent for FTB owners to have insurance covering such occurrences. Municipalities can choose to have the structure covered by their general liability insurance policy while private owners may arrange for a rider for the FTB on an existing insurance policy.

Q: If the tires used in my FTB are "branded," will this limit my liability for tires washed up on private property?

R: Yes, it will, if the character of the brand is not made known to the general public. This method of branding would also help you to retain property rights

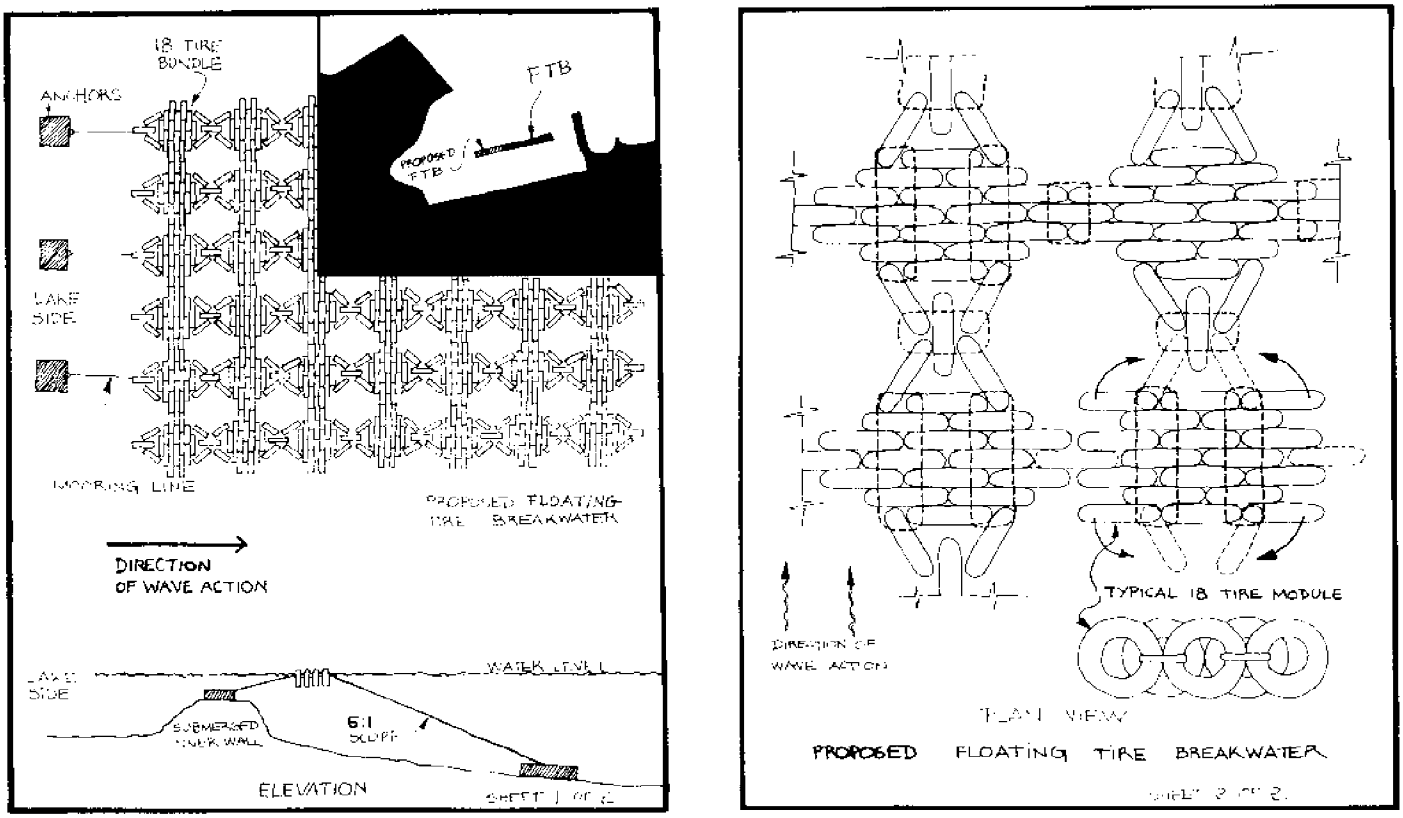

Figure 3. Sketches for a FTB permit application.

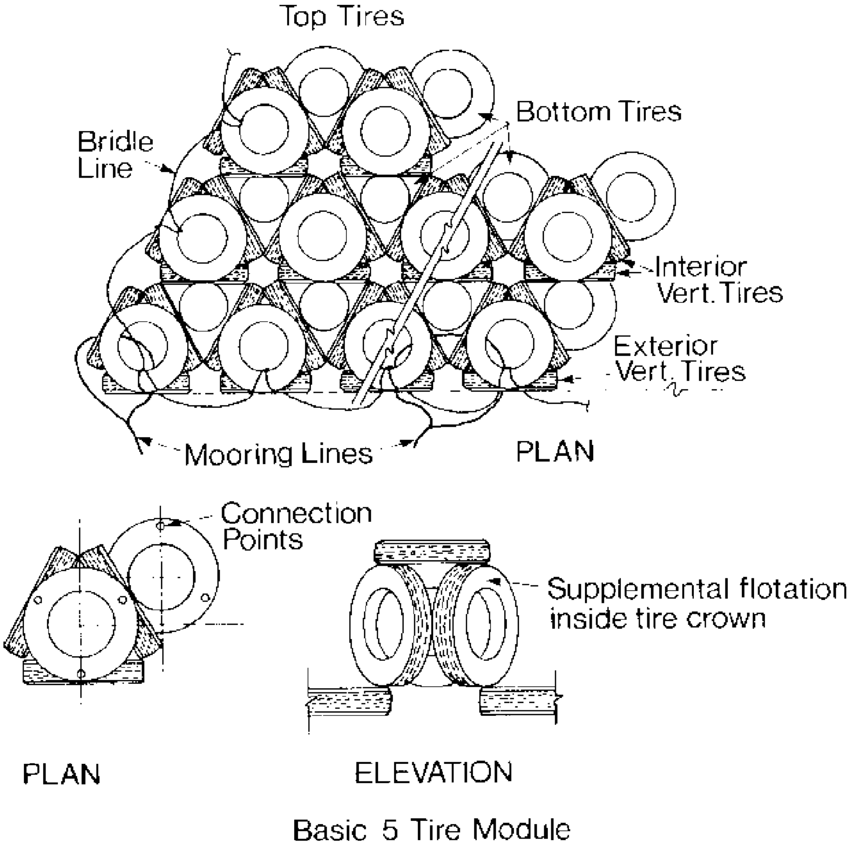

Figure 4. Detailed arrangement of tires in a Wave Maze

should someone try to tow your structure from its moorage site. After all, you have invested money in your FTB.

Q: If, under severe storm conditions (an act of God), the FTB is deposited upon someone's property, how quickly must it be removed? Can it be left until after the storm has subsided?

R: You will have a reasonable amount of time to remove the FTB (say 1 to 2 weeks) from the standpoint of legal responsibilities. If the structure should break loose under severe storm conditions, recovering it would generally not be considered a trespass of private property rights. You would be given access rights to reclaim the structure. Barring real property damage, usually you would not be liable for the presence of the FTB on someone's coastal property.

Q: What if adjacent property owners perceive the FTB as causing increased coastal erosion. Might I be liable for damages?

R: If propery owners can prove that the FTB is the proximate cause of increased coastal erosion, they may retain a lawyer and seek an injunction to stop its use. The physical attributes of nature are quite complex, thereby making it difficult for someone to obtain the burden of proof necessary for such action.

Types and Costs of FTBs

An FTB is composed primarily of tires and it characteristically achieves wave energy reduction by changing incoming wave energy into turbulence within and around the tires. There are three main types of FTB currently in use:

1. Wave Maze

The pioneer FTB, called the Wave Maze, has a patented design consisting of a vertically oriented layer of tires sandwiched between layers of horizontally oriented tires (fig. 4). There have been a few field installations in California and Australia, including a breakwater consisting of 16,000 truck tires in San Francisco Bay. The 610 m x 12 m (2,000 ft x 40 ft) Wave Maze in San Francisco Bay was estimated to cost approximately $65/sq m ($6/sq ft) in 1978. It is moored in water depths up to 13 m (45 ft). Assuming an annual inflation rate of 10 percent from 1978 to 1981, the 1981 unit cost becomes $87/sq m ($8.10/sq ft).

2. Goodyear

The second generation FTB, developed by the Goodyear Tire and Rubber Company in cooperation with the University of Rhode Island, is known as the Goodyear FTB. It consists of modules, each containing 18 tires, interconnected to form a flexible mat as shown in figure 5. There have been more than 150 field installations in the United States, Canada, United Kingdom, New Zealand, Australia, France, and other countries, including the 35,000 car-tire breakwater in Burlington, Ontario, Canada (fig. 6).

The 1,700-module Goodyear FTB in Burlington, constructed by a private construction company, cost approximately $210,000 in 1981. This breakwater consists of five sections (5 or 9 modules wide) and is moored in water depths of 3 to 13 m (10 to 43 ft). The 1981 unit cost is $29/sq m ($2.70 sq ft).

The proposed 165 x 10 module Goodyear FTB for Lyttelton Harbor in New Zealand is expected to cost about $120,000 in U.S. currency using internal harbor board labor. This 300 m x 16 m (980 ft x 52 ft) breakwater will be situated in water 4 m (13 ft) deep. The 1981 unit cost is $25/sq m ($2.30/sq ft).

The 86 x 11 module Goodyear FTB constructed at Lorain, Ohio, cost approximately $103,000. This 183 m x 24 m (600 ft x 80 ft) breakwater is situated in water 3 m (10 ft) deep and was constructed by laborers from a government employment program. The 1981 unit cost is $23/sq m ($2.15/sq ft).

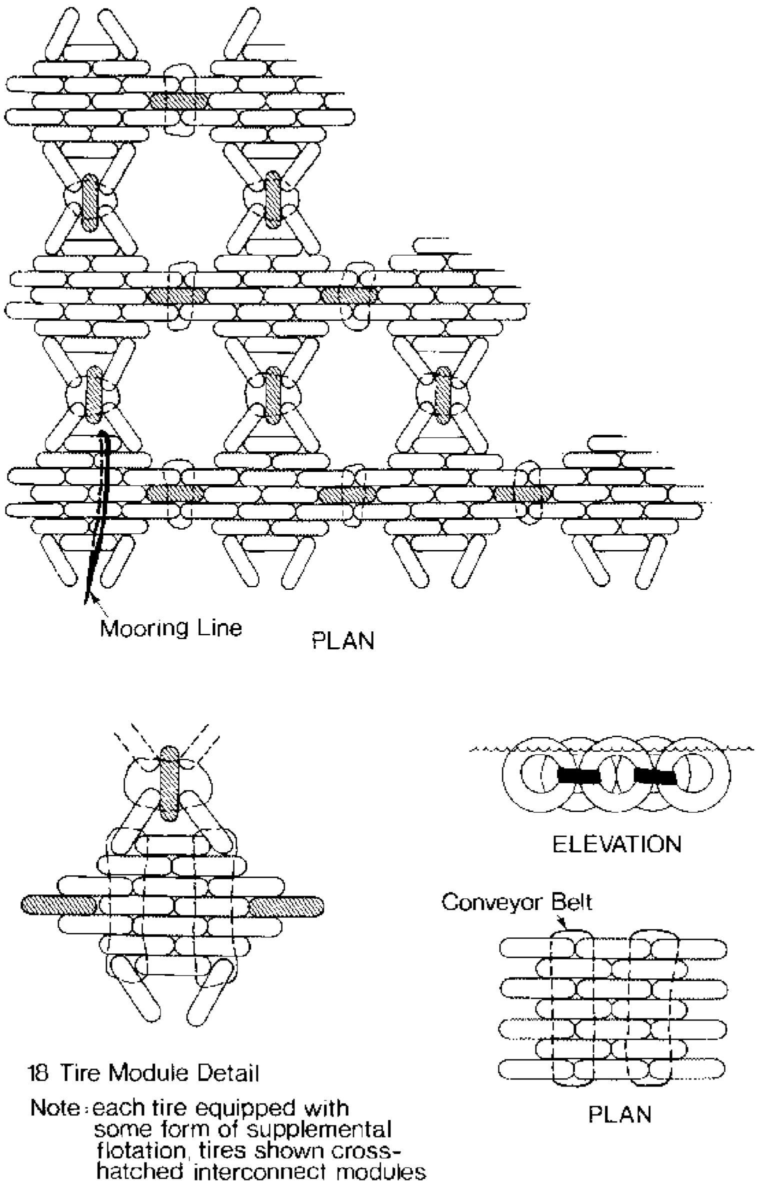

Figure 5. Detailed arrangement of tires in a Goodyear FTB.

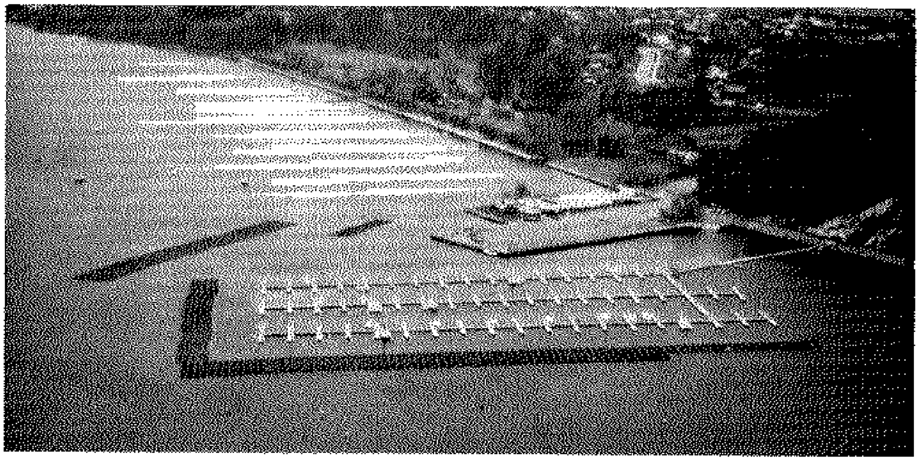

Figure 6. Goodyear FTB at La Salle Park Marina, Burlington, Ontario, Canada. (Bishop and Gallant 1981)

According to model tests the size requirements and performance of a Wave Maze appear to be comparable to those of a Goodyear FTB. Because of its lower cost and readily available (nonproprietary) design information, the Goodyear design has gained wider acceptance than the Wave Maze design.

3. Pipe-Tire

The third generation FTB consists of tire-encased pipes with strings of tires connected to adjacent pipes (fig. 7). The first installation in 1980 was the 75 m x 12 m (250 ft x 40 ft) breakwater consisting of 3,400 truck tires in Long Island Sound, New York (fig. 8). The second installation in 1982 was a 30 m x 15 m (100 ft x 49 ft) test section consisting of 1,650 truck tires in Puget Sound, Washington.

There have been two Pipe-Tire breakwater field installations but, unfortunately, cost information applicable to other sites is unavailable. However, a 1981 unit cost estimate of \$110/sq m (\$10.20/sq ft) can be made from material cost estimates. For equal wave-energy reduction the Pipe-Tire breakwater requires a smaller beam than a Goodyear or Wave Maze breakwater, and therefore its higher unit cost is partly compensated by its smaller size. The benefits of a Pipe-Tire breakwater include its smaller beam requirement and, possibly, its predicted ability to survive heavier seas.

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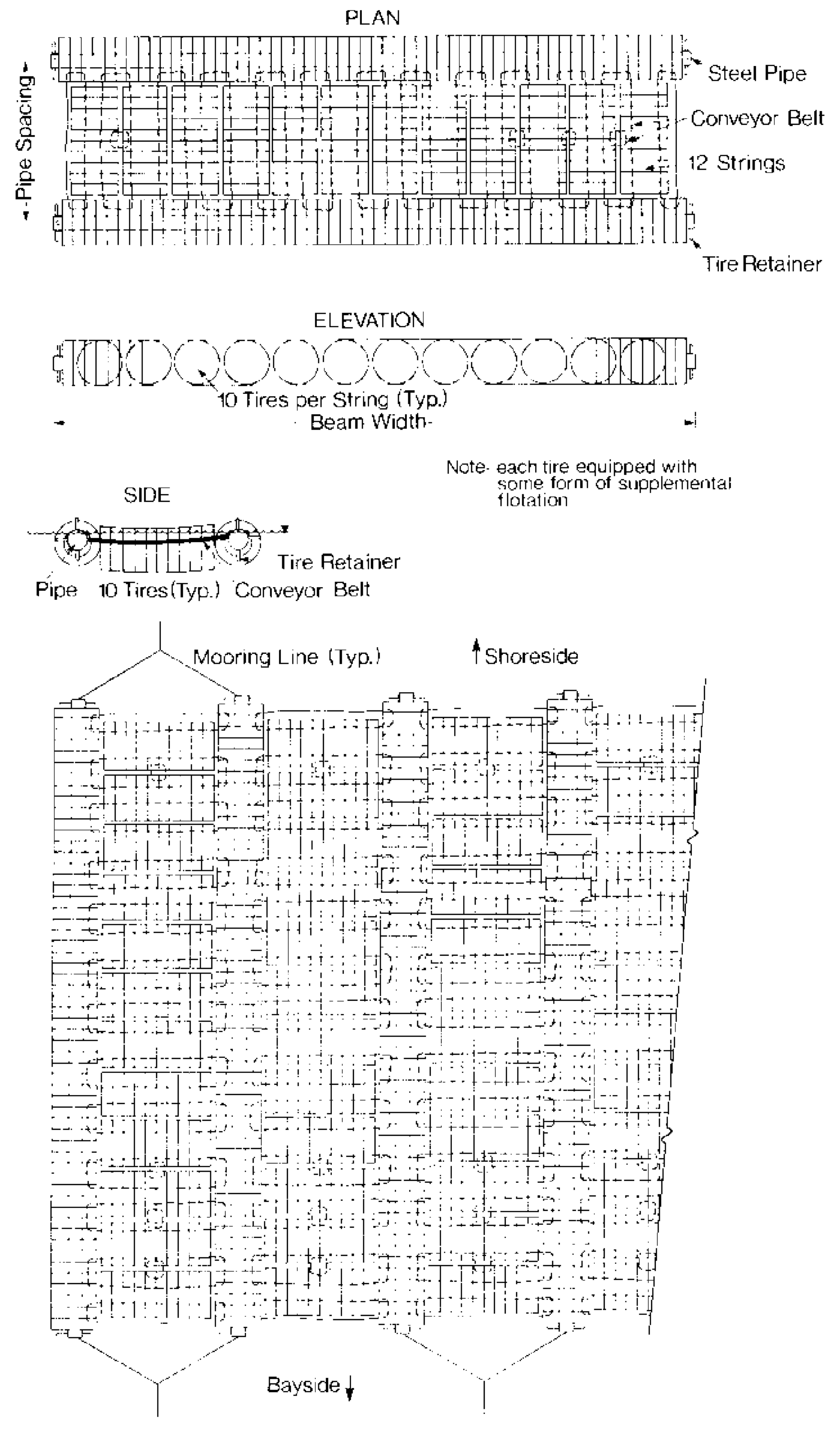

Figure 7. Detailed arrangement of tires in a Pipe-Tire breakwater

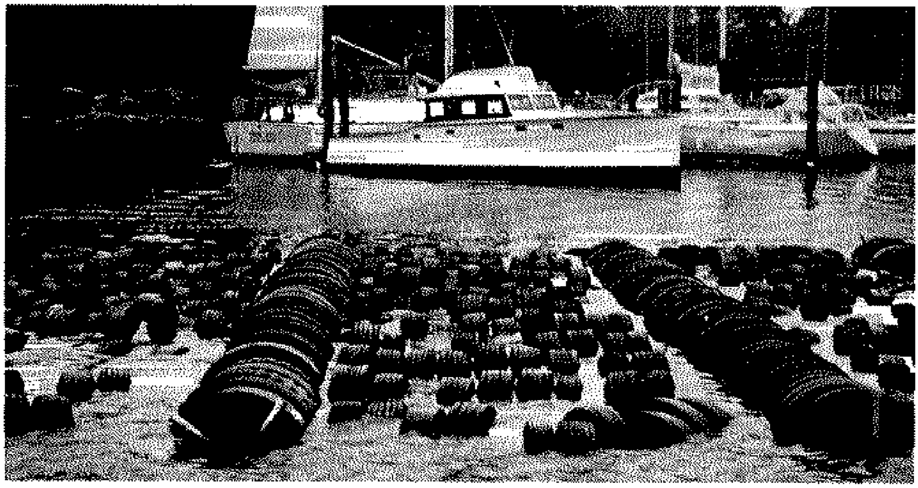

Figure 8. View across the beam of a Pipe-Tire breakwater.

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Design, Size, and Mooring Systems of FTBs

The design of a successful FTB involves the following steps:

1. Assessment of the unprotected wave climate for the particular site;

2. Identification of acceptable wave conditions at that site;

3. Determination of suitable breakwater dimensions (beam, length, and tire size) and orientation to conform with the site's conditions.

Guidelines for assessing a site's wave climate can be found in the Shore Protection Manual of the U.S. Army Coastal Engineering Research Center. A simplified approach useful for evaluating potential FTB sites can be found in Bishop (1980). A complete study of wave climate would consist of a tabulation, by direction, of the number of hours over a known period of time (usually a boating season or a full year) of wave heights and periods (table 1). In this example, the majority of waves are less than 2 feet high and have periods of less than 4.5 seconds. Criteria for acceptable wave conditions in small craft marinas are summarized in Table 2. This can serve as a guideline in determining acceptable conditions for small craft in the lee of an FTB.

The design of an FTB is not simple, therefore, design details are not provided here. A coastal engineer familiar with state-of-the-art FTB technology should be consulted at the design stage. Publications cited at the end of this section contain this engineering information. To understand various FTB size requirements for equal wave height reduction, examples of typical beam dimensions for a Wave Maze, Goodyear FTB, and Pipe-Tire breakwater are given in Table 3. In determining the best design for a given area, space requirements and costs are important factors.

Table 1. An example of wave climate in one harbor.

Wave height ft (m)	Period (seconds)														Row total (hour)
	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	
	Number of Hours														
0-1 (0.15)	7	138	245	381	586	425	99	7	3						1891
1-2 (0.46)					7	249	544	381	31						1212
2-3 (0.76)							5	73	233	109	2				422
3-4 (1.07)									11	73	70				154
4-5 (1.37)											12	55			67
5-6 (1.68)												1	11		12
6-7 (1.98)												3		9	12

Table 2. An acceptable wave climate for a small craft marina. Adapted from a Study to Determine Acceptable Wave Climate in Small Craft Harbors. Northwest Hydraulic Consultants Ltd. 1980.

Wave direction	Wave period, T (in seconds)	Significant Wave Height (m)		
		Not to be exceeded once		
		in 50 years	per year	per week
Head Sea	2 >T	—		0.3
Head Sea	2< T<6	0.6	0.3	0.15
Head Sea	T>6	0.6	0.3	0.15
Beam Sea	2 >T		—	0.3
Beam Sea	2< T<6	0.23	0.15	0.08
Beam Sea	T>6	0.23	0.15	0.08

Table 3. Beam sizes necessary to attain equal wave energy reduction are shown for the three types of FTBs. The examples show FTB beam dimensions expand with increases in wave height and wave length. Some FTBs are more efficient than others of equal size, but cost factors must be considered also in choosing a design.

Wave characteristics		Measurement			
Incoming wave height	H(m)	0.6	0.9	1.2	1.5
Wave period	T(s)	3.0	3.5	4.0	4.5
Wave length (deep water)	L(m)	14.0	19.1	25.0	31.6
Transmitted wave height	H_t(m)	0.3	0.3	0.6	0.6
Transmission coefficient	$C_t=\frac{H_t}{H}$	0.5	0.33	0.5	0.4
Type of FTB		**Beam dimensions (meters)**			
Wave Maze		15	31	27	45
Goodyear		17	27	30	43
Pipe-Tire		9.4	24	17	39

Source: Wave Maze—Harms 1979; Kamel and Davidson 1968; Goodyear Bishop 1982; Pipe Tire - Harms et al 1981.

Floating breakwaters protect a region on their leeward side sometimes called the shadow region. The location and size of this shadow region depend on the breakwater length, the direction and magnitude of the incoming waves, and the distance from the breakwater. An FTB's appropriate length and orientation for a particular site should be determined with professional assistance.

After determining the breakwater beam (width) and length requirements, the number of tires required to construct an FTB can be estimated from the following guidelines:

Wave Maze	2.2 truck tires/sq m (0.24 tires/sq ft) 7.2 car tires/sq m (0.67 tires/sq ft)
Goodyear	1.9 truck tires/sq m (0.18 tires/sq ft) 4.8 car tires/sq m (0.45 tires/sq ft)
Pipe-Tire	(assuming pipe space = 3.3 truck tire diameters, beam = 12.2 m (40 ft)) 3.8 truck tires/sq m (0.35 tires/sq ft) 11.9 car tires/sq m (1.1 tires/sq ft)

These estimates have been made assuming 1.0 m (3.3 ft) and 0.6 m (2.0 ft) outside diameter truck and car tires; these sizes are representative of typical North American tires. Smaller car tires increase the number of tires needed per unit area. For example, a Goodyear FTB constructed in New Zealand required 7.0 car tires per sq m (0.65 tires/sq ft).

An FTBs effectiveness in reducing wave heights improves as the breakwater occupies more of the water depth. Therefore, if the price and availability of car and truck tires are comparable, and the greater weight of the truck tires does not pose a construction problem, use truck tires to increase the structure's draft.

Mooring System Design

The design of a successful FTB mooring system involves the following steps:

1. Estimation of mooring loads exerted by waves, currents, and ice.
2. Assessment of mean water level fluctuations.
3. Assessment of bottom conditions.
4. Design of suitable moorings.

An adequate mooring system is crucial to the success of an FTB. It is recommended that a coastal or marine engineer be consulted in estimating FTB mooring loads and in designing a mooring system. A licensed engineer can be helpful in locating a marine engineer.

The estimation of wave-induced mooring loads is not simple. Therefore, reference publications are provided at this section's conclusion. It has been found that the mooring loads are sensitive to the load-deflection characteristics of the mooring system, to the ratio of breakwater draft to water depth, to the wave steepness, and to the wave height and period. The existing wave induced mooring load data for conditions other than those tested should be used only with great caution. Most of the mooring load data available for the Pipe-Tire breakwater is based on tests in which the mooring lines incorporated shock absorbers in the form of tires.

Estimates of mooring loads induced by currents, tidal or river, can be made using the results of Bishop (1981). The estimation of ice-induced mooring loads is complicated and should be based on local experience with similar structures. Some guidelines can be obtained from Wortley.

The expected range of mean water levels should be assessed, including seasonal, tidal, and storm variations. A minimum length for the mooring line of 6 m for each 1 m of water depth (a ratio referred to as a 6:1 scope) is needed for most FTB installations. Generally, the longer the mooring line in relation to water depth, the more effective the mooring. For example, a 10 to 1 ratio usually has a greater holding capacity than that of 6 to 1. At those sites where a long mooring line is not practical, heavier mooring equipment is necessary.

The selection of the type of mooring system depends on the mooring load.

bottom conditions, the availability of various anchors, and the available methods for installing anchors. The most commonly used anchor for FTBs is the deadweight or gravity anchor. Other types that are used include pile anchors, embedment anchors, and screw anchors.

A commonly used FTB mooring system is shown in figure 9. It consists of the primary anchor or pile, ground tackle chain, a clump anchor or float, and a mooring line. The mooring line includes a shock absorber constructed of tires belted together.

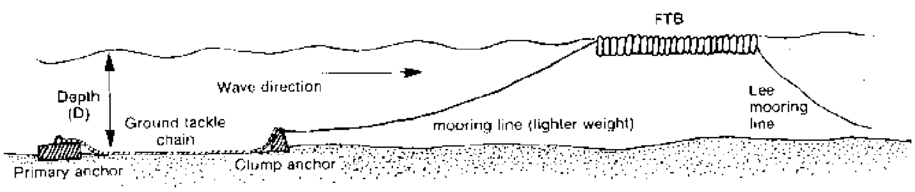

Figure 9. A commonly used FTB mooring system. Scope is the ratio of the length of mooring line (L) to the depth of water (D). Scope L/D.

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Construction Materials

Tires

Tires are the main component of an FTB. Used or rejected tires that are unsuitable for further use on vehicles may still be structurally sound for use as a construction material in FTBs. These tires may be available from tire retail outlets, recapping factories, garages, trucking firms, and others, usually at no cost except that of transportation to a construction site. In areas where landfills charge for tire disposal, it may be possible to be paid to accept tires.

Since the local availability of used tires varies, it is advisable to make arrangements for the required number of tires several months in advance of the planned construction date. Allow for about 10 percent of the tires to be unsuitable for FTB use because of ripped casings or large holes.

Car tire FTBs are usually made of the 36 and 38 cm (14 and 15 in.) rim sizes. The outside diameters are smaller on compact cars. Truck tire FTBs are usually made of tires ranging in rim size from 46 to 57 cm (18 to 22.5 in.). The larger and heavier truck tires are not as available as are car tires. Floating tire breakwater construction is made easier by using tires of a relatively uniform size.

Pipes

For Pipe-Tire breakwaters made of truck tires, steel pipes of 40 cm (16 in.) diameter with a wall thickness of at least 6 mm (0.25 in.) should be used. For Pipe-Tire breakwaters made of car tires, steel pipes of 25 cm (10 in.) diameter with a wall thickness of about 4.8 mm (0.1875 in.) are recommended. New or structurally sound used pipes are acceptable.

Binding Materials

A binding material is used to connect component parts or modules of an FTB. Field testing of binding materials has led to recognition that conveyor belting is preferable in most situations. Such belting is available from conveyor belt dealers and most tire manufacturers. The belting should be at least 12 mm (0.50 in.) thick with three or more synthetic fabric plies. Belting of this type has a breaking strength of roughly 1000 kg per centimeter width (6000 lb per in. width). The belting is cut into strips 8- to 13-cm (3 to 5 in.) wide and delivered on rolls (fig. 10).

Abrasion by barnacles may be a shortcoming of rubber-belting binding material. In one instance, dense barnacle growth on an FTB in Louisiana apparently abraded the belting used to bind modules in a Goodyear FTB. Local experience with these fouling organisms may be an important consideration in choosing or rejecting rubber belting for use in FTBs.

Several other materials have been used to bind some FTBs and have been found less satisfactory:

- Steel chain because of its weight (which must be buoyancy compensated), cost, and corrosion.
- Ropes, (including synthetic and natural material) because of poor abrasion resistance, knot loosening, degradation from ultraviolet light.
- Metal cables or banding because of problems with corrosion and metal fatigue.

All the above binding materials, except belting, can cut into the tire casings.

Connectors

The overlapping conveyor belt ends can be fastened with bolts, nuts, and washers. Galvanized steel hardware is suitable for freshwater FTB installations while nylon hardware is more durable in salt water. Supplies of nylon hardware can be identified by contacting distributors of fasteners and connectors. A typical connector would consist of a bolt 50 mm long by 12 mm in diameter (2 in. x 0.50 in.), a flat washer on each side, a lock washer under the nut, and the nut. To reduce possible ultraviolet degradation of the nylon, the nylon connectors should be dyed black. This can be accomplished by immersing the nylon parts in a mixture of household dye and hot water for several minutes.

One commonly used bolting pattern is shown in fig. 11. Strength tests on various bolt materials and patterns, as well as alternative fastening methods, are under way (sponsored by New York Sea Grant) and results should be available by 1984.

Anchors

Anchors should be suited to the site's bottom and exposure conditions; weight, structural strength, and drag (if pulled loose) are important anchor characteristics to consider. The choice of an anchoring system should be based on local mooring experiences, bottom soil survey, and predicted mooring loads.

Gravity anchor systems commonly use large concrete blocks or quarried rock. Concrete-filled tractor tires or scrap iron and steel are also used. Surplus concrete blocks (1 cubic m or 1 cubic yd) are often available from concrete suppliers at nominal cost; however, the steel lifting hoops are often inadequate for long-term mooring use.

Embedment anchors (conventional Navy stockless, mushroom, and stock admiralty) or light-weight anchors (Danforth) can also be used. Another alternative is to moor an FTB to piles. The piles can be cut off a short distance above the bed level.

Mooring Lines

Most FTBs have been moored to their anchors with welded steel chain, especially as heavy ground tackle from the anchor. Nylon rope or conveyor belt strips have been used in some cases. For more rigid structures such as the Pipe-Tire breakwater, a shock absorber or mooring force damper is desirable for each mooring line. Effective damping may be achieved by incorporating a string of tires

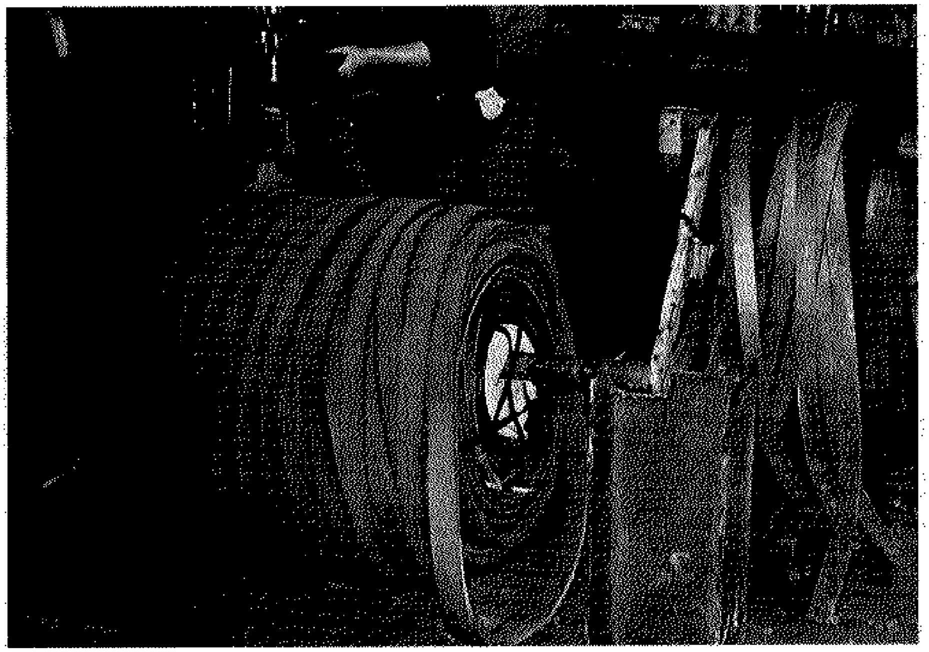

Figure 10. Strips of conveyor belting.

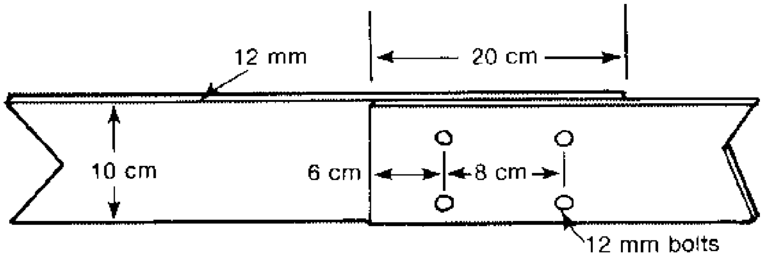

Figure 11. Conveyor belting bolted for use as a binding material.

in each mooring line (fig. 12). The tires should have holes punched in their treads to allow sediment to escape. The ends of the mooring lines can be attached to both the FTB and anchors with steel shackles. If chain is used all the way up to the FTB, its weight may require additional flotation to prevent sinking.

To distribute mooring loads on the Goodyear FTB, each mooring line should be attached in such a way that the load is distributed throughout a module. It is suggested that each line be threaded through the center tires of each module (fig. 5) rather than through those on the outer edge.

For a Wave Maze or Pipe-Tire breakwater, the mooring lines could be connected to the breakwaters perimeter (figs. 4, 12).

Although not fully field-tested, strips of conveyor belting have been used successfully as FTB mooring lines leading to the ground tackle. The advantages of belting over steel chain include its lower cost and weight and its lack of corrosion susceptibility. Its disadvantages center on its newness in this field of application. Results of ongoing research on the use of belting in mooring lines (sponsored by New York State Sea Grant) should be available by 1984.

Flotation

The most important characteristic of an FTB is that it remain afloat. Nevertheless, the most frequently encountered problem with FTBs has been their tendency to sink. Although a newly installed FTB will float for a period of weeks or months due to the buoyant force provided by air trapped in the crowns of tires, it is now recognized that *supplemental flotation must be provided* to ensure continued flotation of the breakwater. An FTBs buoyancy decreases with time for the following reasons:

1. Increase in weight due to marine growth on the tires.
2. Increase in weight due to the accumulation of sediment in the bottoms of tires.
3. Trapped air leaks out or dissolves in the water, or the effectiveness of the supplemental flotation decreases.

In a test section of Goodyear FTB in Lyttelton Harbor, New Zealand, modules with no supplemental flotation were observed to sink after about six months, while adjacent modules equipped with various kinds of supplemental flotation continued to float.

The marine growth on tires in a temperate salt water environment can be astonishing (fig. 13). Factors that affect the growth on an FTB include the following:

- Water characteristics—temperature, salinity, dissolved nutrient level.
- Duration of FTB immersion or interval between FTB cleanings.
- Wave activity.

Factors that influence the accumulation of sediment in tires of an FTB include the following:

- Sediment concentration at the level of the tires (influenced by the bottom sediment characteristics, the wave climate, the depth of water, the existence of other sediment sources).
- Whether or not holes have been punched in the bottoms of the tires.
- Size of the tires.

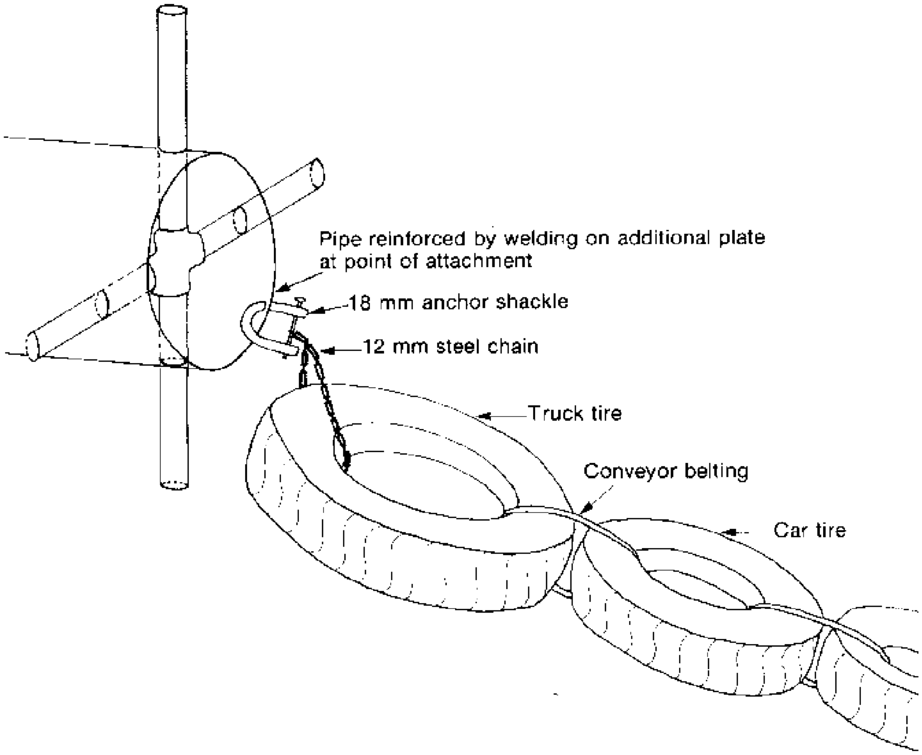

Figure 12. Mooring lines with a 5-tire shock absorber.

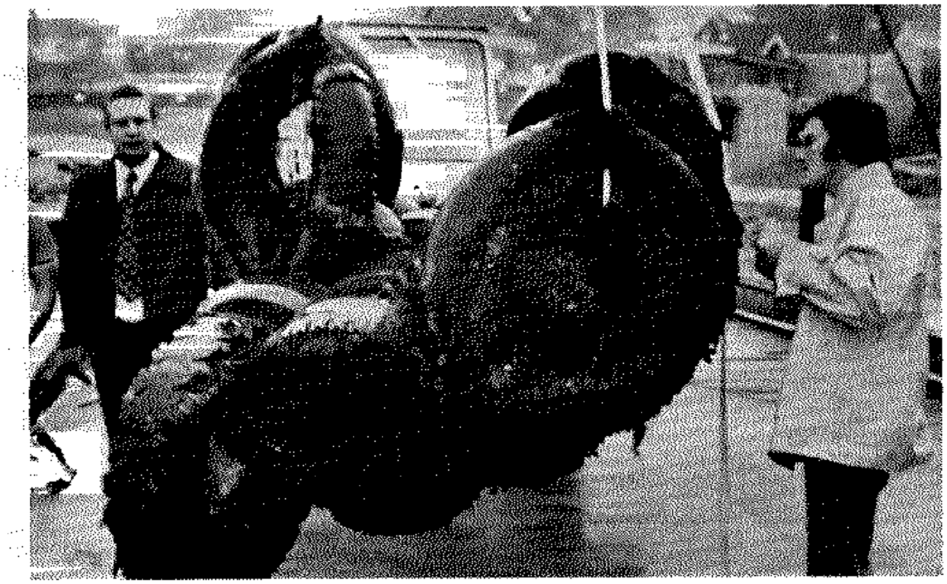

Figure 13. Algae and other marine life collect on FTBs.

It is recommended that an elliptical hole with approximate dimensions of 125 mm x 75 mm (5 in. x 3 in.) be punched in the bottom of each tire if the sediment load potential is great.

Supplemental flotation should be provided for all FTBs with the possible exception of those used for less than three months or those that are removed from the water and thoroughly cleaned of marine growth and sediment at intervals of not more than three months. Appropriate amounts of supplemental flotation for each tire must be computed based on the tire size and the potential fouling biomass and sediment loads. When calculating supplemental flotation requirements refer to Bishop.

Experience with FTBs equipped with supplemental flotation suggest that more study is necessary to determine cost-effective methods of providing reserve buoyancy. The state-of-the-art method is to spray polyurethane foam directly into the crowns of the tires before assembling the FTB; unfortunately, the service life of foam used in this manner is not known. Each vertical tire in a Wave Maze, and each tire in a Goodyear FTB, or in a Pipe-Tire breakwater should be foamed. Furthermore, the pipes of a Pipe-Tire breakwater should be filled with foam. The operation of filling a tire with foam is shown in figure 14.

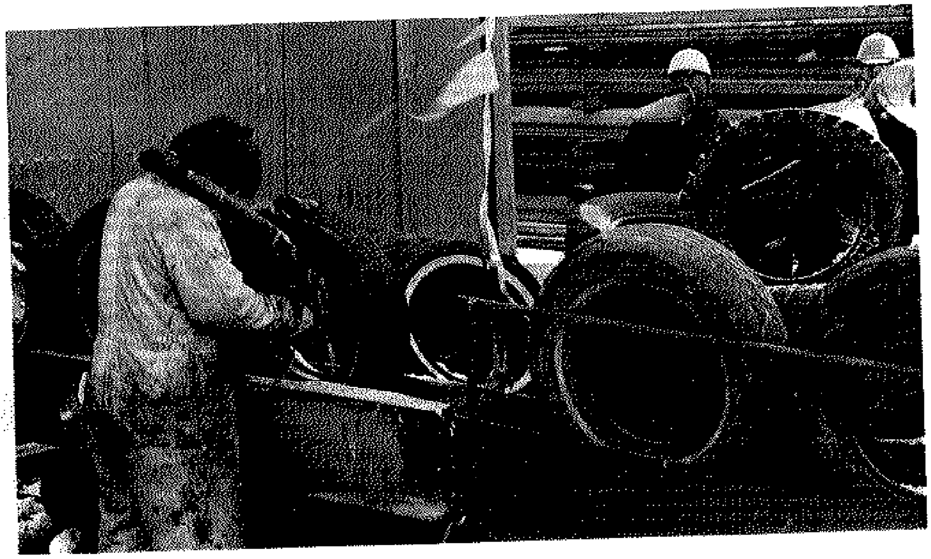
Figure 14. Spraying foam in tires. (Bishop and Gallant 1981)


Figure 15. Tire frames used to assemble Goodyear FTB modules. (Bishop and Gallant 1981)

Other methods of providing supplemental flotation that have been tried and found unsatisfactory include:

- Jamming an empty, sealed, plastic container into the crown of each tire; the containers eventually crack and fill with water, or pop out of the tire.
- Jamming a block of polyurethane, polystyrene or similar material into the crown of each tire; the blocks eventually break apart or erode and work their way out of the tire.
- Providing the supplemental flotation after assembling the FTB.

Rigid plastic containers filled with polyurethane foam that are then jammed into the tire crowns may offer the longest service life of any of the methods of providing supplemental flotation. Another promising method involves heat-sealing preformed foam blocks inside polyethylene bags and then inserting the bag in the crown of each tire.

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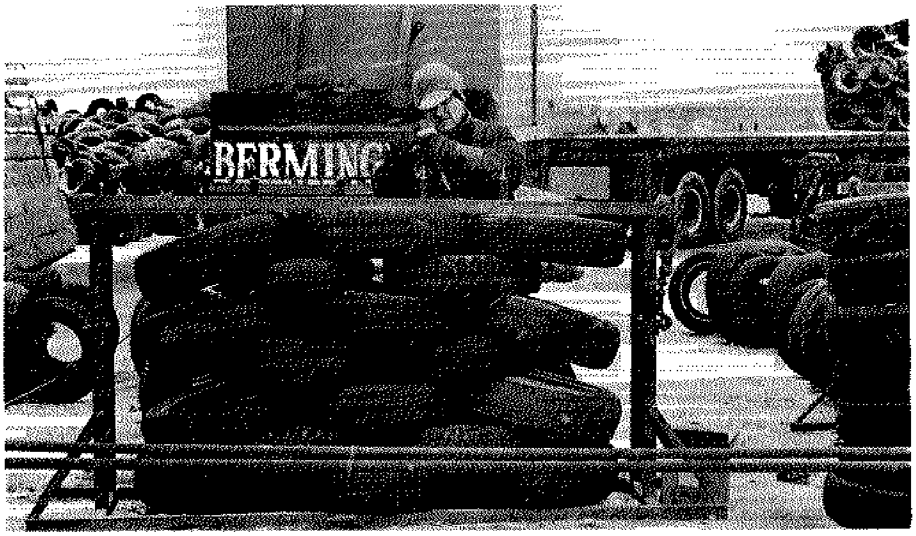

Figure 16. Eighteen-tire module is compressed. (Bishop and Gallant 1981)

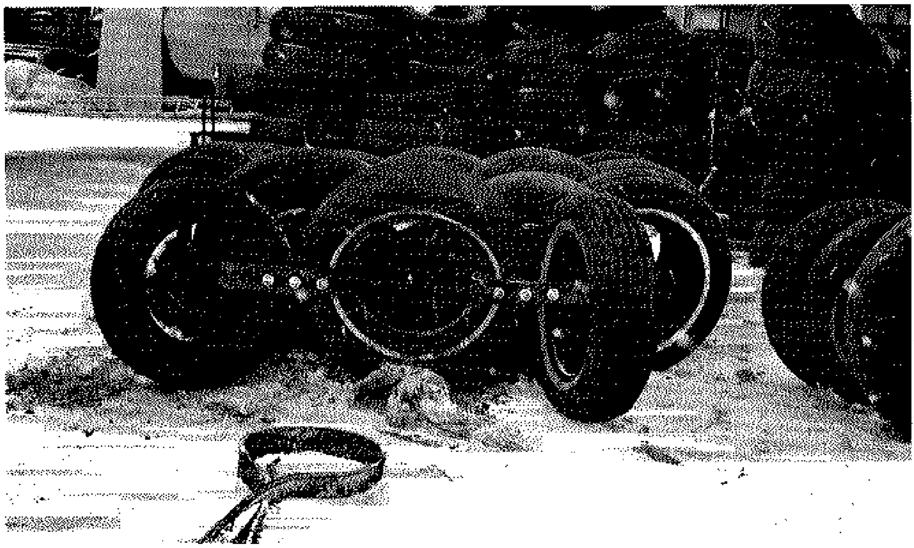

Figure 17. Assembled Goodyear module.

Figure 18. Row of 9-module-wide Goodyear FTB is lifted into the water. (Bishop and Gallant 1981)

Construction Techniques

Site

The construction site for an FTB should be near the water's edge, preferably at an elevation higher than the high water level. The construction of a Goodyear FTB at Westfield, New York, was seriously delayed when assembled modules left on a wharf were inundated during a storm and the tires were filled with sediment.

In colder climates, FTBs can be assembled on the ice cover of the body of water. Goodyear FTBs have been assembled and installed successfully from the ice covers of Lake Champlain, New York, and Lake Charlevoix, Michigan.

Tire Preparation

Discard tires that lack structural integrity such as those with ripped casings or large holes. Sort and discard tires that are not of the selected uniform size. If required, punch a hole in the bottom of each tire. The easiest way to accomplish this is to use a pneumatic punch.

Provide tires with supplemental flotation.

Goodyear

A Goodyear FTB is assembled from basic modules which consist of 18 tires in a 3-2-3-2-3-2-3 vertical arrangement (figs. 5, 16). Each module is bound together with two pieces of binding material. Each piece of binding material should be about 3.0 m (9.8 ft) long for a car tire module, or about 5.0 m (16.4 ft) long for a truck tire module. Provided with a stockpile of prepared tires and precut lengths of binding material with holes predrilled for connectors, a two-member team can assemble car tire modules at the rate of three per hour. Each module should be bound as tightly as possible to minimize chafing between tires and the binding material. The use of a tire frame (fig. 15) will facilitate module assembly. In one case, modules assembled in a tire frame with a removable top were compressed about 15 cm (6 in.) using load-binders (fig. 16).

A homemade tire frame can be assembled from steel channels and pipes. It is important that the frame be built so the four interior pipes can be removed from the base of the tire frame; this allows the completed module to be removed from the tire frame (fig. 17).

The interconnection of modules to form a breakwater requires a slight alteration of tire position and the addition of two link tires per module. First, the four corner tires of each module are turned inward toward each other (fig. 5), then link tires are inserted at each module-to-module connection. Modules are connected with binding material. For this purpose, each piece of binding material should be about 2.0 m (6.6 ft) long for car-tire modules and about 3.0 m (9.8 ft) long for truck-tire modules. Modules should be connected tightly to reduce chafing.

The modules on the FTBs windward edge and corners bear the brunt of the wave attack. For this reason, it may be worthwhile to duplicate the module connections of the first two rows of the FTB and at the corners (use two separate loops of binding material per connection).

The breakwater mat is usually assembled on land, and then pushed, pulled, or lifted into the water one row at a time (figs. 18, 19). A crane is almost always necessary although some car-tire Goodyear FTBs have been built with the aid of only a high-lift tractor.

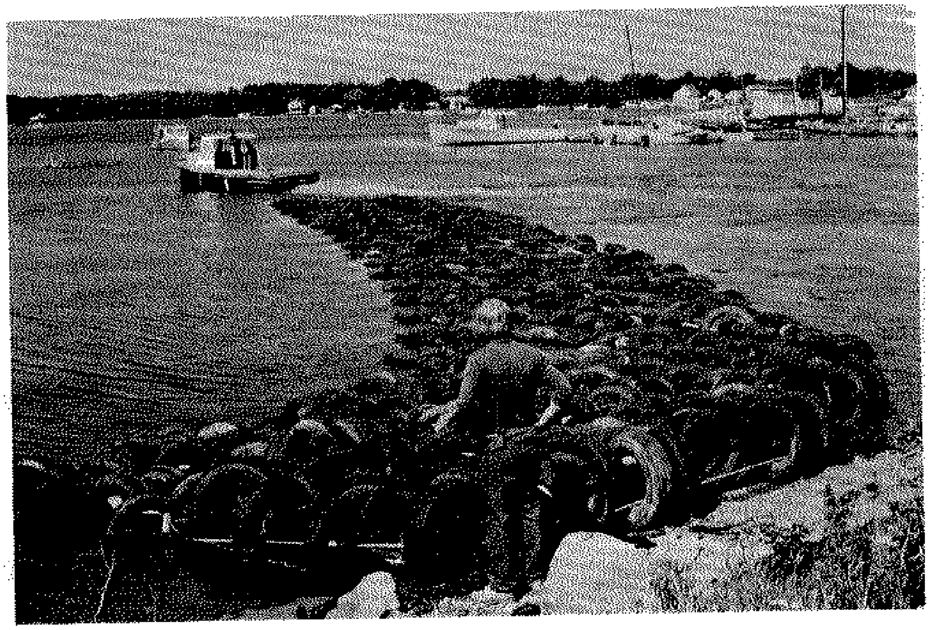

Figure 19. Goodyear FTB is pulled into the water.

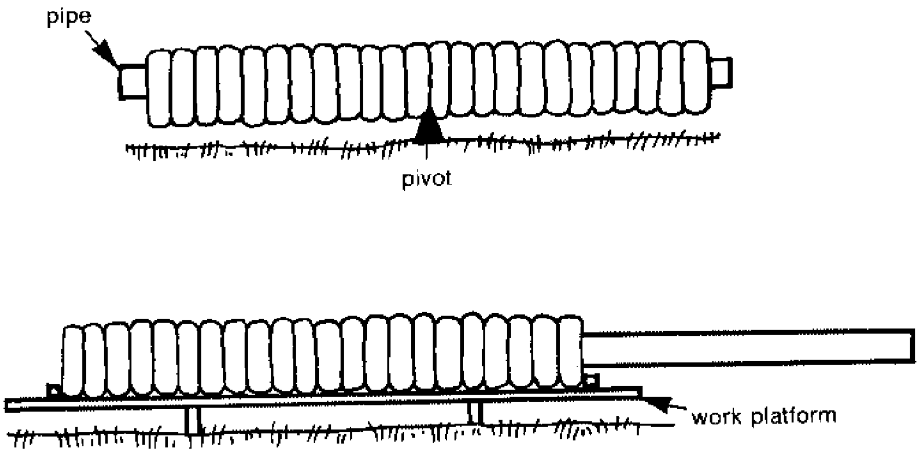

Figure 20. Methods of sheathing pipes with tires. (Bishop 1980)

Pipe-Tire Breakwater

A Pipe-Tire breakwater is assembled with tire encased pipes. These pipes are then attached to each other with conveyor belting strung through tires (fig. 7, side view). Pipes are sheathed with tires by balancing pipes on a pivot, or by threading a pipe through a set of prearranged tires (fig. 20). The tires should be tightly packed on the pipes, then secured by tire retainers (fig. 21).

With two tire encased pipes lying parallel to each other, separated by a distance G, tires can be rolled into position between the pipes to form tire strings. Loops of binding material going through the tire strings are attached to specific tires on the pipes as shown in fig. 7. Each loop should be continuous with the ends bolted together. To prevent excessive lateral movement of the tire string, the four leading and two trailing tire strings should be connected with loops of binding material at the middle.

After assembling two or more pipe sections, the leading section should be lifted or pushed into the water so that new construction always takes place at the water's edge.

Wave Maze

The most important aspect of Wave Maze construction is the tire-to-tire connection. The designer of the Wave Maze recommends bolted connections with local reinforcement at each joint. The reinforcement specified by the designer consists of pieces of rubber cut from tire casings or conveyor belting, approximately 10 cm x 10 cm x 12 mm (4 in. x 4 in. x .5 in.) in size. At least two such pieces of rubber should be added to the inside of each tire casing. Oversized heavy-duty washers should also be used. Omission of rubber reinforcements can lead to breakwater failure because the washers pull through the holes in the tire casings.

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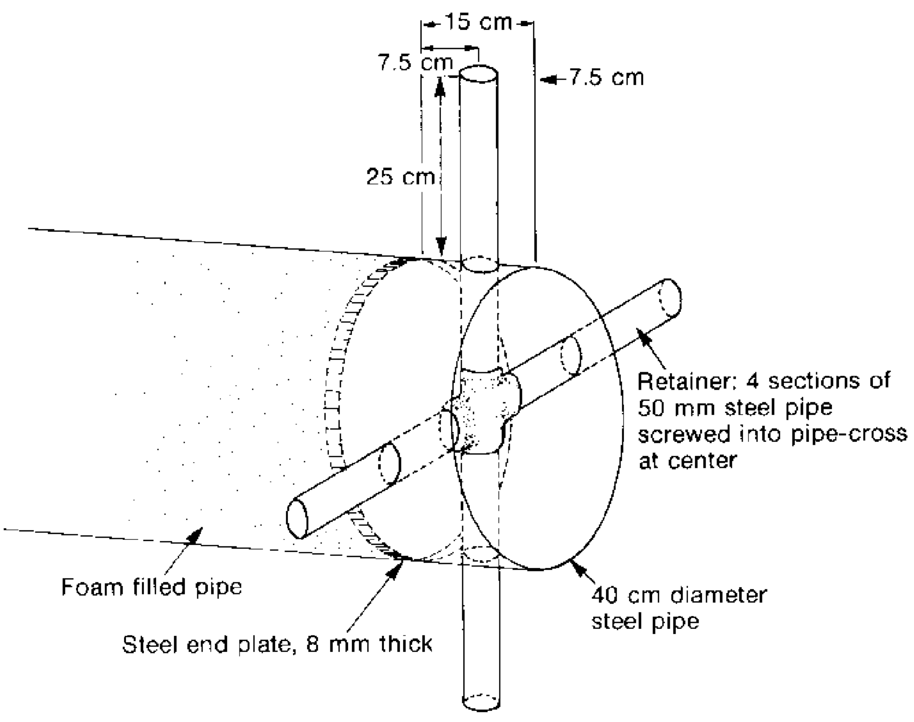

Figure 21. Steel pipe is used at the ends of the tire sheathed pipes to hold the tires in place. This arrangement is called a tire retainer.

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Mooring an FTB

It is preferable that anchors first be positioned by a survey team and then be driven or installed from a barge before towing the FTB to its anchorage. The anchors are usually placed with mooring lines attached unless piles are used, in which case divers would make underwater connections. If a rope is attached to the surface end of each mooring line, it can be used later to retrieve the mooring lines from the bottom.

If there are no opposing currents it is quite easy to tow an FTB. Small craft equipped with outboard engines have been used to tow some FTBs but boats with more power provide greater maneuverability.

One way of mooring an FTB is to tow the FTB to its anchorage and position its windward side vertically above its windward anchors. Retrieve the windward mooring lines and connect them to the FTB. Then push the FTB leeward so that its leeward side is almost vertically above its leeward anchors. Retrieve the leeward mooring lines and connect them to the FTB. The lengths of the mooring lines usually need to be adjusted to straighten the breakwater.

Anchors at the corners of an FTB are very important. Several mooring systems have failed in a progressive manner when one anchor, usually a corner one, failed and then the adjacent anchor failed and so on. Therefore, it is suggested that each corner anchor have twice the holding power of the interior anchors.

A typical anchor arrangement for an FTB has double-sized anchors at the corners and the mooring lines increase in length in deeper water. Leeward anchors should be sized for the greater of either the estimated leeward mooring force or 20 percent of the windward requirement. The spacing of leeward anchors is usually twice that of the windward anchors.

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Maintenance of FTBs

Well-built FTBs are only as good as their maintenance. Since all floating structures are subject to movement, structural failures, and sinking, they must be considered to be temporary structures. Even though FTBs can be expected to have a 10-year life with good maintenance, they are temporary when compared with the permanence of a rubblemound breakwater. The history of FTBs shows failures to each part of the system (except the tires) including sinking, loss of foam, anchor movement, mooring line breaks, and module separation. While some of these failures may be attributed to inadequate design or construction, many could have been prevented if aggressive maintenance had been practiced.

While floating breakwaters are designed to absorb limited wave conditions, they must also be able to ride out bigger, longer period waves without significant structural damage. Such conditions place great strain on mooring systems and interconnecting parts. Regular post-storm inspection and repair of worn or damaged parts is required.

Keeping FTBs afloat has been the most common problem, especially of the earlier installations. Assuming that sufficient supplemental flotation was built into the FTB before launching, annual maintenance will include replacing damaged or lost flotation. Insufficient flotation will necessitate frequent removal of entrapped sediment or fouling growth. In the Goodyear design, the outside leading row of modules usually needs the most maintenance. If any modules are observed to be losing flotation, take remedial action immediately.

The tires can absorb large amounts of energy by yielding and deforming with virtually no replacement required for many years. Thus, the useful life of an FTB may be extended by preplanned replacement of its less durable parts.

Vandalism has not been reported to be a major problem yet, but the potential exists and should be anticipated in a maintenance program. Turtles, muskrats, and marine borers have caused damage to tying materials and foam flotation. As discussed earlier, abrasion of rubber belting by barnacles may be a problem.

Perhaps the greatest FTB maintenance failure has been the lack of planning and budget for routine inspection and repairs. All too frequently funding is only for construction and installation. Only well-maintained FTBs continue to give satisfactory service. The following maintenance check list should provide a useful guide.

Maintenance Check List

☐ Inspection frequency. At intervals dependent on conditions and age of FTB.
☐ Flotation. Replace or repair as necessary.
☐ Trapped sediment in tires. If holes are plugged, reopen with a water jet or hand tool. If no holes were punched, attempt to remove sediment by water jet, pump, or hand tools.
☐ Fouling growth. Clean with water jet or by removing structure from water in winter.
☐ Binding (tying) materials. Check integrity of belting, wear, tearing, abrasion of tires, effects of fouling (e.g., barnacles).
☐ Fasteners. Check for corrosion (if metal), loosening, pulling through belting, shearing, missing.
☐ Tire retainers on Pipe-Tire breakwaters. Tighten, or replace if broken.
☐ Mooring lines and ground tackle. Integrity of line, wear, corrosion, connections to FTB and to anchor/mooring.
☐ Anchor/mooring. Look for movement, embedment, integrity, eye bolt wear; if pile—look for uplift, marine borer attack.
☐ Debris. Remove as required.
☐ Navigation markers. Service as required.

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Baird, A., and N. W. Ross. 1982. Field experiences with floating breakwaters in the eastern United States. Miscellaneous report 82-4. U. S. Army Coastal Engineering Research Center, Fort Belvoir, VA.

Ecological Aspects of FTBs

Rubber has been used successfully for more than 100 years as gaskets in London's underground water mains. Tires have been used for more than 20 years in the construction of massive artificial fishing reefs, and the U.S. Environmental Protection Agency considers them to be excellent for such uses. Thus, tires (including white walls) appear to be nontoxic and stable in water.

Floating tire breakwaters become floating fishing reefs quite soon after installation. The tires provide an excellent surface for marine growth, which is both food and habitat for game fish. As an artificial reef, this floating structure is felt to be more effective than a structure placed on the bottom because in the upper layer of the water, light intensities are higher, temperatures warmer, and oxygen levels greater.

Biological studies in southern New England have identified 167 species living on and in the FTB, including various seaweeds, sponges, anemones, worms, clams, mussels, oysters, snails, shrimp, crabs, barnacles, starfish, and tunicates. Blue mussels constituted the most abundant species present in Rhode Island but in New Zealand stalked tunicates dominated. FTBs seem to have potential for aquacultural production of shellfish. Similar floating tire systems have been used in fresh water as fishing reefs in Wingfoot Lake, Ohio, and as protection for the spawning grounds of large-mouth bass in experiments by researchers at the University of Oklahoma.

The wave dampening effect of FTBs can help reduce shoreline erosion and slow sand movement along the shore. As with any coastal structure, FTBs collect floating debris which can be easily "harvested," and reports indicate the debris attracts sea gulls away from recreational boats. Other potential benefits include reduced damage to docks, boats, and moorings; fewer runaway boats during storms; increased periods for boat launching and haul out in spring and fall; and improved comfort, safety, and public relations with boaters.

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Checklist for Planning an FTB

FTB Planning and Installation

Waves—for seasons of use

1. Directions
2. Fetches and wind speeds

3. Wave climate (heights, periods, lengths)

4. Shore configuration (wave diffraction and reflection)

5. Bottom configuration (wave refraction)

6. Ship wake

FTB location

1. Distance from area to be protected (shadow of protection)

2. Water circulation (tide and current)

3. Effect on navigation

4. Seasonal variation

FTB system

1. Design: Goodyear, Pipe-Tire, Wave Maze, other
   - ☐ Length
   - ☐ Width
   - ☐ Tire orientation
   - ☐ Pattern of mat

2. Source and average size of tires (car or truck)

3. Flotation
   - ☐ Foam, other
   - ☐ Percentage reserve buoyancy necessary for possible sediment accumulation, marine growth, and/or mooring chain weight
   - ☐ Resistance to biological attack, water absorption

4. Tying material
   - ☐ Type
   - ☐ Strength
   - ☐ Method of fastening (bolts, other)
   - ☐ Expected life of material under conditions of abrasion, corrosion, fatigue, ultraviolet exposure, biological attack
   - ☐ Length required
   - ☐ Source of supply

5. Expected service life of FTB

FTB mooring system

1. Mooring loads expected

2. Depth of water (normal and storm range)

3. Type of bottom (sand, rock, silt, mud)

4. Anchoring system
   - ☐ Type (gravity anchor, pile, other)
   - ☐ Mooring line and ground tackle material (rope, chain, belting)
   - ☐ Spacing (windward, leeward, and side)
   - ☐ Scope
   - ☐ Method of attachment to breakwater

FTB environmental impact

1. Wave suppression; shore and facility protection

2. Effect on water and sediment movement

3. Biological habitat (artificial reef)

4. Appearance

Legal liability

1. Person or firm responsible

2. Permits required (local, state/provincial, federal)

3. Bonding requirements

4. Branding tires for identification

Installation

1. Dates

2. Contractor or own labor

3. Possible expansion plans

Estimated total cost of planning, constructing, and installing the FTB (materials and labor)

FTB Maintenance

Person or firm responsible

Anticipated maintenance

1. Flotation

2. Mooring system

3. Tying material

4. Remove trapped debris and flotsam

5. Damage from floating objects (boats, barges, trees)

6. Ice movement, seasonal storage

Estimated annual cost

FTB Removal or Ultimate Disposal

Expected life or use of FTB system at site. Anticipated disposal date

Disposal plan alternatives

1. Disassemble, remove, and dispose on land

2. Bury the system

3. Use as protective tire mats for shore erosion control

4. Sink FTB in approved artificial reef site

5. Transfer ownership and move to another site

Anticipated disposal cost

Permit Granting Agencies

In Canada, the Federal Ministry of Transportation grants authority for FTB installation. Under the Navigable Waters Protection Act, correspondence for proposed FTB installations should be addressed to:

Chief, Aids to Navigation
Canadian Coast Guard
Transport Canada Building
Tower A, Floor 6-G
Place de Ville
Ottawa, Ontario
K1A 0N7

In the United States, authorization for installation of structures into public waterways usually requires permits from the following:

1. City, town, village, or municipality

2. State department of conservation

3. U.S. Army Corps of Engineers district engineer

In navigable waterways, the Coast Guard will require private aids to navigation be installed. Coast Guard representatives will provide appropriate guidelines for this and often will visit your proposed site.

Addresses for more Information

1. In the United States, publications sponsored by Sea Grant can be obtained through interlibrary loan at some state colleges or by requesting them directly from:

National Sea Grant Depository
Pell Library, Bay Campus
University of Rhode Island
Narragansett, RI 02882

2. Copies of reports from Canada's National Water Research Institute can be obtained from:

FTB Information
Hydraulics Division
National Water Research Institute
Canada Centre for Inland Waters
P.O. Box 5050
Burlington, Ontario L7R 4A6
Canada

3. Copies of U.S. Army Coastal Engineering Research Center reports can be obtained from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4600

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