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Data and Procedures for the Design of Floating Tire Breakwaters

by

Volker W. Harms

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CONVERSION TABLE
U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain	
inches	25.4	millimeters	mm
	2.54	centimeters	cm
square inches	6.452	square centimeters	cm^2
cubic inches	16.39	cubic centimeters	cm^3
feet	30.48	centimeters	cm
	0.3048	meters	m
square feet	0.0929	square meters	m^2
cubic feet	0.0283	cubic meters	m^3
yards	0.9144	meters	m
square yards	0.836	square meters	m^2
cubic yards	0.7646	cubic meters	m^3
miles	1.6093	kilometers	km
square miles	259.0	hectares	ha
knots	1.8520	kilometers per hour	km/h
acres	0.4047	hectares	ha
foot-pounds	0.1383	kilogram-meters	kg_f/m
millibars	1.0197×10^{-3}	kilograms per square centimeter	kg_f/cm^2
ounces	28.35	gram-force (gram)*	gm_f(gm)
pounds	453.6	gram-force (gram)*	gm_f(gm)
	0.4536	kilogram-force (kilogram)*	kg_f(kg)
ton, long	1.0160	metric tons	ton
ton, short	0.9072	metric tons	ton
degrees (angle)	0.1745	radians	rad
Fahrenheit degrees, °F	C = 5/9(F -32)	Celsius degrees	°C
Celsius degrees, °C	add 273.15°C	Kelvin degrees	°K

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*These designations are here applied to force-units as is commonly done in engineering practice although this is not strictly correct since kilogram (kg) and gram (gm) are actually units of mass. A kilogram-force is defined as kg_f = 9.8066 N where N = kg · m/sec. A gram-force is $kg_f/1000$.

List of Symbols

b	log-spacing in Wave-Guard FTB
B	breakwater beam size (dimension in direction of wave progress)
C_d	effective drag coefficient of automobile tires
C_t	wave-height transmission ratio, equal to H_t/H
d	water depth
D	breakwater draft (generally $D = 0.85\ D_t$)
D_t	tire diameter
F	maximum (peak) horizontal mooring force on seaward mooring line (per unit length y of breakwater)
FTB	floating tire breakwater
g	gravitational acceleration
G	string-spacing in Wave-Guard FTB
H, H_t	wave height seaward, and shoreward of the breakwater
L	incident wave length
T	wave period
x	beam period
x	beam direction
y	length of breakwater (dimension parallel to wave crest line)
z	vertical direction
γ	specific weight of fluid
ρ	density of fluid
ν	kinematic viscosity of fluid
F_o	fetch length used in wave-generation calculations
U	wind speed used in wave-generation calculations

DATA AND PROCEDURES FOR THE DESIGN OF FLOATING TIRE BREAKWATERS

by Volker W. Harms

I. Introduction

Floating structures have been utilized as wave-attenuation devices for some time: Reid's floating breakwater goes back to 1842 and the concept is probably as old as the need for protected ship moorings. Military needs provided an early incentive for the deployment of floating breakwaters: the Bombardon breakwater (Lochner, 1948) used for the protection of amphibious naval operations during the invasion of Normandy in World War II represents the first major utilization of such structures. Presently the largest demand for floating breakwaters is generated by the pleasure boat market (Richey and Nece, 1974): an increasing demand for mooring space, and the simultaneous depletion of suitable construction sites with natural protection, creates a need for artificial, low-cost protection of marinas and harbors. The floating tire breakwater (FTB) is a recent innovation (Stitt, 1963; Kowalski, 1974) evolving out of this increasing demand for low-cost wave-protection structures. It is a flexible breakwater constructed almost entirely of scrap automobile tires, and is intended for short-fetch (say less than 15 km) or semi-protected locations. The utilization of scrap automobile tires as basic building components, and a modular design for ease of construction, makes it possible to keep the installed cost below $50 per linear foot, as reported by Candle (1977) and Shaw and Ross (1977). Some fundamental advantages of floating breakwaters include the following:

they may be effectively employed in water prohibitively deep for conventional bottom-resting structures; they continue to be effective during large seasonal water level fluctuations in lakes and reservoirs; they generally do not interfere with natural water circulation patterns, sediment transport, life of benthic organisms and fish migrations to the extent that conventional bottom-resting structures do; they may be towed to different locations as the need for wave protection changes.

Although the technical feasibility of many floating-breakwater designs can be established, e.g., that of the tethered-sphere breakwater (Seymour, 1974), and it is certainly possible with today's technology to develop floating structures to protect from any sea state, it is the consideration of economic-feasibility that is frequently neglected (Griffin, 1972) and this can, when finally addressed, lead to sobering results (Moffatt and Nichol, 1977). In this regard the evolution of the FTB is perhaps an exception, with economic feasibility a primary concern from the beginning: to the extent that the technical and economic feasibility had been demonstrated in the prototype (Wave-Maze FTB, Stitts, 1963) long before a laboratory evaluation of its effectiveness was initiated (Kamel, 1968). Even to the present time a similar trend can be detected, with the construction and installation of FTB's proceeding without the support of adequate engineering design criteria. This report is intended as a contribution towards the establishment of such needed design criteria for floating tire breakwaters.

Three configurations are here considered under the generic name of floating tire breakwater: the Wave-Maze FTB (Noble, 1969), the Goodyear FTB (Kowalski and Ross, 1975) and the Wave-Guard FTB (Harms and Bender, 1978). They differ principally in terms of tire arrangement, and therefore spatial tire-density (i.e., number of tires per unit volume of breakwater), and binding material used. Laboratory tests on the more recent FTB-versions, the Goodyear and Wave-Guard configurations, were performed on 1/4-scale and 1/8-scale models and results for the Goodyear FTB compared to some full-scale measurements performed at the U.S. Army Coastal Engineering Research Center (Giles, 1978). A description of the hydraulic model tests performed in the Hydraulic Laboratory of the Canada Centre for Inland Waters in Burlington, Ontario may be found in Appendix I.A (the data itself in Appendix I.B - I.F). Figure 1 depicts the drained wave tank and some of the breakwater models that were tested. The full-scale data is contained in Appendix II, where it is also compared to small-scale measurements. Laboratory tests on the pioneer in the FTB-field, the Wave-maze FTB, were not undertaken. Instead, existing 1/4-scale laboratory data from the U.S. Army Engineer Waterways Experiment Station was analyzed and is here included for completeness in Appendix I.D.

The Goodyear FTB consists of bundles of automobile tires that are interconnected as shown in the breakwater models of Fig. 1 and 2. The installed breakwater floats near the water surface with only the crown of the vertically-floating tires exposed, as shown in the Dunkirk-Harbor field installation of Fig. 3. The bundles have, in the past, been held together and interconnected with rope, cable and chain, but for state-of-the-art construction the use of conveyor-belt edging and nylon bolts is presently recommended (Davis, 1977). Detailed construction procedures incorporating the most recent improvements are contained in a report by Shaw and Ross (1977) entitled, "How to Construct a (Goodyear) Floating Tire Breakwater." This report has here been included, for the

Figure 1. FTB's in drained wave tank (tethered-sphere breakwater in foreground)

Figure 2. 1/4 and 1/8-scale Goodyear-FTB Models (waves would move left-right)

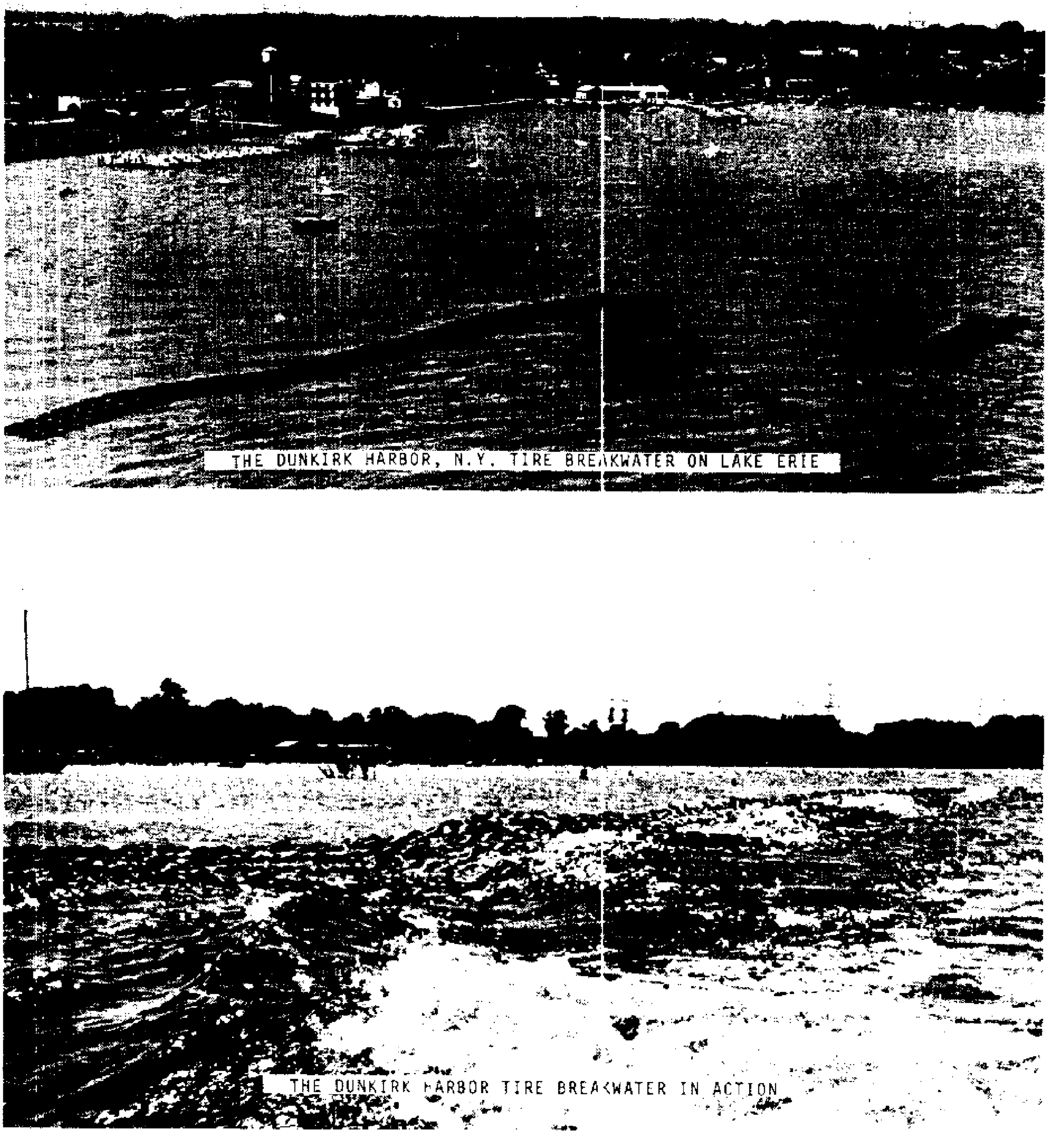


Figure 3. Prototype installation of Goodyear FTB at Dunkirk, New York (photo courtesy of Goodyear Tire & Rubber Co.)

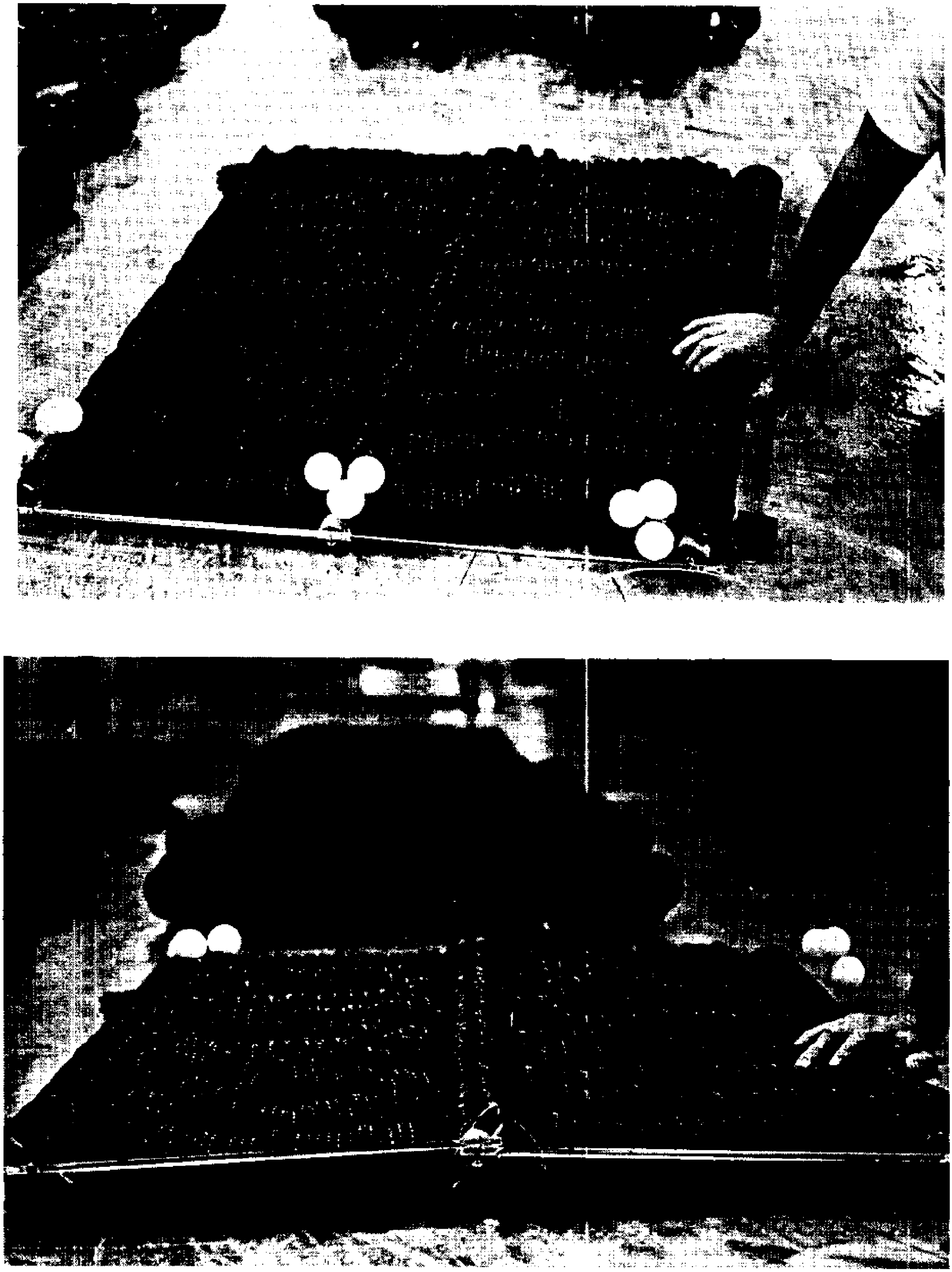


Figure 4. Two views of 1/8-scale Wave-Guard FTB with recommended tire spacing.

Figure 5. Wave-Maze FTB in Tomales Bay, Calif.

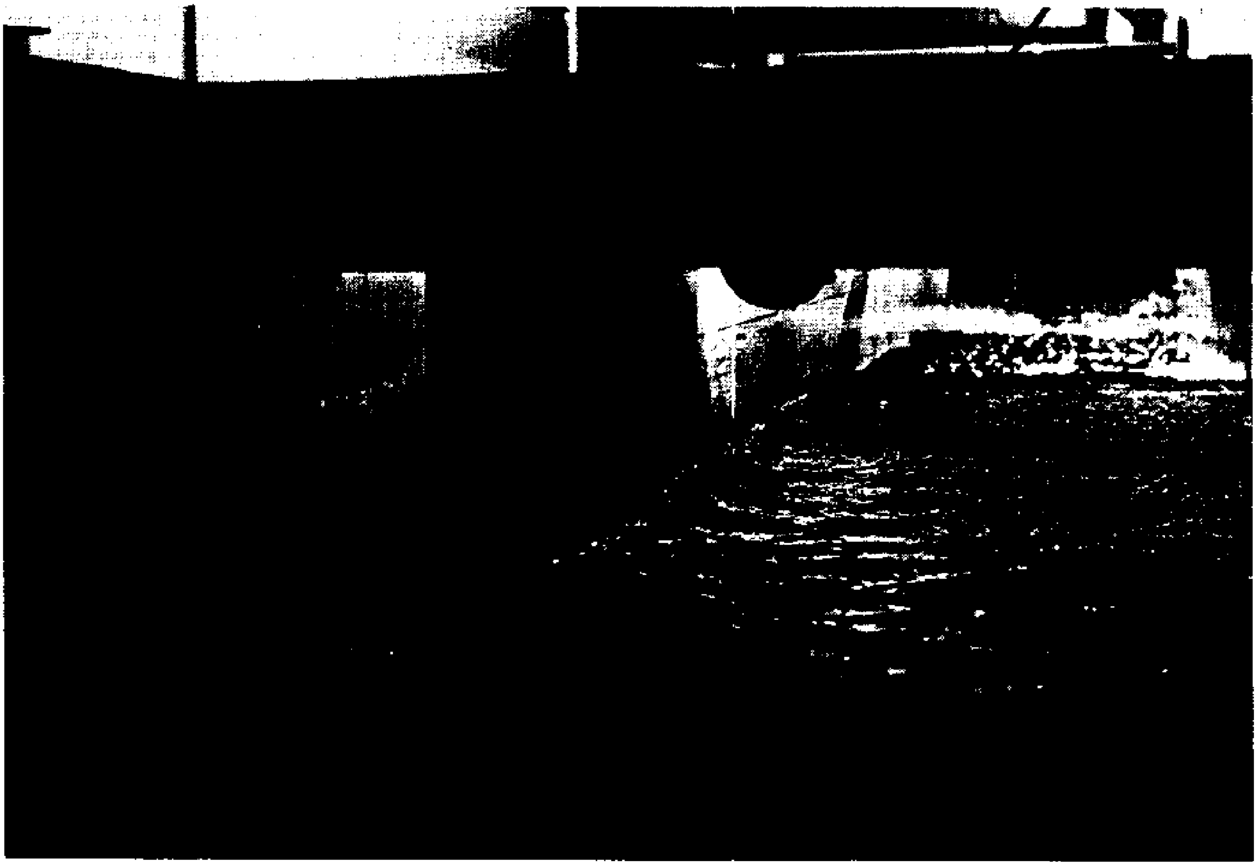


Figure 6. Attenuation of wind-generated waves. View upwind: FTB in right channel, incident wave is left.

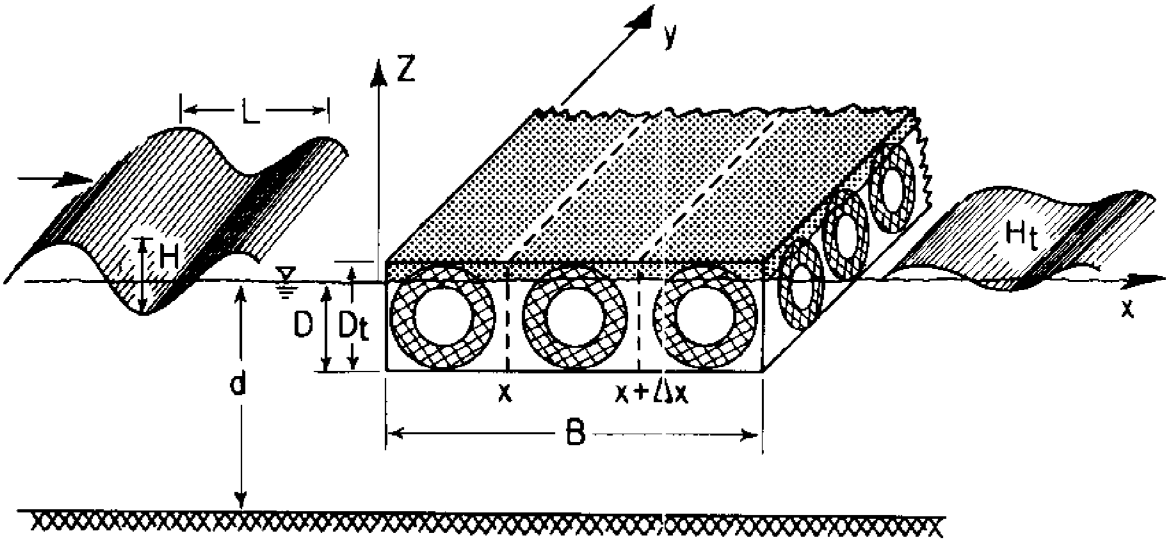


Figure 7. Definition Sketch

convenience of the user, as Appendix IV.B. For additional information on the construction of a Goodyear FTB the reader is also referred to reports by R.D. Candle (1977) and Giles and Sorensen (1978).

The Wave-Guard FTB, shown in Figs. 1 and 4, differs from the Goodyear FTB in several ways:

(i) Massive logs (or telephone poles, steel beams, reinforced concrete beams, etc.) are utilized as structural components.

(ii) Strips of conveyor belting connect one log to the next, and onto these (as well as the logs themselves) tires are strung as "beads on a string."

(iii) The tire-strings are closely spaced so that the spatial-tire-density (number of tires per unit volume of breakwater) is relatively high and a tightly-packed structure results.

(iv) A significantly smaller structure (planform area) is required to attain the same wave-attenuation performance.

Information about recommended breakwater components and construction procedures for the Wave-Guard FTB is contained in Appendix IV.A.

The Wave-Maze FTB is shown in Fig. 5. This breakwater differs from both the Goodyear and Wave-Guard FTB in several regards:

(i) Only truck tires are used (typical tire diameter: 3.3 feet).

(ii) A more rigid, and perhaps rugged, structure is obtained by interconnecting all tires with steel bolts and washers: the casing of each tire is locally reinforced and penetrated by several bolts.

(iii) Some tires are horizontally orientated: a layer of vertically-floating tires is sandwiched between two layers of horizontally floating tires.

The Wave-Maze FTB has been privately patented. A small royalty must consequently be paid for the use of this breakwater concept. Construction details may be found in reports by Noble (1969, 1976) and a brochure by Stitt (1963).

This report focuses on two design parameters that are generally most difficult to evaluate and are, at the same time, among the most important: the beam size B needed for effective wave protection (i.e., the horizontal dimension in the direction of wave progress, as shown in Fig. 7), and the associated maximum mooring force required to restrain the breakwater. These parameters are considered in detail in Sections III and IV of this report. The length y of the breakwater is here not considered since this dimension will generally be chosen equal to the particular shoreline distance to be protected: the influence of wave diffraction around the extremities of structure actually demands that the structure be somewhat larger than this (perhaps one additional wave-length) but a detailed, site-specific analysis of this is presently not considered practically worthwhile for FTB's. Only 2-dimensional laboratory tests were performed: each model extended across the full width of the channel in which it was located, so that diffraction-affects are precluded. This is shown in the attenuation of wind waves in Fig. 6.

Before discussing specific characteristics of a particular type of FTB (wave-transmission and mooring-force response), it is perhaps helpful to consider some general features of these structures. A floating tire breakwater is essentially a mat composed of a large number of interconnected, flexible elements floating near the surface so as to provide a sheltered region of reduced wave activity. A FTB differs not only structurally from most other floating impermeable breakwaters but also, because of this, exhibits fundamentally different functional characteristics as a "break-water,"i.e., the manner in which it intercepts and alters the incident wave motion to create a sheltered zone. Most breakwaters function primarily as wave reflectors: although some of the intercepted wave energy is indeed dissipated upon the structure, the larger portion is generally redirected seaward again. The converse is true for the typical FTB: it is principally a wave-energy dissipator. Most of the incident wave energy is transformed into turbulence within and around the many components of this structure (eventually being converted to thermal energy), while only a small portion of the wave energy is reflected. This fundamental characteristic of the FTB is exhibited in Fig. 8, where the ratio of energy-dissipated to energy-reflected is shown: the reflected energy is only between 7-20% as large as that dissipated, depending upon the relative wave length L/B. This relationship was extracted from laboratory measurements of Kamel (1968) using regular waves and 1/4-scale models of the Wave-Maze FTB, and should apply as well to the Goodyear and Wave-Guard FTB.

It is instructive to compare the wave-transmission characteristics of FTB's to some other breakwaters that behave dominantly as wave reflectors (for very steep waves, of course, significant energy dissipation occurs even on vertical-walled, smooth, impermeable structures). For this purpose the experimentally-determined wave-transmission curve for a "dissipative" FTB (type: Goodyear) is compared to two simple examples of "reflective" structures: in Fig. 9 a fixed, vertical plate simulating a wave barrier constructed of siding mounted on a pile structure (Wiegel, 1960) is considered, and in Fig. 10 a rigid horizontal plate fixed, and also floating at the still-water level. Comparison of the experimental data for the Goodyear FTB (Figs.I.10-I.11 in Appendix I.B) to that for the vertical plate indicates that a Goodyear FTB with beam size B = 12D offers approximately the same level of wave attenuation as a fixed vertical plate of equal draft D. Comparison to the theoretical wave-

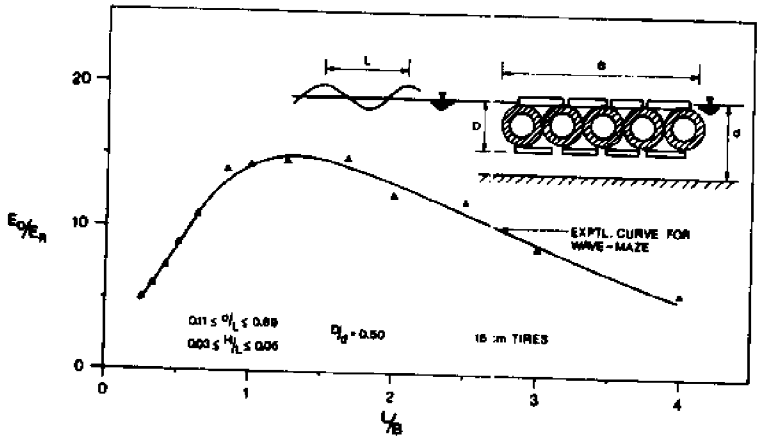


Figure 8. Ratio of Energy Dissipated to Energy Reflected by FTB.

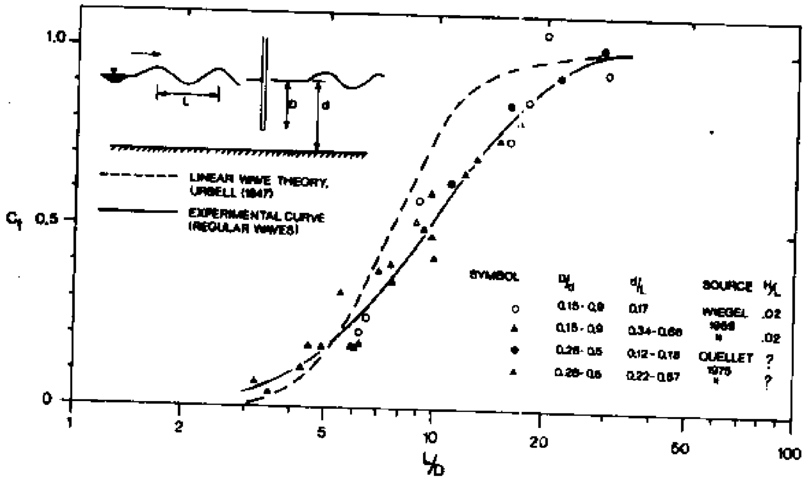


Figure 9. Wave Transmission Past Vertical Plate.

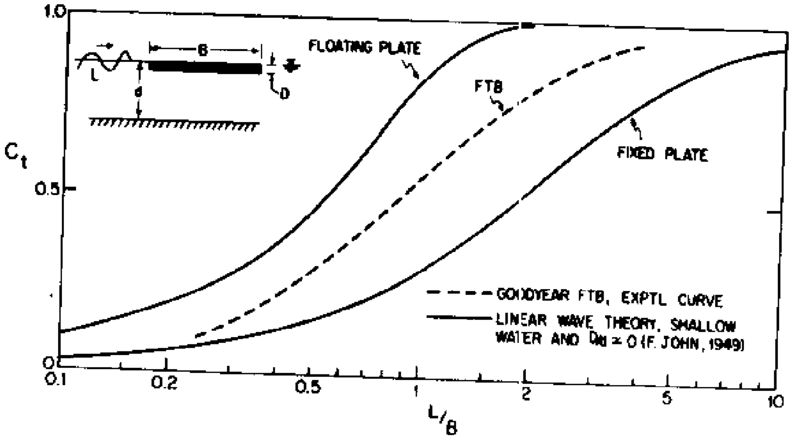


Figure 10. Wave Transmission Past Horizontal Plate.

transmission characteristics of the horizontal plates in Fig. 10 indicates that the performance of the Goodyear FTB lies approximately midway between that of the fixed and floating plate, i.e., for the same beam size B, the FTB is less effective than the fixed plate but more effective than the floating one. The large improvement in wave-attenuation performance that may be realized by fixing the plate should be noted, although it must be recognized that this generally also implies a large increase in wave-induced structural loads, among other things.

II. Estimated Construction Costs

It is our intention in this section to provide the potential FTB-user with adequate cost information for a first assessment of the relative economic merits of the Goodyear, Wave-Guard and Wave-Maze FTB's. The figure of merit used for this purpose is the cost per unit-length-of-breakwater (e.g., \$ per foot of length in the y-direction, see Fig. 7). The cost of a structure is obviously very dependent upon the beam size B. Since the wave-attenuation performance of the three types of breakwaters under consideration are quite different even for the same beam size, a proper cost comparison cannot be based upon equal beam size but must account for differences in their effectiveness. The calculations in this section do just that. They are based upon the principle of "equal-wave-protection": the cost of each structure was only evaluated after having first "sized" each of the three breakwaters so as to provide the same degree of wave protection ($C_t = 0.5$). The cost of the mooring system has not been included in these figures because it is so inherently site-dependent and variable and would, furthermore, not vary greatly from one type of breakwater to another. It should be noted that the cost-estimates are just that, "estimates," and that prices will vary with time and locality. Nevertheless, the figures used are the best that could be obtained from a variety of (sometimes conflicting) sources engaged in the construction, research or promotion of FTB's or FTB-components (as of June 1978).

A potential FTB-user clearly needs to know how large an initial capital investment will be required for the construction and installation of a particular FTB. Beyond this, he should certainly know how much wave protection he is buying with this structure (this information is largely contained in this report), and he should also be able to estimate the useful life-span of the structure (and associated maintenance costs).

The last consideration is probably the most difficult to address because the FTB itself is a relatively recent innovation with little historic field data upon which to base life-span estimates:

(i) The oldest field installation of a Goodyear FTB is that on a small lake in Ohio (Wingfoot Lake: miles in length), having been in the water continuously for four years. The history of this installation (as well as others) would suggest that the useful life of a properly-constructed Goodyear FTB is well in excess of four years if the structure is located on a small lake, or otherwise subjected only to relatively benign wave conditions.

(ii) The Wave-Maze FTB is the only FTB with long-term salt water exposure: the field installation in Tomales Bay, California has been in continuous operation for 15 years (little information exists on the repair history and local wave conditions).

(iii) The Wave-Guard FTB has only been tested in the laboratory.

The construction-cost estimates on the following pages apply to three different types of FTB's that were each designed to provide the same level of wave protection, i.e., to reduce waves 1.6 feet in height and 40 feet in length down to a transmitted height of 0.8 feet (i.e., $C_t = 0.50$ with $H/L = 0.04$). The absolute cost figures that were arrived at are certainly of interest: they indicate that it is indeed possible to obtain the cited level of wave protection for less than $50 per foot (installed) by using a Goodyear or Wave-Guard FTB. But a comparison of construction costs for the three structures is perhaps equally revealing, indicating that:

(i) The Wave-Guard FTB is somewhat less costly than the Goodyear FTB and is, at the same time, significantly smaller for the same degree of wave protection.

(ii) The Wave-Maze FTB is far more costly than either the Goodyear or Wave-Guard FTB, but perhaps also has a longer useful life and greater extreme-event survival capabilities.

Cost Estimate

Goodyear FTB

wave length L = 40 ft

breakwater length y = 504 ft (72 modules @ 7.0 ft)

beam size B = 46 ft (7 modules @ 6.5 ft)

C_t = 0.50

tire diameter D_t = 2.1 ft (14" automobile tires)

Item	Quantity	Unit Cost $	Cost/Module $	Total Cost $	Cost/ft of BW $/ft
Scrap Auto Tires	10,080	.15	3.00	1,512.00	3.00
Flotation Urethane Foam (if used)	5,040 lbs	.70	7.00	3,528.00	7.00
Conveyor Belting @ 30 ft/mod	15,120	.20	6.00	3,024.00	6.00
Nylon Bolts @ 8 bolts/mod	4,032	.50	4.00	2,016.00	4.00
Labor @ 2 hrs/mod	1,008 hrs	6.00	12.00	6,048.00	12.00

Total Cost = $16,128.00

Cost per foot of BW (without floatation) = $ 25.00

Cost per foot of BW (with floatation) = $ 32.00
(without mooring system)

Cost Estimate

Wave-Guard FTB

wave length $L = 40$
breakwater length $y = 504$ ft (42 sections @ 12 ft)
beam size $B = 28.6$ ft
$C_t = 0.50$
pole spacing $b = 12.0$ ft
tire spacing $G = 2.4$ ft
tire diameter $D_t = 2.1$ ft (14" automobile tires)

Item	Quantity	Unit Cost $	Cost 12 ft sections $	Total Cost $	Cost/ft of BW
Scrap Auto Tires	12,600	.15	45.00	1,890.00	3.75
Flotation Urethane Foam (if used)	6,300 lbs	.70	105.00	4,410.00	8.75
Conveyor Belting @ 228 ft/section	9,576 ft	.20	45.60	1,915.20	3.80
Telephone poles or Wooden piles	42	50.00 @ 50% of new cost	50.00	2,100.00	4.20
Nylon Bolts @ 40/section	1,680	.50	20.00	840	1.67
Labor @ 12 hrs/section	504 hrs	6.00	72.00	3,024.00	6.00
Miscellaneous	--	--	6.00	250.00	.50

Total Cost = $14,430.00

Cost per foot of BW (without floatation) = $ 19.88

Cost per foot of BW (with floatation) = $ 28.63
(without mooring system)

Cost Estimate

Wave-Maze FTB

wave length $L = 40$ ft

breakwater length $y = 504$ ft

beam size $B = 43$ ft

$C_t = 0.50$

tire diameter $D_t = 3.3$ ft (20" truck tires)

The construction of a large Wave-Maze FTB is presently in progress on the West Coast (San Francisco Chronicle, 8. August 1978). This would indicate that the cost per square foot of breakwater (planform area) is somewhat in excess of \$6. From personal communications with M. Noble (the designer of this structure and co-developer of the Wave-Maze concept) it was determined that the installed cost generally varies between \$4 - \$6 per square foot. Using 5 $\$/ft^2$ in the cost estimate for the 504' x 43' Wave-Maze FTB:

Total Cost = \$108,000

Cost per foot of BW = \$215 (including mooring system)

III. Design Curves

Two important FTB design parameters are considered in this report, these are:

A. The wave-attenuation performance of the structure as given in terms of the wave-transmission coefficient C_t, which represents the ratio of the transmitted wave height to the incident wave height (for irregular waves the average wave height of the wave train has been used to assign values to both C_t and the wave steepness, H/L). The parameter C_t is a measure of the wave-sheltering effectiveness of the breakwater: for a wave of unit height impinging upon the structure the value of C_t is a direct measure of the transmitted wave height, e.g., a value of $C_t = 0.3$ implies that a wave 1.0 ft in height will be reduced to 0.3 ft as it passes through the breakwater. The transmission of regular (monochromatic) waves through a Goodyear FTB is depicted in Fig. 11, a photograph taken through the glass wall of the wave tank. The attenuation of irregular wind-generated waves by a Goodyear FTB (located in the right channel, Channel I) is shown in the photograph-sequence of Fig. 12.

B. The peak mooring force that the breakwater will exert on the seaward mooring line. It should be noted that the force magnitudes here listed only apply to mooring lines that provide predominantly a horizontal restraining force, i.e., when the length of mooring line is at least equal to, say, seven times the local water depth. In the case of the Wave-Guard FTB a 3-tire mooring damper was inserted between pole-connection and anchor line (see Appendix I.A. for details). In prototypes of the Wave-Guard FTB such mooring dampers should also be installed in order to avoid higher peak mooring loads.

Figure 11. 6-module Goodyear FTB in action (view through wall of tank; waves approaching from right)

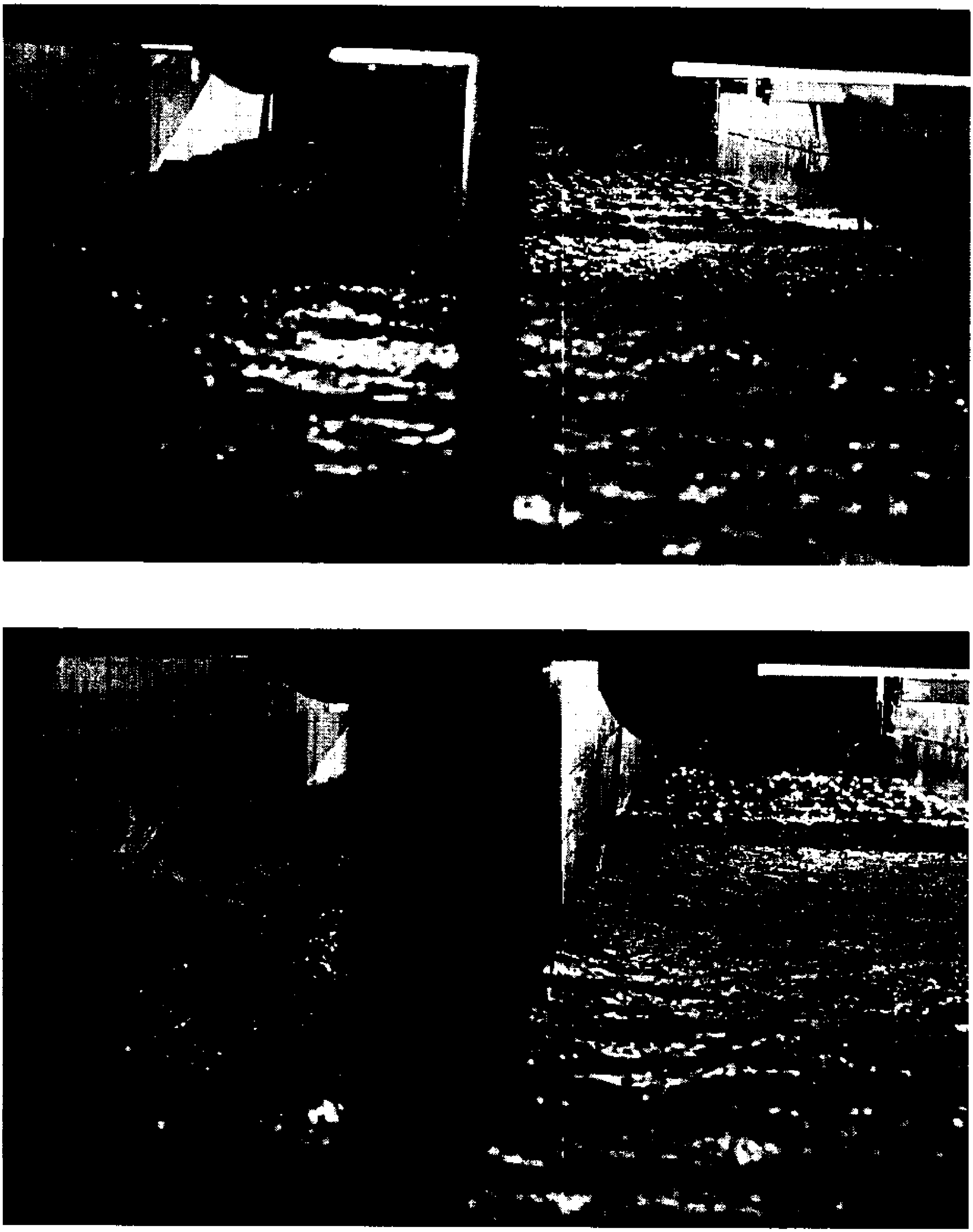


Figure 12. Attenuation of wind-generated waves by FTB for two different wind speeds (view upwind; FTB located in right channel, left channel unobstructed)

Although the use of the design curves is perhaps adequately described in the examples of Section IV, the following information will assist in making the design data more readily accessible:

A. Several parameters that are repeatedly used will be once more defined,

wave-height transmission ratio $C_t = \frac{H_t}{H} = \frac{\text{transmitted wave height}}{\text{incident wave height}}$

force parameter $\frac{F}{\gamma B^2} = \frac{\text{(peak mooring force per unit length of breakwater)}}{\text{(specific weight of fluid)(beam size)(beam size)}}$

relative wave length $\frac{L}{B} = \frac{\text{wave length}}{\text{beam size}}$

wave steepness $\frac{H}{L} = \frac{\text{wave height}}{\text{wave length}}$

relative draft $\frac{D}{d} = \frac{\text{breakwater draft}}{\text{water depth}}$

B. Both the wave-height transmission ratio C_t and the force parameter $\frac{F}{\gamma B^2}$ are considered to be functions of L/B, H/L and D/d only.

C. The draft D of both the Goodyear and Wave-Guard FTB is related to the tire diameter D_t used, and may be approximated by $D = 0.85\ D_t$. For the Wave-Maze FTB the equivalent relationship is typically $D = 1.3\ D_t$.

D. In tests performed by Giles and Sorenson (1978) the peak mooring force on the shoreward mooring lines did not exceed 10% of the seaward-peak-mooring-force. It is therefore suggested that a figure of 20% be used for design purposes (if no significant waves can approach from the shoreward side).

E. The values obtained from the vertical axis of the force diagrams represent 100,000 times the value of $F/\gamma B^2$. Using $\gamma = 62.4\ \text{lb/ft}^3$ ($1000\ \text{kg}_f/\text{m}^3$)

for fresh water (γ = specific gravity of fluid) one finds that

$\frac{F}{\gamma B^2} \times 10^5 = 1600 \frac{F}{B^2}$ if the English System of units with B in feet and F in pounds per foot is used, and

$\frac{F}{\gamma B^2} \times 10^5 = 100 \frac{F}{B^2}$ if the International System of units with B in meters and F in kg_f per meter is used.

The peak mooring force F is therefore easily obtained from the diagrams once the beam size B is specified.

The following very general, but useful, observations can be made about the FTB-design-curves:

A. The effectiveness of the structure (as a wave barrier) decreases with increasing wave length, and increases with increasing wave steepness.

B. The peak mooring force increases with increasing wave length and also increases with increasing wave steepness.

C. Laboratory experiments performed at the Canada Centre for Inland Waters were restricted to 1/4-scale and 1/8-scale models of FTB's. Design curves for both wave-transmission and peak-mooring-force were generated from this relatively extensive data base and compared to some measurements performed on full-scale breakwaters at the U.S. Army Coastal Engineering Center. The model data and existing full-scale data are compared in Appendix II: the agreement is very good. The use of hydraulic-model data in the design of FTB's is therefore well justified, and the many advantages of model tests over prototype tests can thus be realized. Difficulties certainly exist in modelling the mooring system but, to a large extent, even these can be overcome by innovative modelling techniques.

D. Although wave-transmission design curves have only been drawn for a wave steepness of approximately 4%, it is possible to estimate values of C_t for higher or lower values of wave steepness by referring to the actual data-point distributions upon which these curves are based (Appendix I and II). The value of C_t generally decreases as the wave steepness H/L increases. For the Goodyear FTB two additional wave-transmission performance curves for an estimated wave steepness of 1% and 8% are given in Fig. I.16 of Appendix I.B.

E. In tests with the Wave-Guard FTB a mooring line with a 3-tire mooring damper was used (see Appendix I.A for a description). With this damper installed the mooring connection at the breakwater end can be made directly to the massive wooden poles, as opposed to the more flexible but weaker tire-strings, without incurring excessively high peak mooring loads. In prototype structures such mooring dampers should also be installed. Since full-scale tires are "stiffer" than the 1/8-scale model tires tested, it is recommended that at least five tires be used in the full-scale mooring Damper. It is here relevant to note that structural failures in Goodyear FTB's are frequently related to stress concentrations in the vicinity of the mooring connection.

F. Multi-layer-Goodyear FTB's (shown in Appendix I.E.) were tested but are presently not considered worthwhile alternatives except, perhaps, in very special applications. The familiar, single-layer-Goodyear FTB provides more wave protection than a multi-layer-Goodyear FTB constructed of the same number of modules. Design curves for 2-layer and 3-layer Goodyear FTB's are, nevertheless, included in Appendix I.E.

DESIGN CURVES

GOODYEAR FTB

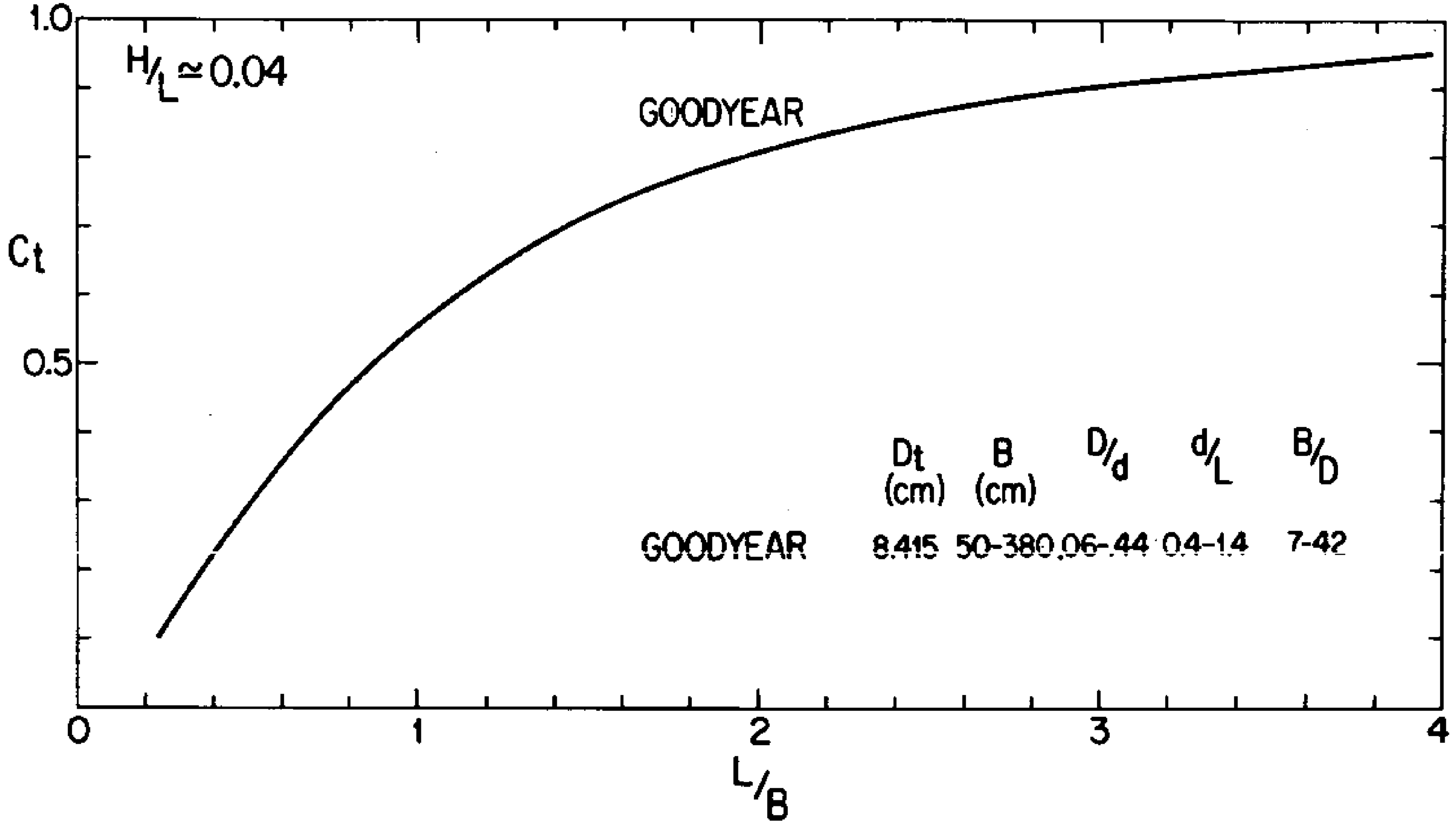


Figure 13. Wave-Transmission Design Curve for Goodyear FTB

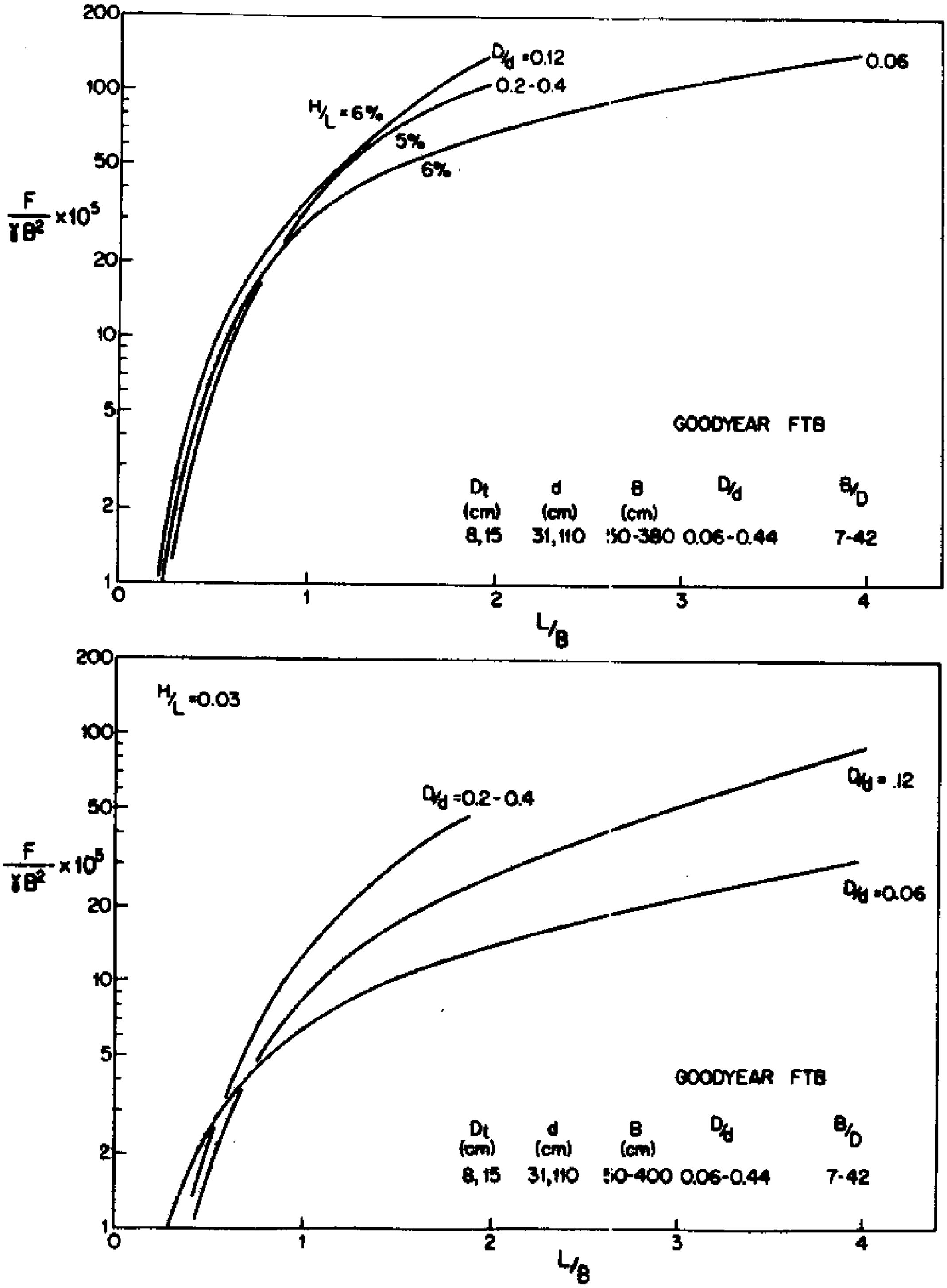


Figure 14. Force Design Curves for Goodyear FTB

DESIGN CURVES

WAVE-GUARD FTB

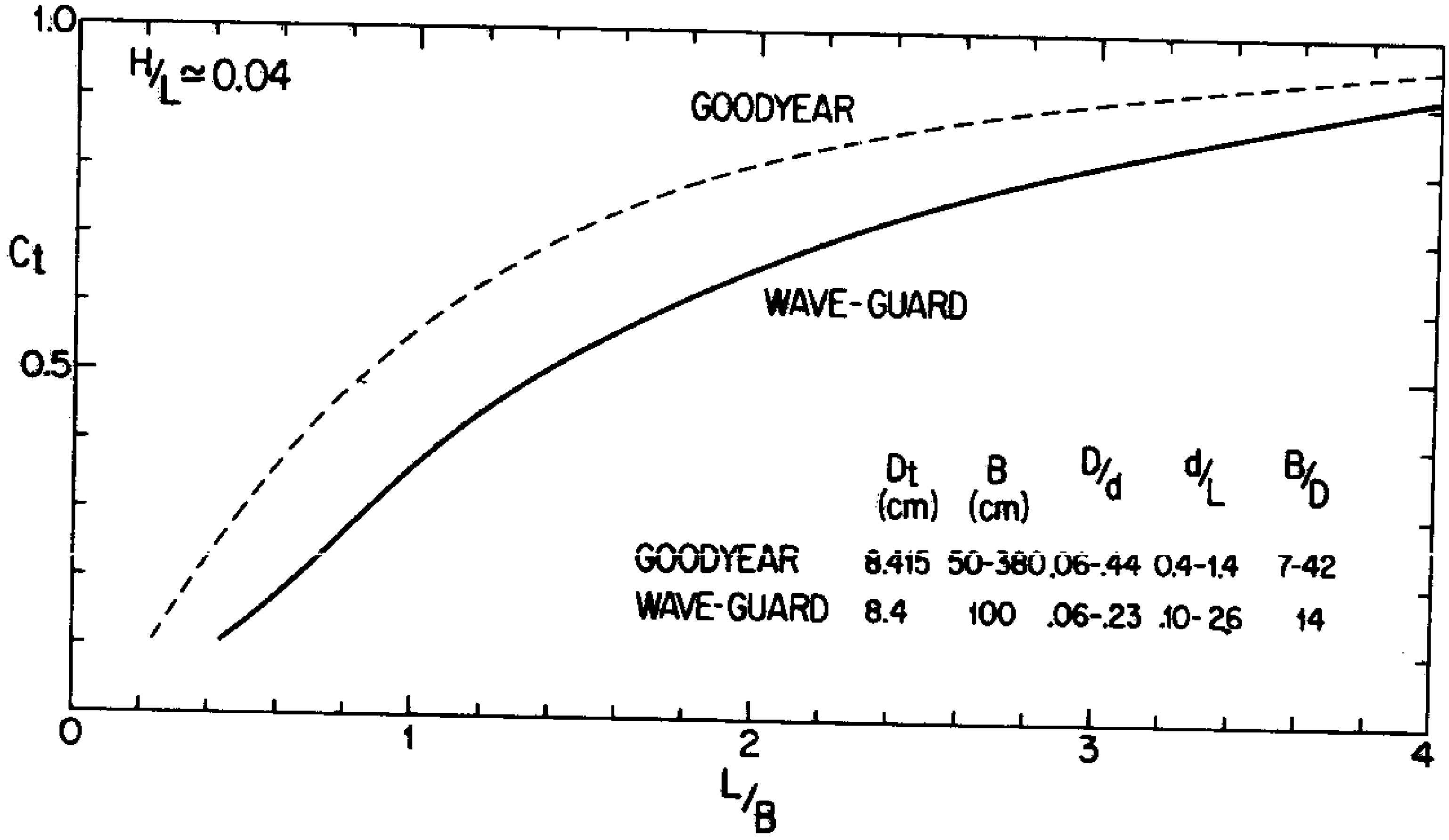


Figure 15. Wave-Transmission Design Curve for Wave-Guard FTB ($b/D_t = 5.4$)

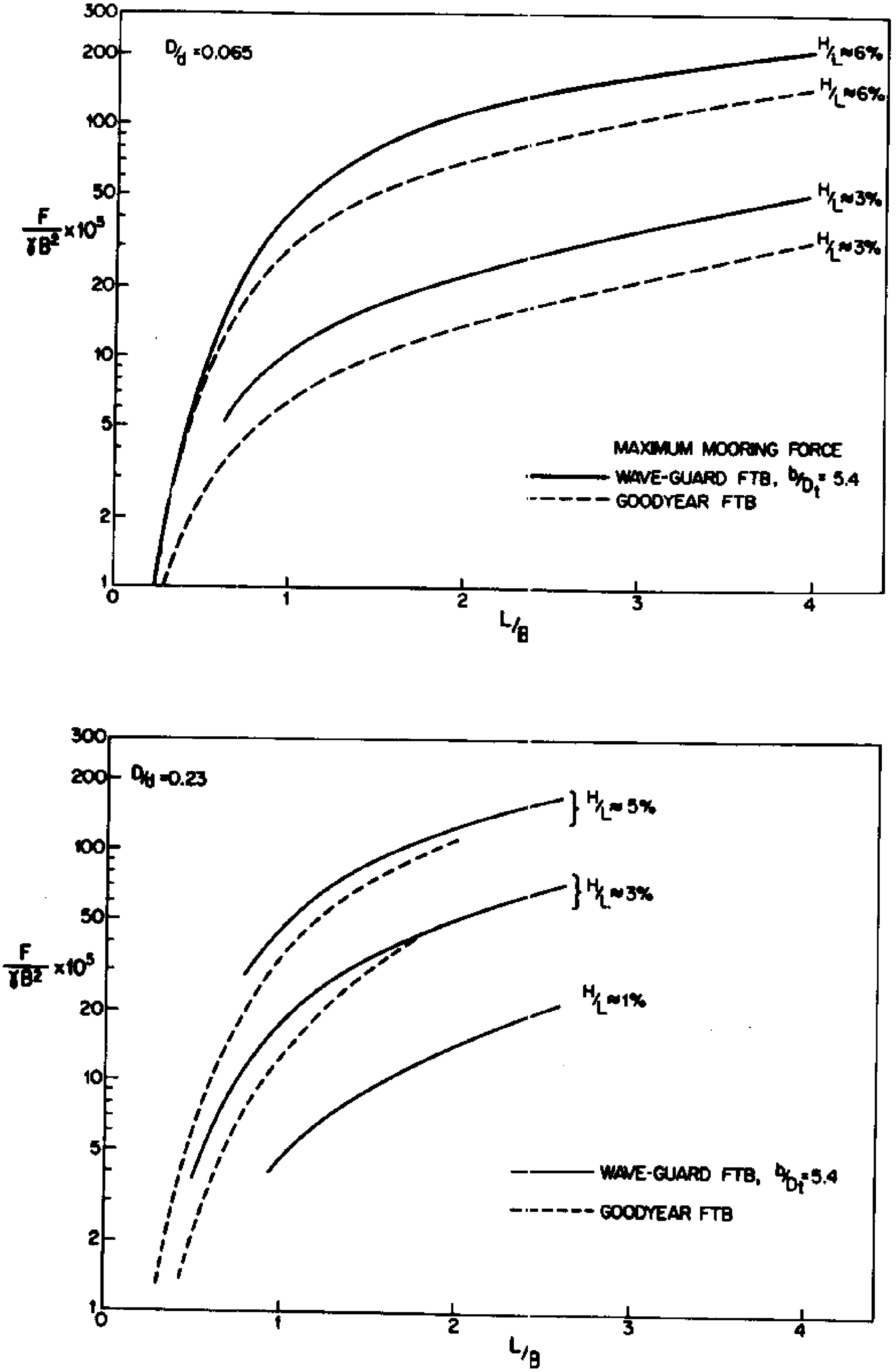
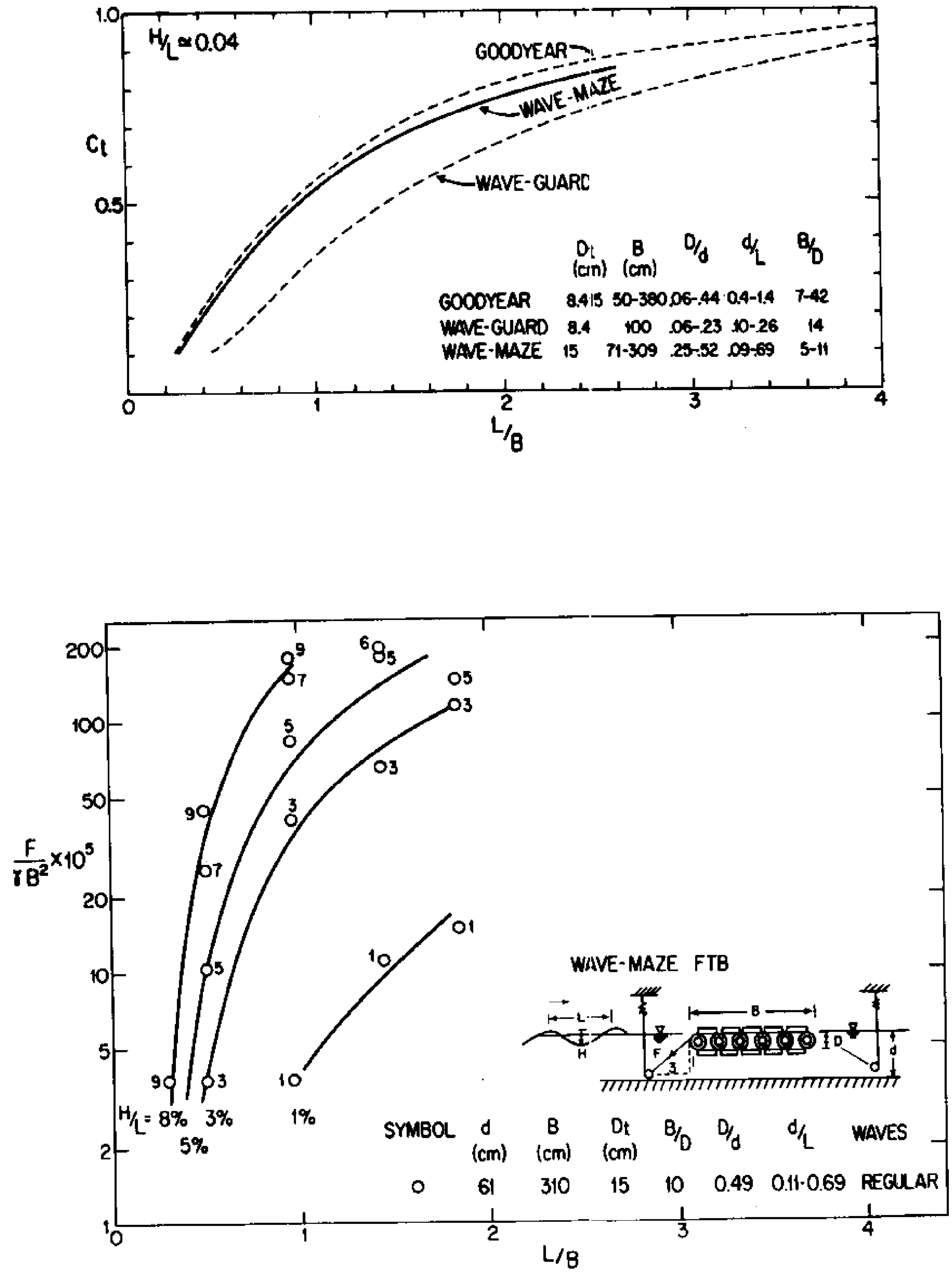


Figure 16. Force Design Curves for Wave-Guard FTB

DESIGN CURVES

WAVE-MAZE FTB



	Dt (cm)	B (cm)	D/d	d/L	B/D
GOODYEAR	8.4 15	50-380	.06-.44	0.4-1.4	7-42
WAVE-GUARD	8.4	100	.06-.23	.10-.26	14
WAVE-MAZE	15	71-309	.25-.52	.09-.69	5-11

SYMBOL	d (cm)	B (cm)	Dt (cm)	B/D	D/d	d/L	WAVES
○	61	310	15	10	0.49	0.11-0.69	REGULAR

Figure 17. Wave-Transmission and Force Design Curves for Wave-Maze FTB

IV. Design Procedure

The design procedure here presented has been developed with the potential user in mind: experience has shown that he is generally a person with, at best, a limited technical-engineering background, and frequently none at all. It would consequently be inappropriate to develop a sophisticated design procedure demanding a data-base that will, in practice, never be acquired and a level of technical expertise that cannot normally be counted upon. It is our aim instead to present a simple design procedure that represents (a) a significant improvement over the present state of affairs (i.e. existing "rules of thumb") while at the same time, (b) keeping the design-effort (or design cost) associated with a FTB small compared to the construction effort (or total capital investment). Although wave refraction and diffraction are neglected in the basic procedure here outlined, their influence can readily be incorporated after having been separately analyzed. This should be done whenever practically feasible. An outline of the design procedure with reference to the Goodyear FTB follows:

1. Specify site and tire characteristics
   - A. Average tire diameter, D_t
   - B. Average water depth at FTB location, d
   - C. Fetch length for prevailing storm direction, F_o
2. Define Wave Conditions
   - A. Beam-design-wave (i.e. prevalent wave condition to be mitigated): perform measurements to obtain representative local wave period T and height H
   - B. Force-design-wave (i.e. extreme event): use graphs of Appendix III to obtain extreme wave period T_x for specified wind velocity U, average water depth d and fetch length F_o associated with prevailing storm direction (if possible, account for refraction and diffraction)

3. Specify Degree of Wave Protection Desired

   Choose a wave-height reduction factor C_t for the beam-design-wave (C_t = transmitted wave height/incident wave height).

4. Determine Wave Length

   Enter Fig. 18 with known wave period and water depth to obtain wave length L (for each design wave).

5. Determine Wave Steepness and Relative Draft

   A. Relative draft D/d: use D = 0.85 D_t and values of d and D_t from 1.

   B. Wave Steepness, H/L: use values of H and L for beam-design-wave but use resulting value of H/L for both design waves (in the absence of more detailed information).

6. Use Design Curves

   A. Determine beam size B: use Fig. 13 with specified value of C_t (from 3) and the value of L for the beam-design-wave (from 4).

   B. Determine peak-mooring-force F for beam-design-wave: use Fig. 14 with wavelength L of beam-design-wave (from 4) and known value of B (from 6.A) and H/L and D/d (from 5).

   C. Determine peak-mooring-force F for extreme event: use Fig. 14 with wavelength L of force-design-wave from 4 and B from 6.A, and H/L and D/d from 5 as before.

Example 1

Boats moored within a marina located on a small lake undergo violent motions during a frequently occurring wave condition. This wave condition was measured and found to correspond to a wave period of T = 3.2 seconds and a wave height of H = 2.5 feet (this specifies the beam-design-wave). The worst storm-generated waves to be anticipated during the life of the structure were estimated to be those generated by a 60 mph wind blowing across 5 miles of the lake, where the average water depth is 30 feet (this defines the extreme event, or force-design-wave). The installation of a Goodyear FTB has been proposed for the protection of the marina.

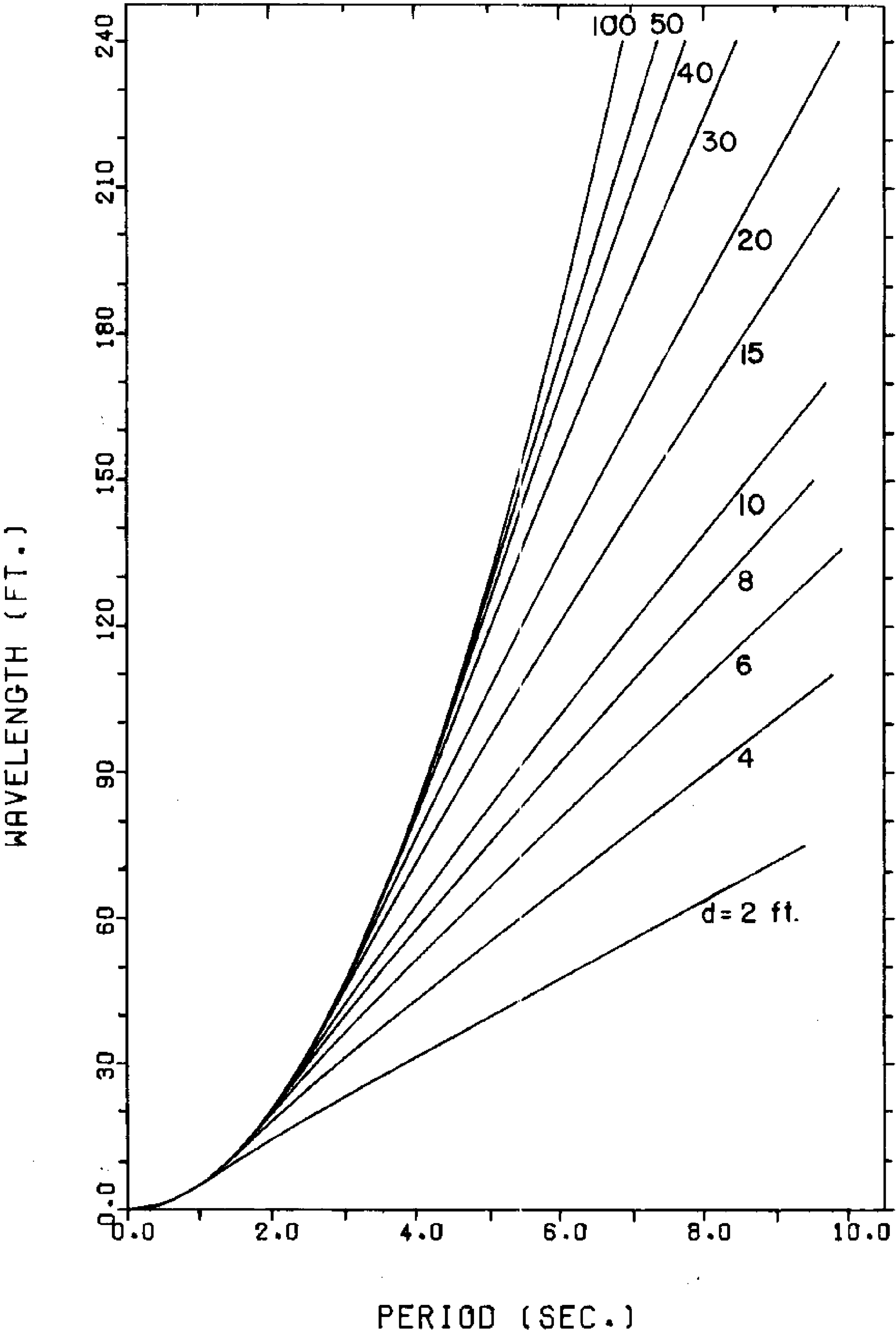


Figure 18. Relationship Between Wavelength, Wave Period and Water Depth (linear theory)

The average water depth at the proposed site is 6 feet, and the local supply of scrap tires indicates that an outside diameter of $D_t = 2.1$ feet is typical. If the beam-design-wave is to be reduced to a height of $H_t = 1.4$ feet, determine the beam-size B required for the Goodyear FTB to accomplish this, as well as the peak mooring force F to be anticipated for a structure of this size. Assume that waves approach the breakwater normally, as shown on page 39. When this is not the case, it is suggested that the dimension of the structure along the direction of wave approach be used instead of B (e.g., for a wave incidence angle of 45° use 1.4 B instead of simply B), at least until more specific data becomes available.

Solution:

1. Site and Tire Characteristics
   A. $D_t = 2.1$ ft
   B. $d = 6$ ft
   C. $F_o = 5$ miles with $\bar{d} = 30$ ft
2. Wave Conditions
   A. Beam-design-wave: $T = 3.2$ sec, $H = 2.5$ ft (measured at site)
   B. Force-design-wave: from Fig. III.6 with $U = 60$ mph, $F_o = 5$ miles and $\bar{d} = 30$ ft, obtain $T_x = 4.5$ sec
3. Protection Desired

   Reduction of wave height to 1.4 feet implies that the wave-transmission ratio is $C_t = \frac{1.4}{2.5} = 0.56$
4. Wave Lengths
   A. Beam-Design-Wave:

   With $T = 3.2$ sec, $d = 6' \rightarrow \underline{L = 40 \text{ ft}}$ from Fig. 18

   B. Force-Design Wave:

   With $T_x = 4.5$ sec, $d = 6' \rightarrow \underline{L = 60 \text{ ft}}$ from Fig. 18

5. Wave Steepness and Relative Draft

   A. Relative draft, D/d: with $D = (0.85)(2.1) = 1.8'$ and

   $$d = 6' \rightarrow D/d = 0.30$$

   B. Wave steepness H/L (from 4A): $H/L = \frac{2.5}{40} = 0.063$

6. Design Curves

   A. Beam size B: with $C_t = 0.56$ and $H/L \simeq 0.04 \rightarrow L/B = 1.0$ since $L = 40$ ft $\rightarrow \underline{\underline{B = 40 \text{ ft}}}$ which is somewhat conservative because actually $H/L = 0.063$

   B. Peak mooring force F for beam-design-wave:

   with $L/B = 1.0$, $H/L = 0.063$, $D/d = 0.30$ in Fig. 14 ,

   have $\frac{F}{\gamma B^2} \times 10^5 = 1600 \frac{F}{B^2} \simeq 45$ (Fig. I.19 is here also helpful)

   $$F = 45 \cdot \frac{(40)^2}{1600}$$

   $$F = \underline{45 \text{ lb/ft}}$$

   C. Peak mooring force F for force-design-wave: with $L/B = \frac{60}{40}$ $= 1.5$ and H/L, D/d as before, from Fig. 14 have

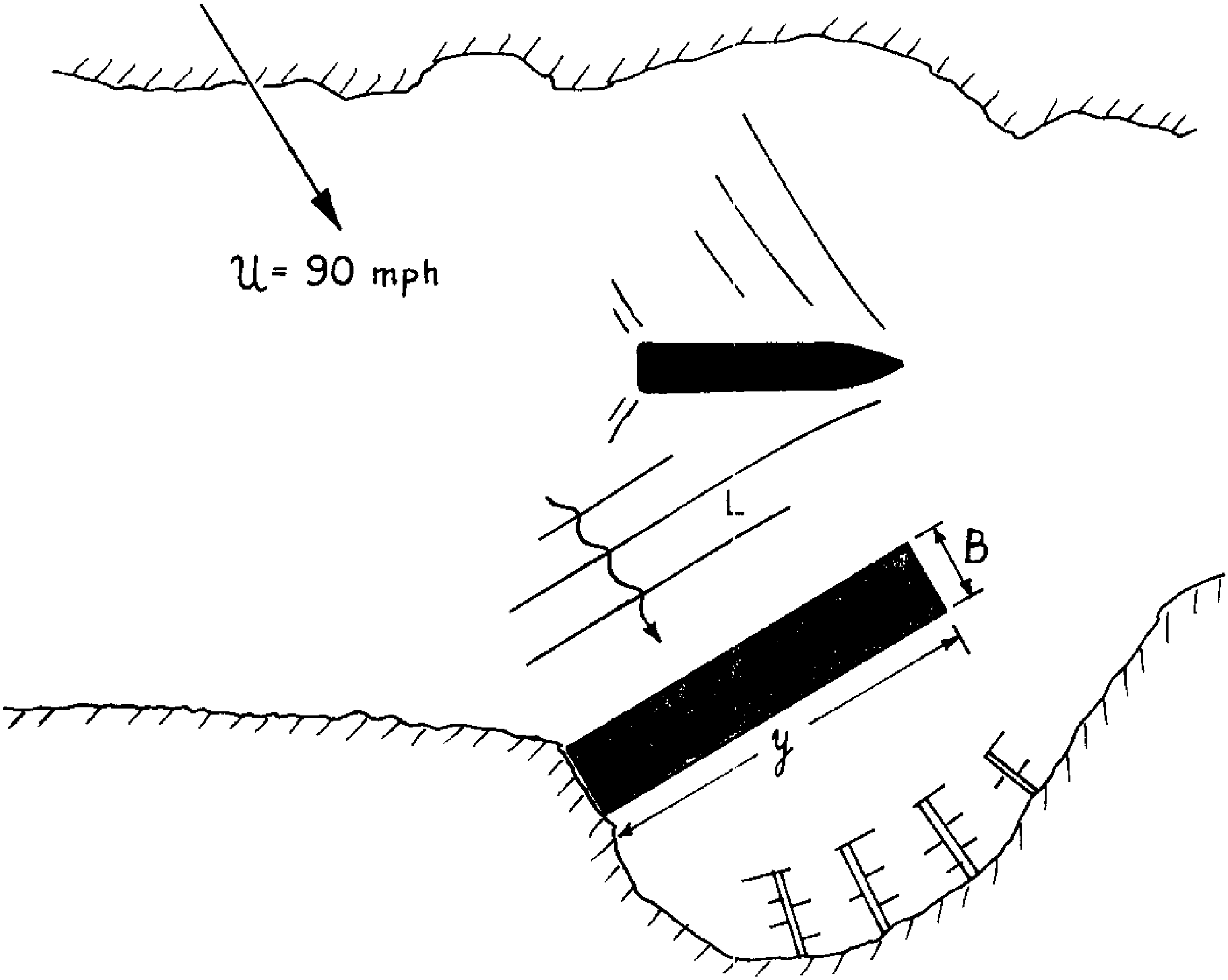
   $1600 \frac{F}{B^2} \simeq 100$, so that $F = 100 \cdot \frac{(40)^2}{1600}$

   $$\underline{\underline{F = 100 \text{ lb/ft}}}$$

<u>Summary</u>: In order to reduce the wave height of the beam-design-wave to approximately 1/2 requires a Goodyear FTB with B = 40 feet (i.e., a 6-module beam), and in order to remain moored during the extreme event a restraining force of 100 lbs per foot of breakwater length must be provided for this structure. Most frequently the so-called force-design-wave (extreme event) yields the highest mooring-force demand, as was here the case, but exceptions to this rule may be encountered.

Example 2

A floating tire breakwater is proposed for the protection of a river marina that periodically suffers wave damage from the passage of large fishing vessels. It was determined that a representative large fishing boat moving at 14 knots generated 3.6 second waves 2.0 ft in height (the beam-design-wave). These waves are to be reduced by the breakwater to a height of 8 inches. The most severe storm-generated waves to be anticipated during the life of the structure were estimated to be those generated by a 90 mph wind blowing across 3 miles of water (with average depth



of 20 ft). Under all conditions it may be assumed that waves approach the breakwater at right angles as shown in the sketch. The water depth at the location of the proposed FTB is 12 ft. Truck tires with average outside diameter of $D_t = 3.2$ ft are available and will be used. Determine the beam-size B of an appropriate FTB (either Goodyear or Wave-Guard type) and the associated maximum mooring force F for the above regular design waves.

Solution:

1. Site and Tire Characteristics

   A. $D_t = 3.2$ ft

   B. $d = 12$ ft

   C. $F_o = 3$ miles with $\bar{d} = 20$ ft

2. Wave Conditions

   A. Beam-design-wave: $T = 3.6$ sec, $H = 2.0$ ft (measured at site)

   B. Force-design-wave: From Fig. III.4 with $U = 90$ mph, $F_o = 3$ miles and $\bar{d} = 20$ ft, obtain $T_x = 4.5$ sec

3. Protection Desired

   Reduction of wave height to 0.67 feet implies that the wave-transmission ratio is $C_t = \frac{0.67}{2.0} = 0.33$

4. Wave Lengths

   A. Beam-Design-Wave:

   $T = 3.6$ sec, $d = 12$ ft $\rightarrow \underline{L = 56 \text{ ft}}$

   B. Force-Design-Wave:

   $T = 4.5$ sec, $d = 12$ ft $\rightarrow \underline{L = 80 \text{ ft}}$

5. Wave Steepness, and Relative Draft

   A. Relative draft, D/d: with $D = (0.85)(3.2) = 2.7'$

   and $d = 12' \rightarrow D/d = 0.23$

   B. Wave steepness H/L (from 4A): $H/L = \frac{2.0}{56} = 0.036$

6. Design Curves (Goodyear FTB)

   A. Beam size B: with $C_t = 0.33$ and $H/L \simeq 0.04 \rightarrow L/B = 0.56$,

   since $L = 56$ ft $\rightarrow \underline{\underline{B = 100 \text{ ft}}}$

   B. Peak mooring force F for beam-design-wave:

   with $L/B = 0.56$, $H/L = 0.036$, $D/d = 0.23$ in Fig. 14 and (interpolating), obtain

$$1600 \frac{F}{B^2} \simeq 5$$

$$F = 5 \cdot \frac{(100)^2}{1600}$$

$$\underline{\underline{F = 31 \text{ lb/ft}}}$$

   C. Peak mooring force F for force-design-wave:

   with $L/B = \frac{80}{100} = 0.80$, $H/L = 0.036$, $D/d = 0.23$ in Fig. 14 and (interpolating), obtain

$$1600 \frac{F}{B^2} \simeq 11$$

$$\underline{\underline{F = 69 \text{ lb/ft}}}$$

7. Design Curves (Wave-Guard FTB)

   A. Beam size B (Fig. 15): with $C_t = 0.33$ and

   $H/L \simeq 0.04 \rightarrow L/B = 0.96$

   since $L = 56$ ft $\rightarrow \underline{\underline{B = 58 \text{ ft}}}$

   B. Peak mooring force F for beam-design-wave:

   with $L/B = 0.96$, $H/L = 0.036$, $D/d = 0.23$ in

Fig. 16 (interpolating) obtain

$$1600\,\frac{F}{B^2} \simeq 22$$

$$F = 22\,\frac{(58)^2}{1600}$$

$$\underline{F = 46 \text{ lb/ft}}$$

C. Peak mooring force F for force-design-wave:

with $L/B = \frac{80}{58} = 1.4$, $H/L = 0.036$, $D/d = 0.23$ in

Fig. 16 (interpolating), obtain

$$1600\,\frac{F}{B^2} \simeq 41$$

$$\underline{\underline{F = 86 \text{ lb/ft}}}$$

<u>Summary</u>: For equal wave-attenuation performance the Wave-Guard FTB is significantly smaller than the Goodyear FTB (58 ft-beam as compared to 100 ft-beam), but requires somewhat higher mooring-restraining-forces for the case considered (86 lb/ft as compared to 69 lb/ft).

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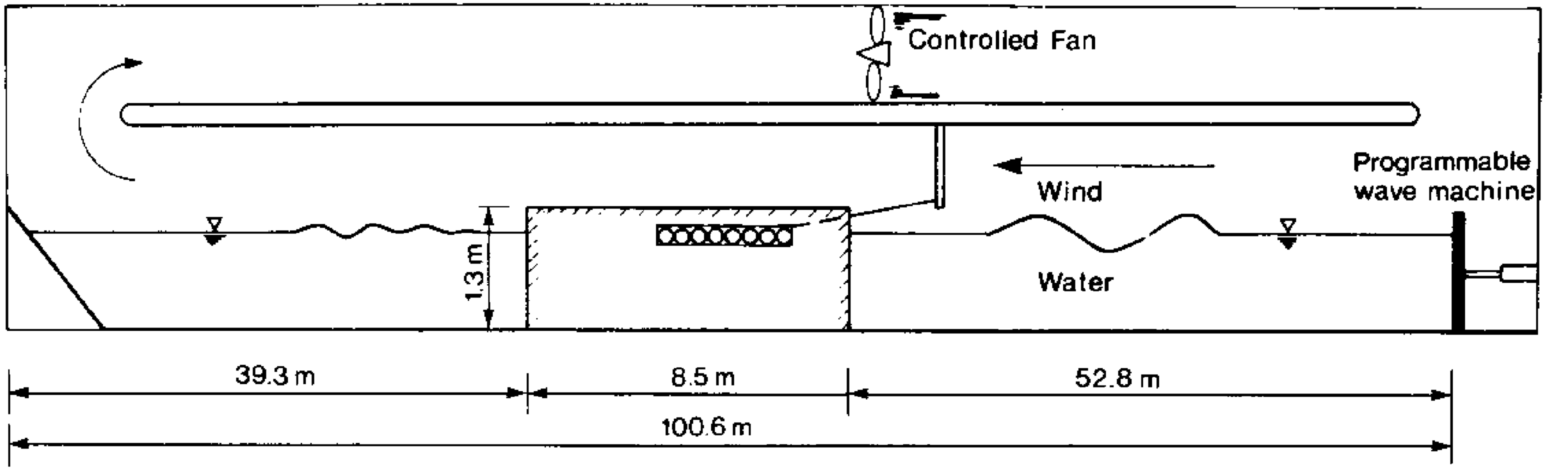
Appendix I.A. Laboratory Facilities and Experimental Procedures

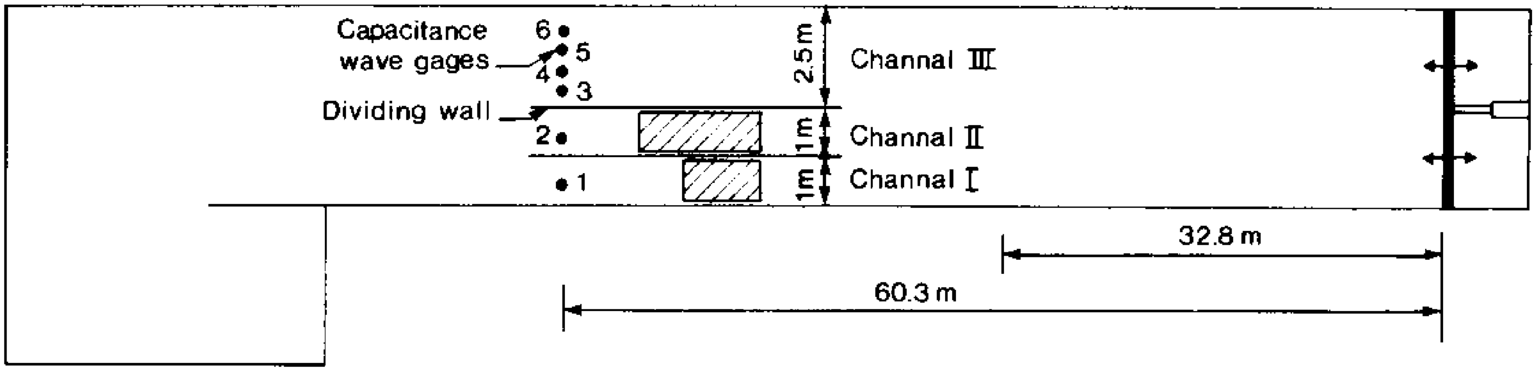
Tests were conducted in the large wind wave tank of the Hydraulics Laboratory at the Canada Centre for Inland Waters in Burlington, Ontario. The tank, shown in Fig. I.1 is 109 meters in length, 4.5 meters wide and can be operated at a water depth of up to 1.2 meters. Waves can be generated by a hydraulically-driven piston-type wave machine or by operating the tank as a wind tunnel at speeds up to 64 km/h. Multiple reflections from fibrous beaches within the harbor-like basin at the end of the tank are utilized for wave-energy dissipation. Wave heights were measured with capacitance wave probes and mooring forces were obtained from the strain-gauge cantilever-force-transducers shown in Fig. I.2 and I.9. Analog signals from wave gauges and force transducers were monitored on a 6-channel Brush oscillographic recorder and simultaneously stored on magnetic tape. A sample data trace from the recorder is shown in Fig. I.3. Time-series analysis of the wave and force data was performed on the wave tank mini-computer (shown in Fig. I.4) using programs available at the Canada Centre for Inland Waters. The test section, consisting of three sub-channels 8.5 m in length (1 m, 1 m and 2.5 m wide) located approximately 55 m from the wave generator and 45 m from the beach, is depicted in Fig. I.5. This position normally permitted individual runs to be completed before waves reflected from the beach or generator could influence measurements. Two breakwaters were generally tested simultaneously, in Channels I and II as shown in Fig. I.1, while the incident-wave characteristics were measured in the remaining unobstructed Channel III. The mooring system and position of the breakwater within the test section are shown in Fig. I.2 for the two water levels tested. The mooring lines, consisting of 0.37 mm stainless steel wire, provided essentially a horizontal restraining force since the slope was always less than IV:30H. A 6 mm plastic rod was fastened to the breakwater along its horizontal leading edge. In the case of the Wave-Guard FTB, a 3-tire mooring damper (shown in Fig. I.8 on a preliminary Wave-Guard FTB model), was installed at the end of this rod (where the plastic rod connects directly to the massive log), between the plastic rod and the 2-wire bridle leading to the force cantilever. Tire mooring dampers were generally not used on the Goodyear FTB because that structure is already so very flexible throughout, so that the 3-tire damper would have little effect. But from separate tests it was found that a 20-tire mooring damper did reduce peak mooring forces significantly on the Goodyear FTB. The installation of tire-mooring-dampers therefore appears to be a practical way to reduce peak mooring forces without reducing the effectiveness of the structure but more extensive tests will be required to establish this. The plastic rod was used on all breakwaters: it prevented the structures from contracting laterally and made model changes easier. Mooring forces were only measured on the seaward mooring line, and only peak values are here reported. A 100 gram counterweight provided a constant restoring force to the breakwater via the rear (shoreward) wire, as shown in Fig. I.2. The rear cable and small restoring force prevented the breakwater from drifting between runs and also made possible the measurement of small seaward forces using only a single force cantilever per breakwater. In Fig. I.6 models of the Goodyear and Wave-Guard FTB are shown resting on the bottom of the drained wind wave tank (a tethered sphere breakwater is shown in the background). Models of the Goodyear FTB were fabricated according to construction guidelines by Candle (1977) and Shaw and Ross (1977): the standard 18-tire module used in existing field installations can be seen in Fig. I.6. The Wave-Guard FTB incorporates wooden logs (telephone poles, etc.) that are aligned with the direction of wave progress. Several strips of conveyor belting connect one log to the next, and onto these (as well as the logs themselves) tires are strung as "beads on a string." The result is a tightly-packed structure with many more tires per unit surface area (not a significant cost factor), as shown in the models on page 6 .

The use of regular waves had been envisioned in the laboratory test program (with subsequent investigations to be performed using wave spectra). But it was not possible to obtain regular waves less than 1.3 m in length at the location of the test section, approximately 60 m from the wave generator, even though the writer has himself performed tests with regular waves under similar conditions in other tanks at a distance of up to 30 m from the wave generator. It was not determined whether Benjamin-Feir wave instabilities were incurred due to the increased distance of travel, or if the wave generator itself was the source of the problem. Since these shorter waves with periods of 1 sec or less were required to adequately define the wave-attenuation performance of the model breakwaters, and yet were irregular at the test section, it became necessary to combine this irregular-wave (narrow-spectra) data with that from other tests with regular waves. The equivalent-monochromatic wave height and length needed for this purpose were defined as the average wave height and peak-energy wave length, respectively, obtained from time-series analysis of the water surface elevation. The number appearing next to each data symbol in this report represents the wave steepness in percent, and the letters r, m, w designate regular waves, machine-generated wave-spectra and wind-generated waves, respectively. The generation of wind waves is shown in Fig. I.7 and their attenuation by a

Goodyear FTB on page 8 . The letter x indicates that the value of C_t was obtained directly from the analog trace of the 6-channel Brush recorder, not from time-series analysis. An absence of the letter x indicates that the value of C_t was obtained from time series analysis (mooring forces were always obtained directly from the analog wave record). By applying dimensional analysis to a particular type of FTB and mooring system it can be shown that the wave-height transmission ratio C_t and the force parameter $F/\gamma B^2$ are functions of the relative wave length L/B, wave steepness H/L, relative draft D/d and beam-to-draft ratio B/D. These will be the governing parameters in model and prototype if it can be ensured that (i) geometric scaling exists and the same fluids are used, (ii) scaling of elastic and inertia properties of tires, binding material and mooring system has been accomplished, and (iii) only small motions of the structure are allowed. Although strict compliance with these demands cannot be assured (e.g., inertia and elasticity properties of model and prototype tires are not precisely scaled, see Table 1 on page 55 as well as Figs. I.37 and I.38), the above nondimensional parameters were used as the framework for this engineering investigation.

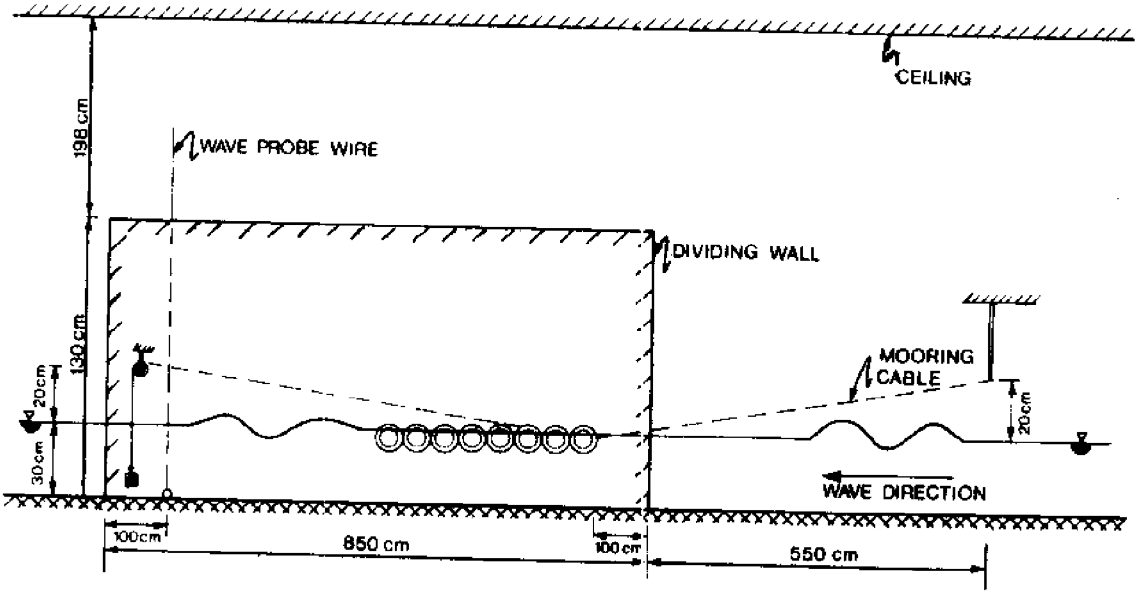


ELEVATION

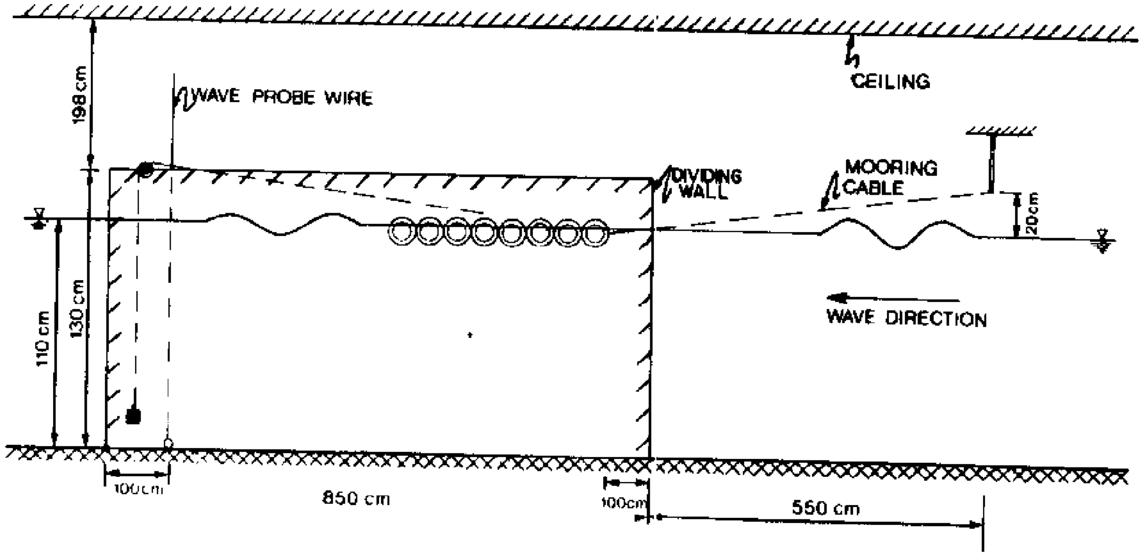


PLAN

Figure I.1. Schematic Diagram of Wind Wave Flume



ELEVATION-SHALLOW WATER (NOT TO SCALE)



ELEVATION-DEEP WATER (NOT TO SCALE)

Figure I.2. Diagram of Test Section and Breakwater Installation

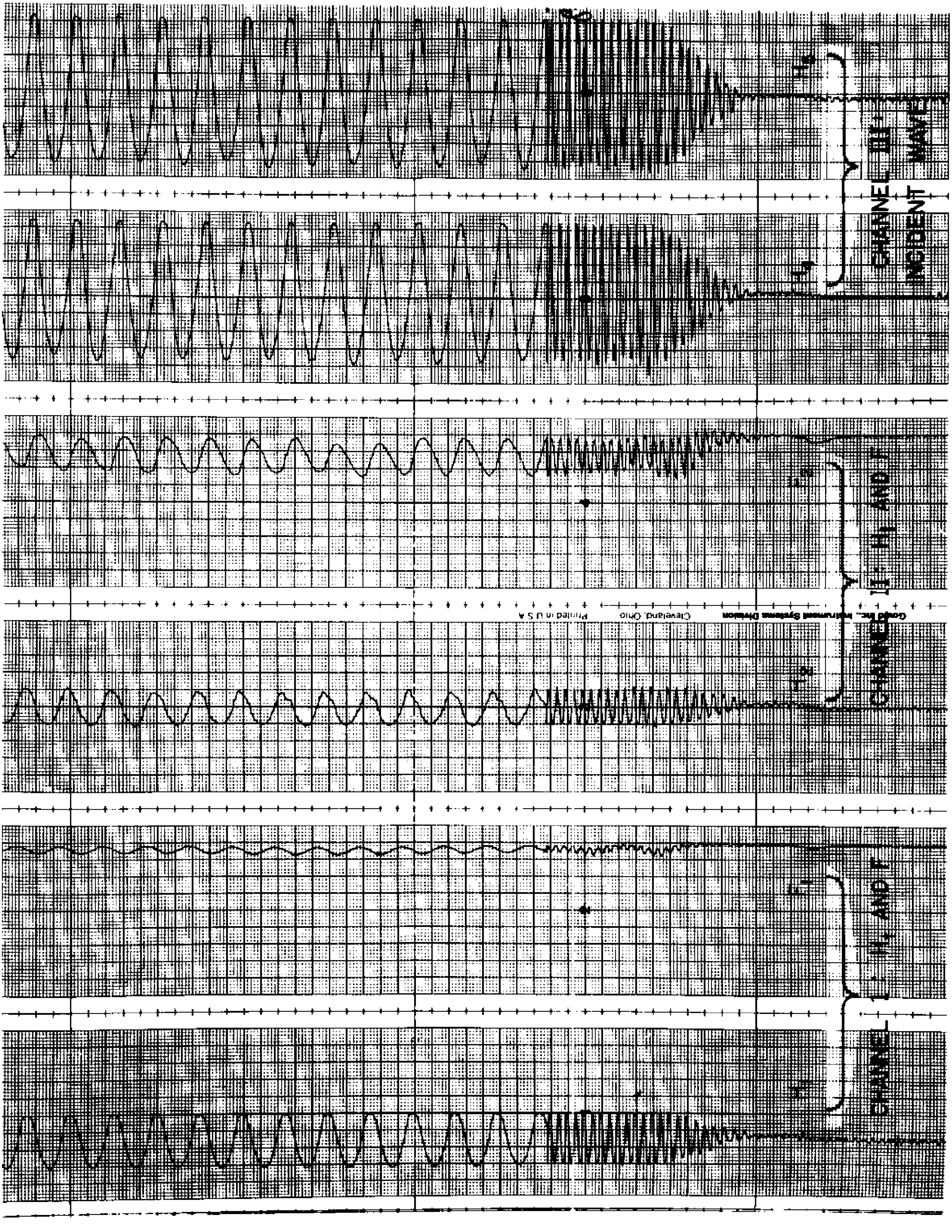


Figure I.3. Sample Data Trace from 6-channel Recorder

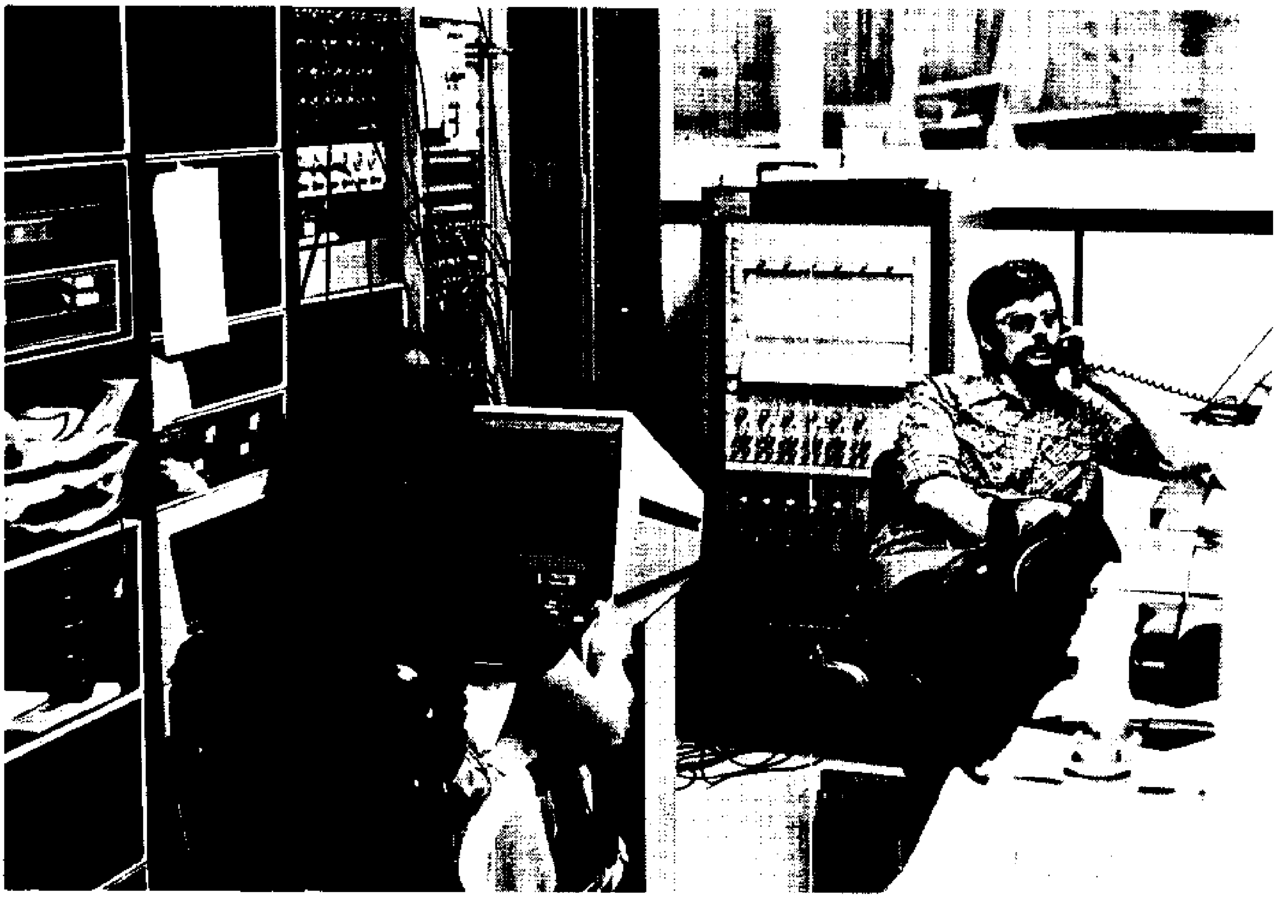


Figure I.4. Control Room for Wave Tank at Canada Centre for Inland Waters

Figure I.5. Wave Tank with 3-channel Test Section (view towards wave generator)

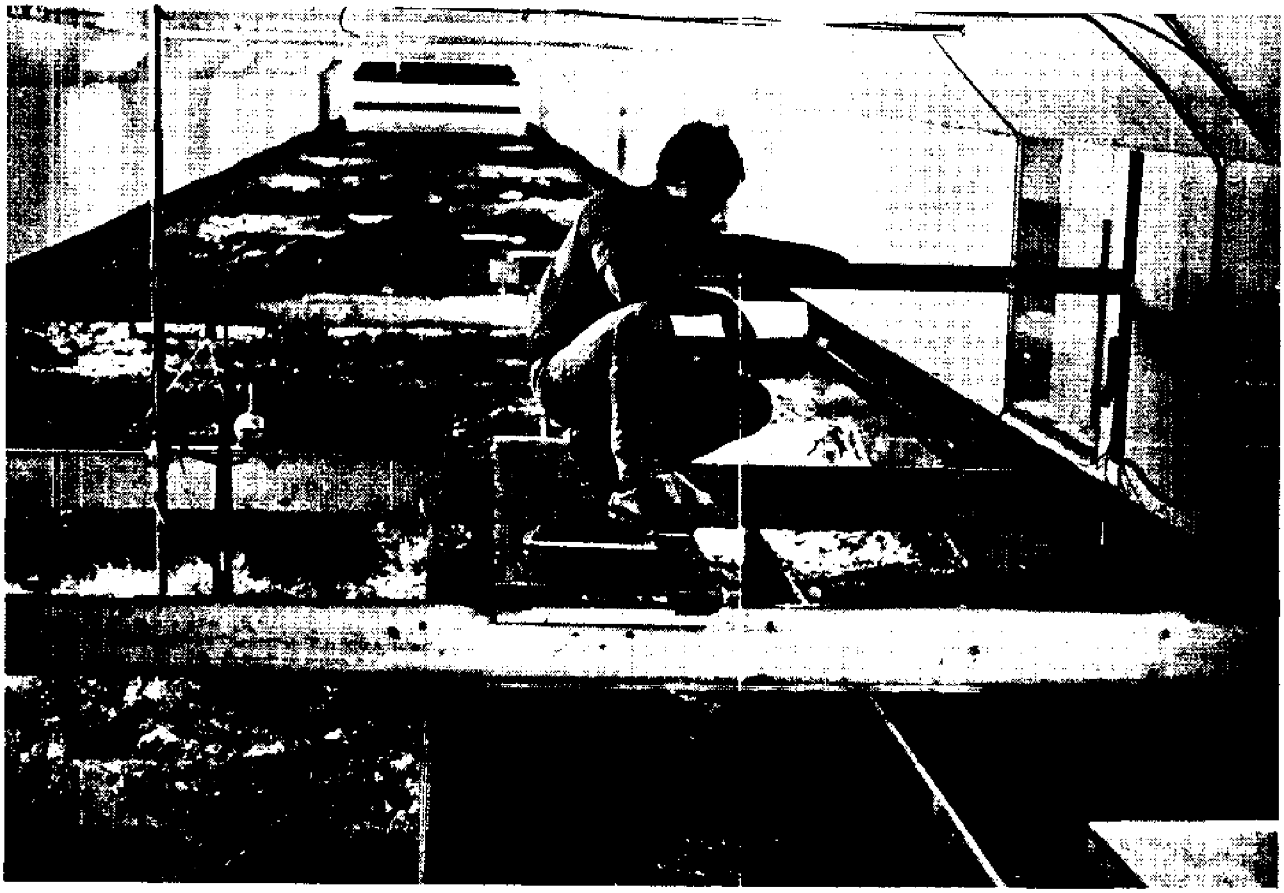


Figure I.7. Wind-generated Waves (looking upwind, U = 16 m/sec)

Figure I.6. 1/4 and 1/8-scale FTB Models (tethered-sphere breakwater in background)

Figure I.8. 3-Tire Mooring Dampers on Preliminary Model of Wave-Guard FTB

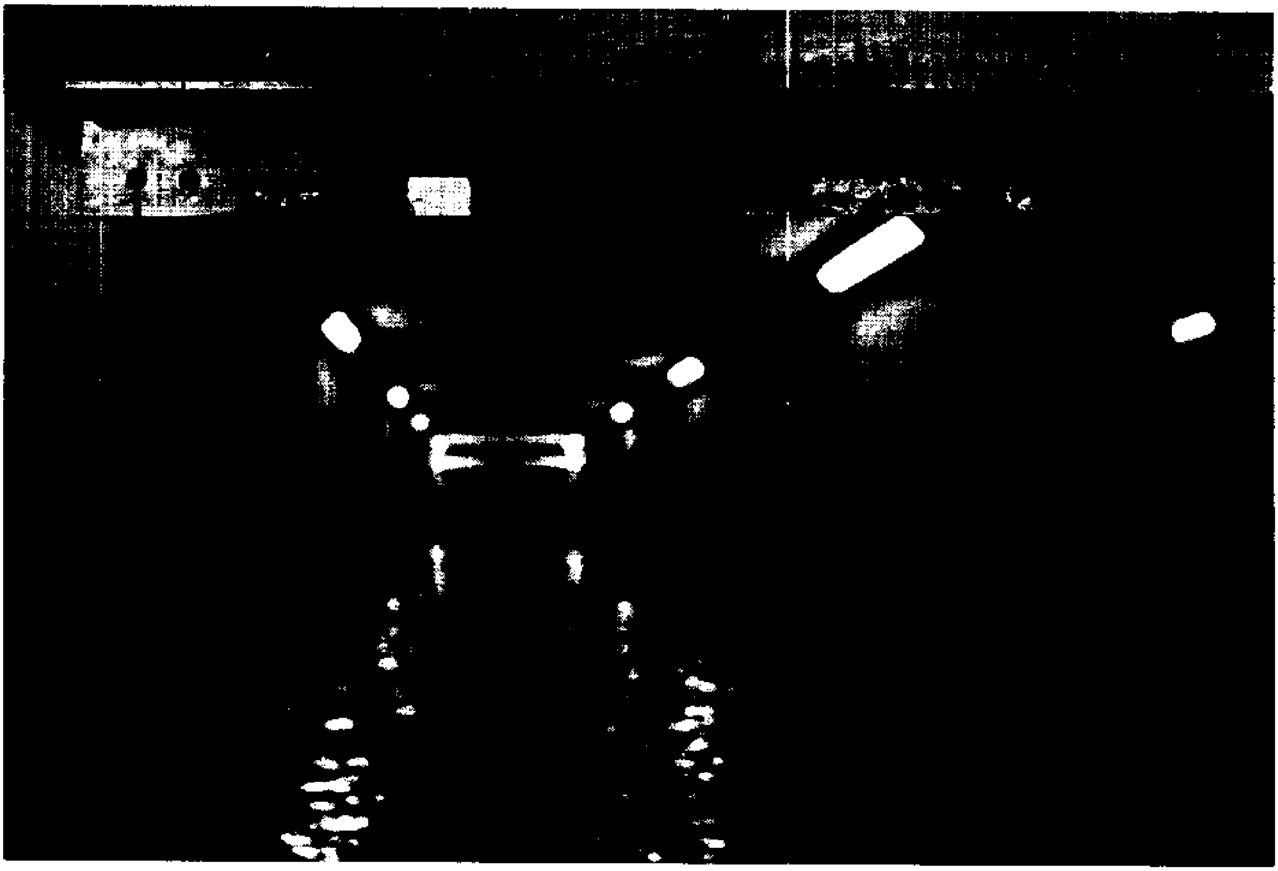


Figure I.9. Cantilever Force Transducer with Strain Gauge

Table 1

AUTOMOBILE TIRE SPECIFICATIONS

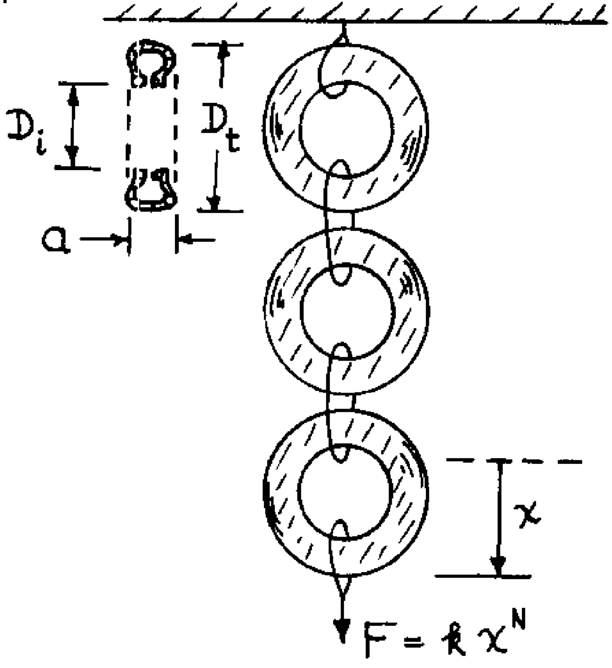
Scale	D_t (cm)	$\frac{D_i}{D_t}$	$\frac{a}{D_t}$	ρ (gm/cc)	W (in air) (kg_f)	W_w (in water) (kg_f)	W_{WA} (in water) (kg_f)
1/16	4.0	0.538	0.250	1.25	0.005	0.001	---
1/8	8.5	0.600	0.259	1.00	0.025	0.000	-0.009
1/4	15.2	0.513	0.283	1.25	0.195	0.039	-0.56
1/1	63.5	0.550	0.290	1.20	7.620	1.270	-5.000

Scale	L_R	$\frac{M}{M_1} \cdot L_R^3$	$\frac{W_{WA}}{W_{WA1}} \cdot L_R^3$	N	K (kg_f/cm^N)
1/16	15.9	2.64	---	---	---
1/8	7.47	1.37	1.11	1.3	0.18
1/4	4.18	1.87	0.82	---	---
1/1	1.00	1.00	1.00	2.4	0.12

W = Mg - (buoyancy force) = net weight in fluid

W_{WA} = net weight in fresh water with air trapped in crown of tire

L_R = length ratio = $\frac{\text{Dia. of prototype}}{\text{Dia. of model}}$



Appendix I.B

Laboratory Data for the Goodyear FTB

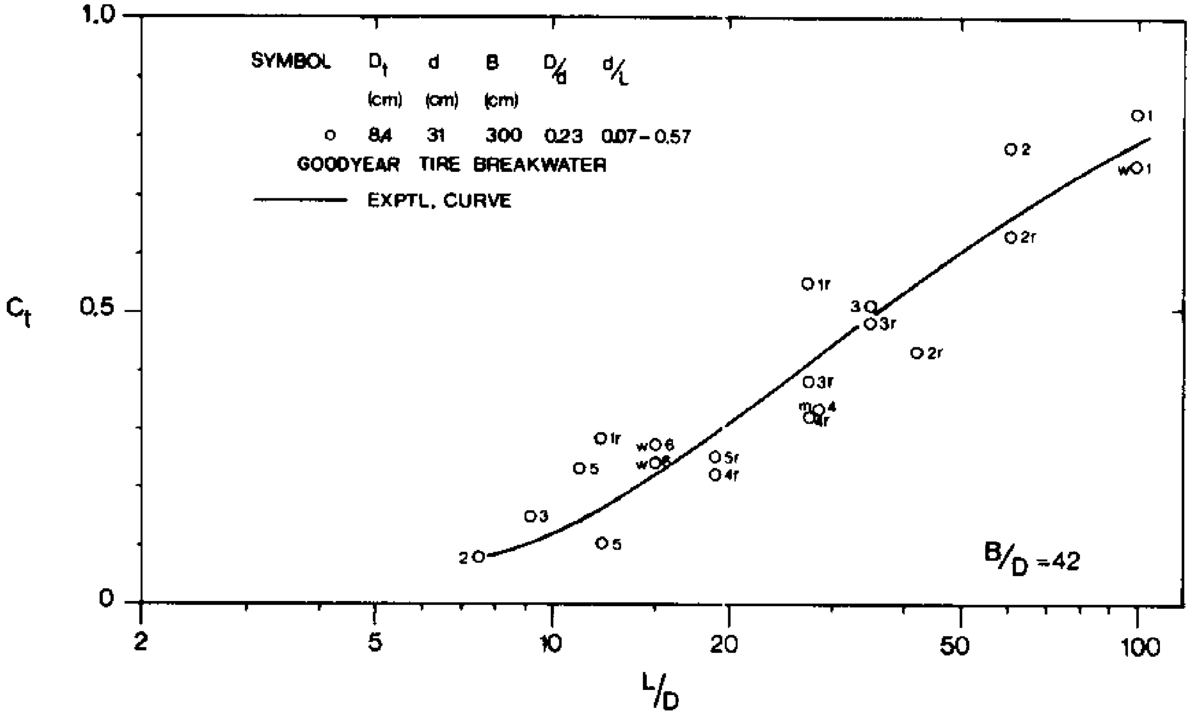


Fig. I.10 Transmission Data for Goodyear FTB
(12-module beam)

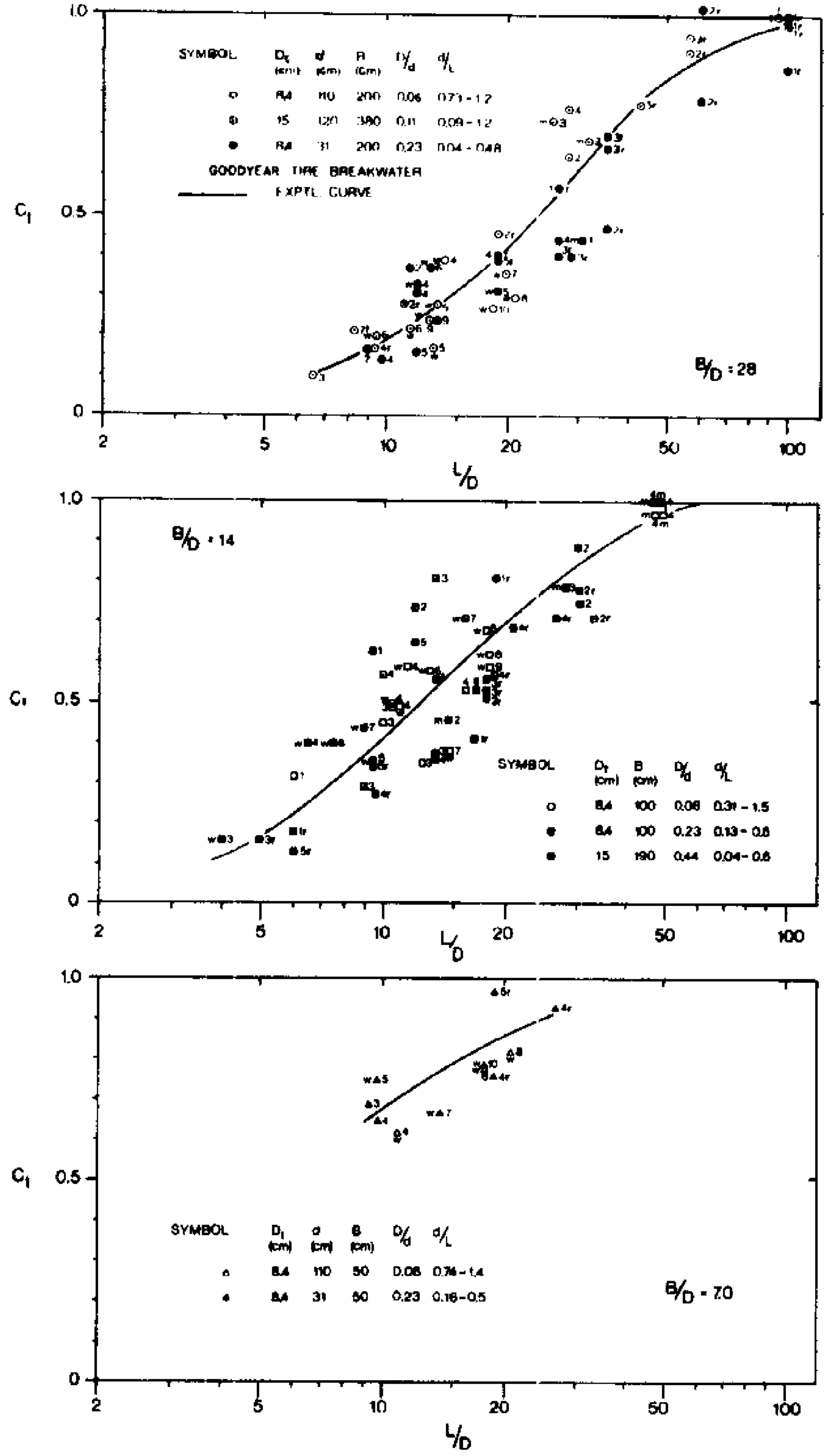


Fig. I.11 Transmission Data for Goodyear FTB (2, 4, and 8-module beam sizes)

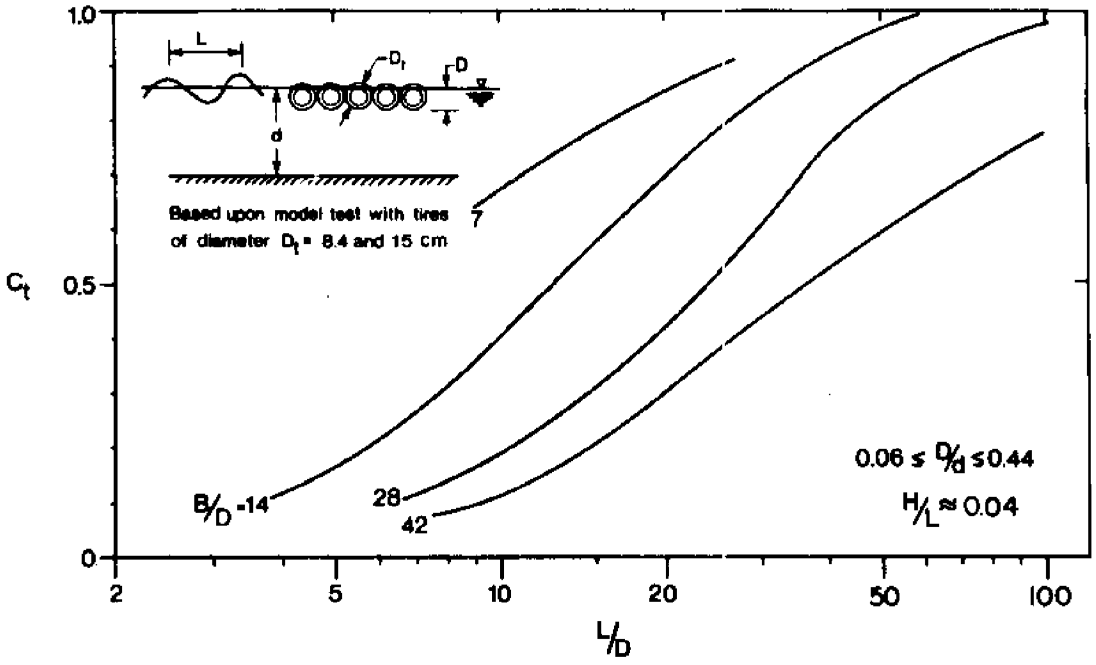


Fig. I.12 Transmission Curves from Fig. I.10 and I.11, $C_t = f(L/D)$

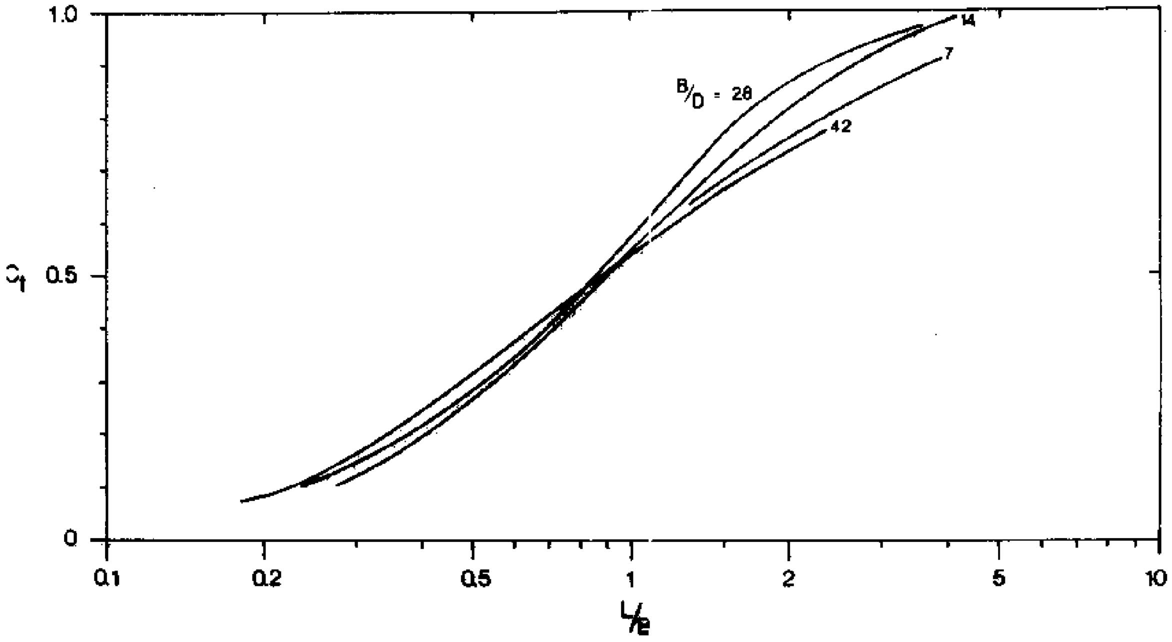


Figure I.13. Transmission Curves from Fig. I.12, C_t = f(L/B) now.

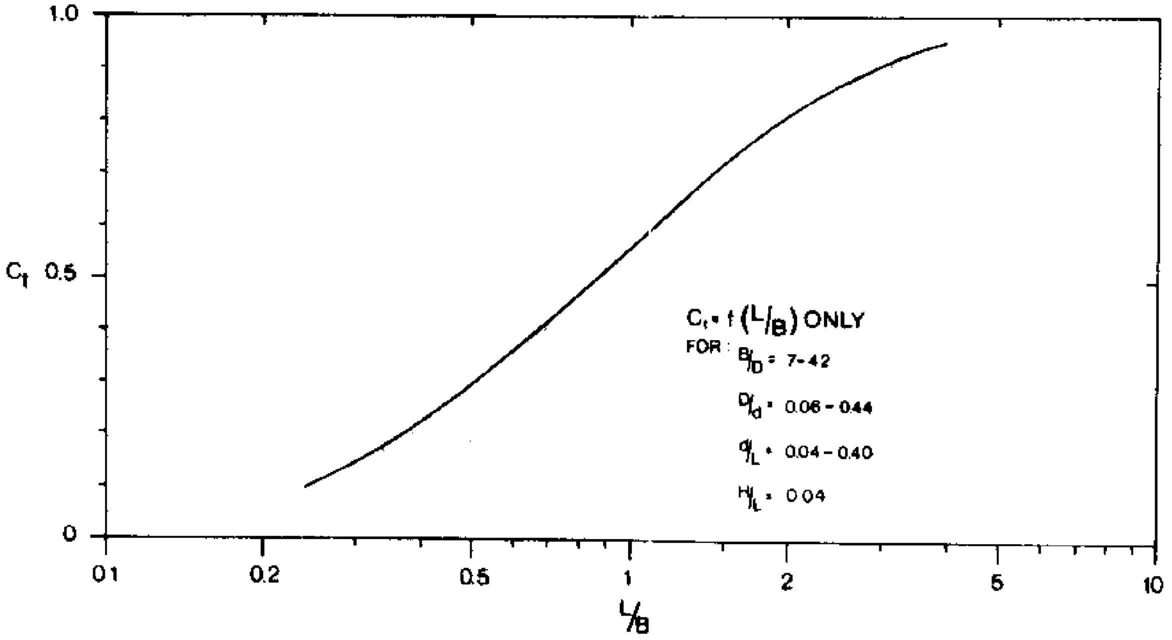


Figure I.14. Single Averaged Transmission Curve (from Fig. I.13)

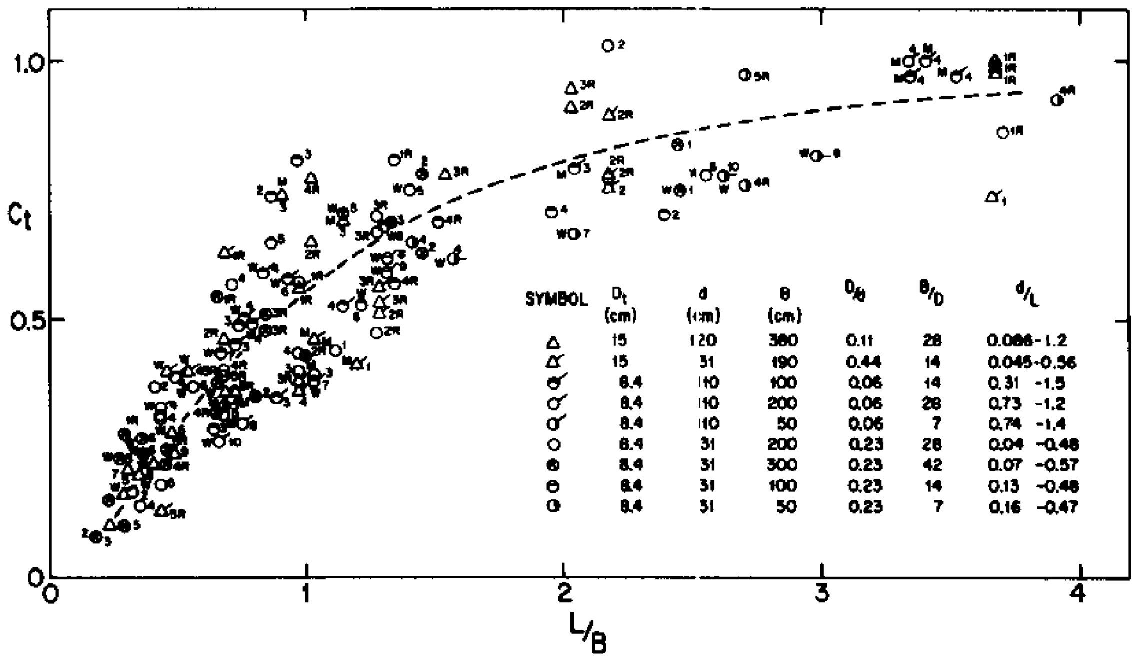


Figure I.15. Summary of all data (curve from Fig. I.14)

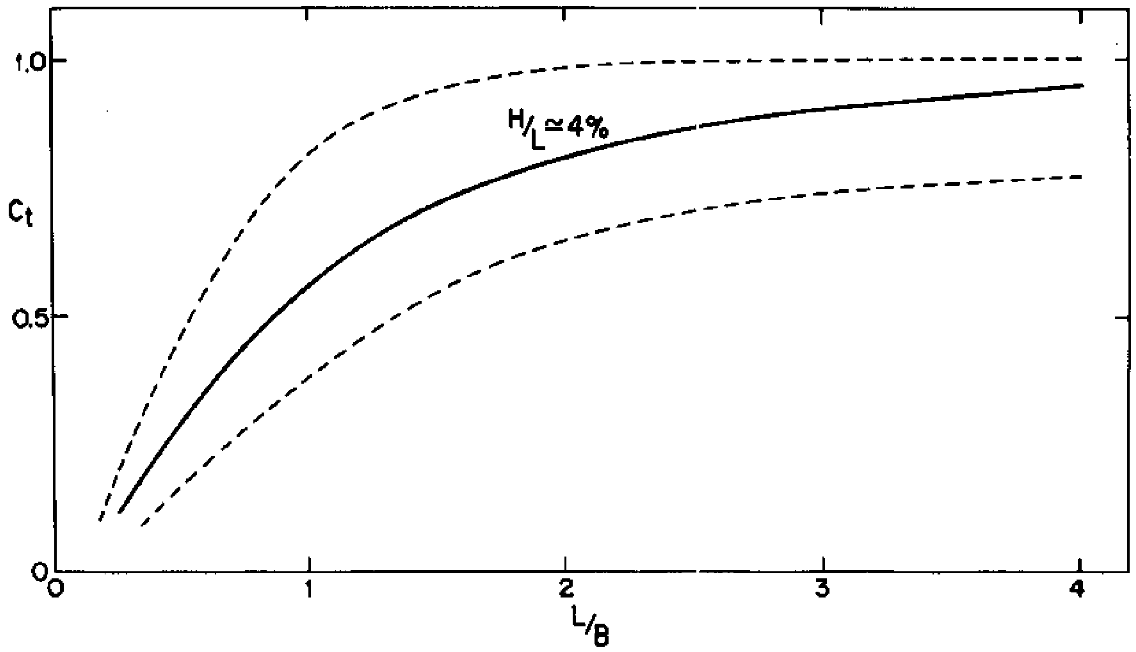


Figure I.16. 4%-Design-Curve and Limits of Data

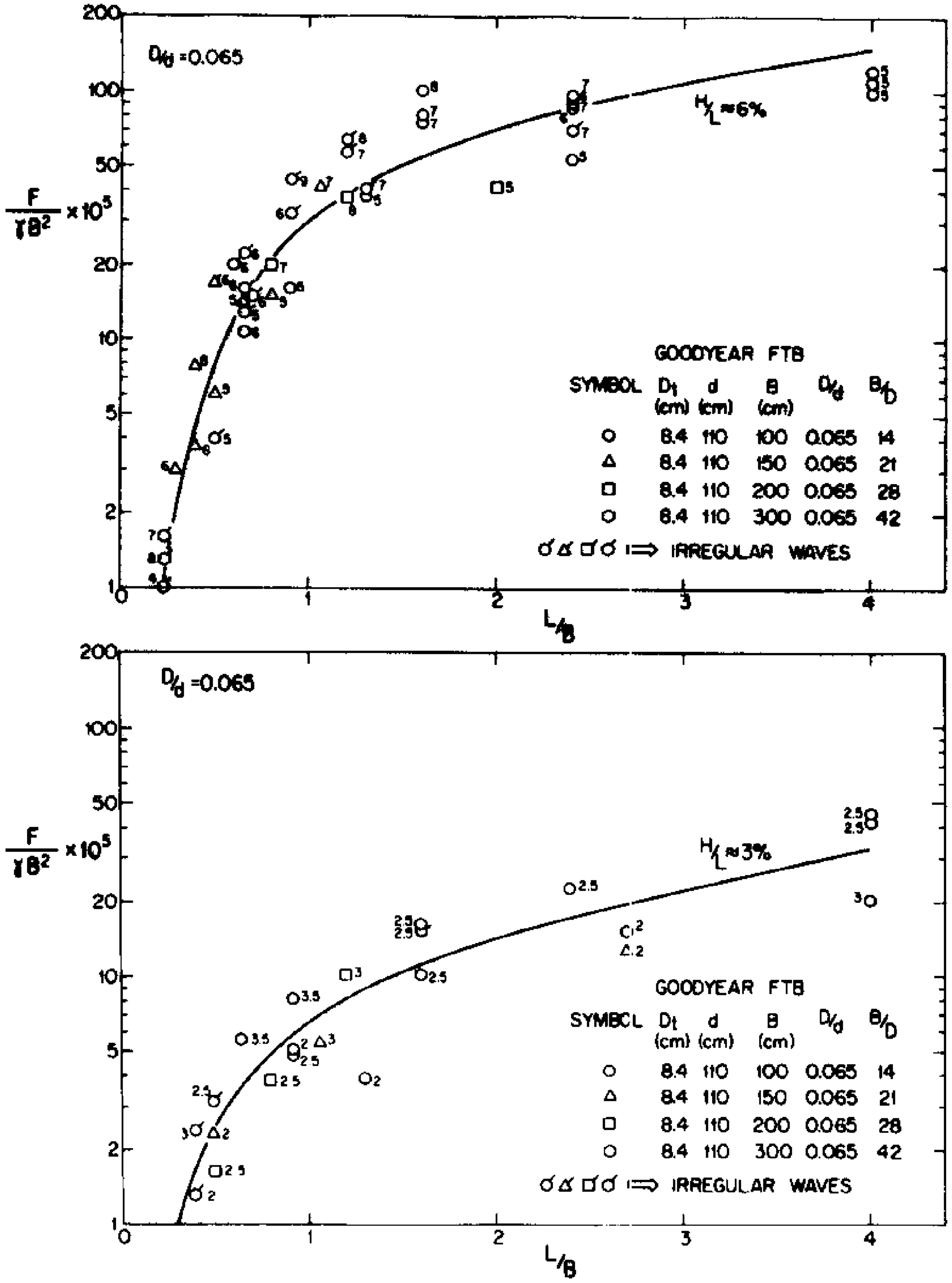


Figure I.17. Force Data for D/d = 0.065 (H/L = 3% and 6%)

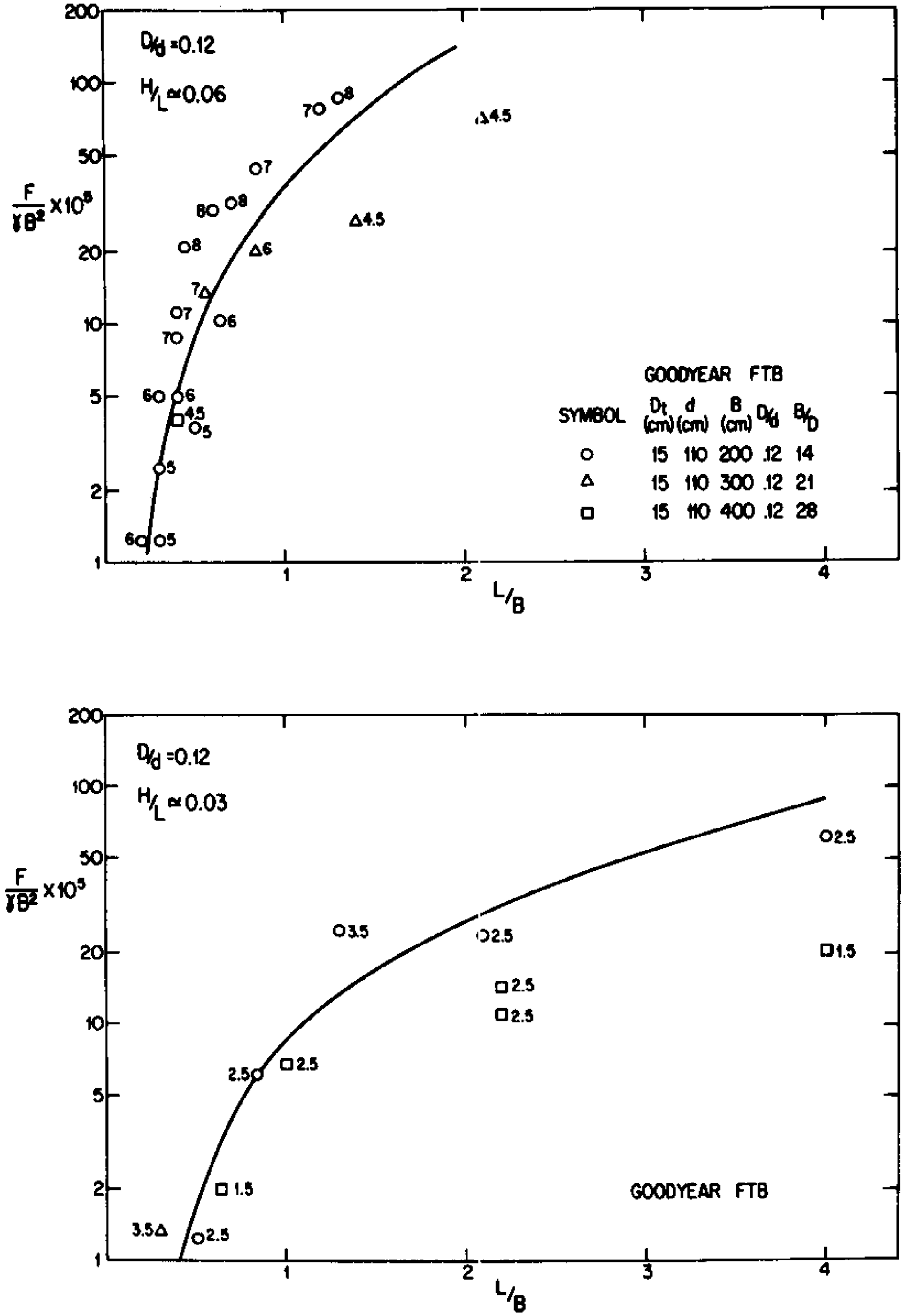


Figure I.18. Force Data for D/d = 0.12 (H/L = 3% and 6%)

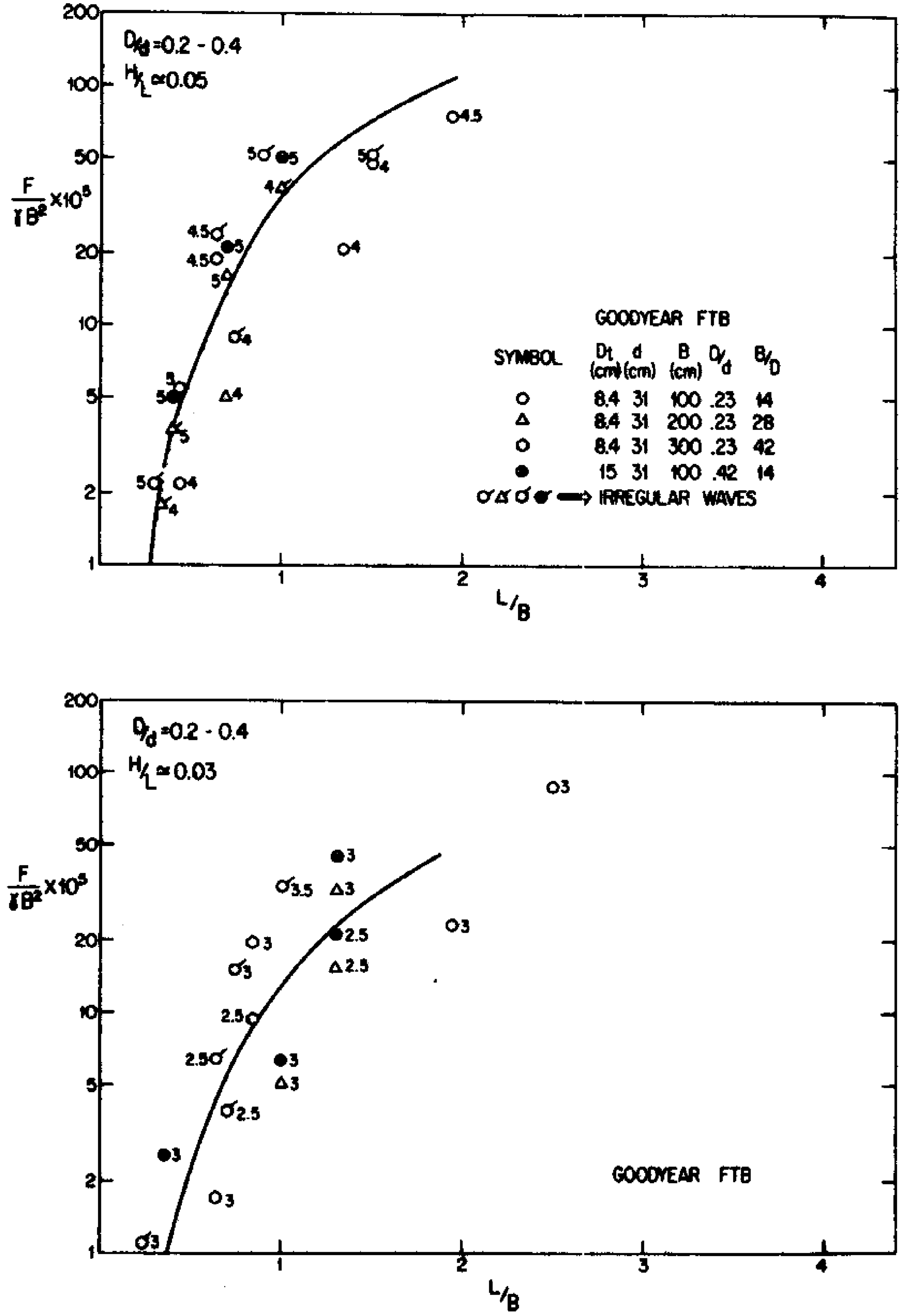


Figure I.19. Force Data for D/d = 0.2 - 0.4 (H/L = 3% and 5%)

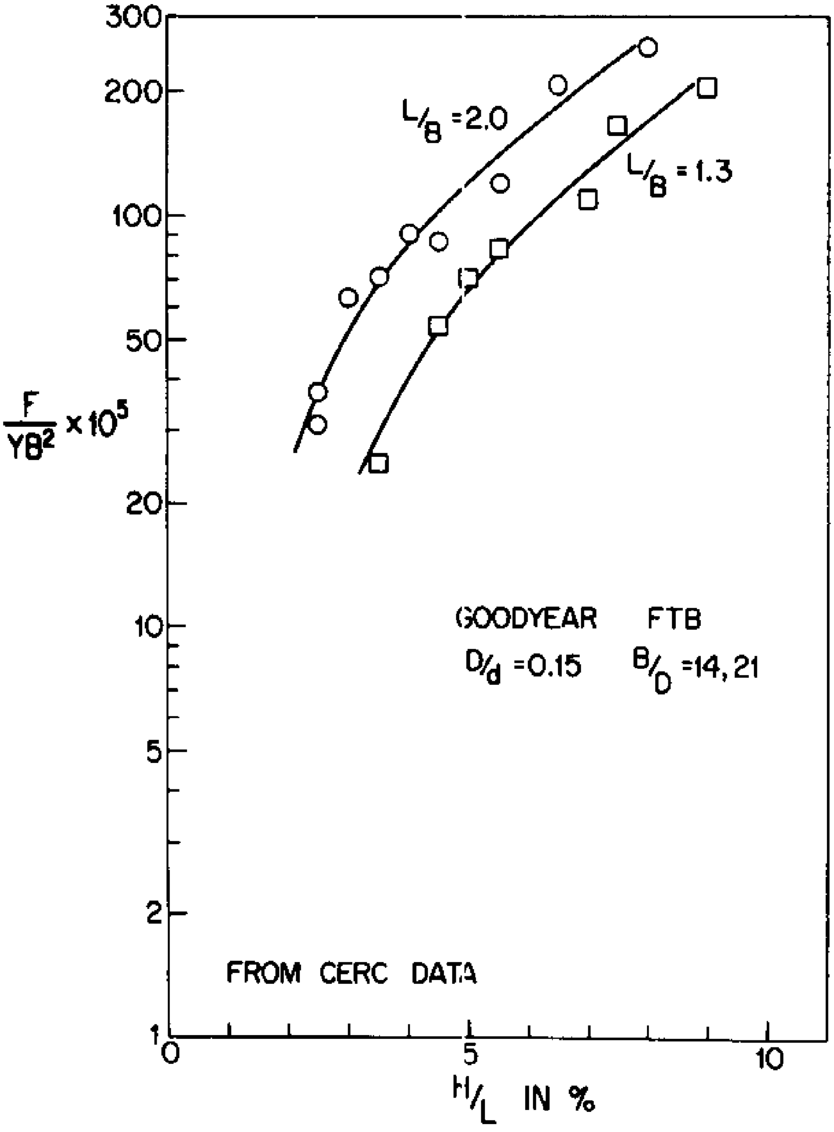


Figure I.20. Influence of Wave Steepness Upon Mooring Force

APPENDIX I.C.

LABORATORY DATA FOR THE WAVE-GUARD FTB

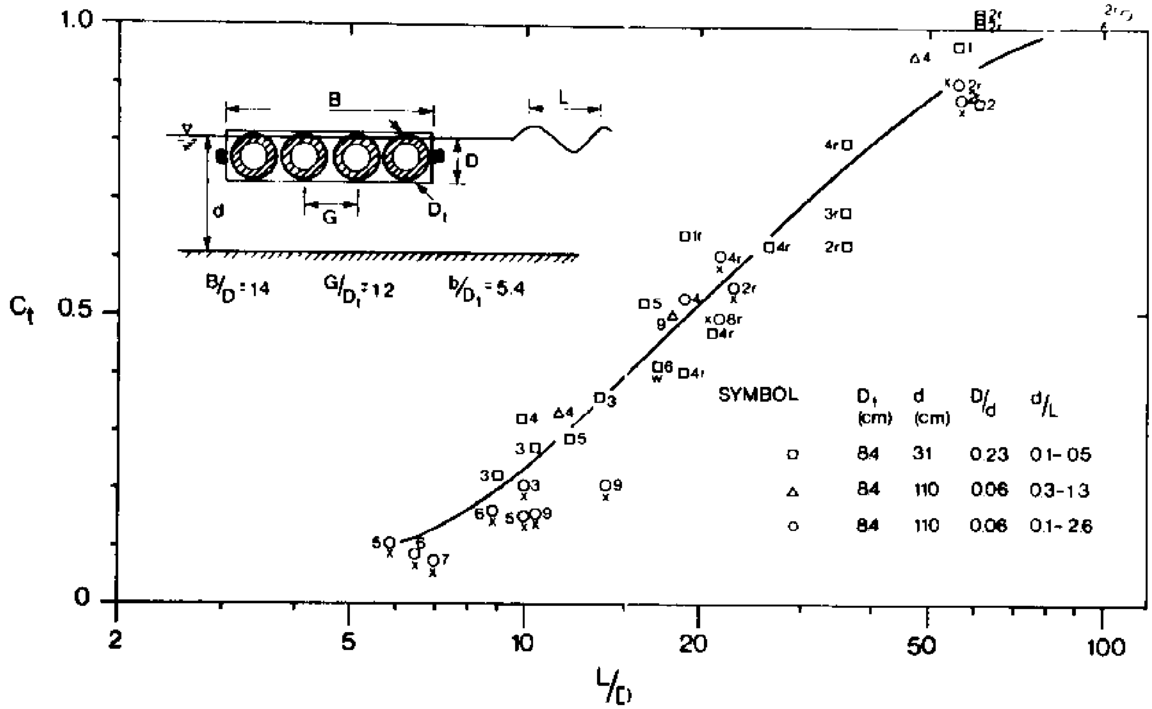


Figure I.21. Transmission Data for Wave-Guard FTB (normal floatation)

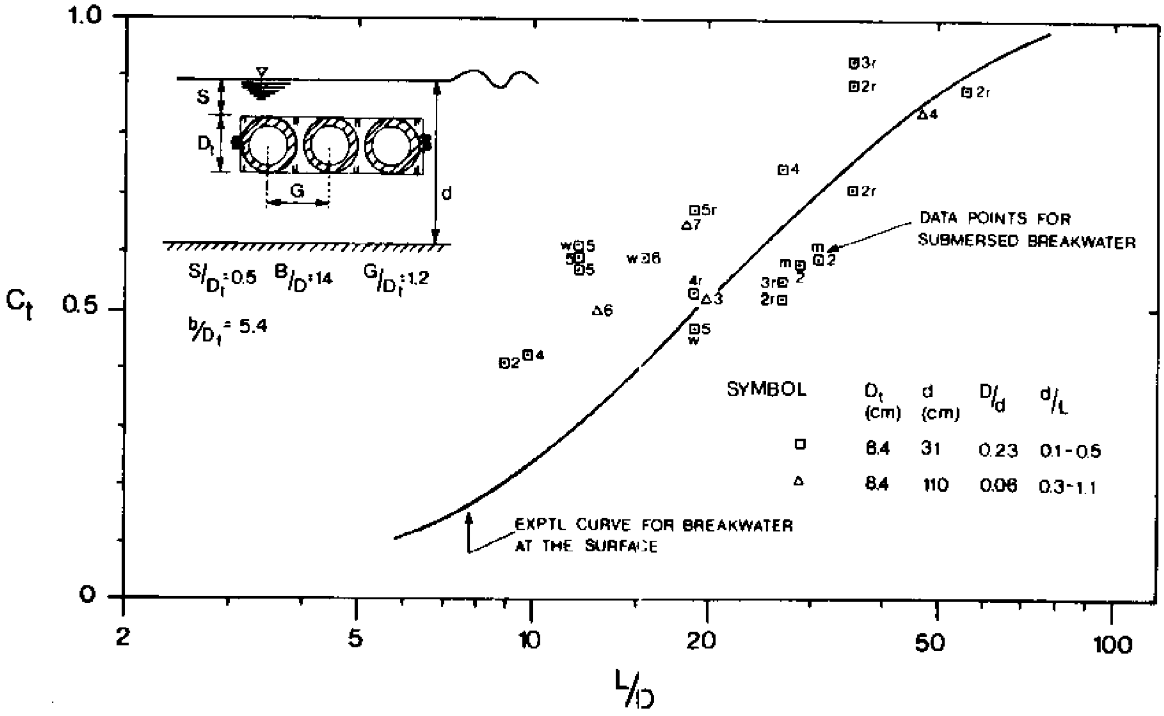


Figure I.22. Transmission Data for Wave-Guard FTB (submerged case)

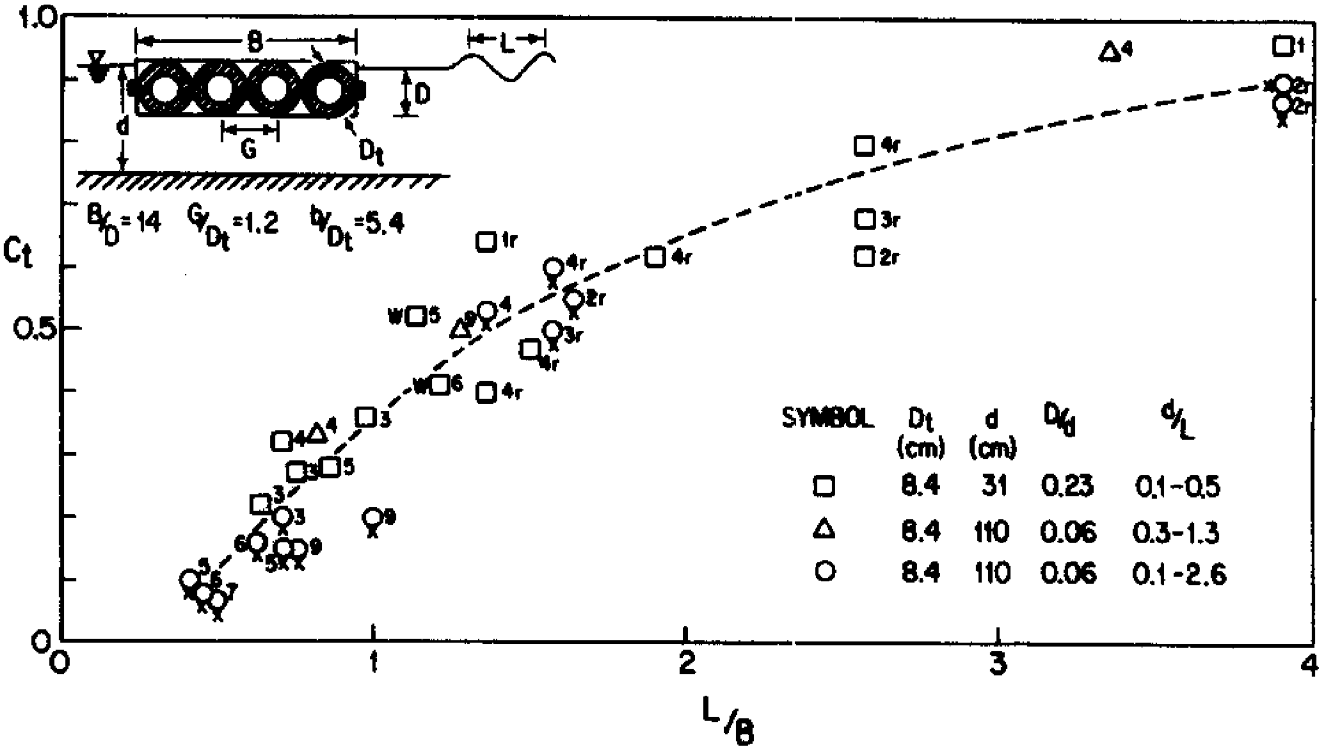


Figure I.23. Transmission Data Plotted as Function of L/B (from Fig. I.21)

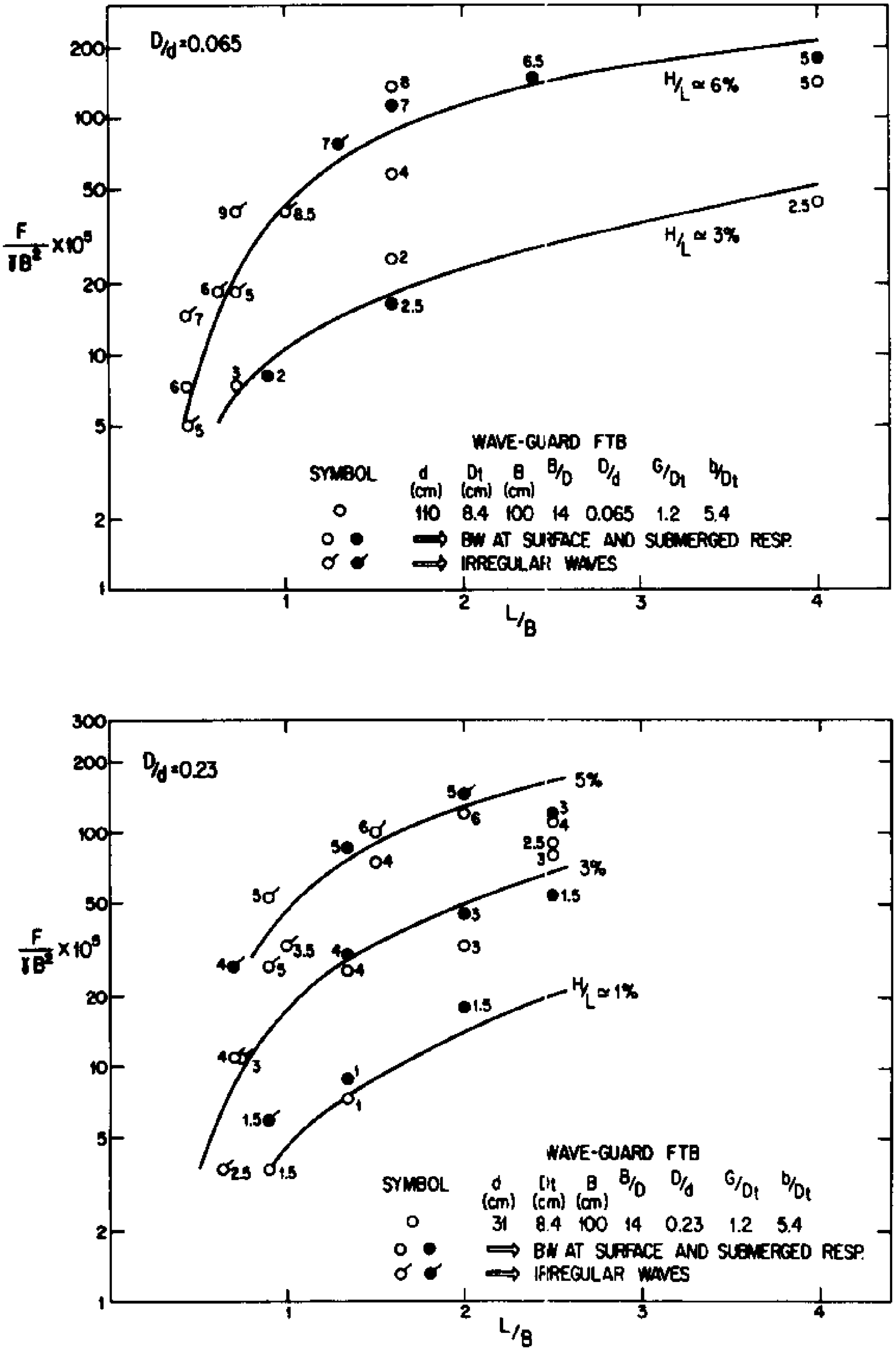


Figure I.24. Force Data for Wave-Guard FTB (D/d = 0.065 and 0.23)

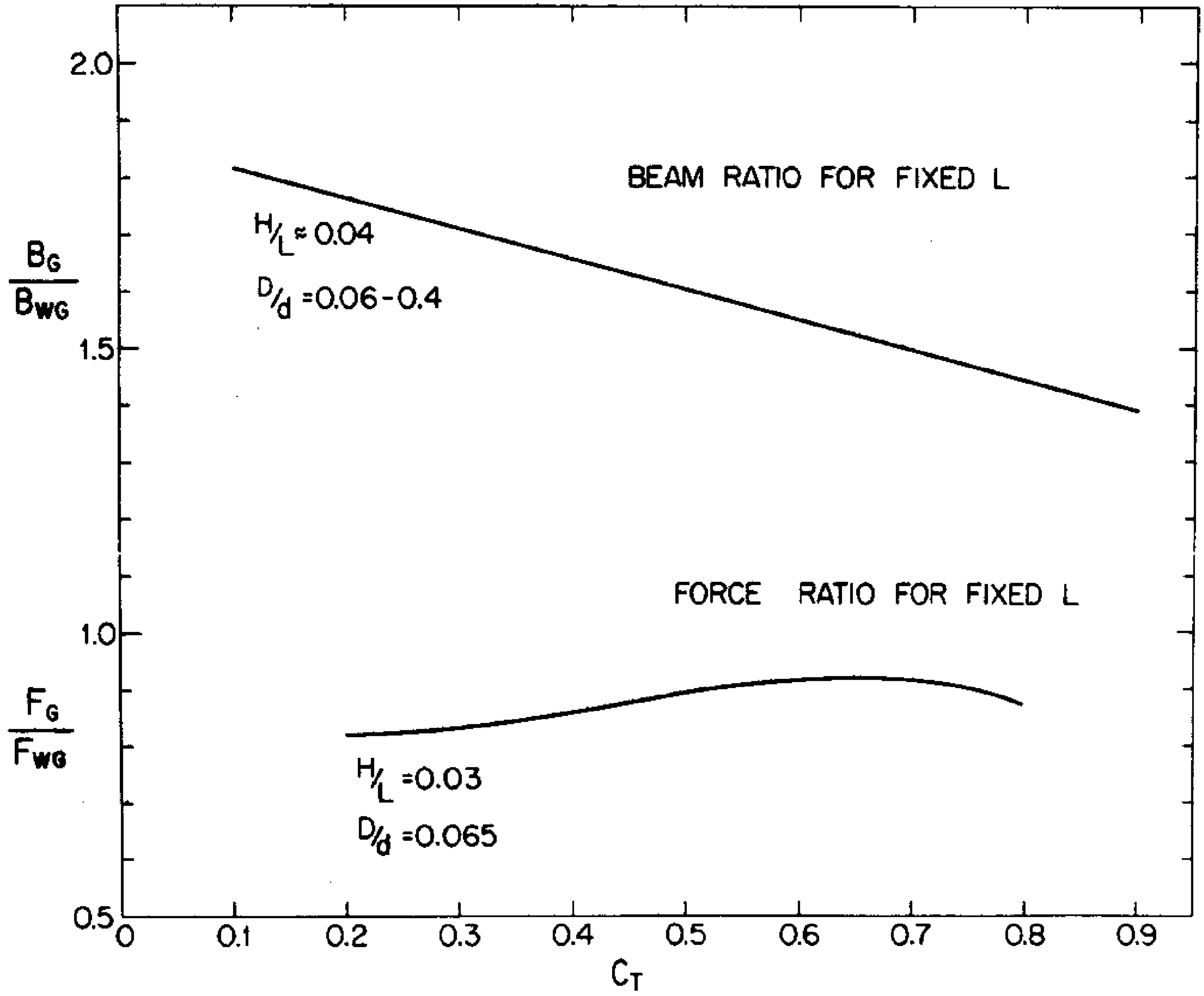


Figure I.25. Comparison of Beam Size and Mooring Force for Goodyear (G) and Wave-Guard (WG) FTB

APPENDIX I.D.

LABORATORY DATA FOR WAVE-MAZE FTB
[Data Source: Kamel (1968)]

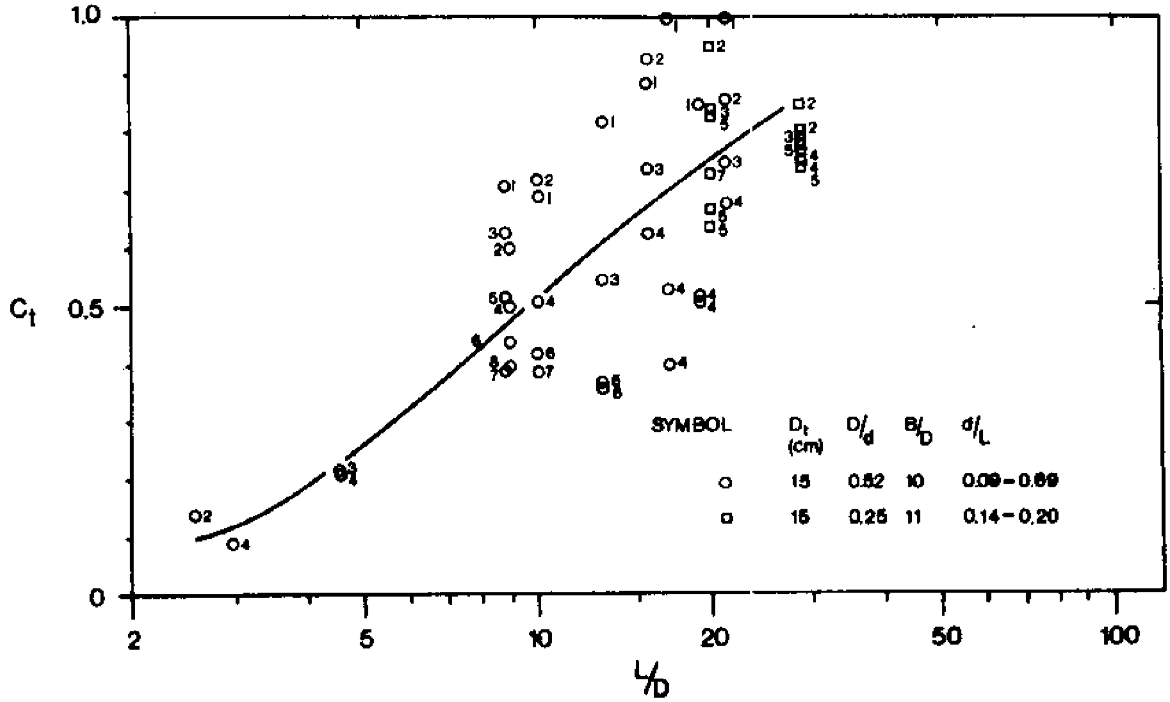


Figure I.26. Transmission Data for Wave-Maze FTB (B/D = 10 and 11)

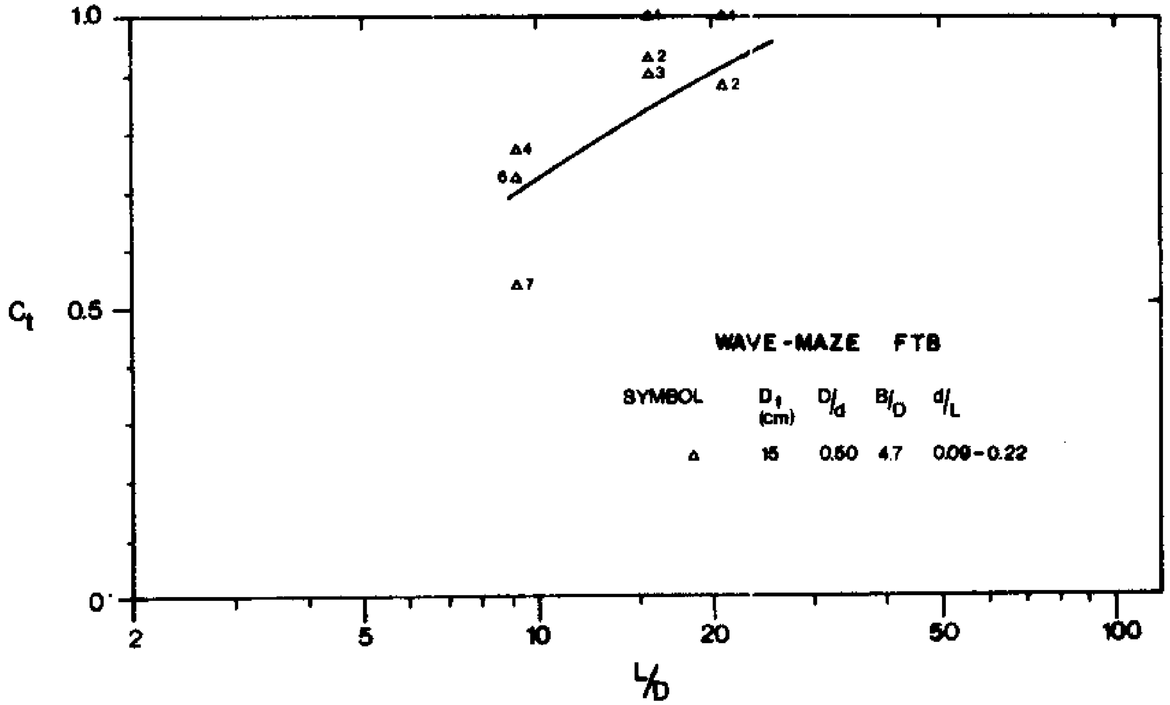


Figure I.27. Transmission Data for Wave-Maze FTB (B/D = 4.7)

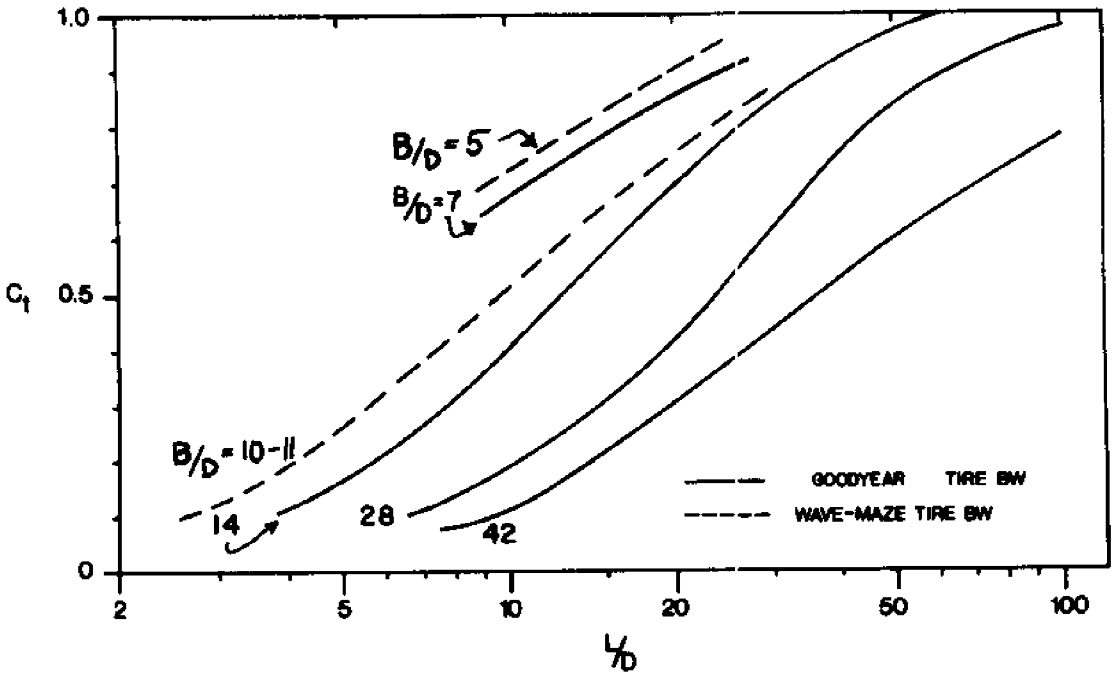


Figure I.28. Comparison of Wave-Maze and Goodyear Transmission Curves

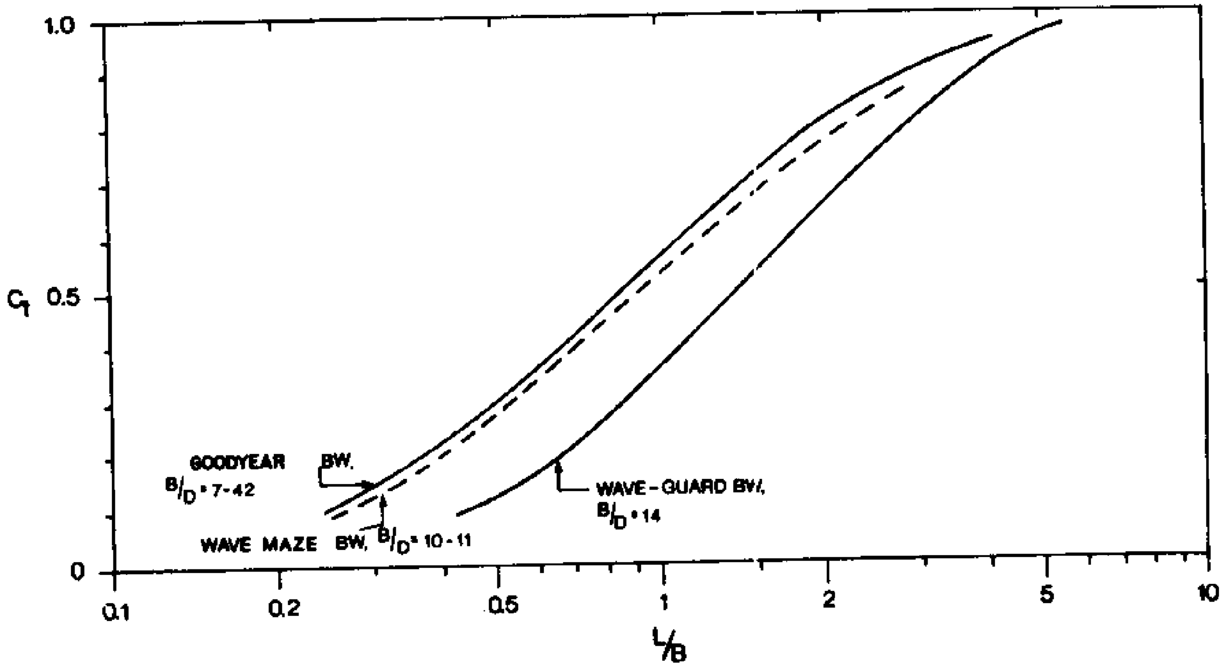


Figure I.29. Comparison of Wave-Maze, Goodyear and Wave-Guard Transmission Curves

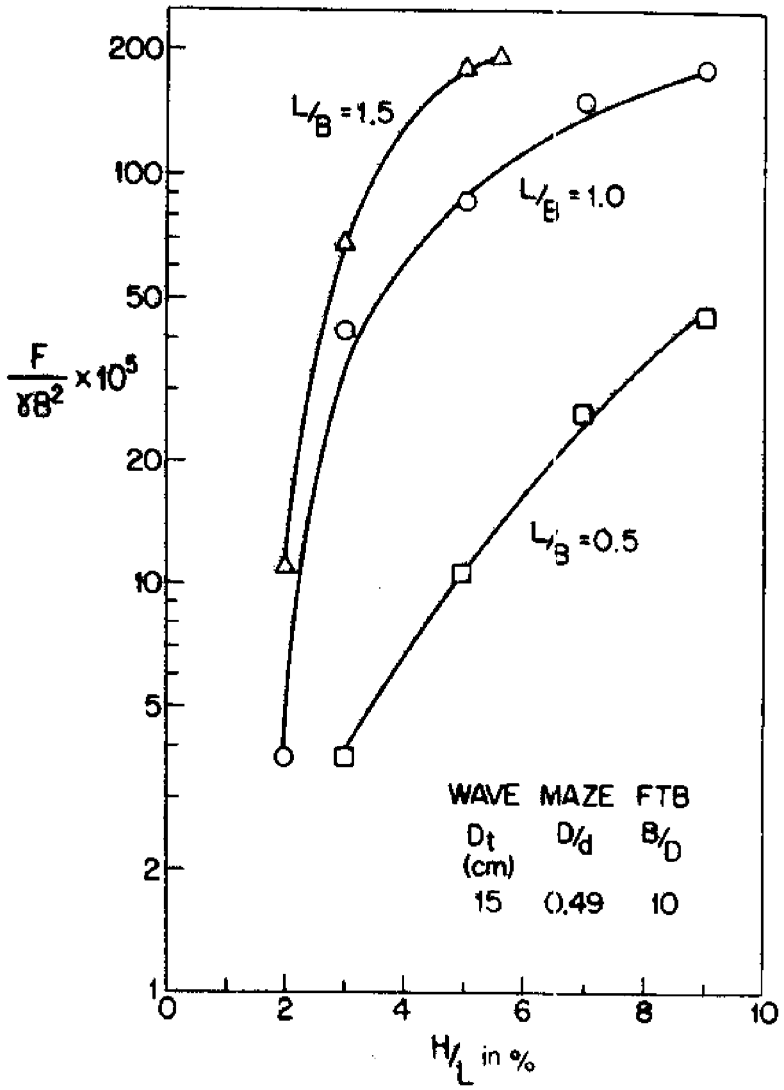


Figure I.30. Influence of Wave Steepness Upon Peak Mooring Force

APPENDIX I.E.

LABORATORY DATA FOR MULTI-LAYER-GOODYEAR FTB

Figure I.31. Two-Layer-Goodyear FTB (elevation)

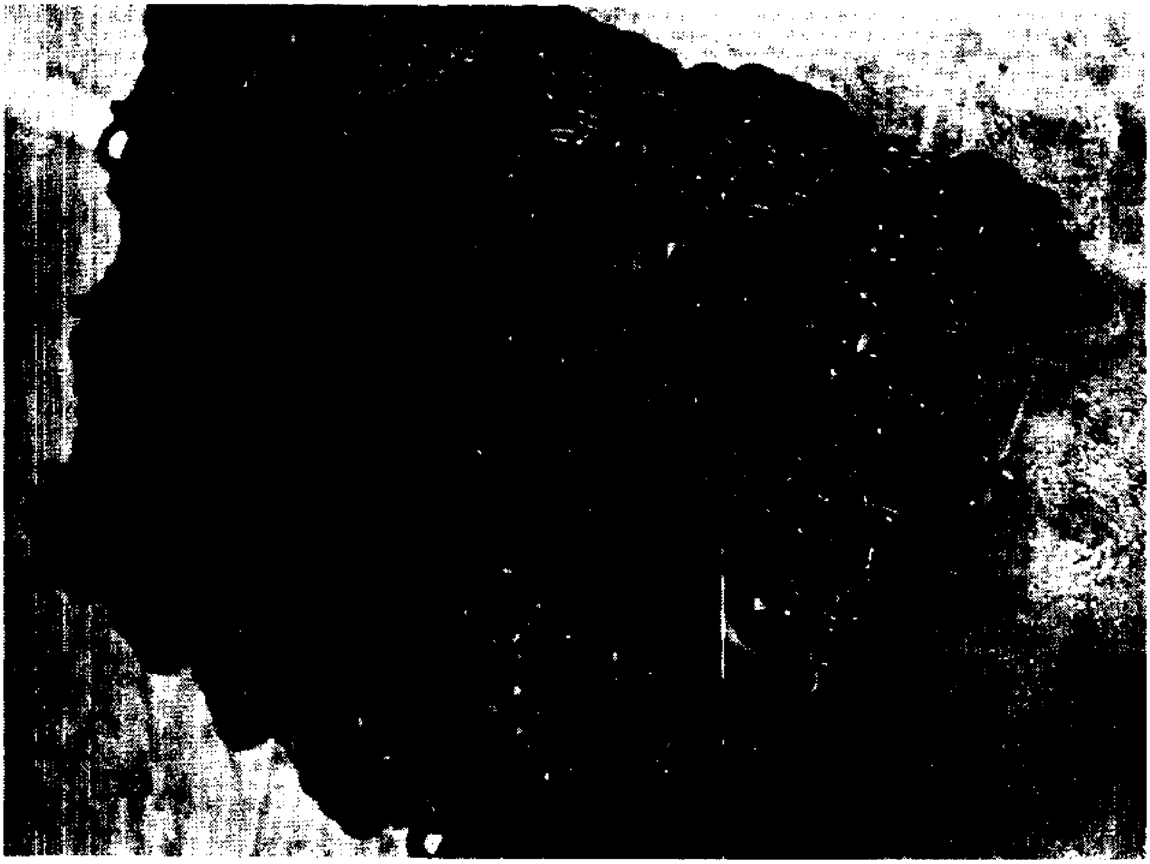


Figure I.32. Plan View of Two-Layer-Goodyear FTB.

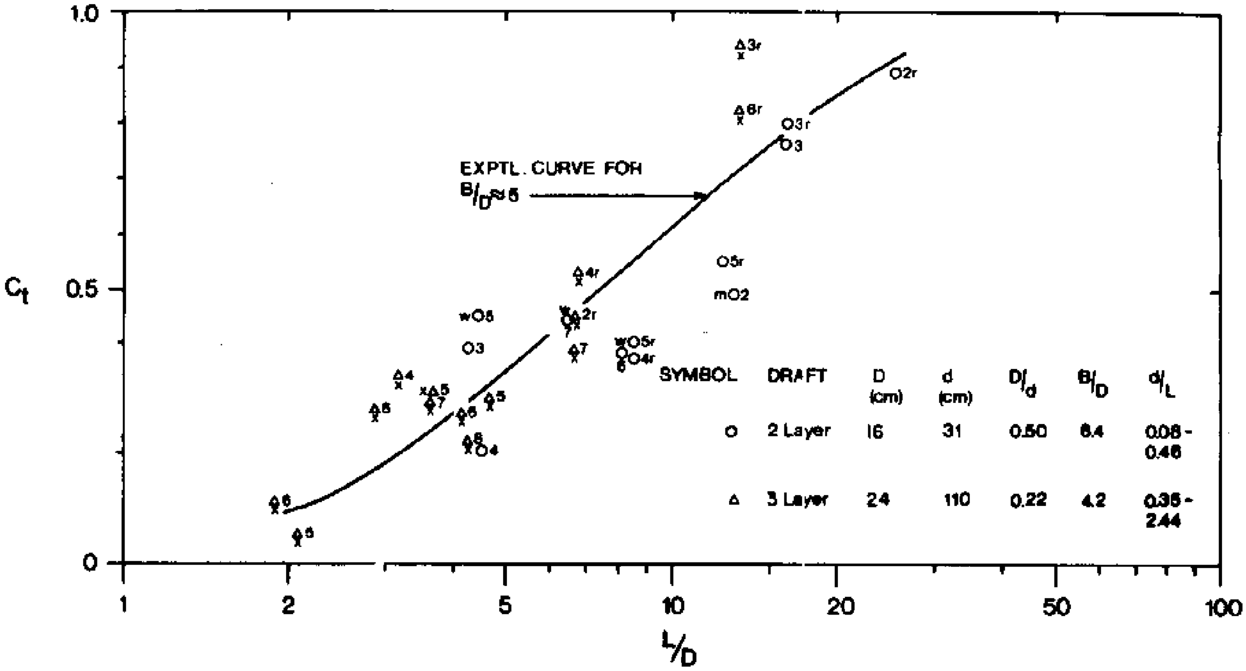


Figure I.33. Transmission Data for Two-Layer-Goodyear FTB

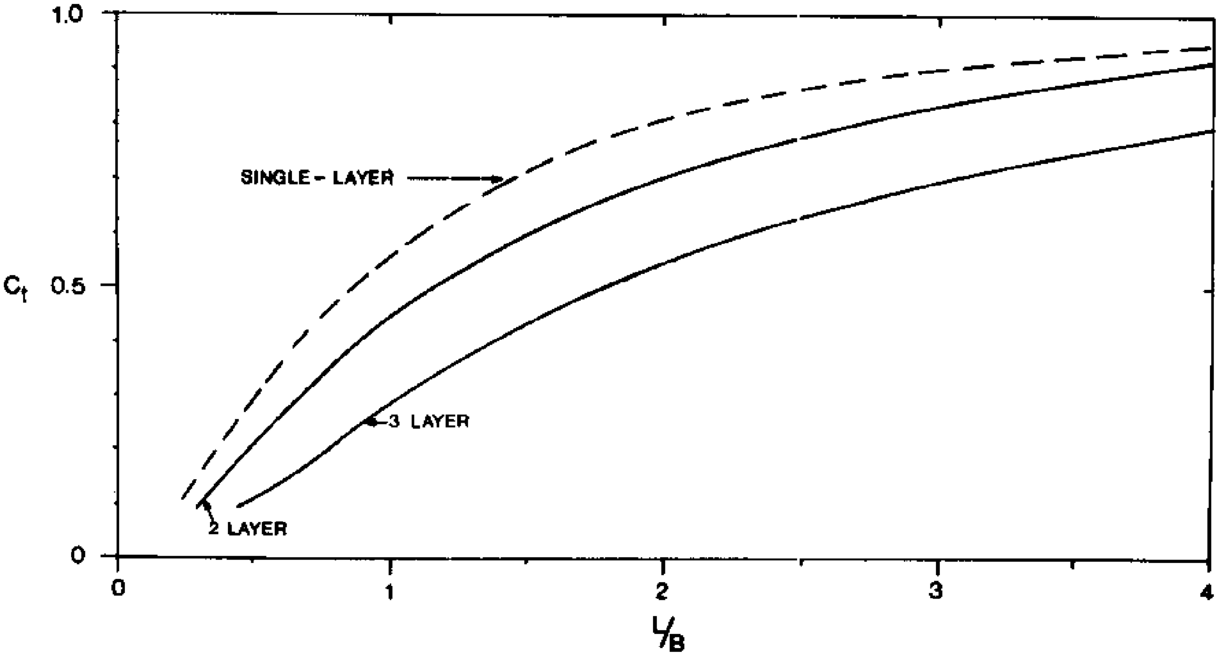


Figure I.34. Approximate Design Curves for 2-Layer and 3-Layer Goodyear FTB's

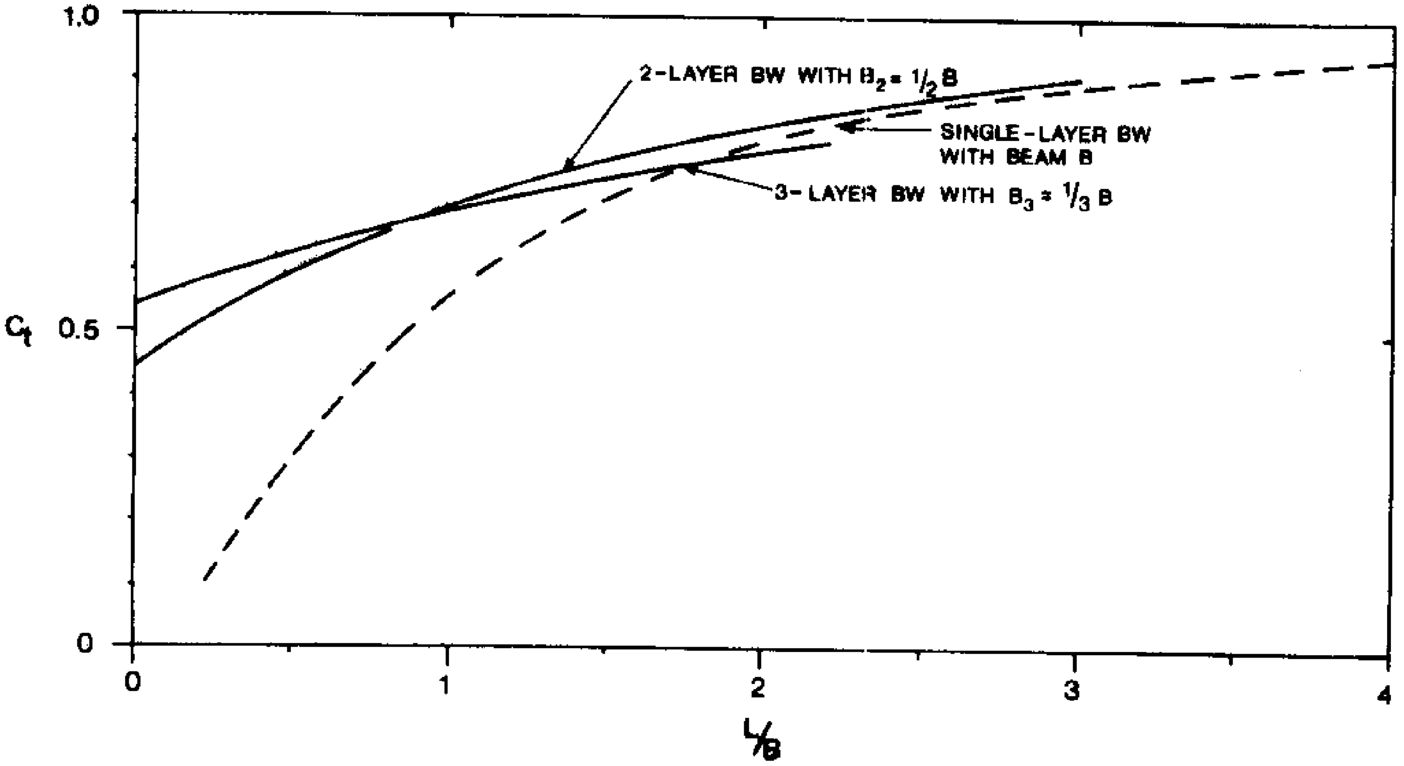


Figure I.35. Comparison of Transmission Curves of Single-Layer and Multi-Layer Goodyear FTB's (all assembled from an equal number of tire modules)

APPENDIX I.F.

INFLUENCE OF TIRE MOORING DAMPER

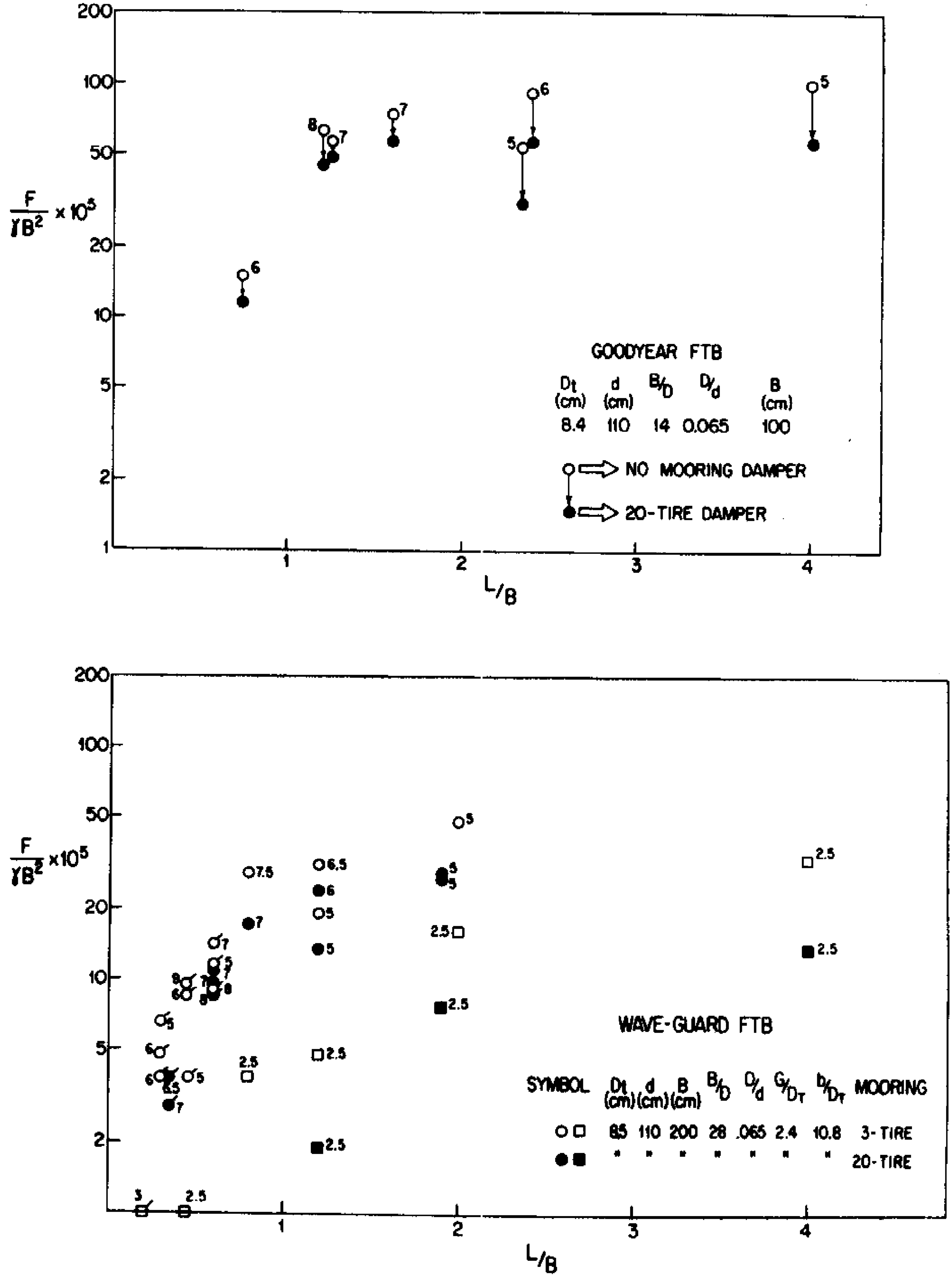


Figure I.36. Influence of 20-Tire Mooring Damper on Goodyear and Wave-Guard FTB

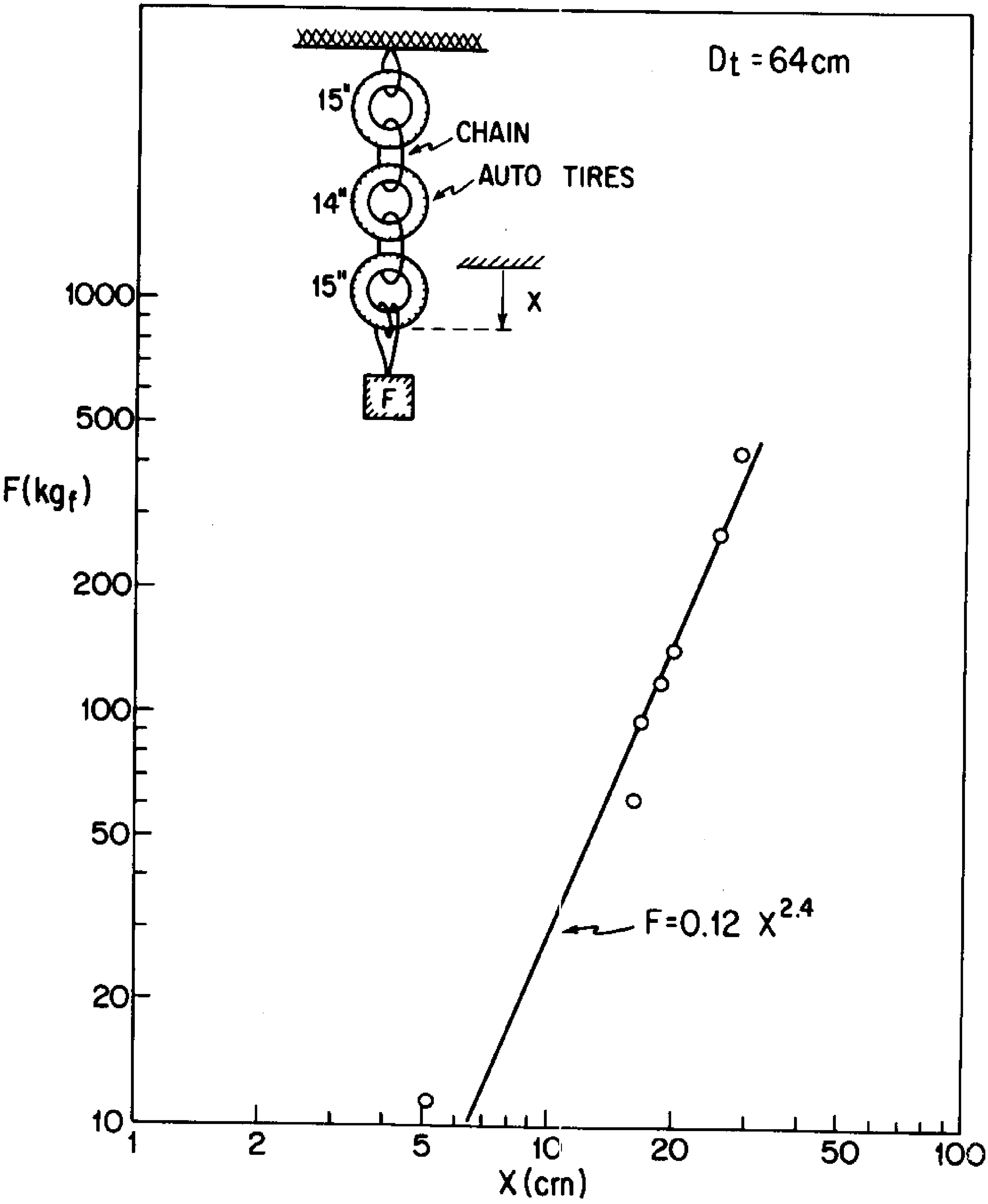


Figure I.37. Force-Displacement Relationship for Prototype 3-Tire Mooring Damper

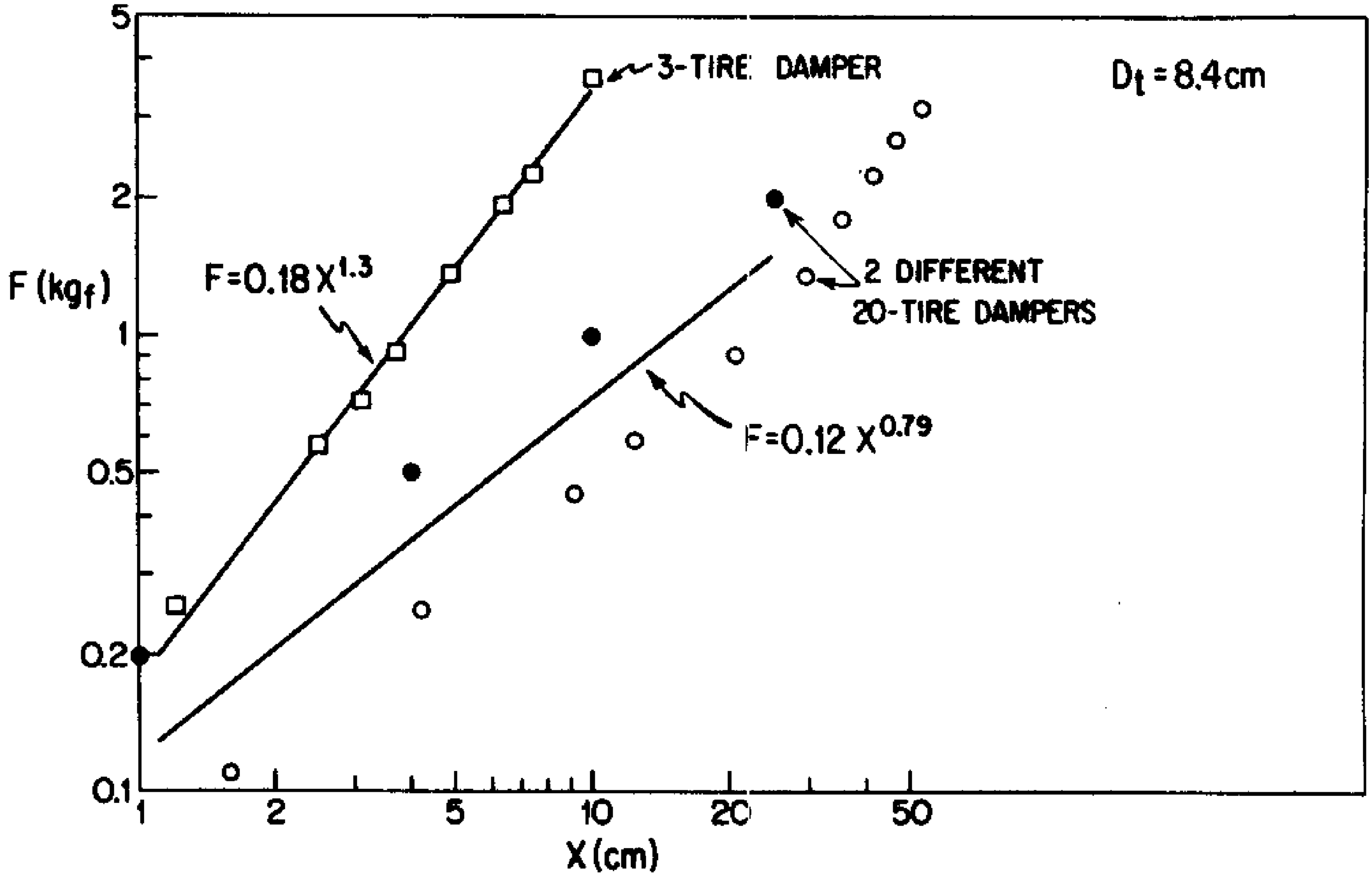


Figure I.38. Force-Displacement Relationship for 1/8-Scale Tire Mooring Dampers

APPENDIX II

FULL-SCALE VERIFICATION OF MODEL DATA

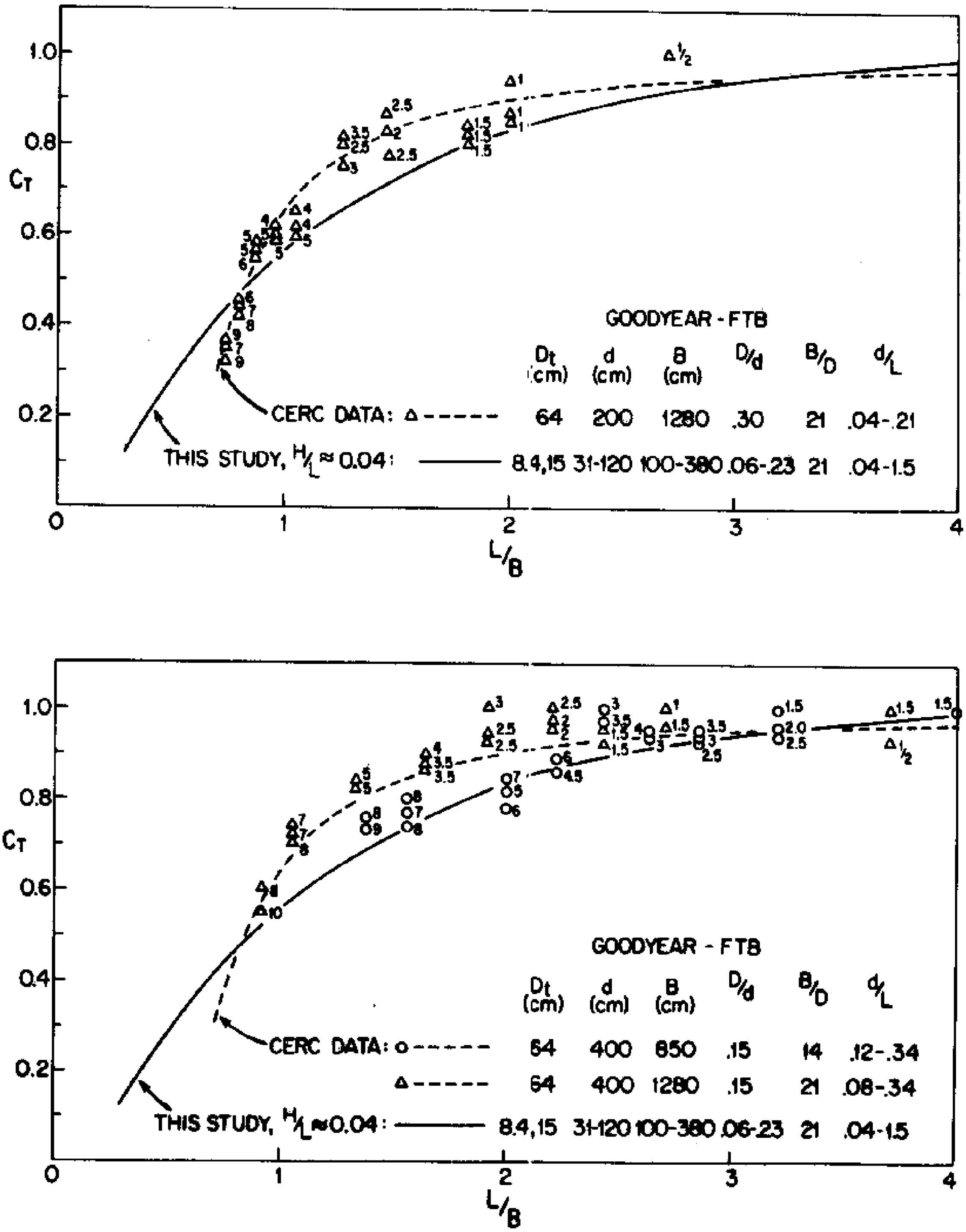


Figure II.1. Comparison of Full-Scale Wave-Transmission Data (D/d = 0.3 and 0.15) With 1/4 and 1/8-Scale Model Data

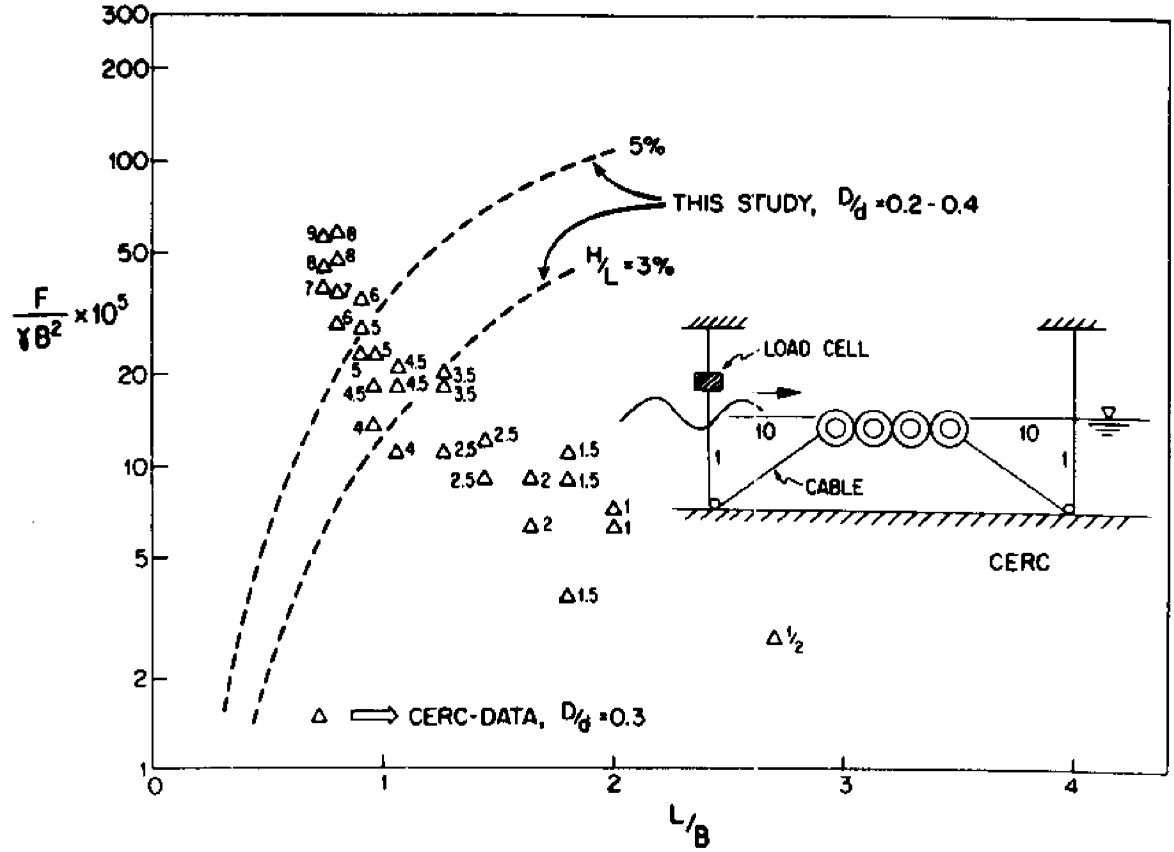


Figure II.2. Full-Scale Force Data Compared to Model Data (D/d = 0.3)

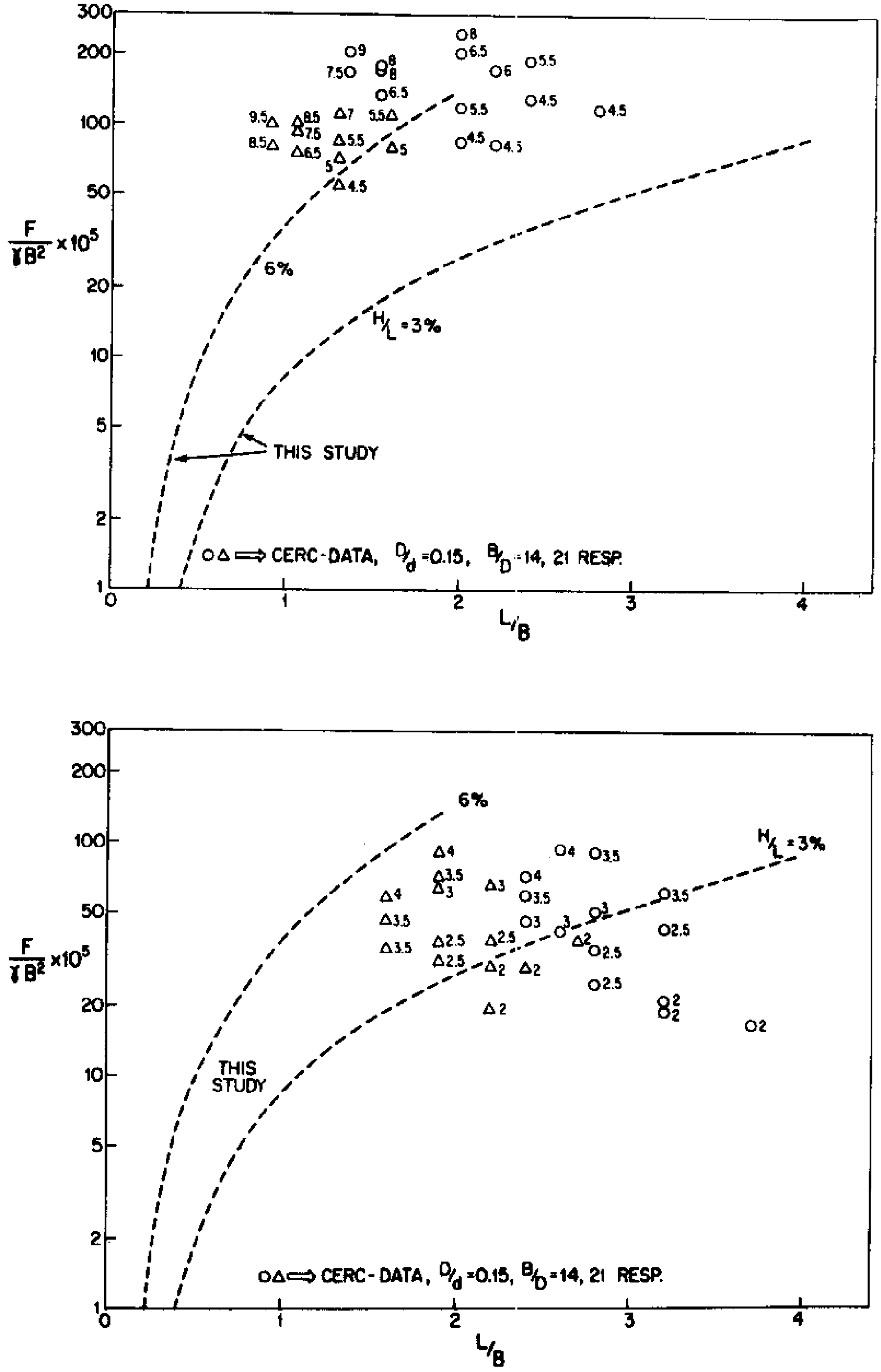


Figure II.3. Full-Scale Force Data Compared to Model Data (D/d = 0.15)

Appendix III Generation of Wind Waves - Wave Period T_x

The figures in this section have been reproduced from the Shore Protection Manual (SPM) of the U.S. Army Coastal Engineering Research Center, Second Edition, 1975. Figures III.1 - III.10 are used for estimating heights and periods of waves generated by winds blowing over relatively shallow bodies of water (from 5 to 50 feet in depth). For depths in excess of 50 feet, it is suggested that Fig. III.11, "Deepwater Wave Forecasting Curves," be used. The extreme-event wave period, T_x, that is needed in the design procedure of Section IV, is obtained from these graphs: this parameter is simply labelled "T" in Fig. III.1 - III.10, and referred to as "significant period" in Fig. III.11.

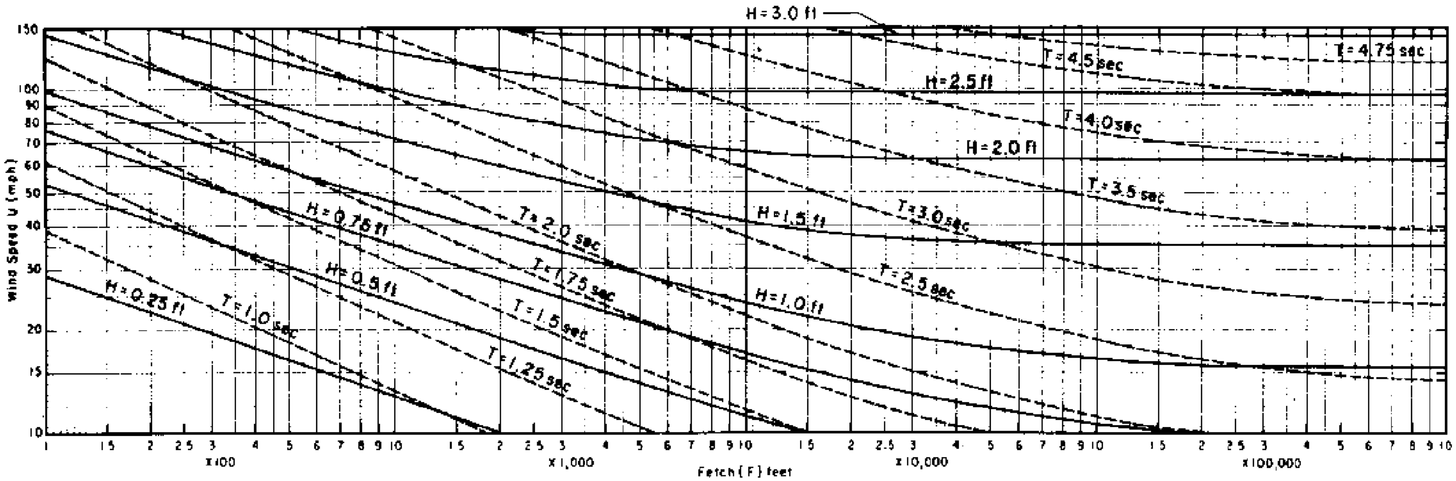


Figure III.1 Forecasting Curves for Shallow-Water Waves. Constant Depth = 5 feet.

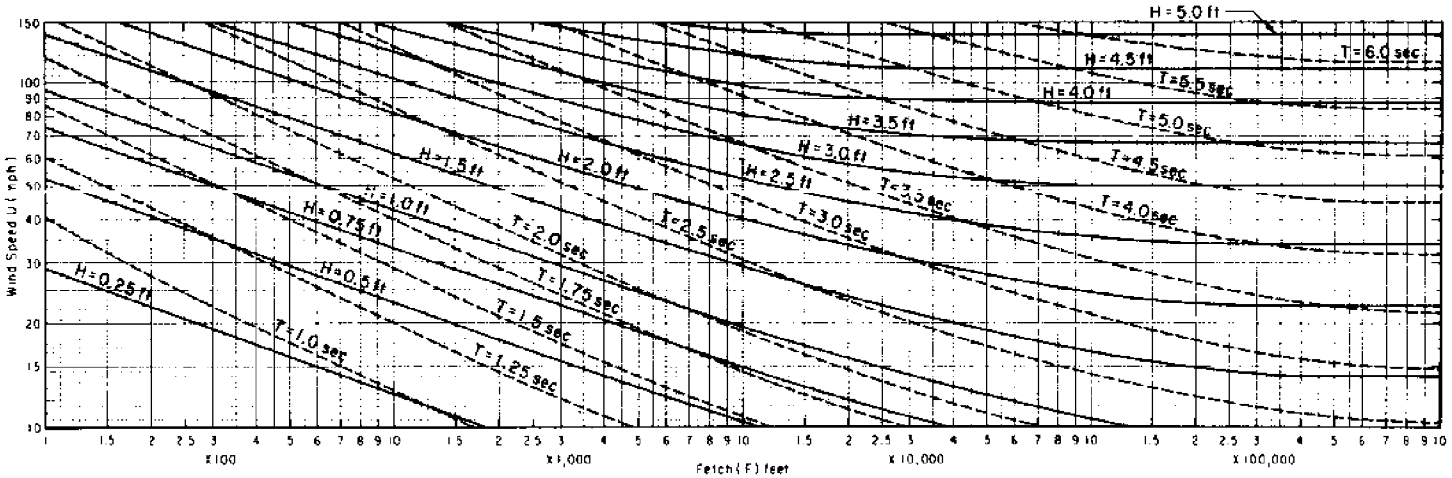


Figure III.2 Forecasting Curves for Shallow-Water Waves. Constant Depth = 10 feet.

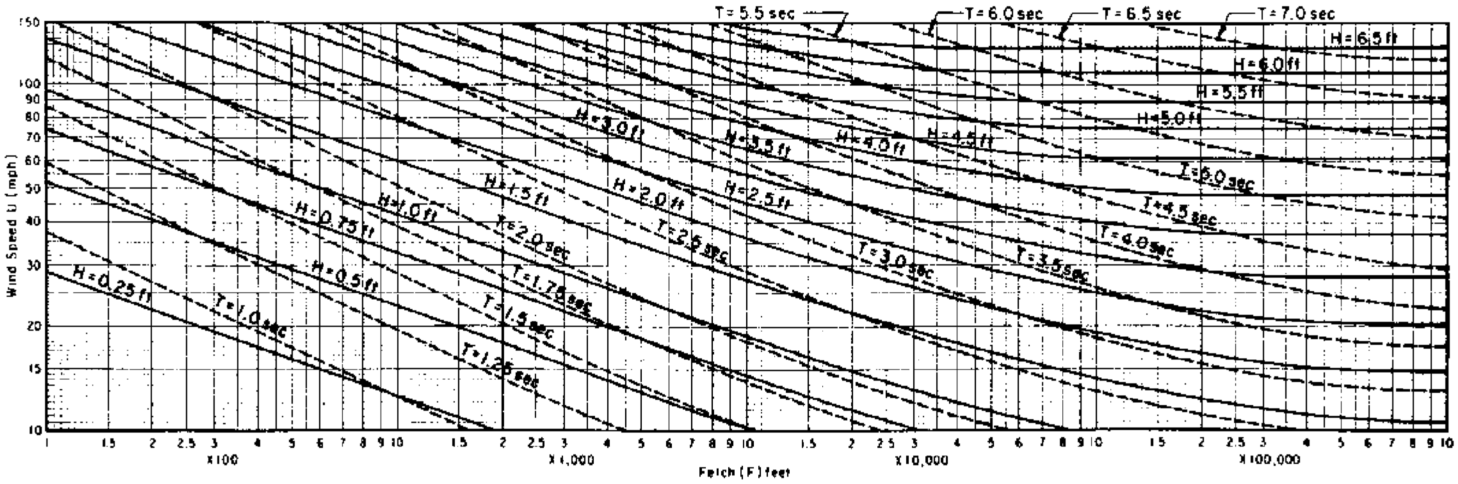


Figure III.3 Forecasting Curves for Shallow-Water Waves. Constant Depth = 15 feet.

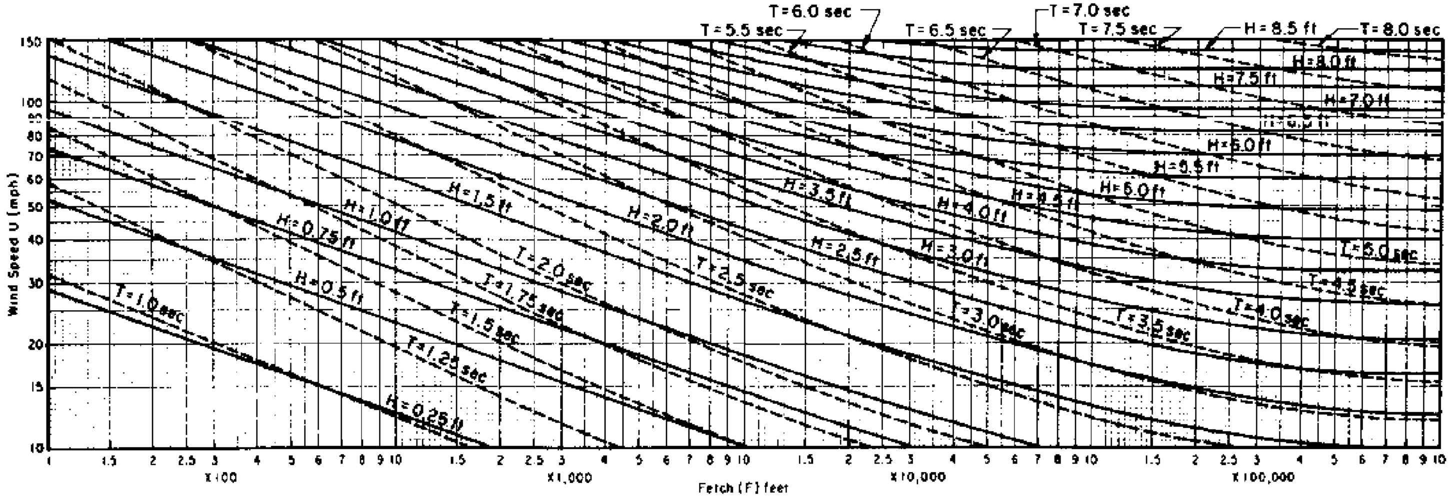


Figure III.4 Forecasting Curves for Shallow-Water Waves. Constant Depth = 20 feet.

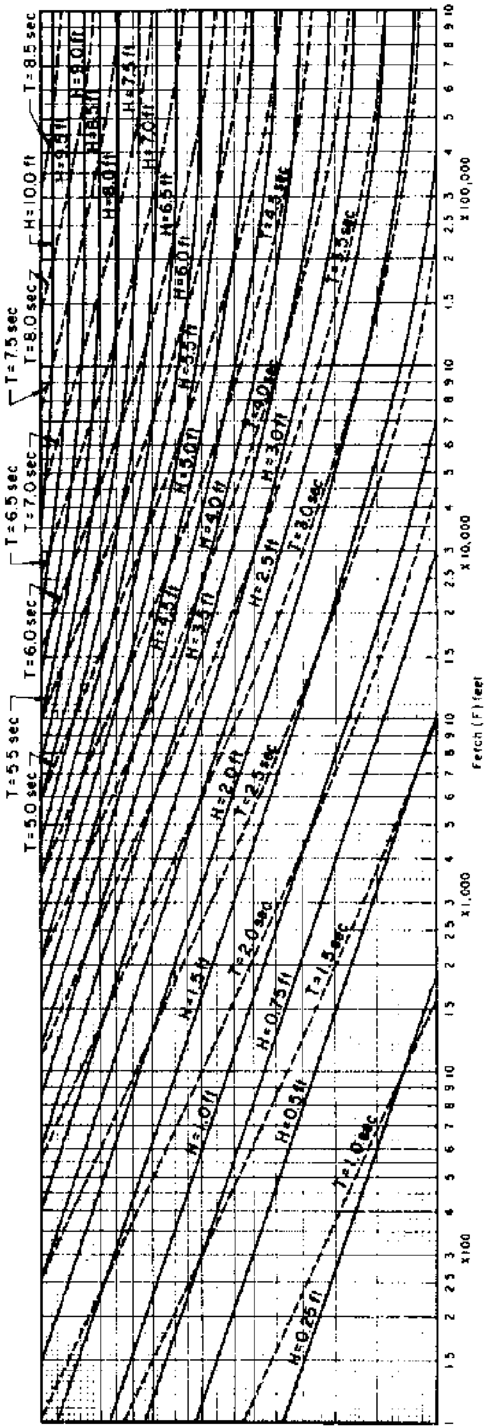


Figure III.5 Forecasting Curves for Shallow-Water Waves. Constant Depth = 25 feet.

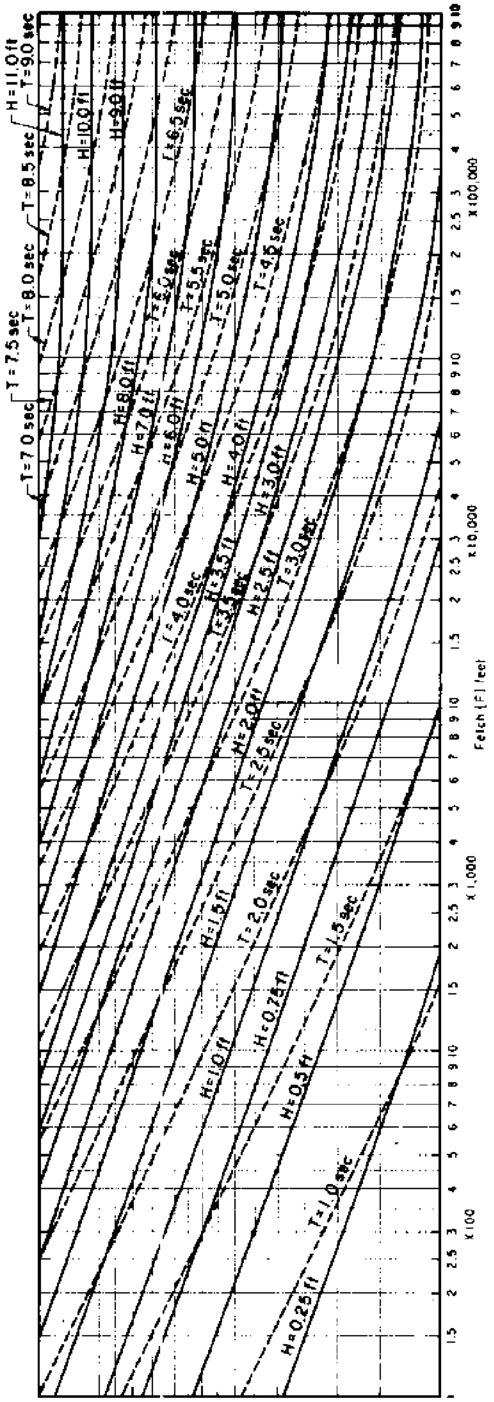


Figure III.6 Forecasting Curves for Shallow-Water Waves. Constant Depth = 30 feet.

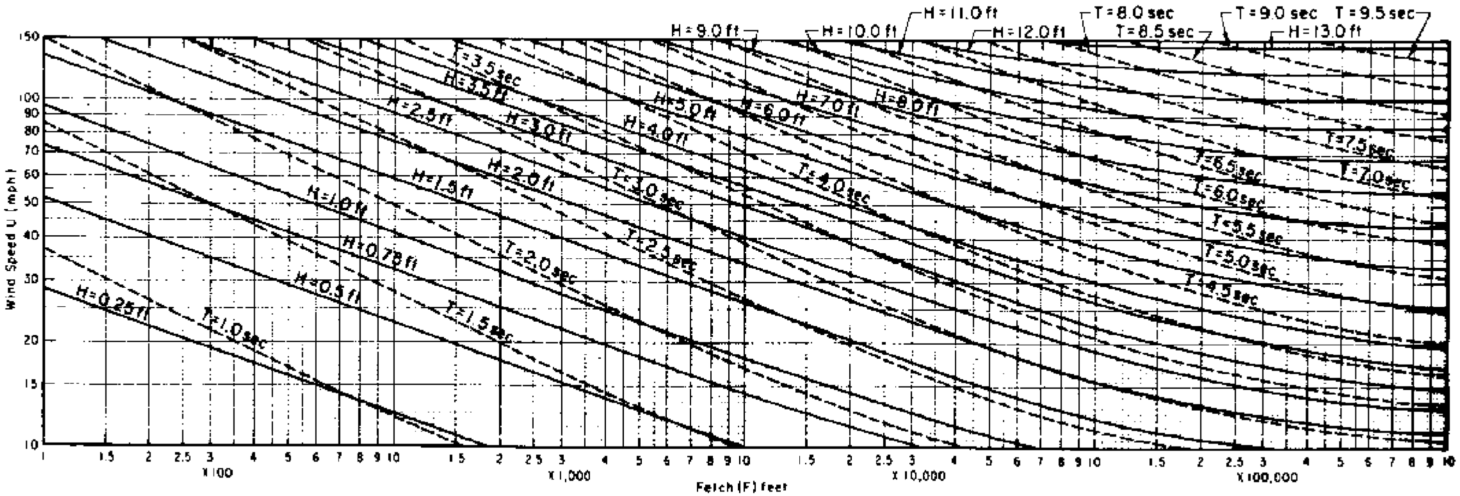


Figure III.7 Forecasting Curves for Shallow-Water Waves. Constant Depth = 35 feet.

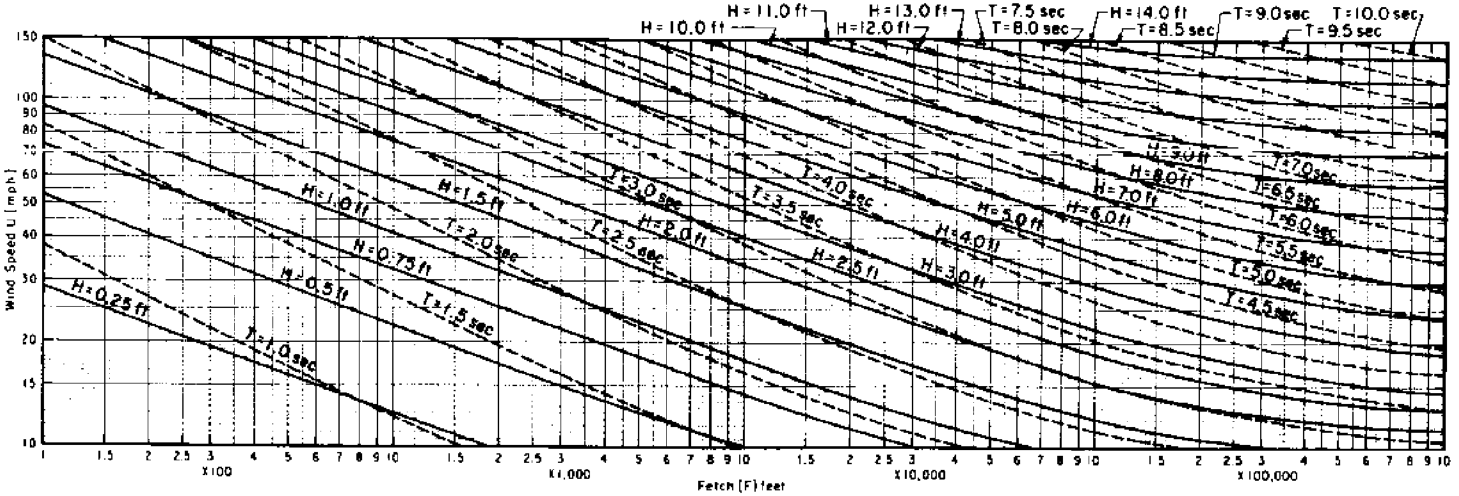


Figure III.8 Forecasting Curves for Shallow-Water Waves. Constant Depth = 40 feet.

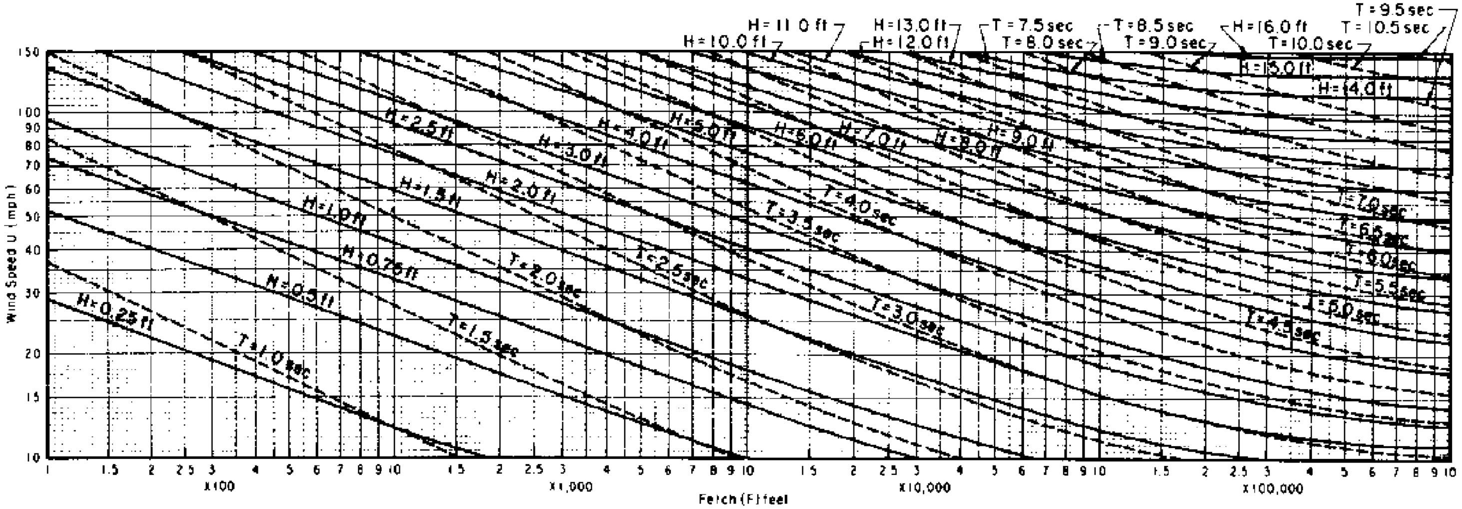


Figure III.9 Forecasting Curves for Shallow-Water Waves. Constant Depth = 45 feet.

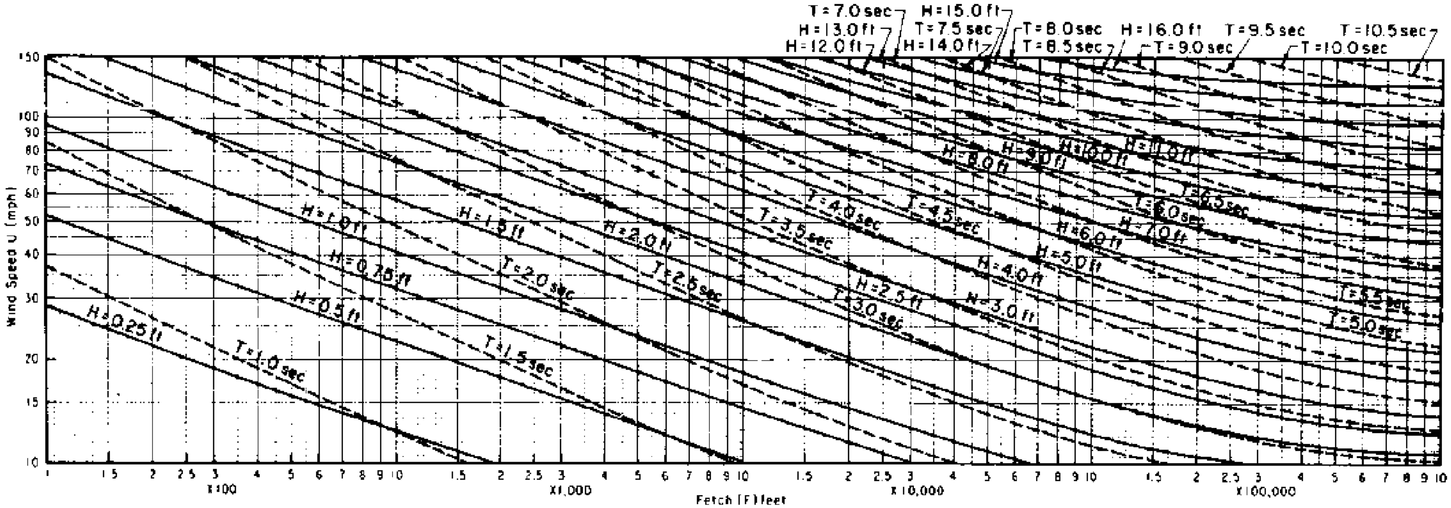
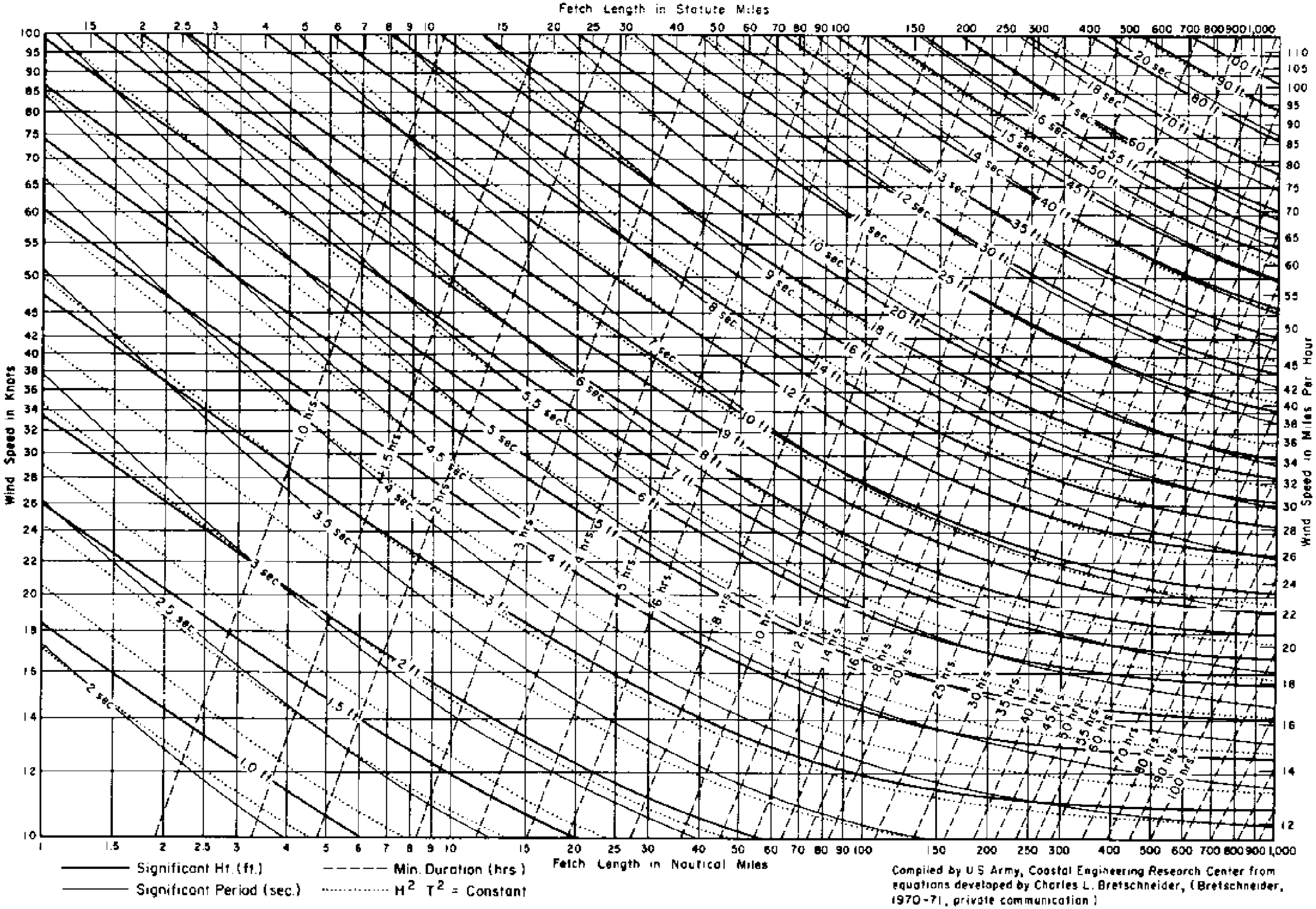


Figure III.10 Forecasting Curves for Shallow-Water Waves. Constant Depth = 50 feet.



Compiled by U S Army, Coastal Engineering Research Center from equations developed by Charles L. Bretschneider, (Bretschneider, 1970-71, private communication)

Figure III.11 DEEP WATER WAVE FORECASTING CURVES AS A FUNCTION OF WIND SPEED, FETCH LENGTH, AND WIND DURATION

(for Fetches 1 to 1,000 miles)

Appendix IV.A. Construction Details for the Wave-Guard FTB

Materials

Scrap tires can be obtained in significant quantities in almost any area from tire dealers, garages and landfill sites. In many areas it is now necessary to circumferentially slit tires before thay can be landfilled: this makes uncut tires even more readily available since many owners of used tires would prefer to avoid the added disposal cost and instead deliver the uncut tires to a breakwater construction site without charge. Even if this is not the case, a delivery charge of not more than $0.15 per tire is generally encountered (Candle, 1977).

A sketch of the Wave-Guard FTB, including mooring system and recommended pole-spacing, is shown in Fig. IV.1. The term "pole" is here only intended to be descriptive: wooden piles or buoyant reinforced-concrete or steel beams could be used as well. Used telephone poles appear to be the most economical and readily available source and can often be procured for less than $50 per pole. These are generally available from telephone companies. The price will vary according to size, condition and hauling distance. Only poles that are structurally sound should be used, and additional creosoting may be advisable for increased wood-preservation. A 50 ft telephone pole, (class 1, douglas fir), weighs approximately 1900 lbs and costs about $200 new, including treatment (Koppers Co., Shortville, N.Y.): the pole diameter at the top is typically about 9" and near the bottom approximately 15" for a 50 ft pole.

Only tested and proven binding materials should be used in FTB-construction since it has been found that it is this structural component that generally fails first. In-situ salt water tests were performed at the

University of Rhode Island in 1976 on 12 different binding materials (Davis, 1977). Conveyor-belt edging material was found to possess the most suitable properties, but heavy galvanized steel chain (minimum wire diameter 1/2") has also been successfully used. Tests performed on 3" wide strips of belting that were joined together with two 1/2" nylon bolts gave an average tensile strength of 2150 lbs. The belting itself displays an ultimate tensile strength of approximately 9500 psi. The main advantages of conveyor belting are that it is:

1) Relatively inexpensive (from \$0.25 - \$1.00 per sq ft)
2) Lightweight and easy to handle
3) Non-corrosive
4) Non-abrasive in conjunction with other breakwater components generally used

It is recommended that the belting for the Wave Guard FTB be 4" wide and 1/2" thick. Davis (1977) found that nylon bolts, nuts, and washers are a good way to fasten conveyor belting: the tying system then being inert in the marine environment, easy to assemble and of acceptable strength. Since nylon is degraded by sunlight it is recommended that the nylon fasteners be dyed black. At least four 1/2" bolts with flat washers should be used to fasten the belting at each connection. A sketch of the recommended connection is shown in Fig. IV.2. This pattern should provide well over 3000 lbs of tensile strergth. Galvanized 1/2" open-link steel chain could also be used in place of the belting but this is more expensive (approx. \$0.80/ft) and necessitates additional buoyancy.

Each tire floating in an upright position will trap air and provide about 11 lbs of reserve buoyancy (see pg.55 for tire characteristics). After a period of time the air will escape if the tires are not periodically recharged with air either manually or by wave action. Experience with the Goodyear FTB in fresh water has shown that supplemental floatation is not needed if the structure is regularly cleaned and the accumulation of sand within the tires is minimal. The passage of waves allows the tires to periodically retrap new air and therefore will keep the breakwater afloat indefinitely. Salt water is more of a problem because tires are an excellent habitat for the growth of seaweed, muscles, barnacles and the like. This added weight reduces the effective buoyancy of the tires and, without regular maintenance, this may cause parts of the structure to become submerged, and eventually all of it. If it has been decided to construct the Wave-Guard FTB without supplemental floatation, then it is recommended that the structure be regularly monitored for local submergence and be cleaned at least annually. It has recently been found that compressed air can be effectively used to refloat portions of FTB's that have lost their buoyancy, and that compressed air can also be employed to clean the tires of trapped sediments and some marine growth. The use of supplemental floatation becomes necessary if this periodic maintenance and cleaning cannot be provided. In this case it is recommended that the tops of every tire be foamed with 1/2 lb of urethane foam (kits are available for mixing and injecting the foam). This should support any added marine growth or sediment accumulations. Supplemental floatation increases the cost of FTB's substantially.

The recommended mooring line consists of a tire-mooring-damper located at the breakwater end of the mooring line plus an anchor chain near the bottom, as shown in Fig. IV.1. For the chain portion the use of 1/2" open-link low-carbon chain appears to be most economical. The chain has an average tensile strength of 2200 lbs and is heavy enough to withstand years

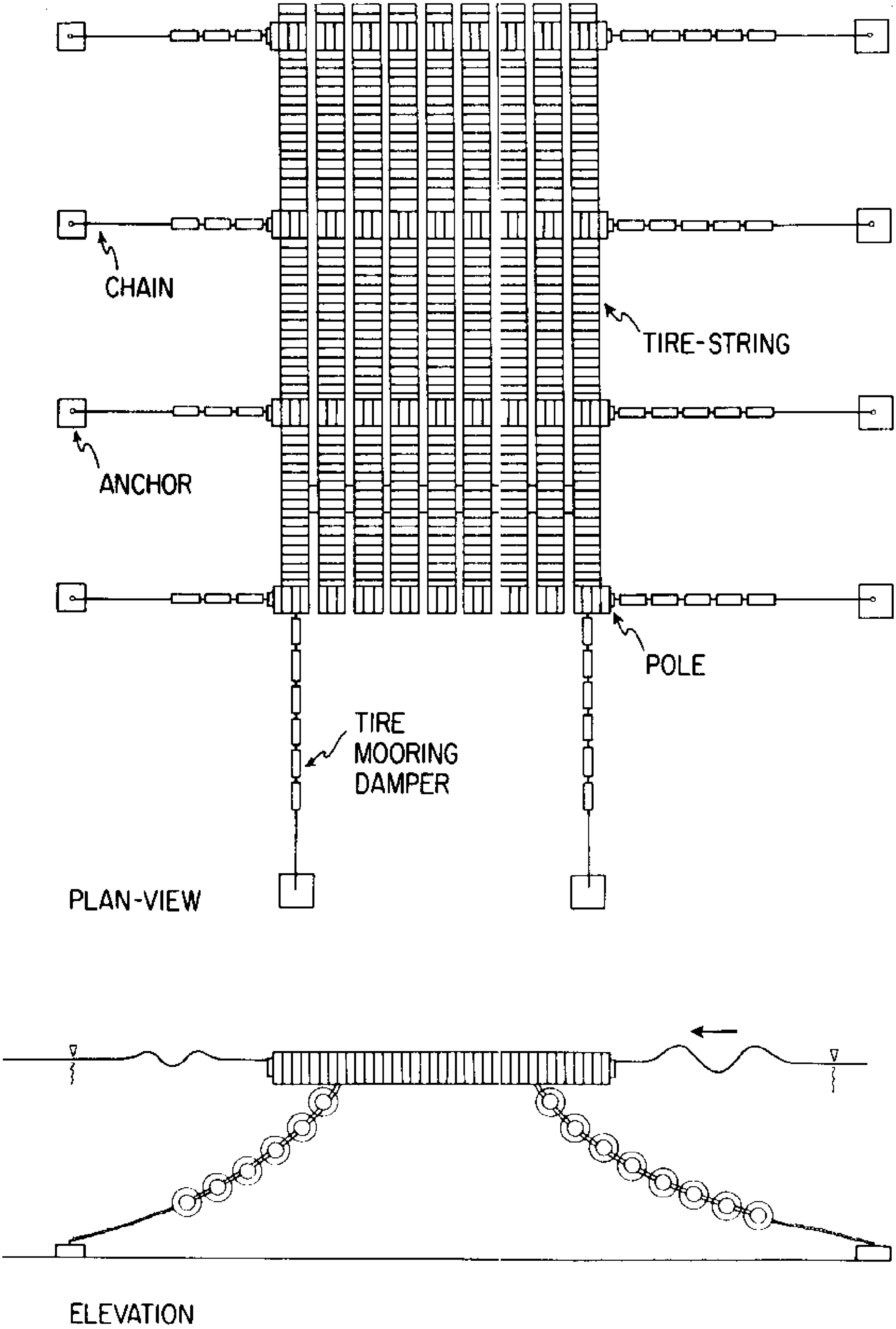


Figure IV.1. Schematic of Wave-Guard FTB and Mooring System

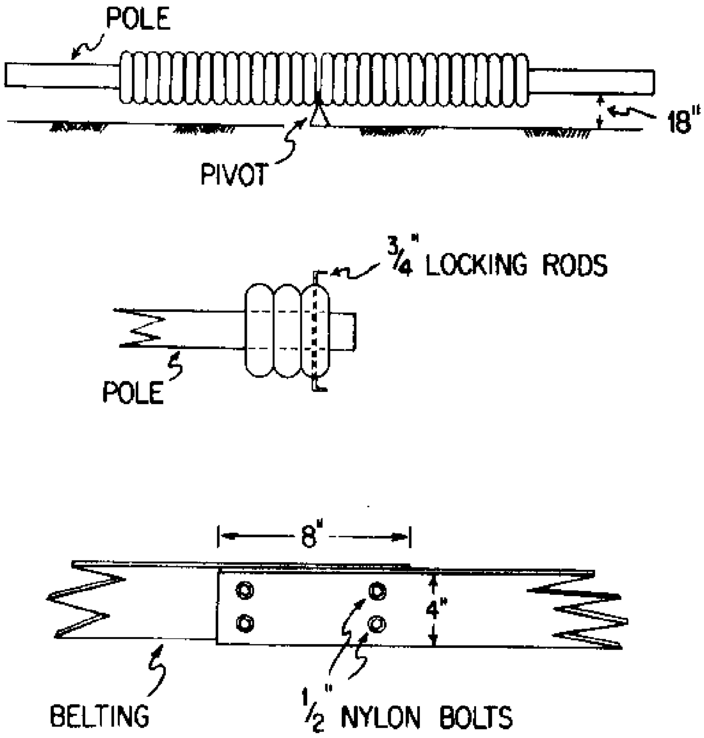


Figure IV.2. Construction Details Showing Belt Connection, Locking Rods and Pole Pivot

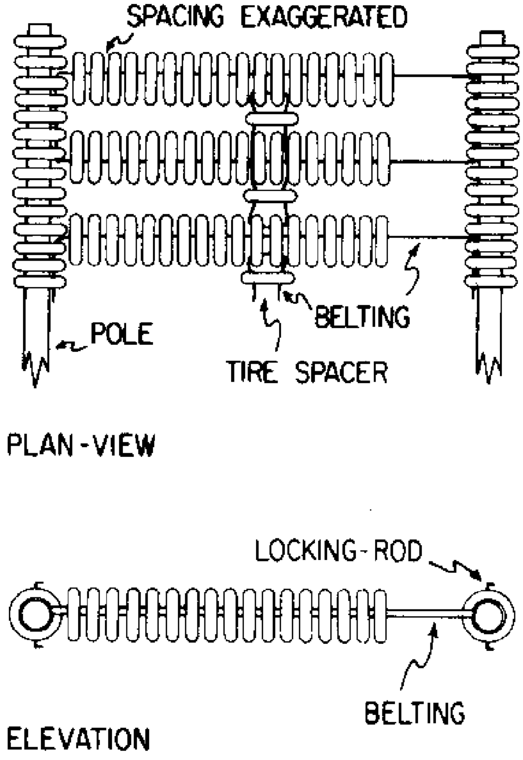


Figure IV.3. Interconnection of Tire-Strings and Poles

Figure IV.4. Tires may be Interconnected with Steel Chain or, Preferably, Conveyor Belting. (Photo courtesy of Goodyear Tire & Rubber Co.)

of abrasion and corrosion. Careful consideration must, however, be given to the mooring loads to be anticipated, and the number of mooring lines to be used, before actually selecting the chain.

Construction

The Wave-Guard concept was developed with the following goals in mind:

(i) It should be an effective wave attenuator

(ii) It should be simple to construct and at a low cost (minimum construction effort).

(iii) It should be a rugged structure that can resist years of wave action.

The Wave-Guard FTB should be built as near as possible to the water's edge. The structure may even be assembled in shallow water and then towed to the site of deployment. A beach near the site would be an ideal location for the construction of a FTB. If the breakwater is to be built complete on a beach, the poles should be placed perpendicular to the water's edge to facilitate the subsequent transport into the water (push-pull). A farm tractor or some comparable machinery is the heaviest equipment needed to maneuver poles and transport the structure into the water.

Since the log spacing b should not exceed $6D_t$ (where D_t is the diameter of the tires used) and the string spacing G should be approximately equal to $1.2\ D_t$, it follows that b = 12 ft and G = 2.4 ft when typical 14" automobile tires with $D_t \simeq 2.1$ ft are used. The tires should be distributed along the construction site to minimize the amount of handling. The poles are moved into position and then lifted and balanced on a pivot point approximately 18" off the ground as shown in Fig. IV.2. Tires can then be easily placed over the entire pole. Once the pole is armoured with tires, steel bars (3 ft in length) are pushed through the end-tires and through the pole, in order to lock the tires onto the pole. It is suggested that this also be done at 15 ft intervals along the pole. The holes in the poles should be large enough for a 3/4" steel rod. Two holes should be punched in the tire so that the rod can be inserted through the tire and pole as shown in Fig. IV.2, and after locally heating the rod the ends should be bent over to lock the rod in place. The log is now armoured with tires.

With poles arranged parallel to one another at the proper distance, the tire-strings can be constructed and connected to the poles. Each string of tires will consist of approximately 20 - 25 tires depending upon the compression desired in the strings and will be placed about 6" apart (tread to tread). The belting or binding material is strung through the tires as shown in Fig. IV.3: each loop is approximately 30 ft in length. Each loop of belting will fasten two tire-strings to the pole members by threading the belting through five tires on each pole, as shown. The belting can be joined anywhere along the loop but preferably not near the pole. The belting should be overlapped at least 8" and fastened with four 1/2" nylon bolts. A mechanical punch is used to make bolt holes in the belting. Before bolting and punching, the belting should be pulled as tight as practically possible to remove any unwanted slack, and the excess belting trimmed as needed. Tire spacers are used between adjacent tire-strings as shown in Fig. IV.3. The belting is guided through two tires on the tire-strings and comes back through the spacers. The belting connections are the same as those described for the strings. Depending upon the availability of machinery, it may be advantageous to perform some of the final assembly in 2 - 3 ft of water. This would avoid the final land-to-water transport phase which is frequently the most demanding. The armoured logs and tire-strings would be rolled into the water individually after having been completed on the beach, and subsequently connected. The FTB would then be towed to its final destination. This procedure requires that a sheltered, accessible beach be found, but would eliminate the use of heavy machinery.

The use of tire mooring dampers with at least five tires in series is recommended. Belting may be used to tie the tires together using the techniques discussed. The mooring line is fastened to the pole through two tires about 10 tires from the end. The opposite end of the mooring line is connected to the anchor with chain or belting of suitable length and size. Tire-to-tire connections, Using steel chain and conveyor belting are shown in Fig. IV.4.

APPENDIX IV.B

HOW TO BUILD A FLOATING TIRE BREAKWATER

George Shaw
Neil Ross

September, 1977

University of Maine/University of New Hampshire
Cooperative Institutional Sea Grant Program

Introduction

The floating tire breakwater (FTB) concept was developed as more people realized the need for an environmentally acceptable, low cost breakwater. Many public boat mooring sites, marinas and yacht clubs are situated in exposed areas and need protection from wind waves and boat wakes. Obtaining permits to construct bulkheads, rock groins, jetties and other conventional breakwaters is becoming increasingly difficult. Furthermore, the high cost of constructing such breakwaters is usually prohibitive. Recent cost estimates range from $500 per linear foot for wooden bulkheads to $1000 or more per linear foot for rock groins, depending on exposure, depth of water, tidal currents and other environmental factors.

A properly constructed and maintained FTB, however, should cost under $50 per linear foot, at today's costs, and should have a lifespan of ten years.

The original research on construction of an environmentally acceptable, low cost breakwater was begun in 1972 by the Marine Advisory Service at the University of Rhode Island. At that time, Goodyear Tire and Rubber Company was seeking potential uses for scrap tires. URI and Goodyear researchers cooperated in research efforts, which resulted in an 18-tire modular construction design, conceived by a Goodyear research engineer. This modular design has become the accepted way to construct FTBs.

Modular Design

The modular design of the breakwater calls for a vertical arrangement of tires into connected units, or bundles.

Construction of the breakwater is very simple and requires a minimum of binding material. Its design depends on the three dimensions of a unit: length, beam and draft.

Length: The dimension parallel to the oncoming waves, is determined by the size of the area to be protected. The best arrangement in a cove is two overlapping breakwater sections that extend outward from opposite shores to form an "entrance" where the two sections overlap. If the pre-

Mast-hauling operations at the Great Bay Marina in Newington, New Hampshire, have benefitted from the installation of a 21' x 150' floating tire breakwater.

The Great Bay Marina floating tire breakwater in action on a brisk and breezy November day.

dominant direction of the waves is known, a shorter breakwater facing the waves might be sufficient. Its length and shape would then depend on the physical characteristics of the area to be protected as well as wave refraction around the ends of the unit. To control refracted waves, a longer breakwater or an L-shaped one may be needed.

Beam: Width is determined by the predominant wave length in the area to be protected. Increasing the width increases the wave length that will be suppressed. The general rule is that the beam must be greater than half of the significant wave length.

To determine the significant wave length, first determine the period (T) of the oncoming waves by measuring the average time in seconds between successive wave crests passing a given point (such as a piling or buoy) in the space of about five minutes. Then, calculate the significant wave length (L) using this formula:

$$L = 5T^2$$

This formula applies to deep-water waves or those where the depth of water is greater than half of the wave length (L).

Most of the early FTBs were three bundles wide, or about 20 feet. Many full-scale field tests have been performed by Sea Grant at the University of Rhode Island to substantiate the performance of the breakwater. Automobile tire structure widths of 20 and 26 feet were found to be 80 percent effective in suppressing three-to-four-foot waves. Therefore, it is recommended that a structure 26 feet, or four bundles, wide by one unit deep be considered for suppressing three-foot high waves.

Draft: Immersed depth is determined by the height of significant waves occurring in the area. Again, a general rule: draft should be greater than one-half the height of the significant wave. Breakwaters built of standard automobile tires are effective in seas up to five feet. Such breakwaters will suppress about 70 to 85 percent of the incoming wave height. Larger truck or tractor tires will increase the depth of the breakwater and control higher waves.

First Steps

The breakwater should be situated with its leading edge parallel to the oncoming waves. It should be moored as close as possible to the area to be protected so that the wind will not have sufficient fetch to rebuild the waves behind the breakwater.

Since the breakwater is very mobile, the best location can be found by experimentation. In fact, the FTB can be shifted with the seasonal variations in wave direction. The breakwater should be placed in water of sufficient depth to prevent it from touching bottom at low tide or in low water. Doing this will also prevent it from sinking. The returning tide might fill the tires with sand and sink them. For this reason, this type of breakwater should not be installed without supplemental flotation in highly silted rivers. In high silt transport areas, the breakwater might continue to float if 2" x 3" holes were cut in the bottom of each tire to allow the sediment to wash through. This has not yet been tested.

Permits must be obtained from the appropriate agencies before a floating breakwater can be installed in the navigable waters of New Hampshire, Maine and most other states. Briefly stated, approval or acceptance must be received from local abutters, planning and zoning boards, State Fish and Game Departments, and all other state regulatory agencies involved in matters such as these. In addition, the U.S. Army Corps of Engineers must give its approval. Anyone planning a breakwater should allow six to eight months for the permit procedure. To speed up the process all local, state and federal permit requests should be filed at the same time.

Materials

Tires: With an estimated existing stockpile of more than two billion scrap tires in the United States, marinas should not have much difficulty obtaining them. Large quantities are usually available from tire dealers, recapping centers, truck stops, highway departments and town dumps. Most of these places are eager to dispose of them and many will even deliver them to the marina free of charge.

Air trapped in the tire crowns will provide sufficient buoyancy to keep the FTB afloat a while. The tires float approximately six inches above the water level and two feet below the surface, providing about ten pounds of reserve buoyancy per tire, or 200 pounds per unit of 20 standard (14-15 inch) tires.

It is recommended, however, that supplemental flotation be provided in every tire. Any one of several types of closed cell rigid urethane foam, set into the tops of the tires, is suitable for this purpose.

Binding Materials: The binding material can represent as much as one-third of the total cost of the breakwater, with labor and the mooring system accounting for the remainder. The temptation is to economize on binding materials as much as possible, but this kind of economizing should be avoided.

The ideal binding material must be able to hold together for ten years in an aerated-seawater condition where it is subject to corrosion, crevassing, fatiguing and abrasion. To be ideal, it must do this at a reasonable cost. In fresh water, corrosion and crevassing will be less of a problem.

In situ salt water tests were conducted at URI's Narragansett Bay Campus from January through November, 1976 to evaluate the reliability of 12 different materials that were thought suitable for connecting FTB units.* The binding material recommended above all others tested is conveyor belt edging material, a scrap product resulting from the trimming of new conveyor belts. Because of its fabric plies, this material demonstrates ultimate tensile strength on the order of 9,500 p.s.i. when no stress risers, such as bolt holes or cuts are present. The belt material is available from several tire manufacturers in this country, including Goodyear.

Minimum recommended belt dimensions are 2" wide by .375" thick with three or more nylon plies. Dimensions of this scrap material can vary widely, so prior arrangements should be made with the rubber company supplying the belting to avoid shipment of unuseable sized material.

Conveyor belt edging demonstrates several other desirable characteristics. It can be easily cut on a band saw or with a hand hack saw or axe. Holes for bolts can be punched singly or with a multiple gang punch. The material is virtually inert in the marine environment. It is pliable enough to be handled easily by one man during its fabrication and assembly into the tire modules.

As a means of fastening the belting together, the use of nylon bolts, nuts and washers was conceived. This makes a binding system that is totally inert in the marine environment. The nylon fasteners should be dyed black before they are used. Doing this will provide a screen to prevent ultra-violet rays from degrading the nylon over a long period of time. Several minutes of immersion in household dye in boiling water is sufficient for this purpose.

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*Complete test results are available upon request from the University of Rhode Island Marine Advisory Service.

The size and number of fasteners that are employed on each belt section is important for overall strength and fatigue considerations. Two basic systems that have been employed to date are:

1. The use of three (3), 3/8-16 bolts per belt fastening. (See photo on this page.) The belt width used with this pattern should be no less than two inches wide in the bolt zone to prevent the belting from being torn through to the edges. This pattern can support an average load of 2,100 pounds before the bolts fail. Washers must be employed under the bolt head and nut to prevent the head or nut from pulling through the rubber.

Voids in the center of these 3/8-16 injection molded bolts cause the strength of these bolts to vary substantially, by several hundred pounds. For this reason, the second system, explained below, is recommended over the 3/8-16 bolts. Several breakwaters which employ this system are in use at present and have been in the water for more than six months. One of these, at the Great Bay Marina in Newington, New Hampshire, is 150 feet in length and is positioned perpendicular to a daily tidal flow in excess of three knots. It has also withstood the onslaught of winter ice movement with no damage to the binding system to date.

The floating tire breakwater installed at the Great Bay Marina in Newington, New Hampshire, in September, 1976, was bound together with conveyor belt edging material. Three 3/8-16 bolts per fastening were used to secure the bonds.

2. The use of two (2), 1/2-13 bolts per belt fastening. The belt used with this pattern should be no less than two inches, and preferably three inches wide to prevent belt tearing. An average strength of this pattern is 2,150 pounds. In this system, the bolts do not fail. Either the bolts pull through the rubber belting or the belting tears.

These bolts differ from the 3/8-16 bolts in that they are manufactured from cast nylon bar stock on a screw machine and do not have the voids that are present in the 3/8-16 bolts. This system tends to be more predictable as far as repeatable strength limits.

Hints for Use of Nylon Fasteners:

(a) When tightening the nuts, torque limitations should be maintained. These will vary with the size of the bolt being used. Watch the nylon washer (only flat washers are recommended, i.e., no lock washers) for cupping as the nut is tightened. A very slight cupping indicates that the nut is tight enough.

(b) Bolts should be long enough to permit a minimum of ¼" of threads to protrude through the nut. Allowance for varying belt thicknesses and two flat washers should be made accordingly. This ¼" of threads allows a propane soldering tip to melt and distort a sufficient number of threads to prevent the nut from "backing off." Also the growth of marine plants in the exposed threads severely hampers the nut from working loose.

The following information is a result of the in situ test employing rubber conveyor belting and nylon fasteners as the binding system for a floating tire breakwater:

1. The belting and nylon fasteners are inert in the sea water environment.
2. The belting has excellent abrasion resistance to chafing against tire casings, other binding materials and marine growth, such as barnacles and mussels.
3. The belting shows no signs of delamination (separation along fabric plies) after nine months of immersion.
4. A slight increase in tensile strength of the belting (approximately 2-3%) was noticed after six months of immersion. This could be due to a better dissipation of heat, generated by the internal tensile straining, through the wet fiber plies.
5. The material is easily handled by one or two persons during fabrication and assembly.
6. The system allows localized loads to be distributed readily throughout the tire matrix.
7. The system can withstand low water temperatures including ice, high loading conditions caused by currents, wave action and cyclic fatigue loading. It can be towed without undergoing excessive strain.
8. The materials do not pollute the environment.
9. The system has a negligible negative buoyancy effect upon the breakwater modules.
10. The system can be unfastened readily for addition of tires, repairs or for other purposes.

At this time, these materials and fastening methods are the most economical and, probably, the most dependable. Estimated life is ten years.

Second to this system would be chain with a minimum wire diameter of ½", preferably galvanized. In third position relative to reliability would be polypropylene, either braided (for use in splicing) or regular lay. If polypropylene is employed in this capacity it should have an ultra-violet screen shield to retard degradation. All other materials are not recommended as binding material for floating breakwater applications.

Materials not recommended for FTB use are:

1. Nylon lines. They demonstrate poor abrasion resistance, knot loosening and ultra-violet degradation.
2. "Kevlar" line. Internal fiber friction during flexing of rope severely impairs strength characteristics of this material.
3. Any metallic wire rope, such as plain steel, galvanized steel or stainless steel because of inherent corrosive problems (particularly around the clamped or swedged ends), metal fatigue, caused by constant flexing, and the cutting action of the rope on the tire bodies.

Construction

The design of the breakwater is based on a modular concept, in which relatively few tires are secured together to form an easily assembled, portable building unit. This unit then serves as the basic building block for large structures.

The construction procedure is very simple. First, assemble the modular unit. This is done by securing 18 tires together to form a 7' x 6½' x 2½' bundle. The basic method used to construct the bundles is to stack the tires flat in a 3-2-3-2-3-2-3 configuration, as shown in Figure 1 and in the photo on page 8. Weave the binding material through as the tires are stacked. The increasing weight of the tire stack and compression of the

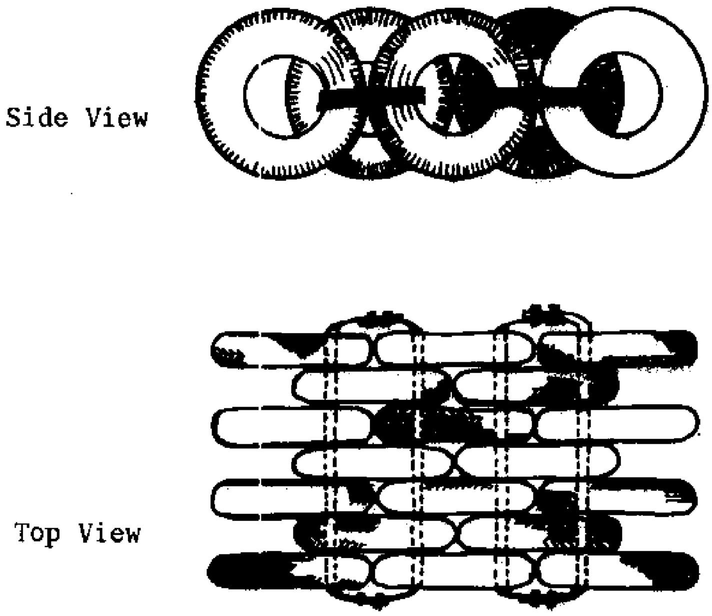


FIGURE 1

Modular Building Unit Shown as Constructed tires by hand will allow easy fastening of the binding material, and will form a tightly secured bundle.

The bundles should be constructed near the installation site, if practical. However, they are relatively easy to transport from the assembly site to where the breakwater will be installed. Be sure to install supplemental flotation in each tire before assembling the tires into bundles.

Connecting the tire units into a long chain to form the breakwater requires only a slight alteration of tire position and the addition of two tires per bundle.

Tire bundles are constructed by stacking the tires flat in a 3-2-3-2-3-2-3 configuration. Binding material--in this case, conveyor belt edging--is woven through the tires as they are stacked to secure the bundle.

First, the four corner tires of each bundle are rotated about 100°, as shown in Figures 2 and 3. Next, the two additional tires are inserted at each end of the module to serve as connectors, interlocking to form the desired shape of the protective structure. (See Figure 3)

The resulting mat, shown in Figure 4, has excellent strength characteristics (as high as 55,000 lbs. breaking strength on a 6½' spaced longitudinal and transverse grid). It also has the ability to absorb great amounts of enery by yielding and deforming when over-loaded. Elongation of more than 30 percent is possible in both directions.

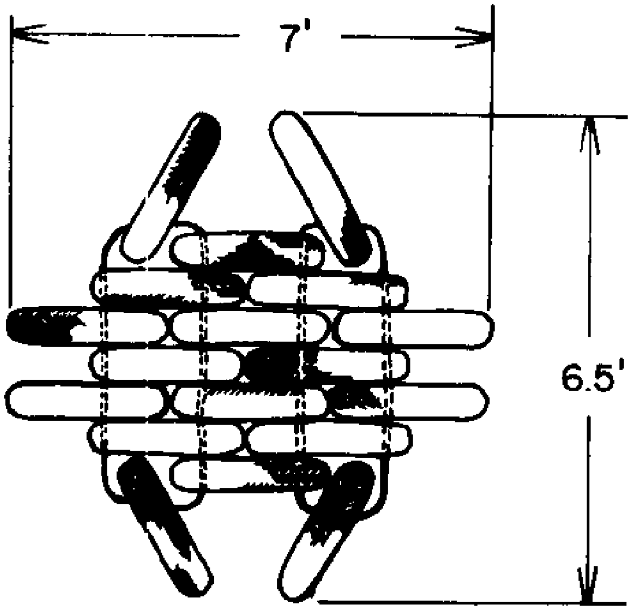


FIGURE 2

Modular Building Unit Shown as Installed

These elongations occur only under extremely high loading conditions, and the tire bundles return to their normal shape under no-load conditions without permanent deformation resulting.

<u>The Bridle</u>. To prevent any individual bundles from separating and drifting away, a bridle line should be threaded through the outside tires around the perimeter of the breakwater. (See Figure 4.) Secure the line to the two outside tires in each bundle to prevent chafing. The material can be one or more lines of synthetic rope or chain (providing the weight is not excessive).

<u>Moorings</u>. The size of the moorings and anchoring system will vary depending on the type of bottom (sand, rock or mud) and local tides and currents as well as the amount of exposure to wind and waves. Anchors, mushroom moorings, concrete and/or granite blocks heavy enough to resist drag are satisfactory.

Design the mooring system as you would for boats over 30 feet long. Local experience with moorings will be the best guide. Wooden pilings with the breakwater built around them may be used in place of moorings. It is recommended that moorings be placed a maximum of 50 feet apart on the wave side and every 100 feet on the lee side. Mooring lines should be attached to the breakwater in such a way that the load is distributed between two or more bundles.

<u>Marking</u>. The FTB could be a navigational hazard unless properly marked and lighted.

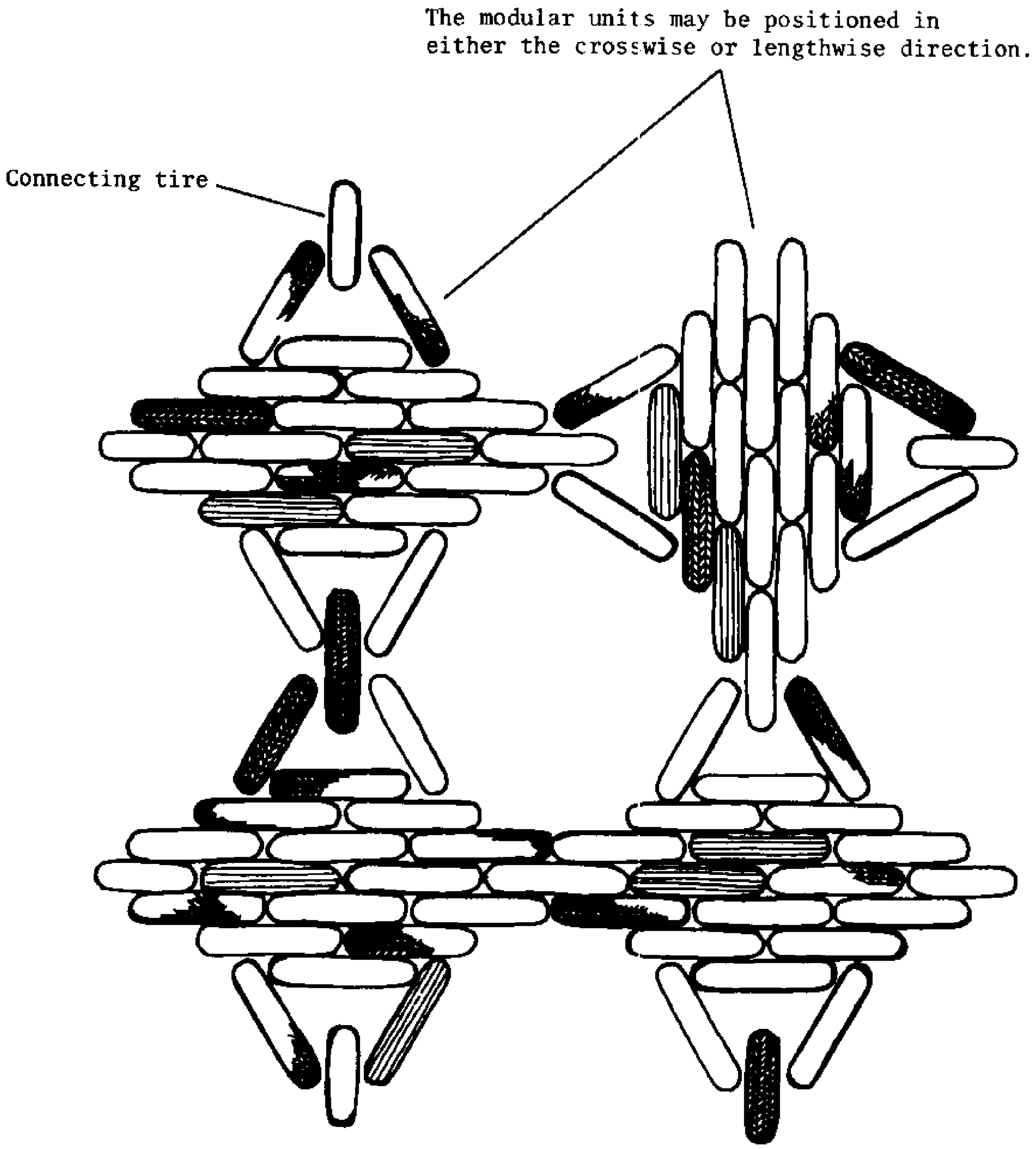
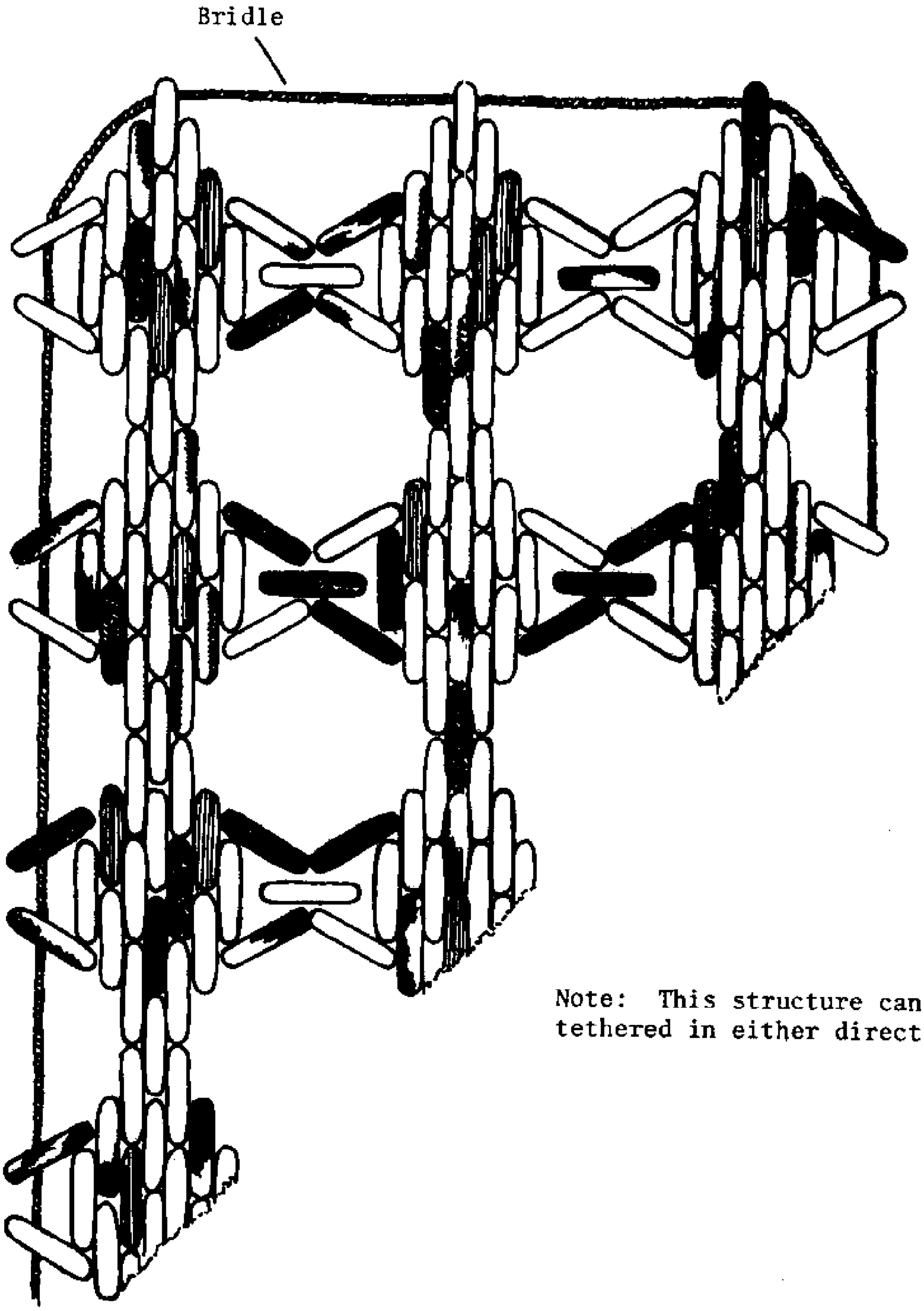


FIGURE 3

Modular Units Connected to Form Mat



Note: This structure can be tethered in either direction.

FIGURE 4

Shore Protection Mat and Connecting Bridle

Maintenance. Being a dynamic structure, the breakwater system will be subject to wear and deterioration. Therefore, it should be inspected regularly and after each storm, especially during the first few months after installation. When breaks in the binding material occur, they should be repaired promptly. Binding materials and mooring lines should be watched for chafing and corrosion. Moorings should be checked annually.

Repairs and clean-up can be made easily in the water. One bundle will support the weight of an average man, and most inspections and repair can be made without moving the breakwater.

The tire mat is a very efficient collector of floating bottles, bags, boards and other debris. Though it is an ecologically sound structure in itself, the breakwater can become an eyesore if it is not frequently policed.

In areas where winter icing conditions are heavy and where currents or strong winds may affect ice floes, it is wise to remove the FTB during the time of possible ice damage.

An Ecological Plus

Floating tire breakwaters become floating fishing reefs, too. Tires provide an excellent substratum for marine growth which, in turn, provides both food and habitat for game fish. It is thought that, as an artificial reef, this floating structure will be more effective than a structure placed on the bottom. This is so because of its location in the upper three feet of the water, where there are higher light intensities, warmer temperatures and higher oxygen levels. Tires are non-toxic and quite stable in the marine environment. Sea Grant researchers believe FTBs have aquacultural potential.