AD-A165 803 PROCEEDINGS OF THE FLOATING TIRE BREAKWATER WORKSHOP HELD IN NIAGARA FALL..(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS C T BISHOP ET AL. NOV 85 1/2

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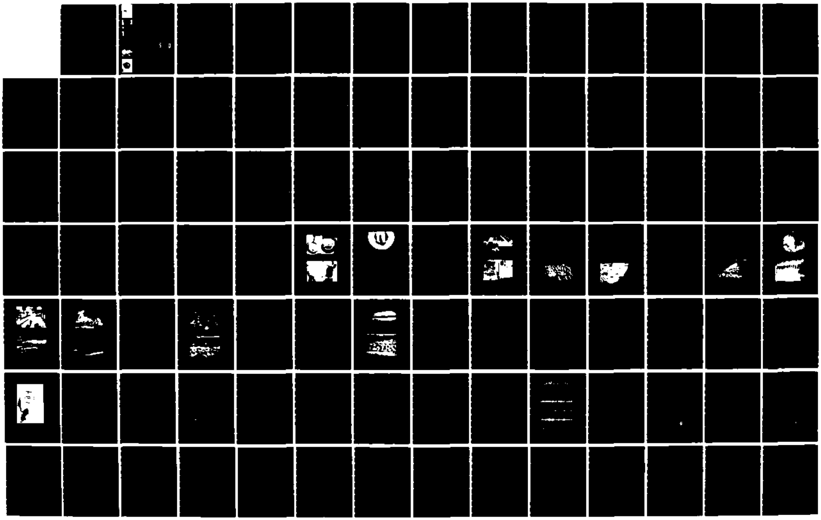

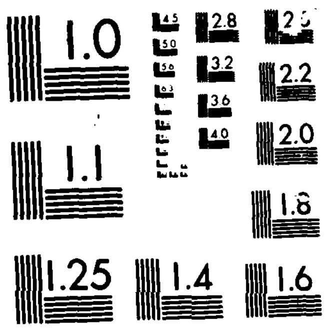

MICROCOPY RESOLUTION TEST CHART

US Army Corps of Engineers

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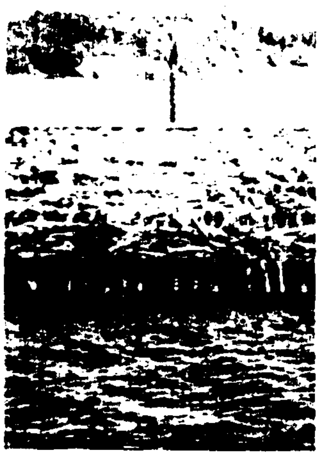

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TECHNICAL REPORT CERC-85-9

PROCEEDINGS OF THE FLOATING TIRE BREAKWATER WORKSHOP 8-9 NOVEMBER 1984

Compiled by

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November 1985
Final Report

Prepared for DEPARTMENT OF THE ARMY
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Field research	Mooring forces	Waves
Floating tire breakwaters	Pipe-tire design	
Goodyear design	Pressure gage	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

These Proceedings provide a record of the papers presented at the Floating Tire Breakwater Workshop conducted on 8-9 November 1984 in Niagara Falls, New York. Topics of discussion included field research efforts, basic design considerations, breakwater performance and maintenance, and alternative fastening and mooring techniques. The Workshop was cosponsored by the Coastal Engineering Research Center of the US Army Engineer Waterways Experiment Station and the Canadian National Water Research Institute.

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PREFACE

On November 8-9, 1984, the Floating Tire Breakwater (FTB) Workshop was held in Niagara Falls, New York, under provisions of Work Unit No. 31679, "Design of Floating Breakwaters," Coastal Structure Evaluation and Design Program, Coastal Engineering Area of Civil Works Research and Development. Authority to conduct this program was contained in a letter from the Office, Chief of Engineers (OCE), US Army, dated 19 May 1972. OCE Technical Monitors were Messrs. Bruce L. McCartney, J. H. Lockhart, J. G. Housley, and Jesse A. Pfeiffer, Jr.

This document is a compilation of the proceedings of the FTB Workshop, which was cosponsored by the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES) and the Canadian National Water Research Institute (NWRI). Mr. C. T. Bishop, NWRI, and Mr. D. D. Davidson and Ms. L. L. Broderick, WES, coordinated the Workshop and edited this report.

This report was prepared under the general direction of Dr. Robert W. Whalin, former Chief, CERC, and Mr. C. C. Calhoun, Jr., Acting Chief, CERC; Mr. C. E. Chatham, Jr., Chief, Wave Dynamics Division, CERC; and Mr. Davidson, Chief, Wave Research Branch.

At the time of publication of this report, COL Allen F. Grum, USA, was Director of WES, and Dr. Whalin was Technical Director.

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Eric Nelson 109

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Laurie L. Broderick 125

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2,000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

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FLOATING TIRE BREAKWATER WORKSHOP

November 8-9, 1984
Ramada Inn
Niagara Falls, New York

AGENDA

Wednesday, 7 November

7:30 p.m.	Registration	
8:00	Floating Tire Breakwater (FTB) Slides and Movies	

Thursday, 8 November

8:30 a.m.	Registration	
8:45	Welcome	
9:00	FTB Design Basics	
9:30	A Marina Manager's Experience with a Truck Tire Goodyear FTB	Clifford T. Biddick, Irish Boat Shop, Inc.
10:00	Break	
10:30	Fastening and Strength Tests of Conveyer Belting	Anthony Franco, State University of New York
11:30	Erie, Pennsylvania, Field Program	Robert E. Pierce, Pennsylvania State University
12:00	Lunch	
1:00	A Sailing Club's Experience with a Car Tire Goodyear FTB	Paul L. Pirie, Burlington, Ontario, Sailing and Boating Club
1:20	Burlington, Ontario, Field Program	Craig T. Bishop, Burlington, Ontario
2:30	Break	
3:00	Puget Sound Test Program	Eric E. Nelson, US Army Engineer District, Seattle
4:00	Data Results from Puget Sound Test Program	Laurie L. Broderick, US Army Engineer Waterways Experiment Station

Friday, 9 November

8:00	Bus departs from Niagara Falls, NY, for field trip	
9:30	LaSalle Park Goodyear FTB	

Friday, 9 November (Continued)

10:15	Tour Hydraulics Laboratory
11:30	Bus departs from Burlington
12:30 p.m.	Arrive Niagara Falls, NY
	Adjourned

INTRODUCTION

In recent years, there has been increased interest in the use of floating breakwaters for providing protection from wave attack. Several types of floating tire breakwaters (FTB's) have demonstrated the ability to effectively dissipate wave energy at a moderate cost in certain locations characterized by relatively short wave periods and fetch lengths. Their value as a functional wave protection alternative is especially apparent in areas where sediment transport problems, deep water, poor foundation conditions, or environmental constraints preclude the use of the more conventional bottom-fixed, rubble-mound or vertical-wall breakwaters. Another advantage lies in their mobility. Unlike the bottom-fixed structures, FTB's may be moved from one location to another, e.g., during severe ice conditions or for easier maintenance access.

This Workshop was conducted to provide an opportunity for engineers, contractors, marina owners and operators, and other interested individuals to exchange information on the use of FTB's. Subjects involving individual field experience were emphasized, particularly related to breakwater performance and maintenance requirements. Topics discussed included basic design considerations, alternative fastening and mooring techniques, and recent field research programs, to name a few. The scheduled speakers included representatives of the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station; the Canadian National Water Research Institute (NWRI); the US Army Engineer District, Seattle (NPS); universities; municipalities; and privately owned marinas. The final day of the Workshop featured a field trip to Ontario, Canada, where participants toured the LaSalle Park Goodyear FTB at Hamilton and the NWRI facilities at Burlington.

This document was published to provide a record of the Workshop itinerary, participants, and the scheduled papers that were presented.

EXPERIENCE WITH A FLOATING TIRE BREAKWATER AT LAKE CHARLEVOIX, MICHIGAN

Clifford D. Biddick

BACKGROUND:

Irish Boat Shop, Inc. operates two boat yards - one in Harbor Springs and one in Charlevoix, Michigan, serving primarily pleasure boats to 75 feet* in length. These marinas maintain and perform all types of boat repair and provide storage and dockage to all customers. In 1977, it was decided to expand the 120-slip capacity at Charlevoix. Water depths varied to 26 feet, making bottom resting breakwaters an expensive proposition. Therefore, we began to investigate the Floating Tire Breakwater concept as an alternative to conventional wave protection structures.

Following a field trip to the known Floating Tire Breakwaters on the east coast of the U.S.A., we set about to design and build a complete harbor enclosure, utilizing the available Floating Tire Breakwater information. We selected the Goodyear design of 18 tire modules as developed by Richard Candle (Goodyear Tire and Rubber Co.) and Neil Ross (University of Rhode Island). With this as a start we designed an enclosed harbor for 62 boats adjacent to our existing 120-slip facility. This structure extended 450 feet out into the lake and was 330 feet wide. Our exposure was to the southeast with an 18-mile fetch down a relatively narrow (3± mile) width. The sea approaching us at worst was about 3 feet from trough to crest, with a 2- to 2.5-second period.

BREAKWATER DESIGN:

The marina has the land forming the west side, a floating car tire breakwater on the southside, with a laid down "F" forming the north and east sides and middle leg. Refer to Figure 1. The "F" was a steel-framed, wood-covered 12-foot-wide dock, supported on fully foamed car tires arranged in a Goodyear pattern (2 modules wide). Outside the top of the "F" was a 3-module row of partially foamed truck tires which formed the major wave reduction breakwater. Refer to Figure 2. The project utilizes 7,500 car tires and 3,500 truck tires. Together they are supported with 10,000 cubic feet of urethane foam.

CONSTRUCTION:

The entire project was planned to be, and ultimately was, assembled on 12 to 24 inches (thick) ice during the winter of 1978-1979. We utilized a ten man crew and a great deal of equipment including a hydraulic crane, fork lift, front end loader, pickup trucks, welders, generators, pumps to thicken the ice, and many trucks and trailers. The temperature ranged down to 26 below zero (Fahrenheit) and despite the cold, morale of the crew was high. The goal was to have the dock and breakwater intact when the ice melted. Work on the ice began in early January and was finished by late March, 1979.

After assembly was complete, we cut holes in the ice and had a diver bury 120 Danforth style anchors and attach them via 1/2 inch 1x7 galvanized cable to the tire modules. With the dock tentatively anchored, we waited anxiously for it to melt through the ice. As it did so, it tipped drastically, but leveled out after all the ice melted.

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* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 4.

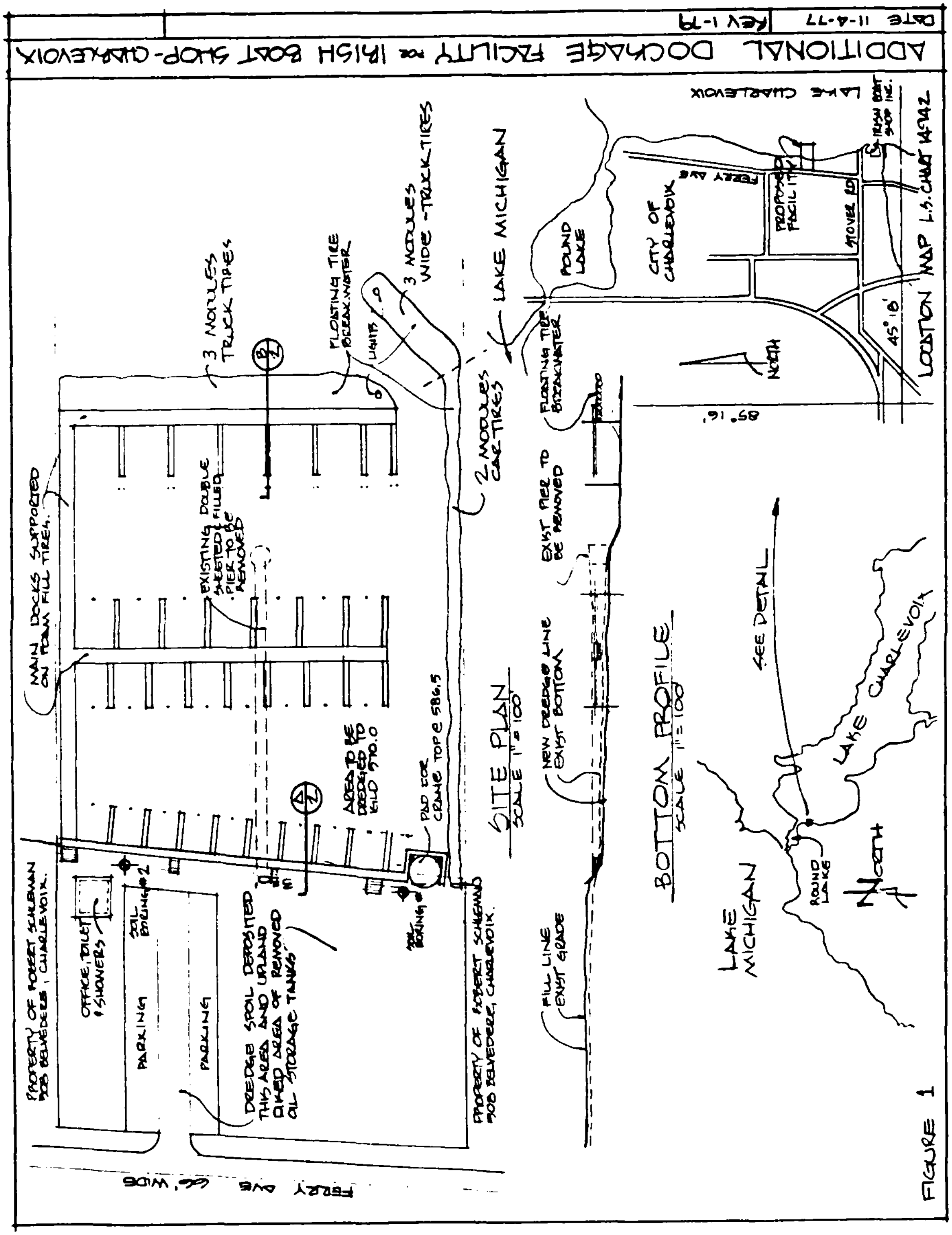
ADDITIONAL DOCKAGE FACILITY for IRISH BOAT SHOP - CHARLEVOIX
DATE 11-4-77
REV 1-79
LAKE CHARLEVOIX
LAKE MICHIGAN
ROUND LAKE
CITY OF CHARLEVOIX
FERRY AVE
PROPOSED FACILITY
STOVER RD
LOCATION MAP L.S. CHART 14942
45° 18'
85° 16'
NORTH
3 MODULES TRUCK TIRES
FLOATING TIRE BREAKWATER
3 MODULES WIDE - TRUCK TIRES
2 MODULES CAR TIRES
MAIN DOCKS SUPPORTED ON FOAM FILL TIRES
EXISTING DOUBLE SHEETED & FILLED PIER TO BE REMOVED
AREA TO BE DREDGED TO 570.0
PAD FOR CRANE TOP E 586.5
SITE PLAN
SCALE 1" = 100
OFFICE, TOILET & SHOWERS
SOIL BORING #2
SOIL BORING #1
PARKING
PARKING
DREDGE SPOIL DEPOSITED THIS AREA AND UPLAND DIKED AREA OF REMOVED OIL STORAGE TANKS
PROPERTY OF ROBERT SCHLEMAN ROB BELVEDERE, CHARLEVOIX
FERRY AVE 66' WIDE
EXIST PIER TO BE REMOVED
NEW DREDGE LINE
EXIST BOTTOM
FILL LINE
EXIST GRADE
BOTTOM PROFILE
SCALE 1" = 100
SEE DETAIL
LAKE CHARLEVOIX
ROUND LAKE
LAKE MICHIGAN
NORTH

FIGURE 1

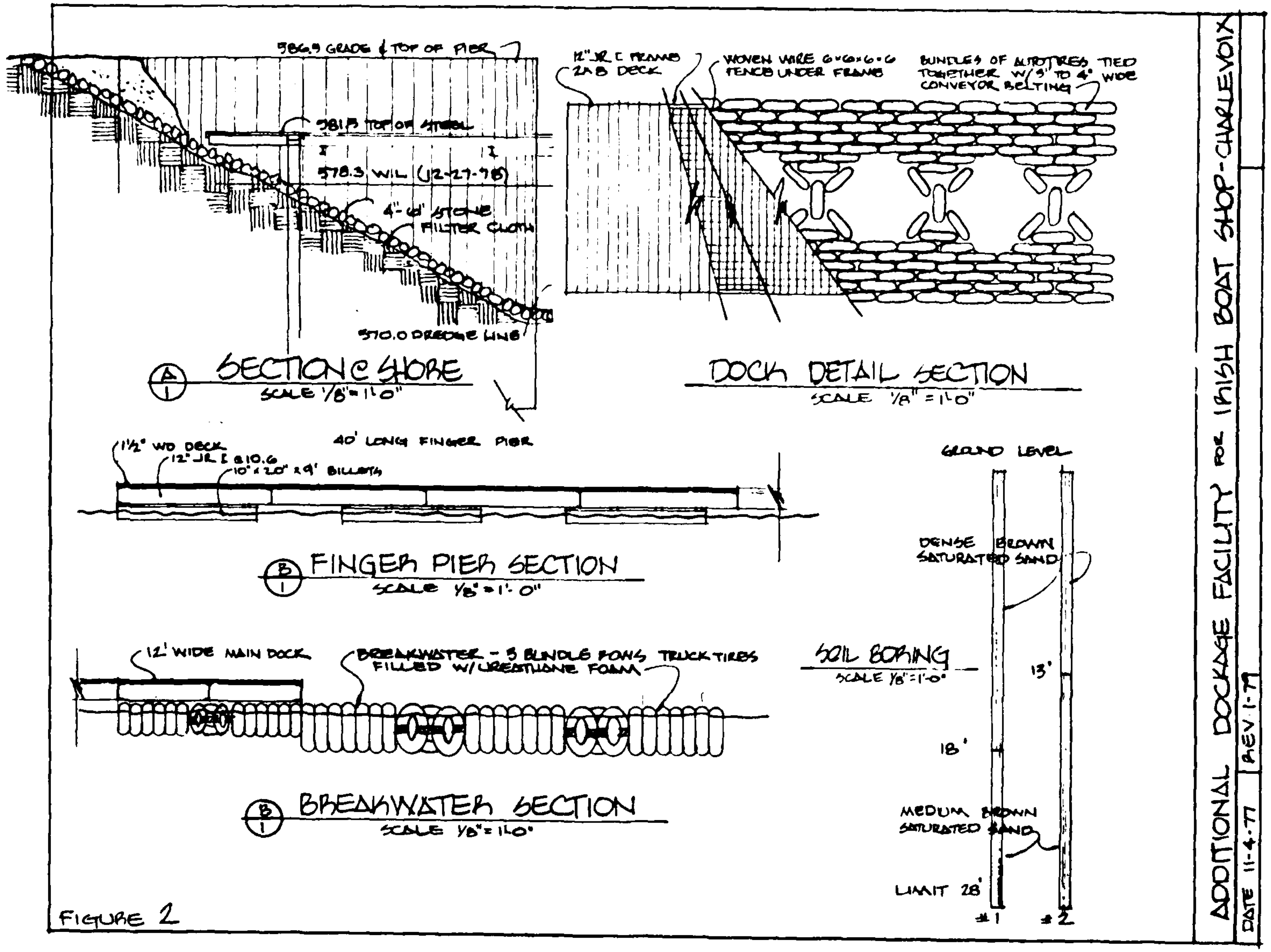
ADDITIONAL DOCKAGE FACILITY FOR IRISH BOAT SHOP-CHARLEVOIX
DATE 11-4-77
REV 1-79
586.9 GRADE & TOP OF PIER
581.3 TOP OF STEEL
578.3 W.L. (12-27-78)
4"-6" STONE
FILTER CLOTH
570.0 DREDGE LINE
A 1 SECTION @ SHORE
SCALE 1/8"=1'-0"
12" JR. I FRAME
2x8 DECK
WOVEN WIRE 6x6x6-6 FENCE UNDER FRAME
BUNDLES OF AUTO TIRES TIED TOGETHER W/3' TO 4' WIDE CONVEYOR BELTING
DOCK DETAIL SECTION
SCALE 1/8"=1'-0"
1½" WD DECK
12" JR. I @10.6
10"x20"x9' BILLETS
40' LONG FINGER PIER
B 1 FINGER PIER SECTION
SCALE 1/8"=1'-0"
12' WIDE MAIN DOCK
BREAKWATER - 5 BUNDLE PONS TRUCK TIRES FILLED W/UREATHANE FOAM
B 1 BREAKWATER SECTION
SCALE 1/8"=1'-0"
GROUND LEVEL
DENSE BROWN SATURATED SAND
SOIL BORING
SCALE 1/8"=1'-0"
13'
18'
MEDIUM BROWN SATURATED SAND
LIMIT 28'
#1
#2

FIGURE 2

The tires are tied with conveyor belt edge trimming ¼" to ½" thick, 2" to 4" wide, with a wide range in quality. They are bolted with 5/16" galvanized bolts, using corrugated washers. Conveyor belt edge trimming was supplied by a tire and rubber company in Cincinnati.

Our assembly took place in a heated shop where the tires were vacuumed, filled with foam as required (partially or fully filled) and assembled into modules before being dragged by their belts 1200 feet down the road to the construction site. There they were arranged into the layout as designed, bolted into the complete breakwater and dock attached to the top as needed.

Once the dock was floating, we added additional anchors and 4" used well casing spiles to hold it in place. There are now about 150 anchors and 50 spiles holding it in place.

COSTS:

Project costs for the breakwater and docks are summarized in Table 1.

PERFORMANCE:

The Floating Tire Breakwater has now been in service six summers and shows promise for six more. There have been no major problems. There have been changes made to the docks over the years, but in general the Floating Tire Breakwater has been very successful.

We find that the effectiveness of the Floating Tire Breakwater is quite adequate. It does not stop a sea entirely. We have observed a reduction of a 30" to 36" incident wave, with a period of 2.5 to 3 seconds to a 6" to 10" transmitted wave with a very tolerable boat motion. I have watched the boats many times lying peacefully and rocking gently while to the north and south of the breakwater, waves were breaking with a roar on the beach. Having been warned of this potential motion, we had designed the harbor to orient the boat's bow and stern into the seas. At no time have the cleats jerked out or lines broken, except from shear wind force. The consensus of our customers is to choose this dock over our fixed structure at our adjacent site.

EXPERIENCE AND PROBLEMS:

We encountered some resistance from neighbors and residents who felt we were in effect making a junk yard of old tires in their lake. We countered this with photographs of existing Floating Tire Breakwaters that looked neat and orderly.

We have experienced some anchor dragging. The surge of the dock together with the pull of 50 tons of boats does have an effect on the anchors. With one anchor for every two modules of tires there is an anchor supposedly for every nine linear feet of dock. In addition, the spiles locate the dock so it doesn't drift far.

FLOATING TIRE BREAKWATER

COSTS

TABLE ONE

PROJECT COSTS (1978 - 1979 PRICES)

Welding Supplies	$305.00
Urethane Foam and Equipment 92-lb density (10,000 cu.ft)	$18,200.00
Pipe 4" used well casing (Spiles - 100)	$3,008.00
Conveyor Belting ¼ - ½ " thick 2"-4" wide	$3,140.00
Tires	$1,545.00
Nails and Tex Screws	$2,237.00
Nuts and Bolts	$3,020.00
Steel 12" I Beams, Re-Rod, Gussets etc.	$32,650.00
Electrical	$20,534.00
Lumber - Decking	$15,751.00
Styrofoam Buoyancy Billets - Finger Piers	$4,746.00
Vinyl Dock Bumper	$999.00
Cleats and Brackets	$475.00
Water	$651.00
Cable ¼" 1x7 Galvanized	$968.00
Anchors - 120	$600.00
Miscellaneous	$1,871.00
MATERIAL TOTAL	$110,700.00
Dredging	$14,000.00
Labor (7,500 man-hours in design, fabrication, and anchoring)	$43,700.00
Other Site Improvements (Sewer, Plumbing, etc.)	$26,000.00
TOTAL COST	$194,400.00
Excluded From Total: Restrooms and Office	$29,750.00

Total cost of $194,400.00 divided by the number of slips of 62 equals a cost per slip of $3,135.00.

If the spiles were all removed, as they are in the fall, the dock will move about 6 feet in any direction. We find it necessary to send a diver down once a year to tension cables. On occasion we will relengthen and reposition the anchor and cable.

The noise of spiles squeaking is annoying to some people, particularly on a quiet summer evening. When the wind is screaming, then the noise is lost in the general noise of the storm. Several alternative designs have been tried but we have yet to arrive at a good solution.

Waste foam ("flashing") breaking off the exterior of the tires and floatation foam eroding and loosening within the tires is common. We find a trip around the breakwater by small boat with a minnow net is an effective way to pick up the small pieces of foam, as well as other debris. The floatation foam loosening may be a problem in a few years and at that time we will replace foam as necessary with "Ethafoam".

Broken conveyor belts and resultant loose tires are not a problem, but as a good neighbor, if someone complains of a stray tire, we go and pick it up. Ours are branded so that we may identify them.

ENGINEERING EVALUATION OF ALTERNATE MATERIALS FOR REDESIGNED MOORING SYSTEMS

Anthony Franco

Abstract

The load-carrying capacity of four types of conveyor belts was investigated to test their applicability for use in both navigational aids and boat moorings. Different methods of fastening the belt to itself were also investigated. Control sample and six-month exposure test results are presented. One-year test samples are still in the water.

Introduction

The purposes of this research were to:

1- Obtain strength data for conveyor belting in a systematic way.

2- To develop an alternate material which is cheaper initially and would have longer service life than the materials being used presently, and still have adequate strength.

3- To make this information available to people responsible for the maintenance, installation, and replacement of navigational and boat moorings.

Consequently, the author dealt primarily with marina owners and townships on Long Island and in Westchester.

The choice of conveyor belt size to test was dictated by the hardware these people use in their marinas. Since the marina owners that the author had discussed fastening techniques with preferred to bolt the belting together, a simple bolt pattern was tried as well as glueing the belt together with various compounds. Their main concern was that the fastening should be easy to fabricate and cheap.

Test Plan

To test the actual strength of the belt, three test specimens were made up from each of the conveyor belts according to the drawing shown in Figure 1. Then a tensile test was performed on a specimen of each material, while the two other specimens were set aside to be tested after exposure to the working environment for six months and one year. A comparison of the three load-deflection curves of each material would then show the deterioration of the material as a result of the exposure.

When performing these tests, the outer rubber covers were not stripped away since in actual practice, the marina owners wouldn't do this before using the belt.

The failure criteria used was either:

1- When either the top or bottom rubber cover separated from the inner synthetic carcass fabric or

2- When the synthetic carcass broke,

whichever occurred first.

The particular tensile test specimen's geometry was obtained after consideration of Figure 802.1 in the Conveyor and Elevator Belt Handbook. This book is published by the Rubber Manufacturers Association, located in Washington, D.C. If one calculates the ratios of $\frac{W}{A}$, $\frac{R}{A}$ and $\frac{R}{W}$ they will be constant regardless of the die number. Since a 2-inch-wide belt was decided upon for testing, making A=2.0, the other dimensions came out as shown in Fig. 1. The second phase was to test the strength of various forms of connections. Five concepts were used.

In order to eliminate any steel in the connection, a fastening concept was designed that used only chemical compounds. It is shown in Figure 2 and is called the first concept. The two compounds used were cold vulcanizing compound and Flexane 80 putty. This particular geometry was chosen for a number of reasons:

1- The belt is easily bent into loops.

2- Looping is the simplest way to bring the belt through shackles and rings. Therefore, this would be a very simple and cheap way to fasten the belt to itself if it was found that the joint formed would have sufficient load-carrying capacity.

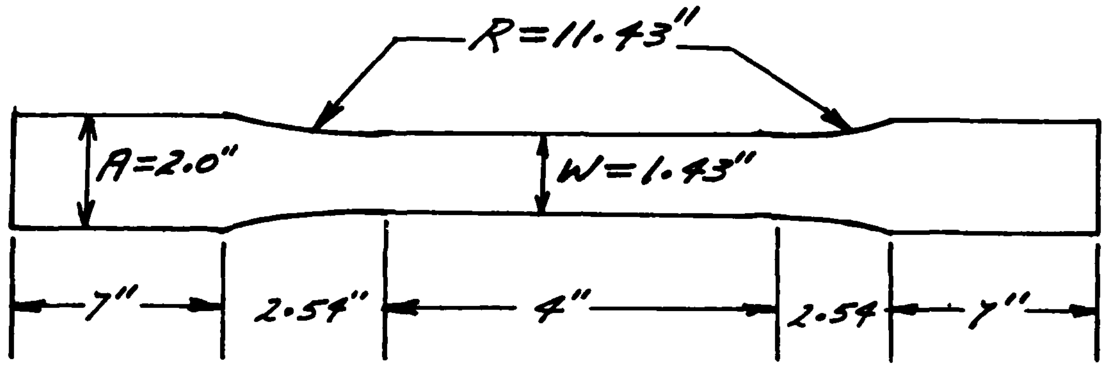

Figure 1. First concept

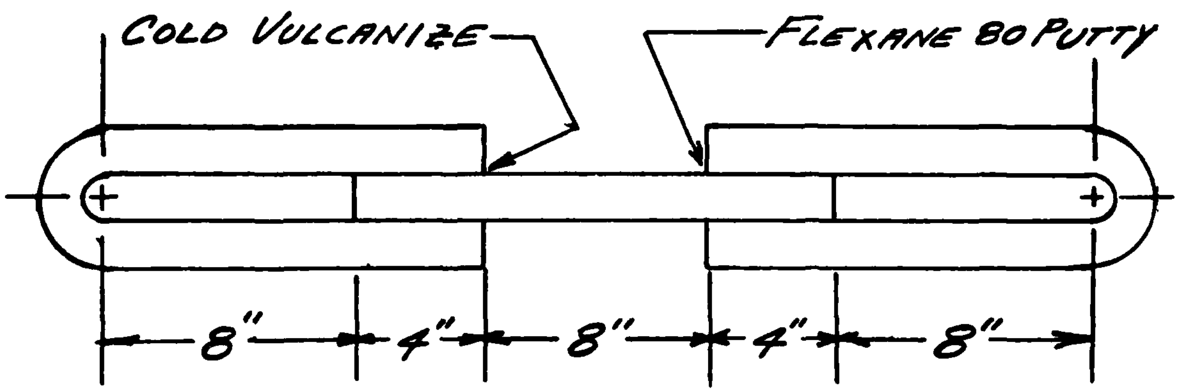

Figure 2. Cold vulcanization and Flexane 80 putty

3- By forming the loops shown, there was no eccentric load in the connection.

4- The loops were made large to eliminate the chafing I had seen in similar connections that were tightly fastened to rings.

In order to see which was stronger, one loop was fastened to the centerpiece using cold vulcanizing compound, the other using Flexane 80 putty.

The cold vulcanizing compound is made up of a cement and an accelerator that is mixed together. It is compounded for bonding rubber to rubber. After mixing, the pot life is approximately 3 hours, and the mixture is very easy to work with. It was applied using the following technique:

1- Use a stiff wire wheel attached to a bench grinder to roughen the surface of the belt. Surface should feel rough to fingers.

2- Wash down the area using alcohol until it is clean and free from dirt and grease.

3- Prepare the cold vulcanizing compound according to instructions given on can.

4- With a small nylon paint brush apply two coats to each surface. The initial coats should be allowed to dry thoroughly.

5- The third coat was applied, and when it felt tacky the parts were assembled.

6- The two parts of the end piece were sandwiched over the center section at the 4-inch overlap, one piece of aluminum sheet metal was placed on each side of the joint and the entire assembly placed in a vise and tightened to firm pressure. Coat the aluminum with a very light coat of grease to prevent it bonding to the rubber.

7- Leave the assembly in the vise for approximately 48 hours.

The entire procedure from step 1 through 6 took about three hours and half the amount purchased would have sufficed.

The Flexane 80 putty is a room-temperature curing urethane, made up of flexane resin and a curing agent that must be mixed together. After mixing, it has a pot life of about 15 minutes and once the two ingredients are mixed together, the mixture thickens and further mixing is extremely difficult.

The manufacturer advised the investigators that new belts were more difficult to bond than used ones and that proper belt preparation was critical. The compound was applied using the following technique:

1- The area to which the Flexane putty was to be applied was roughened by a wire wheel attached to a bench grinder.

2- Using a paper towel and special cleaner provided in the kit, the area was scrubbed clean. Then an abrasive pad (3M Scotchbrite pad) saturated with cleaner was used to scrub the area.

3- Area was then washed again with a paper towel saturated with cleaner and this was repeated until no black transferred to the paper towel. Then let the belts dry. This portion was very long and tedious. Approximately four hours were spent cleaning the surfaces.

4- While the belts were drying the special mold boxes that the investigators had fabricated for this part of the operation were set up and the mold release agent applied to all inside surfaces.

5- While step 4 was being performed, the rubber primer that was supplied with the kit was applied to all surfaces to be bonded. Once this primer is applied, the Flexane putty should be applied within 10 to 60 minutes to insure full bond strength.

6- The Flexane was mixed and poured into the molds to form a half-inch thick layer between the rubber being bonded, to form the section shown in Figure 2.

7- The sections were left in the molds for approximately two days. Room temperature was about 65° to $70^{\circ}F$.

The very short working time for the Flexane 80 putty made spreading the material out and building up the layer difficult. One has to work very rapidly or he will lose the entire batch within 15 minutes.

The two bolted concepts, called the second and third fastening concepts, were based on discussions with marina owners about methods being currently used to connect chain and conveyor belts to the anchor and to the buoys on boat moorings. These two concepts are shown in figures 3 and 4. The bolts were ¼" diameter by 2¼" long steel bolts with oversize washers on each side. The bolts were torqued down until the conveyor belt just started to protrude above the washer surface.

The second concept used the first concept geometry. The object was to compare the first and second techniques to see which was stronger.

The third concept would be the simplest to fabricate in the field. The belt is simply looped over onto itself and bolted. Also, a comparison could be made between the two bolting techniques to see which was stronger.

In order to determine whether the material by itself had any load-carrying capacity at all once the carcass had been cut or drilled through, a fourth concept was tried. It is shown in Figure 5. Shackles were placed through the 3/8" drilled holes and no other preparation was done. Since the water would now be able to quickly penetrate the inner carcass, a measure of how quickly the water deteriorates the fibers could also be obtained.

The first three fastening concepts have one thing in common - they require the belt to be looped around a steel shackle or ring at both ends of the mooring. An attachment method

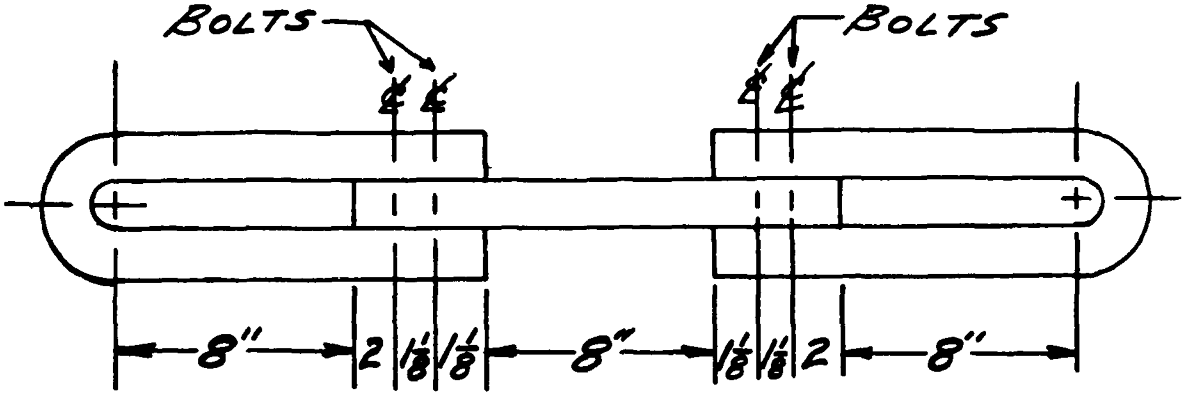

Figure 3. Second concept

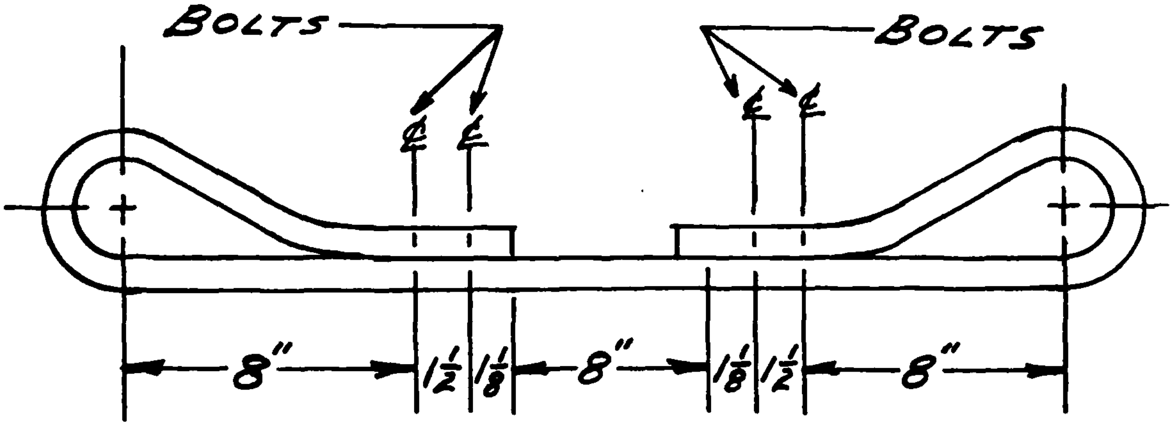

Figure 4. Third concept

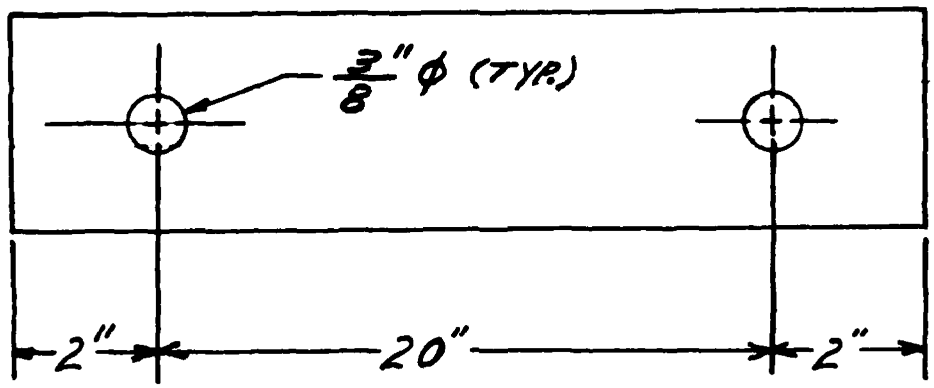

Figure 5. Fourth concept

was designed that would eliminate the metal-to-rubber connection and the possible chafing problem this creates. This fifth fastening concept is shown in figure 6 and is made up of a central core of Flexane 80 putty, the conveyor belt on one end and a steel plate on the other.

This concept has another advantage also. Since rubber is buoyant, there is the possibility that it would be cut by the propeller of a passing boat. This attachment would allow the use of a few feet of chain first to get the belt out of the propeller's way and still eliminate any chafing. The following technique was used:

1- All steel plates were ground on a bench grinder according to the adhesive manufacturer's instructions until white metal showed.

2- Clean steel parts with cleaner provided in the kit, let dry and apply the Flexane Primer for Metal.

3- 3/8-inch-diameter holes were drilled into the belts. Since drills don't cut through the belt cleanly, the holes were then burned out with a heated steel rod.

4- The belts were cleaned and prepared as explained previously.

5- Prepared mold boxes with a release.

6- Flexane 80 putty was mixed and poured into each mold, then the steel and belting were placed in the mold and the putty forced through the drilled holes. Then more Flexane was poured over the steel and conveyor belt.

7- The fastenings were left in the molds for two days at a temperature of 65° to 70°F.

Conveyor Belts Used

Four conveyor belts were used.

1- Uniroyal UsFlex Straightwarp belting. The word "straightwarp" describes a particular type of carcass construction, and is shown in figure 1-7 of the Conveyor and Elevator Belt Handbook. The particular belt used had a single

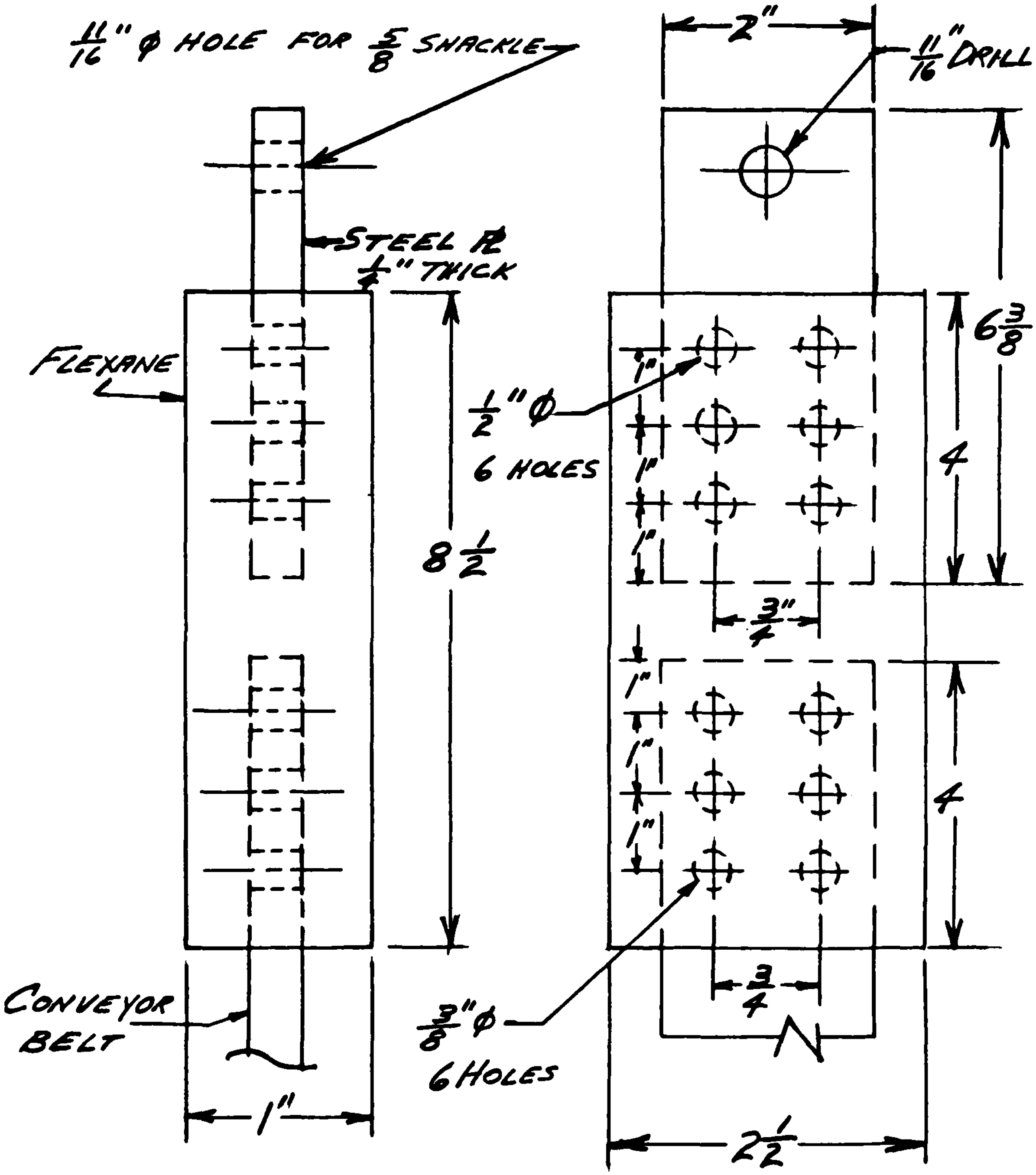

Figure 6. Fifth concept

polyester carcass covered by top and bottom RMA Grade 2 rubber covers. The belt measured 2-3/8" x 1/2".

2- Uniroyal Royalon. This is a multiple-ply belt. The belt tested was a three-ply belt, i.e. it had three layers of a synthetic polyester carcass fabric, and an RMA Grade 2 top and bottom cover with an ASTM compound specification SBR. The belt measured 2" x 30/64" and had a conventional or plain weave.

3- Goodyear. This is also a multiple-ply belt, a two-ply nylon belt, with RMS Grade 2 covers. The material measured 2-1/8" x 7/32". The rubber covers were ASTM compound specification SBR, and the nylon was woven in a plain weave.

4- Empire State. The belt that was tested was a multiple-ply belt, with a two-layer synthetic fabric carcass. The fabric is woven in a plain weave. The rubber covers are RMA Grade 2, with an ASTM compound specification SBR. The belt was supplied by Empire State Belting and Hose company and manufactured by B.F. Goodrich. The material measured 1-61/64" x 3/8".

The Uniroyal UsFlex and Goodyear samples were immersed in salt water in Port Jefferson Harbor on the North Shore of Long Island. To test these concepts, the belting samples were tied together to form two long rubber belts. One belt held a 36-foot sail boat in the inner harbor, and the other held a 33-foot Silverton power boat in the outer harbor. The chain in the inner harbor showed heavy barnacle growth. The rubber was not damaged by this growth. The typical arrangement used is shown in Figure 7.

In addition to being in the water for approximately seven and one half months, these belts were exposed to the environment in the marina yard as any ordinary chain used in moorings would be. They were exposed to snow, ice, rain and sun for approximately two and one half months before being tensile tested.

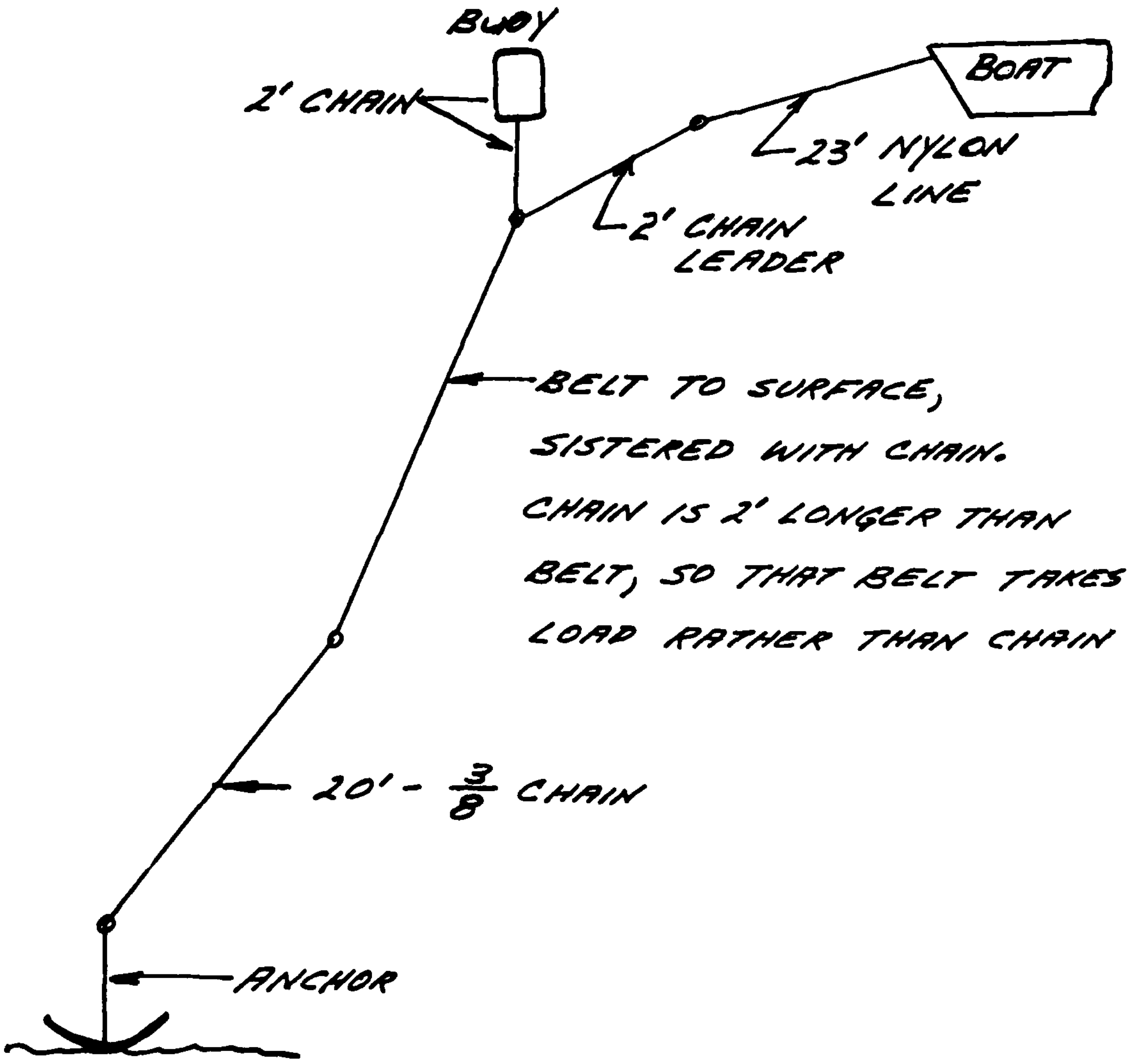

Figure 7. Typical arrangement

The Uniroyal Royalon samples were in salt water in Hempstead Harbor. A long rubber chain was made up using the first, second and third fastening concepts, and this chain was used to hold a navigational buoy in place. A schematic is shown in Figure 8. The fourth and fifth concepts took no service load but were immersed in the water for a longer period of time. Tensile testing began the day after the specimens were removed from the water.

The Empire State samples were exposed to salt water in Long Island Sound off Mamaroneck in Westchester County. None of the pieces had any marine growth on them. All of these specimens saw an entire winter in the water starting in November and were then exposed to the environment for approximately one month prior to testing. They took a light service load since they ran alongside a length of chain between the mooring and the anchor. Essentially, the load was split between the rubber and chain.

Results

In order to establish a basis of comparison, tensile tests were performed on one sample of unexposed fastening concepts and tensile test specimens from each material. In order to avoid stress concentrations when testing the first three fastening concepts, a steel pipe 3-1/2 inches in diameter by 8 inches long with a 3/16-inch wall thickness was placed inside each loop. This tube beared against the upper and lower crossheads of the tensile tester, and then one end of the particular fastening concept was pulled against the other end. After one end failed, jaws were placed in the lower crosshead and the remaining connection was tested to failure. To test the fifth concept a special jig was made up to hold the steel at the lower crosshead, while jaws were used to hold the conveyor belt in the upper crosshead.

The table showing failure loads and mechanisms for the connection control samples is shown in Figure 9.

The table showing failure loads and mechanisms for the connections after approximately six months'exposure is shown in Figure 10.

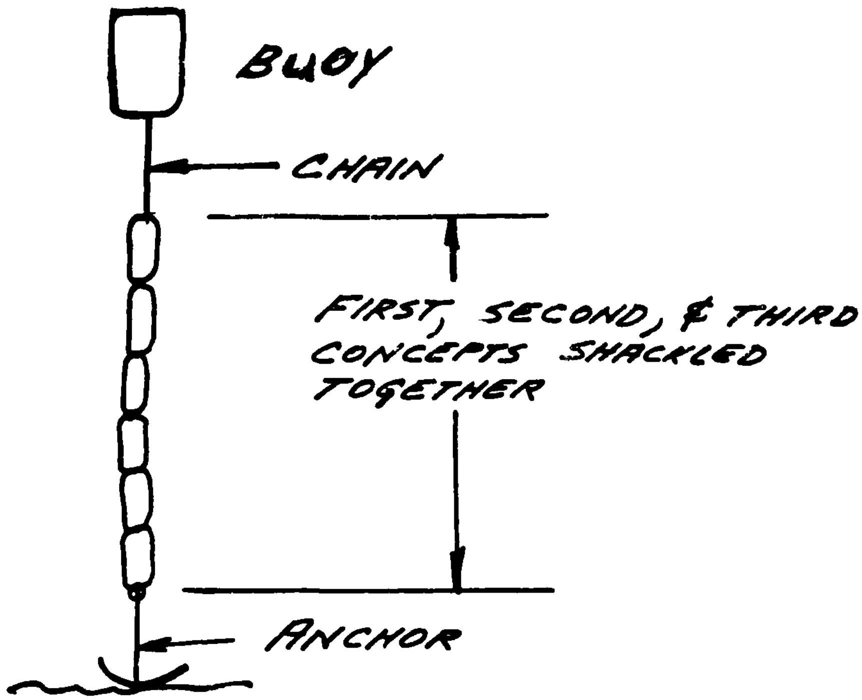

Figure 8. Schematic

FASTENING CONCEPT NUMBER		GOODYEAR	UNIROYAL ROYALON	UNIROYAL USFLEX	EMPIRE STATE
1	COLD VULCANIZE	5340 LBS	5985 LBS	2900 LBS	2170 LBS
		← FAILURE AT CONNECTION →			
	FLEXANE	3000 LBS	3985 LBS	2870 LBS	3980 LBS
		← FLEXANE FAILURE →			
2		1260	1705	2775	1520
		CENTER PIECE FAILURE, THROUGH BOLT HOLE			
3		2300	2795	5260	2140
		MATERIAL FAILED THROUGH BOLT HOLE			
4		455	980	1755	1245
		BOLT TORE THROUGH BOLT HOLE →			
5		1370	1040	1080	760
		FAILURE AT FULL SECTION THROUGH RUBBER			

Figure 9. Connection control samples, fastening concept breaking strength

FASTENING CONCEPT NUMBER		GOODYEAR	UNIROYAL ROYALON	UNIROYAL USFLEX	EMPIRE STATE
1	COLD VULCANIZE	4000 LBS	6220 LBS	2860 LBS	2880 LBS
		FAILURE AT CONNECTION →			
	FLEXANE	4160 LBS	4120 LBS	2420 LBS	2080 LBS
		← FLEXANE FAILURE →			
2		BROKEN, PARTED AT BOLT HOLE	1900	2160	1600
			CENTER PIECE FAILURE, THROUGH BOLT HOLE		
3		BROKEN, PARTED AT BOLT HOLE	2860	3760	2160
			MATERIAL FAILED THROUGH BOLT HOLE		
4		LOST	1500 BOLT TORE THROUGH BOLT HOLE	LOST	LOST
5		LOST	680 FAILED AT FULL SECTION THRU RUBBER	LOST	700 FLEXANE PULLED OFF RUBBER BELT

Figure 10. Connection samples, six months' exposure, fastening concept breaking strength

No belting broke as a result of mooring loads. The Goodyear samples broke when an attempt was made to pull the moorings out by pulling vertically on the rubber chain.

The tensile test specimens were cut according to the diagram shown in Figure 1. A three-inch gauge length was used in all the tests as reference. A steel scale was fixed to the top part of the specimen in order to measure deflection.

The load deflection curves obtained are shown in Figures 11 through 13, with the data sheets shown in Figures 14, 15 and 16 and the failure loads shown in Figure 17. The third column shown in Figure 17 is used to show the relative strengths of each belt on a pound per inch of width basis, and is obtained by dividing the failure load of each belt by the average width in the three-inch gauge length. Note that the thinnest belt is not necessarily the weakest.

In the case of the Uniroyal Royalon and Empire State samples, the thickest rubber cover was still taking load, even though the base fabric and the thin rubber cover had both failed. Neither sample was able to be stretched to total failure. The Uniroyal sample was holding 290 pounds when the gauge marks were 5-1/2" apart and the Empire State sample was holding 100 pounds with the gauge marks at the same distance apart.

All three load deflection curves have a similar shape. The curves provide an indication of the stiffness of the belt, i.e., the amount of deflection the belt allows for a given loading. An inspection of the curves shows that Goodyear allows the most deflection.

The elongation ranged in value from approximately 17% for Goodyear and Uniroyal Royalon to 14% for Empire State. The significance of these numbers lies in the fact that the tensile tests tested the synthetic carcass fabric rather than the rubber covers. The possibility exists that without stripping away the external rubber covers, the jaws of the tensile test machine will bite into the rubber only, and as the strength of the bond between rubber and carcass is exceeded, allowing movement between them, the deflection measurements become a function of the rubber only, not the entire belt. However, since

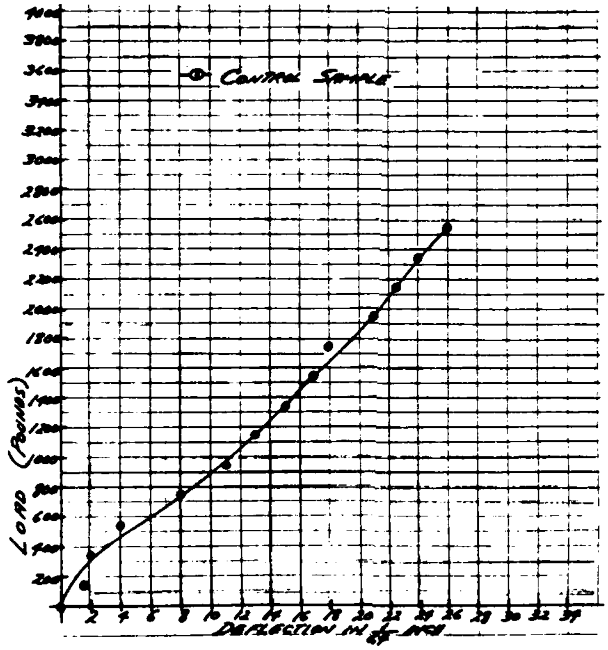

Figure 11. Load-deflection curve, Empire State tensile test

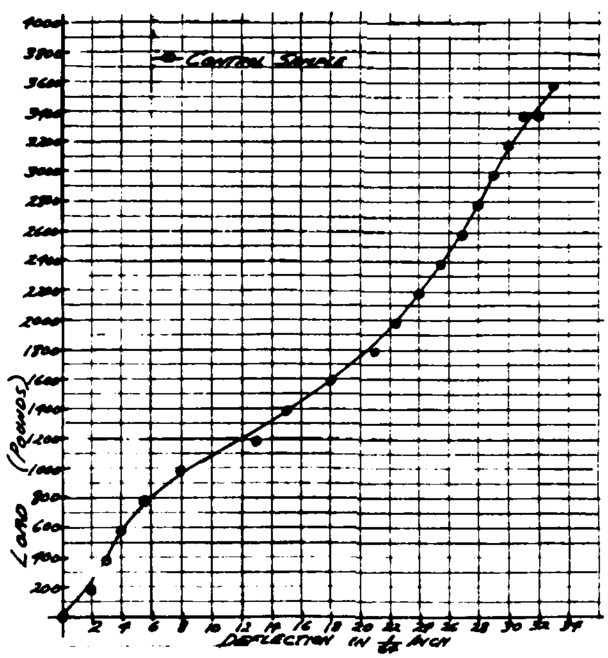

Figure 12. Load-deflection curve, Uniroyal Royalon tensile test

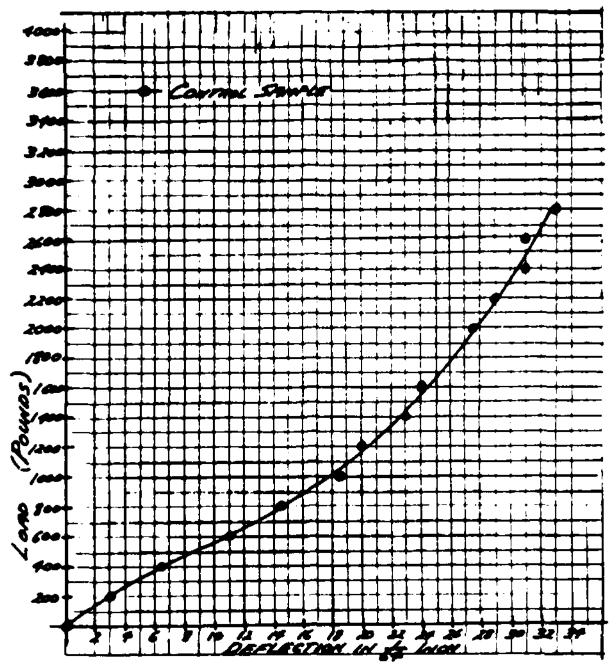

Figure 13. Load-deflection curve, Goodyear tensile test

LOAD (LBS)	DEFLECTION (INCHES)
0	0
200	3/64
400	13/128
600	11/64
800	29/128
1000	37/128
1200	20/64
1400	23/64
1600	24/64
2000	55/128
2200	29/64
2400	31/64
2600	31/64
2800	33/64
2820	FAILURE

Figure 14. Tensile test, unexposed sample, Goodyear

LOAD (LBS)	DEFLECTION (INCHES)
0	0
180	2/64
380	3/64
580	4/64
780	11/128
980	8/64
1180	13/64
1380	15/64
1580	18/64
1780	21/64
1980	45/128
2180	24/64
2380	51/128
2580	27/64
2780	28/64
2980	29/64
3180	30/64
3380	31/64
3380	32/64
3580	33/64
3860	FAILURE

Figure 15. Tensile test, unexposed sample, Uniroyal Royalon

LOAD (LBS.)	DEFLECTION (INCHES)
0	0
140	3/128
340	2/64
540	4/64
740	8/64
940	11/64
1140	13/64
1340	15/64
1540	17/64
1740	18/64
1940	21/64
2140	45/128
2340	24/64
2540	26/64
2660	FAILURE

Figure 16. Tensile test, unexposed sample, Empire State

MATERIAL	FAILURE LOAD (LBS)	FAILURE LOAD (LBS / INCH·WIDTH)
EMPIRE STATE	2660	1779
UNIROYAL ROYALON	3860	2656
GOODYEAR	2820	1926
UNIROYAL USFLEX		2800

Figure 17. Failure loads

the carcass elongates approximately 14% in tensile tests, the results of the tests seem reasonable.

Conclusions

No general conclusions can be drawn at this time since approximately 30% of the fastening concepts are still in the water as are 60% of the tensile test specimens. But there are observable tendencies.

1- Figure 17 indicates that the material can definitely hold tensile loads.

2- An inspection of the tables shown in Figures 9 and 10 show that connections made of conveyor belt can hold considerable load.

3- Of the two bolted connections fabricated, concept 3 had consistently higher failure loads then concept 2, irrespective of material. In the second concept the entire load is transferred to the centerpiece which then fails at the section through the bolt holes.

4- In all cases the use of chemicals produced a stronger bond than the second fastening concept.

Other tendencies can also be seen,

1- If one considers Uniroyal Usflex, for example, one sees that it produces its strongest connection when bolted according to the third fastening concept. This is explainable in terms of the straightwarp weave of the carcass. The weave does not allow the bolt to tear through as easily. The proof of this is shown in Figure 9 using the fourth concept. The Usflex has the highest load, indicating that its weave has the highest load-carrying capacity when drilled through.

2- However, if one compares the third fastening concept for Usflex seven months later, its strength has dropped off; whereas the connection strengths of the Empire State and Royalon belts have remained fairly constant. This indicates that these belts seem to keep their load-carrying capacity for a longer time in water.

3- If we consider the cold vulcanizing data shown in Figure 9, the control summary sheet, it shows that a stronger bond was created with Goodyear and Uniroyal Royalon belts. Since all the connections were manufactured identically, the differences in strength become a function of the type of rubber covers. Although it is possible to classify rubbers to some extent by the basic rubber (polymer) used in their manufacture, for example the ASTM designation used previously, this is only a general description. Each manufacturer will add other items in the manufacture of the rubber.

Cold vulcanizing bonds rubber to rubber in a cohesive bond. The compound melts the rubber layer it is applied to, thus creating a stronger connection.

4- Flexane forms a different type of bond, called an adhesive bond. This bond is made up of a dissimilar material having an affinity for both sides. The variations in the numbers as one reads across the control specimen table can in part be attributed to the very short pot life of the material. The Flexane was curing in the pot as we were pouring it into the molds. Thus some of the connections were made up of some material that had already cured to some extent. There was approximately a four-month wait to allow for curing, between completion of fabrication of the first concept, to initial testing of the control samples. Similarly, three and one-half months were allowed before this concept was placed in the water. If one looks at the six-month summary in Figure 10, the failure loads increased for Goodyear and Royalon. In these two cases the water probably helped cure the material. There are urethanes for which a moisture cure system can provide higher loading.

As you can see, the design of the fastening is complex, and depends on a number of factors.

1- If bolted connections are to be used, the geometry of the connection is as important as the belt's synthetic carcass load-carrying capacity. Exposure time is also a consideration. The weave of the carcass is also extremely important. This has been demonstrated by the Uniroyal UsFlex Belt.

2- If chemicals are used rather than bolts in making up the connection, the interaction between the chemical and the rubber covers becomes the important consideration. In other words, is the rubber cover of the particular belt suited for this application? The next consideration would be the load-carrying capacity of the carcass.

Chemicals can be problematical as the data using Flexane and cold vulcanizing compound suggests. The key factor is that the bond must be fully cured before being put into operation. This could be extremely difficult to determine.

There is an extremely large selection of urethanes available, requiring an exhaustive study to determine which urethanes to use with which rubber. Some of the variables are: the solvent used in the bonding agent, room temperature, air moisture content. Curing time varies with all of these. Keep in mind that these four belts represent a very small sample that one can select from.

However, the material shows great promise and there are marinas on Long Island that have successfully used conveyor belts for boat moorings for the past three to four years.

CONSTRUCTING AND FIELD TESTING A HIGH PERFORMANCE PIPE-TIRE FLOATING BREAKWATER*

Robert E. Pierce

Abstract

A pipe-tire floating breakwater has been assembled and installed in Presque Isle Bay, Erie, Pennsylvania, using mostly standard marina facilities and equipment. Specially developed techniques employed in the construction of the modular-type subassemblies eased the difficulties of launching, towing, and final on-site assembly.

Three unique tire-placement configurations were employed in the construction of the floating breakwater system. Two designs used truck tires exclusively, while the third utilized a combination of truck and car tires. Field observations and measurements indicated that the all-truck-tire designs possess superior wave attenuation characteristics.

Tire-clad tubes integrated into the tire breakwater design provided for a more secure mooring attachment and improved the structural rigidity in the direction of wave advance. When properly foamed, each tire-cladded tube supported the weight of several persons and served as a platform for on-site assembly and maintenance. Small work boats were routinely driven onto the assembly alongside a tire-cladded tube for the purpose of loading or unloading tools and/or personnel.

Other than routine inspection of the assembly and service of the marker lighting system, the breakwater has required no maintenance since its July 1982 installation.

Introduction

All-tire floating breakwater assemblies have been used for some time. One of the more enduring and important of the all-tire floating breakwater designs is the Goodyear modular configuration. Two major installations of this type occurred in recent years, one located at the Burlington Yacht Club, Burlington, Ontario, and the other located in the harbor behind the stone breakwall at the Port of Lorain, Lorain, Ohio.

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* This research was sponsored by New York Sea Grant Institute under a grant from the Office of Sea Grant National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. The U.S. Government (including Sea Grant Office) is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation appearing hereon.

The pipe-tire floating breakwater first conceived by V. Harms is a more recent development. This design utilizes rigid steel tubes judiciously interleaved into the tire arrays such that only flexible rubber connections exist between the tire mazes and the steel tubes.

Engineering tests to obtain wave transmission and mooring force data have been conducted on both the Goodyear[1] all-tire modular and the V. Harms[3] pipe-tire designs. These tests were conducted in the large wave flume at the former Army Corps of Engineers Coastal Engineering Research Center (CERC) at Ft. Belvoir, Virginia. The first series of tests, conducted in 1977, on the Goodyear modular configuration were a joint effort between CERC and Lake Erie Institute for Marine Science (LEIMS). The LEIMS organization provided the prototype scale breakwater section, the anchoring system and the mooring force measuring equipment, while CERC conducted the tests in their large wave flume using CERC wave measuring instrumentation. Pierce and Lewis[5] of the LEIMS organization reported on the general aspects of the test programs, and Giles and Sorenson[2] of CERC reported the detailed engineering data.

In 1979, V. Harms[4] tested a prototype scale pipe-tire configuration dubbed PT-1, which features a heavier design with improved front-to-back structural rigidity. It utilizes a truck tire design with a denser packing of tires than the forerunner Goodyear modular units.

Goodyear type assemblies four modules deep (beam length approx. 28 ft.) and six modules deep (beam length approx. 42 ft.) were tested in 1977. The beam width or depth of the pipe-tire assembly tested in 1979 was 40 ft. The observed differences in the wave attenuation characteristics between the Goodyear type assemblies and the pipe-tire assembly were rather dramatic. The larger draft, the more dense packing of tires, and the increased front-to-back rigidity attributed to the interwoven steel tubes are all factors contributing to the improved attenuation characteristics of the PT-1 design. By contrast, the Goodyear design is much more flexible to upward and downward modal type bending. In addition, considerable lengthwise stretching and compacting occurs with the Goodyear design due principally to tire motion and stretching in the module coupling areas. These structural characteristics tend to permit more accommodation of the wave motion than does a more rigid configuration. Recognizing the need to obtain floating tire breakwater (FTB) performance data in a typical field situation, New York Sea Grant Institute funded the LEIMS organization in 1980 to construct and field test a pipe-tire floating breakwater. A site was selected near the south shore of Presque Isle Bay and a 120-ft. length by 40-ft. beam width pipe-tire floating breakwater assembly was installed approximately 360 ft. off-shore (9-ft. water depth) during the summer of 1982. The site was instrumented to obtain wave transmission data during the time the bay is free of ice.

Fabricated in sections, the breakwater utilized three different design configurations. The first (PT-1) is the original Harms design. The second (PGYM-1) utilizes truck tire mazes fabricated in a Goodyear modular design fastened at each end to the tire-cladded tubes. The fabrication details, installation, and certain field procedures have been reported by Pierce[6]. This paper summarizes some of the previously reported results while treating in more detail certain aspects of the construction procedures. Observations ranging over an extended period and some field measurement results are also included.

Equipment and Personnel Requirements

Component preparation and fabrication of the floating breakwater subassemblies involved certain tasks which were best handled sequentially. For example, tire, steel tube, and belting preparations were best treated independently as a sequence of operations involving the logistics of moving about massive amounts of material from one location to another and the setup of a reasonable, well-planned work area for the execution of single tasks. Only rarely was sufficient space available to execute tasks simultaneously, such as those associated with tire and belting preparations, or tire and steel tube preparations, etc. As the work progressed to the assembly stage, it became necessary to perform some operations simultaneously with the result of some additional loss of prime marina space for recreational purposes.

Within the foregoing constraints, the number of personnel assigned to the project varied from two to six. A crew of three or four was considered optimum for accomplishing most of the tasks. Six people were used in the final phase of launching, towing, and on-site assembly.

A list of principal facilities and equipment and their prime use follows:

1. Dry indoor storage and work area - used primarily for indoor activities such as belt cutting, punching tires and belting, branding tire casings, storing clean dry tire casings prior to foaming, and for storing foam components (foam components must be kept at a cool temperature because of their volatility).

2. Fork lift truck - used to unload materials, move coils of belting, move groups of truck tires, lift ends of steel tubes, and load truck tires onto steel tubes.

3. Traveling boat cradle crane - used to lift and move steel pipe, hold pipe in position while cladding with tires, lift and move tire cladded tubes, and lift and launch floating breakwater subassemblies.

4. Punch (10 hp pneumatically driven) - used to punch tires and belting.

5. Branding iron and gas heater - used to brand tires to US Army Corps of Engineers specifications.

6. Foam mold - used to mold foam slugs for filling steel tubes.

7. Open stake-bed truck - used for hauling tires, belting, and supplies.

All tasks relative to the fabrication and installation of the breakwate subassemblies were effected on-site at Gem City Marina, Erie, Pennsylvania, without appreciable disruption of the marina's normal business activity. At times this required prompt attention to certain tasks and careful scheduling around other marina activities.

Tire Preparations

Truck tire casing procurement and preparation presented a unique challenge as truck tire casings are relatively scarce when compared with car tire casings. Truck tires are also larger and much heavier to handle than car tires. Just as a reminder, Figure 1 illustrates the difference in size between a typical large truck tire and a medium size car tire (rim size at least 14 inches). One does not need to work long with the truck tires before he gains real insight into why a maze of these tires is a more effective absorber of wave energy.

The rate of acquisition of truck tire casings did not meet expectations while dealing directly with retailers in the area. The problem was eliminated when personnel from Goodyear Research Division set up a working relationship with one of its regional distributors. The distributor preselected casings and arranged for pickup of tires over a wide area. This arrangement virtually eliminated the need to return tires which were in excessively poor condition. Pre-selection of the tires is an extremely important service as a significant percentage of truck tire casings are torn up so badly on the interior that it precludes their use. Truck tires tend to be run flat for longer distances resulting in extreme ripping and tearing of the tire cords and, in some cases, fusion and entanglement of the rubber inner tube onto a glob of rubber and cord that can not be cut out in a reasonable time. At the time, the price charged to dispose of a truck tire through an independent agent was approximately $1.50 per casing due to the state's environmental restrictions. Obviously, this was an expenditure to be avoided.

Using a pneumatically driven punch, holes were punched in each tire casing prior to inserting the foam components. The air compressor and punch were loaned to the project by Goodyear Research Division. For steel-belted tires, the holes were punched through the sidewall near the tread rather than directly through the tread surface. Two holes of approximately 3/4-inch diameter were punched in opposite ends of the casings (see Figure 2). These holes were used as water drain holes for drying the casing prior to foaming. It is noted that the foam agents will not cure properly in the presence of water; at the same time, punching holes in the casing to drain the water insures that the tire will be positively buoyant only if sufficient foam is applied to its interior. Figure 3 shows an example of an adequately foamed steel belted tire. The foam slug in this tire weighs approximately 3 lbs. Less foam is required for smaller, non-steel-belted tires.

Steel Tube Preparations

Steel tubes 16 inch in diameter by 40 ft. in length with a wall thickness ranging from 1/4 to 5/16 inches were used in the breakwater assembly. Each tube was filled with cylindrically shaped foamed slugs approximately 2.5 to 3.0 ft. in length and having a diameter very nearly equal to the pipe internal diameter.

Molds for forming the foam slugs (Figure 4) were fabricated by rolling sheet steel into a three-foot-long cylindrical shape. Two 3/4 by 3/4 inch right angle steel bars were welded along the joining edges of each rolled sheet metal tube. Standard hand vise grips applied to the edges of the welded bars firmly closed the rolled sheet. The end profiles of the rolled sheet tubes were cut from 2 ft. x 2 ft. x 3/4 inch sheets of plywood and slipped over both ends of each cylinder to help stabilize the shape. Several molds of this type were manufactured for use in the foaming operations.

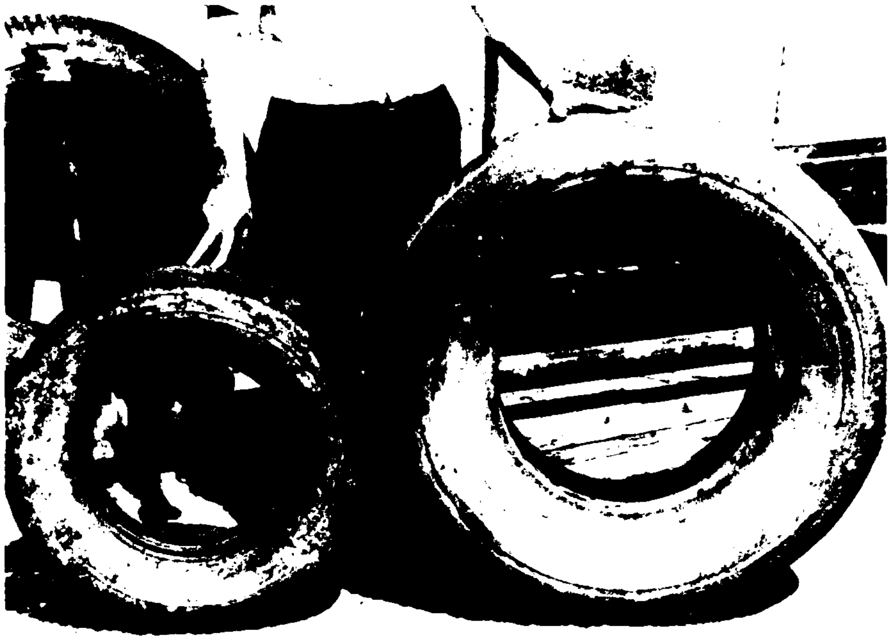

Figure 1. Relative sizes of 14-inch car tire and 20-inch truck tire

Figure 2. Punching hole in tread of truck tire

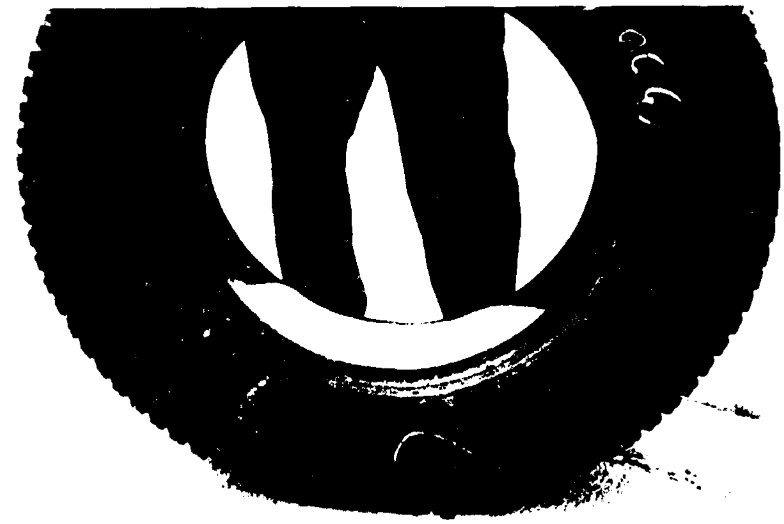

Figure 3. Cured foam slug in steel-belted truck tire

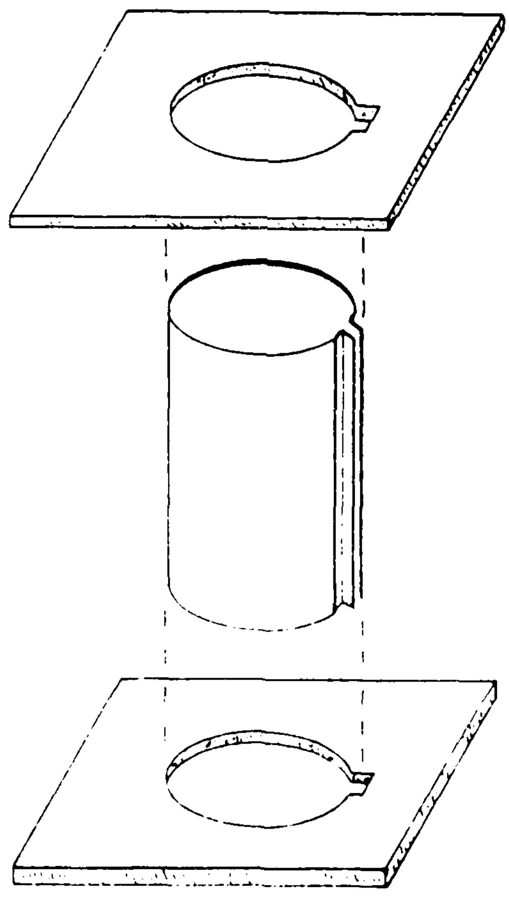

Figure 4. Mold for forming foam slugs

To produce a foam slug, regular automotive cup grease was applied to the interior of a foam mold. Then a large size plastic leaf or garbage bag was inserted into the mold. A measure of two-part polyurethane foam was mixed and poured into the plastic bag liner. As the foam agents reacted, the expansion uniformly filled the interior of the mold, generally resulting in a rounded crown on top. To recover the plastic-covered foam slug, the wooden end retainers were removed along with the vise clamps. The rolled sheet tube immediately opened, permitting the foam slug to slip out. Hand sawing in a mitre-box type fixture removed the crowned end, leaving a regular square cylindrical shape.

The partially greased foamed slugs were pushed into the steel tubes using a pusher rod with a flat plate welded to the end. Void space was kept to an absolute minimum by measuring and cutting the last slug to the correct length.

Steel end caps 1/4 inch thick were welded into place at the ends of the steel tubes. A pipe plug located in the center of each end cap permitted pressurization of the tube to inspect for weld leaks prior to final sealing. Leaks can be located with a filling gauge pressure of approximately 10 lbs. (see Figure 5) using an appropriate soap solution. Calculations indicate that the tubes themselves cannot become negatively buoyant even though leaks should eventually develop.

Figure 6 shows the operation of tire cladding the steel tubes. The far end of the tube is resting on a fixed block and the center is supported by the cradle crane lifting cable.

Breakwater Design, Fabrication and Installation

Having been funded to field test a state-of-the-art floating breakwater, the pipe-tire design with its superior wave attenuation characteristics was selected. This approach also accommodated the author's desire to field test two newly conceived pipe-tire configurations. The matter was resolved by constructing a system incorporating subassemblies of three different designs. Comparisons of relative performance could then be obtained by placing the measuring instruments in appropriate locations aft and near the various assemblies.

The design variations are limited to the manner in which the tire mazes between neighboring tire-clad tubes is configured and attached. Figure 7 illustrates how the tires are positioned on stringers spanning the intervening space and attaching to selected tires on neighboring pairs of tire cladded tubes. This tire maze configuration is the V. Harms PT-1 design. It orients the tire treads in the principal direction of wave advance (see Figure 8). Loose coupling of the tires to the spanning stringers is a characteristic of this design. Consequently, more careful foaming of the tires is required, as each tire must be positively buoyant else it can sink beneath the surface while still on the stringer.

Figure 9 shows details of the truck tire maze stringers for the PGYM-1 design. Each stringer is of Goodyear modular design. This configuration positions the tire openings in the principal direction of wave advance (see Figure 10). It features a tightened bundling of the tires with neighboring tires providing some positive lift in the event a tire is insufficiently

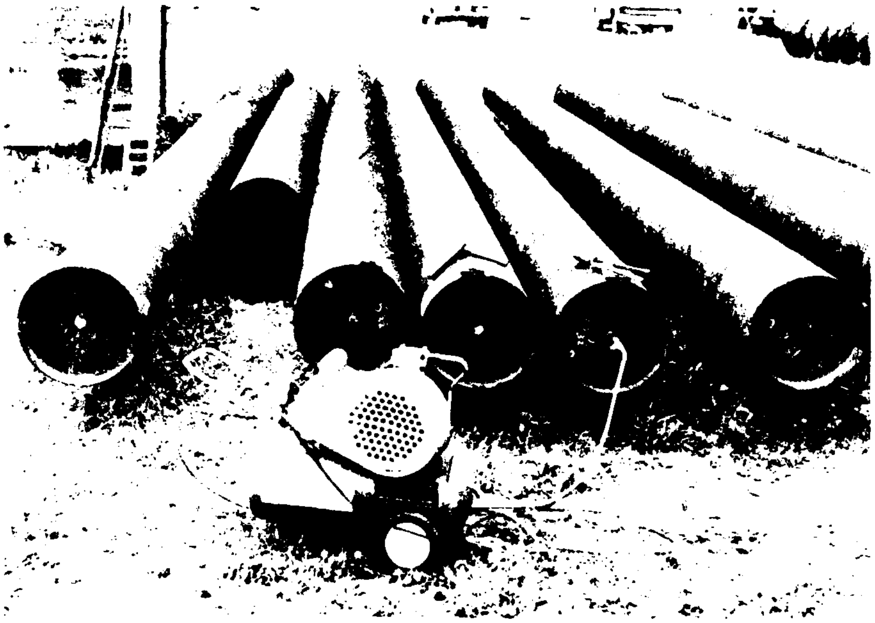

Figure 5. Leak testing steel tubes

Figure 6. Threading truck tires onto steel pipe

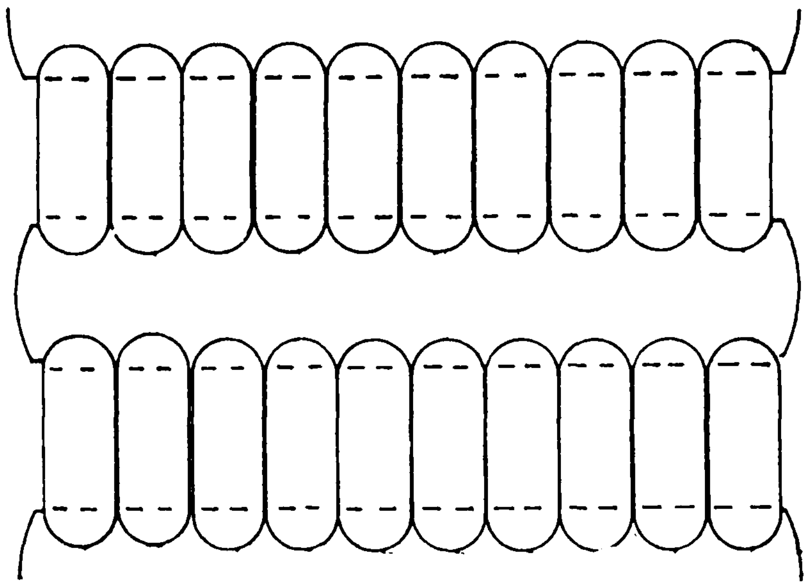

Figure 7. PT-1 tire maze stringer design

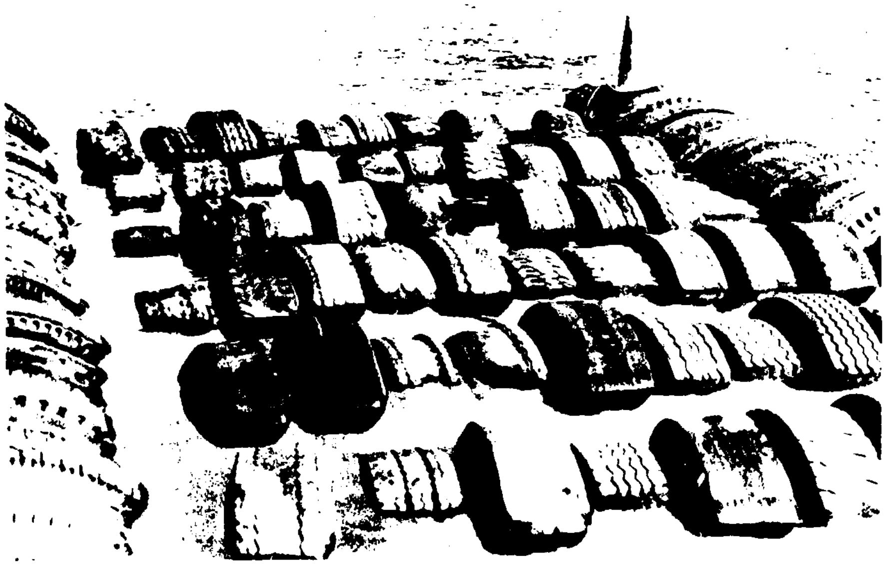

Figure 8. PT-1 assembly in the water

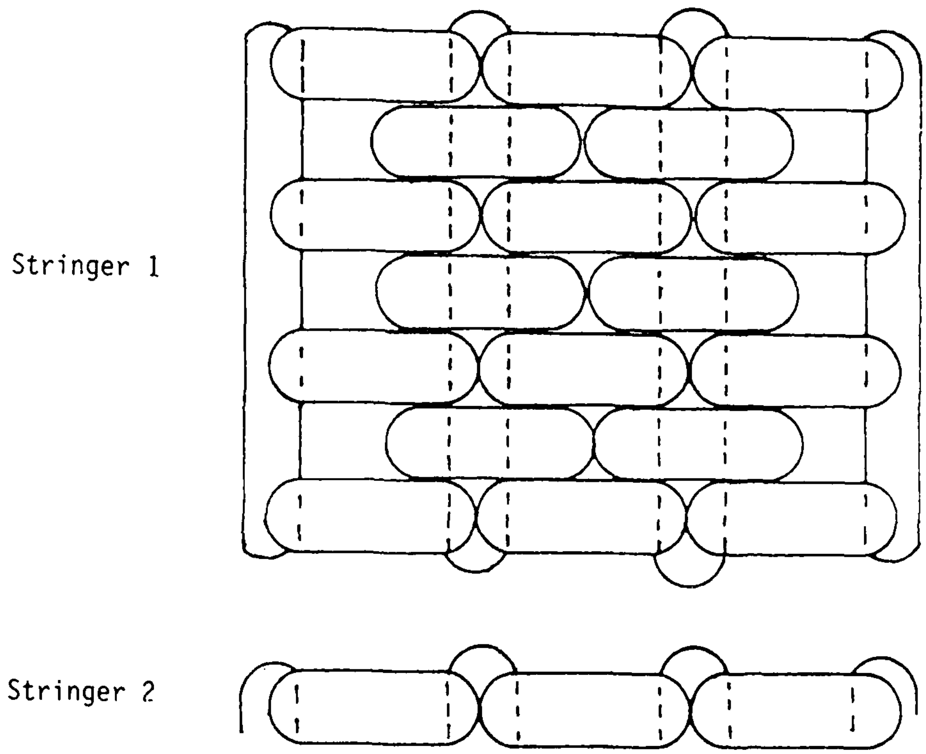

Figure 9. PGYM-1 tire maze stringer design

Figure 10. PGYM-1 assembly prior to launching

buoyant. Being more tightly coupled, each stringer module is stiffer and better retains an overall rectangular shape. A desirable overall floating breakwater shape is more easily achieved using this tire maze design.

Figure 11 shows details of the car tire maze stringers for the PGYM-2 design. Again, each stringer is made from tires assembled in a Goodyear modular arrangement. Two modules were joined at their ends to make one stringer for the maze. These car tire stringers were joined at their ends to truck tires on the tire-cladded tubes using rubber belting. Like the PGYM-1 design, the principal direction of wave advance is directed towards the openings in the tires (see Figure 12).

All subassemblies were fabricated at the marina and consisted of one tire-clad tube with attached tire maze and short loosely assembled joining belts connected to tires on the side later to be joined to the tire-clad tube of the next subassembly. Large-diameter truck tires were belted outside at the ends of the pipe to the first tire on the pipe. These tires provide some measure of damage protection should a boat come in contact with the breakwater in the regions of steel pipe end exposure. Figure 13 shows the short steel tire retaining lugs sandwiched between two end tires.

A subassembly, with mooring lines connected, was lifted with a travelling boat cradle crane by cabling around the tubes (Figure 14) and moved to a position over the launching well. Since the tire maze was assembled with the foam in the top of all tires, the tires came up on the correct side as the assembly was lowered into the water (see Figure 15). As the assembly was eased out of the launching well, a 16-ft.-long boat with outboard drive was lashed to each side. These boats were used to move the subassemblies approximately 3/4 miles to the installation area (see Figure 16). Steering of the assembly was accomplished primarily by increasing motor r.p.m. on one side or the other.

On-site the front mooring line was attached and then the inside boat was decoupled and the remaining boat was shifted into reverse gear. This brought the subassembly next to the already installed section where it could quickly be attached at front and back.

It was necessary to work in the water to complete connection of the section. This was best accomplished by two people, one sitting on the tire-cladded tube handling the tools and hardware with the other in the water fastening the binding belts (see Figure 17).

The site was instrumented using a newly developed real-time wave height, period and direction measuring device. This instrument was placed at the center and fore of the breakwater so as to be able to monitor the incoming waves. A tripod mounted wire wavestaff gauge was placed aft of the breakwater. This instrument was moved from one design configuration to another as required. A long, slim wire wavestaff gauge, which could be inserted down through an opening between tires to rest on the bottom while being hand held at the top, was also used to obtain data.

Figure 18 shows the installation during late November. A public boating launching ramp is located out of view at the lower left with access between the stone groin and the concrete wall shown in the picture.

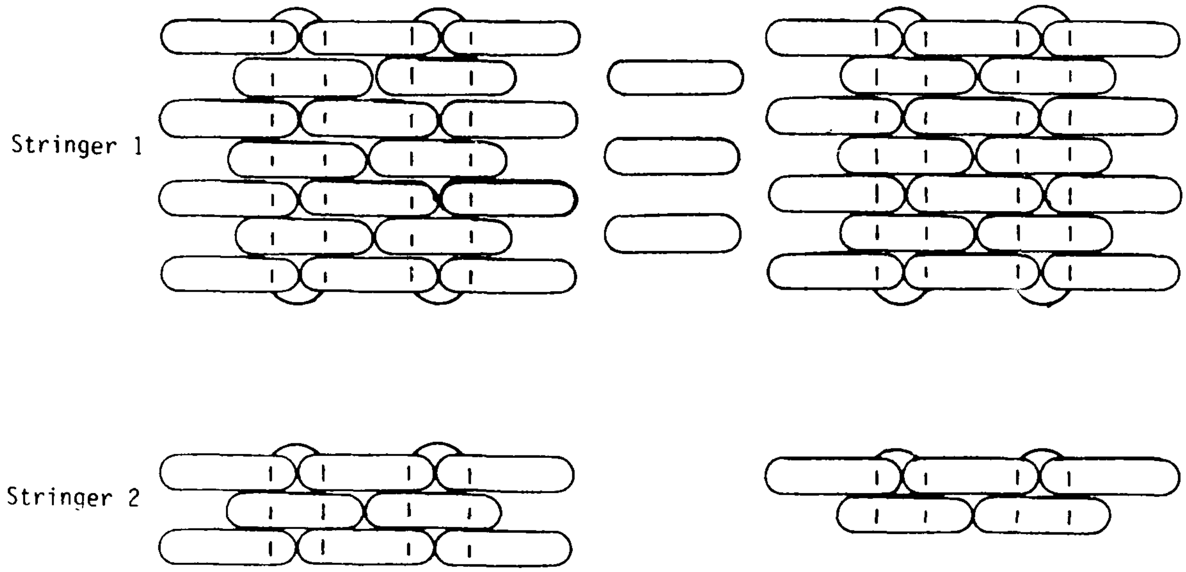

Figure 11. PGYM-2 tire maze stringer design

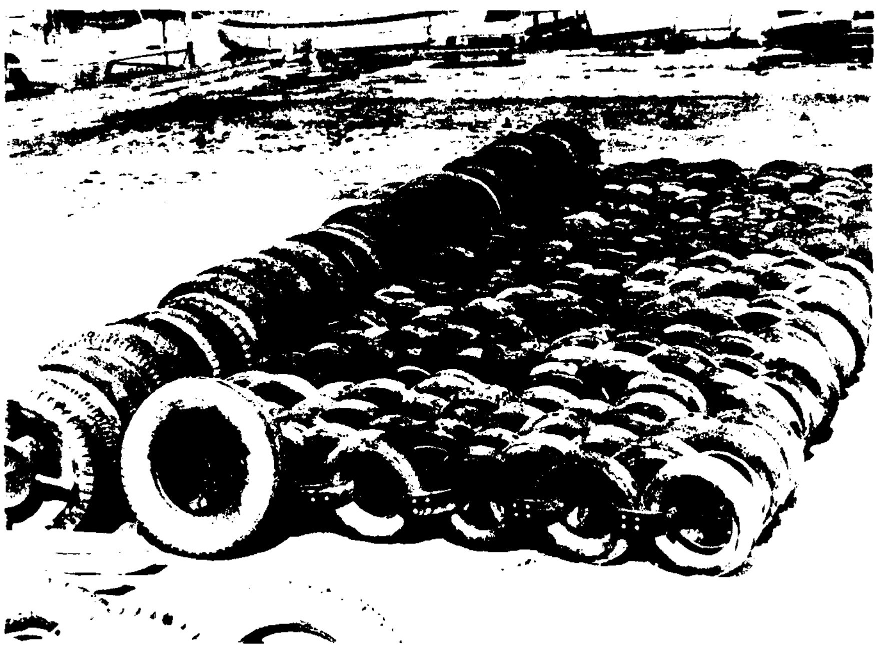

Figure 12. PGYM-2 assembly prior to launching

Figure 13. End tires covering steel retaining lugs

Figure 14. PT-1 section being moved to launching well

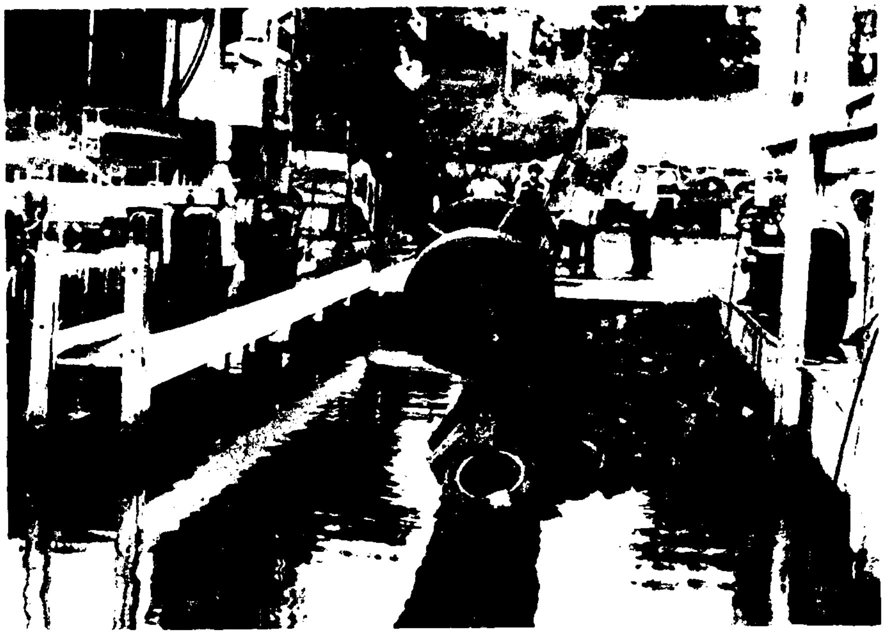

Figure 15. PT-1 section being launched

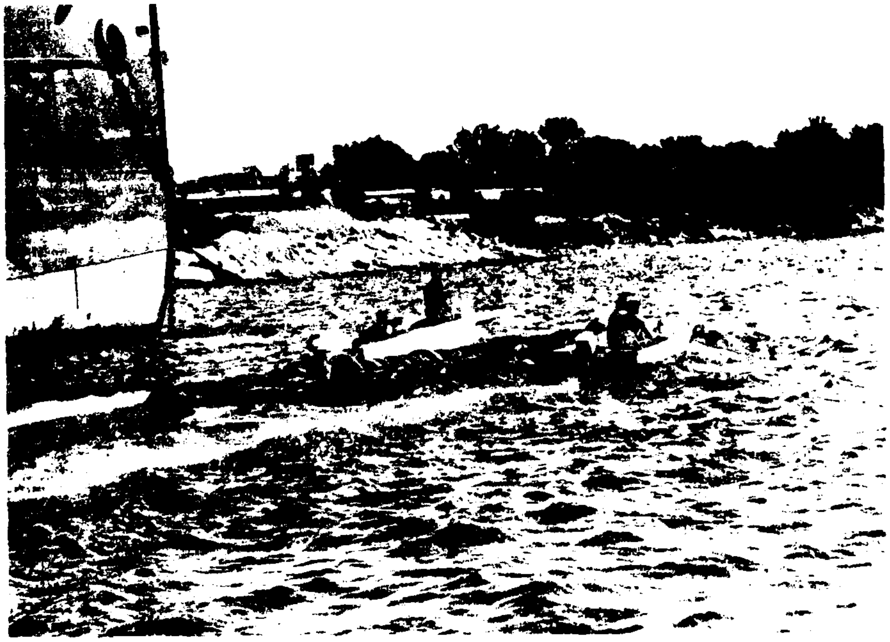

Figure 16. Towing a PT-1 section to test site

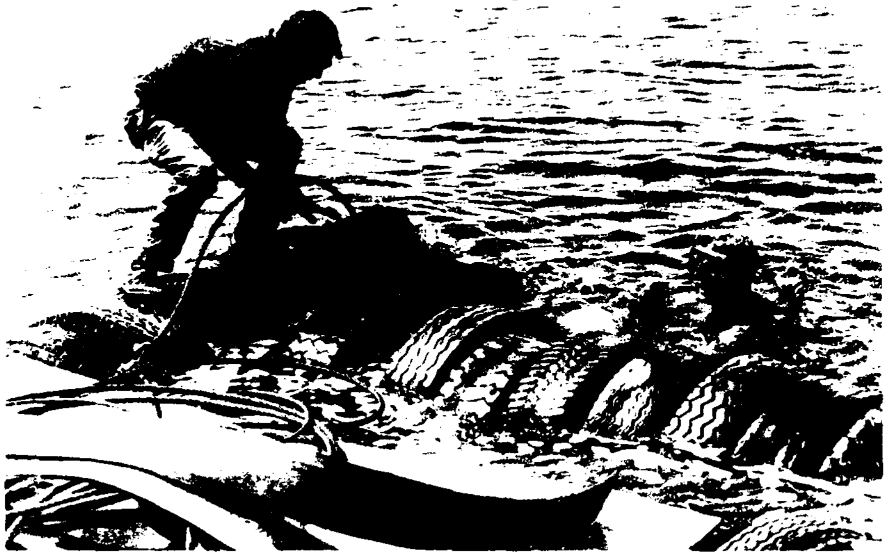

Figure 17. Worker on breakwater assisting in attaching mooring lines

Figure 18. Plan view of test site

Field Observations and Measurements

Installation of the floating breakwater occurred during the summer months of 1982. The tires became so warm during the late summer that feet protection was required when working on the installation. The additional warming of the water by the tires created ideal algae growing conditions. By late fall when the growth subsided the algae completely spanned the open regimes between the tires in several areas of the breakwater. It turned brown during the winter months and resumed growth in April the following year. Figure 19 shows the algae growth that was present two months after installation.

The breakwater has been a bird sanctuary from the beginning (see Figure 20). The bird population varies from month-to-month with an estimated 300 birds having been observed in the structure at various times.

During the more severe weather months, wave action tends to remove any accumulated rubbish. This generally consists of floating beer or pop cans, food wrappers and sticks or twigs. These have been removed on occasion using a long pole with a ring and net attached at the end. One simply walks up and down the tire-clad tubes scooping up the debris.

The dynamic response of the tire mazes to wave action has been observed on many occasions. Literally hours have been spent in a boat alongside the breakwater, standing on the cement pier off to the side of the breakwater, and in the observation tower of the municipal water works just aft of the breakwater. Figure 18 was taken from the latter viewing position. Visual observations indicate a significant difference between the two all-truck-tire sections and the one with the car tire maze. Since the tire-clad tubes are relatively stable in the presence of short-wavelength, low-amplitude waves, they serve as a reference for observing the heaving of the maze tires as the wave propagates through the breakwater. Typically a wave which causes observable heaving of the car stringer tires for two-thirds the beam length will appear to be entirely damped out in approximately one-half that distance when working against a truck tire maze. There appears to be little visual difference in attenuation characteristics between the two truck tire maze designs. The PGYM-1 front tire stringers seem to heave more at the front edge when encountering a wave front than the PT-1 stringers; however, waves do not appear to propagate into the maze a greater distance.

Funds for monitoring breakwater performance were severely limited. Even though the instrumentation was sophisticated and data collection was almost automatic, it still required maintenance, supplies, and personnel to operate. As a result, monitoring of the system was only achieved for several storms occurring over a relatively short period of time. The data collected is shown in Figure 21. In Figure 21, C_t denotes the ratio of transmitted wave heights to incident wave heights, D is the draft of the floating structure and d is the water depth. The dotted line (D/d = .24) shows the trend of the data relative to the PGYM-2 (car tire maze) sections. The solid line (D/d = .38) indicates the general data trend of the PT-1 and PGYM-1 (truck tire maze) sections. There appears to be little difference in PT-1 and PGYM-1 wave transmission performance. The relative draft of the system does appear to influence the wave transmission behaviour. The transmission coefficient data of the all-truck-tire sections appears to be significantly lower when compared to the car-tire maze sections having less relative draft. This difference showed up on all tests and seems to be in agreement with visual observations.

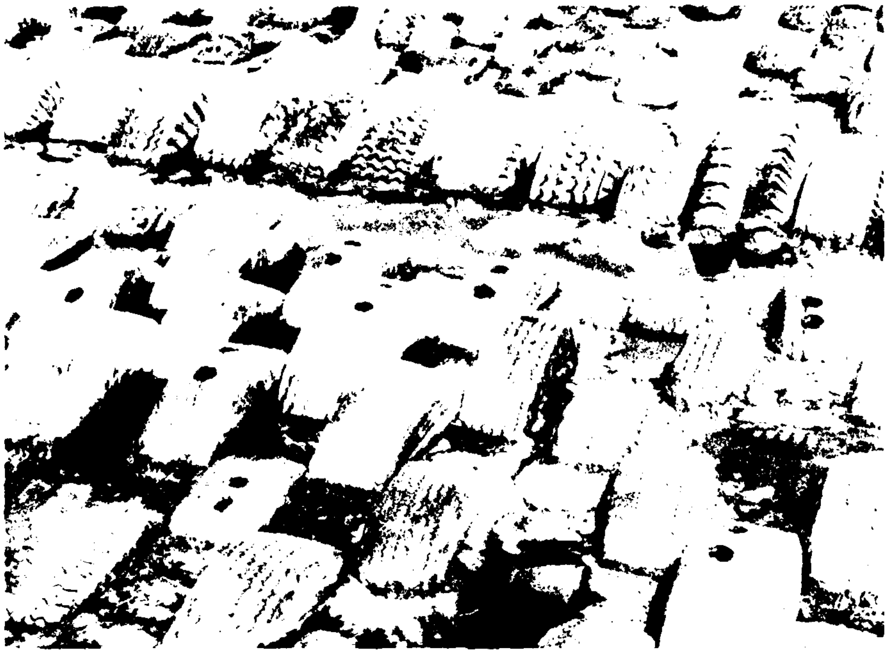

Figure 19. Algae growth on tires two months after installation

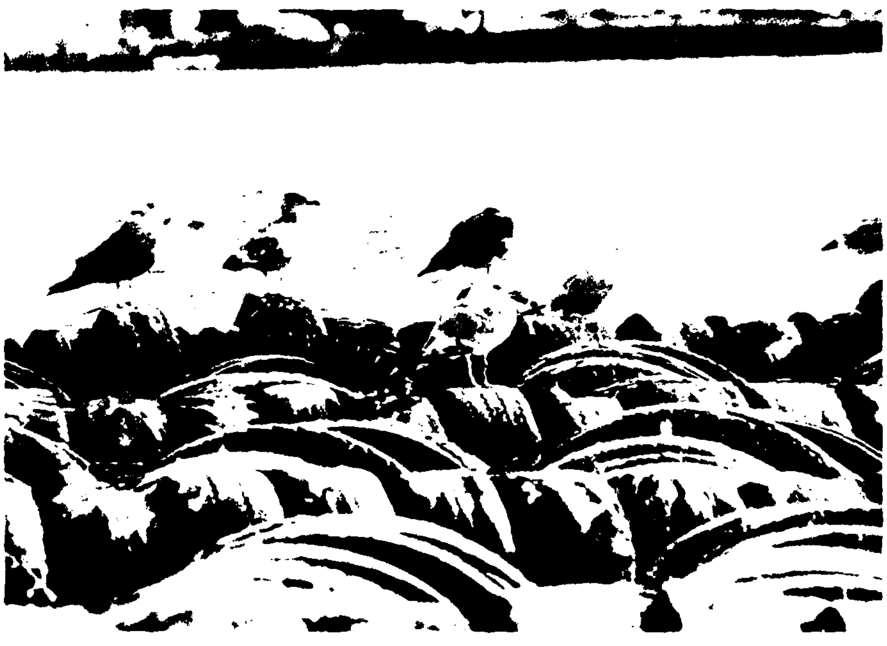

Figure 20. Breakwater as a bird sanctuary

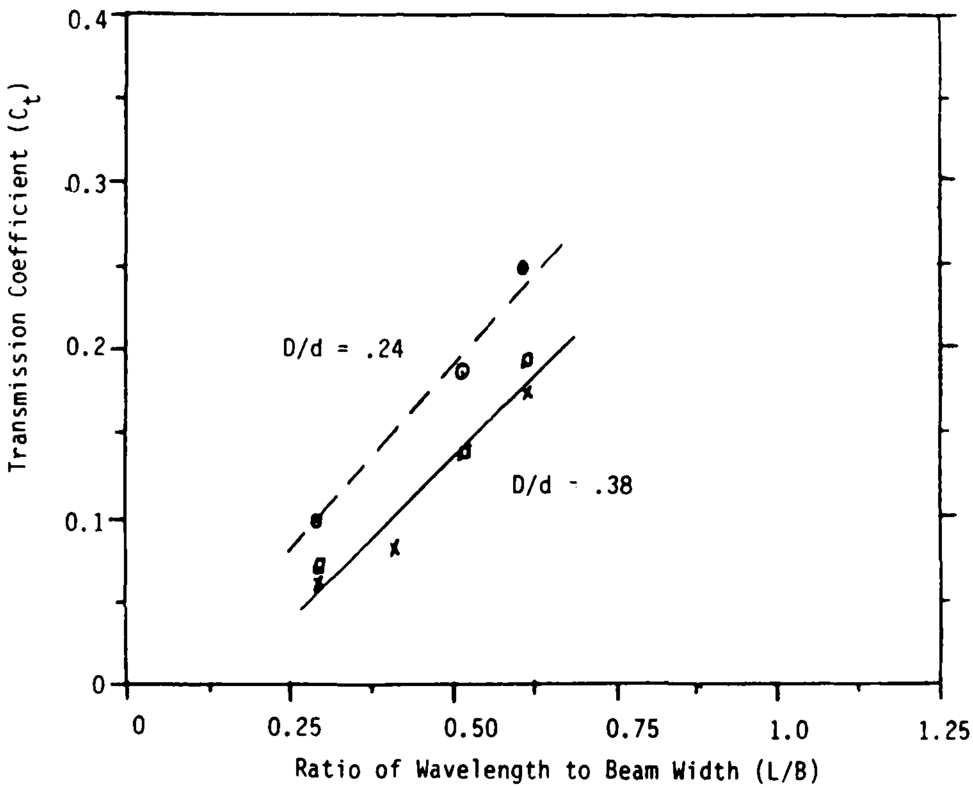

Figure 21. Wave transmission data

Two winters have passed since the breakwater was installed. In each instance, the structure was entirely frozen in the ice during the coldest winter months. Ice dunes up to three feet in height forming on the leading edge seems to be characteristic (see Figure 22). No damage to the structure due to ice movement has yet been observed.

Fabricating the breakwater in sections on land and then performing the final connections on-site works quite well. Tight bundling of all sections was achieved yielding a breakwater that has retained its shape since installation. Figure 23, where the three different design configurations can be observed, attests to this claim.

The pipe-tire floating breakwater is somewhat more expensive to construct than a well designed Goodyear floating tire breakwater. For this extra money one appears to get a more easily maintainable structure, a design that provides for a more secure, conventional, mooring attachment and improved wave attenuation performance.

Conclusions

The pipe-tire floating breakwater has been shown to be a viable design by surviving without fault for a two and one-half year period in Presque Isle Bay, Erie, Pennsylvania. During two winters the breakwater has been frozen in a thick ice cover and has not been damaged by thawing and severe ice flow conditions.

A pipe-tire floating breakwater employing car tires in the design of the tire maze has a higher coefficient of transmission than a similar all-truck-tire design. This appears to be due to relative draft differences between the two designs.

Figure 22. Ice dunes formed on leading edge

Figure 23. Tight bundling achieved in all three design configurations

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A SAILING ORGANIZATION'S EXPERIENCE WITH A GOODYEAR FTB

Paul L. Pirie

BACKGROUND

In 1979, an advisory committee was formed to report to interested area boaters on the feasibility of installing a floating marina at LaSalle Park in Burlington, Ontario.

The City of Burlington had previously made application to the Small Craft Harbours Branch of the Federal Department of Fisheries and Oceans for financial and technical assistance in building protection for boat slips in the area. The Small Craft Harbours Branch reported that their engineering study indicated that a wavebreaker would be effective at LaSalle Park but could not commit to the timing of any financial assistance.

At that time, there were roughly 275 boats kept at LaSalle Park over the summer months. Of these, approximately 75 were on trailers or storage racks in the Burlington Sailing and Boating Club's compound on the dock and about 200 were tied to mooring cans in the Harbour.

The park itself was an attractive site for recreational boating facilities for a number of reasons.

1. It was an active boating centre with some facilities in place (dock, sailing club, storage compound, launching ramp, and mooring area).
2. It had good accessibility to the water with adequate water depth.
3. Parking facilities were available on the dock and on an upper parking level.
4. Boating mixes well with other activities that take place in the park.

During 1980, a plan was formulated to raise funds for the project using a capital contribution per boater covering all boating facilities (slips, walkways, wavebreaker, and the acquisition of waterlots for a one-time cost of \$2800 to \$3000 per slip). In this manner, the taxpayer was not being asked to finance the initial construction of the facility for boaters. The boater, however, could recover his capital contribution when the slip was permanently relinquished with the proviso that a replacement contribution was available to make the capital contribution required.

Boaters on existing mooring cans were given first right of refusal for slip space or if they preferred, their mooring can would be relocated to an alternate area.

The 219-slip facility was installed in time for the 1981 season. Maintenance is funded from a yearly user's fee (approximately $170) with sufficient money being set aside each year to theoretically replace the escalated value of the wavebreaker in 25 years and the slips themselves in 15 years. Funds are also channelled into the maintenance reserve from slip rental and the escalating net proceeds from resold slips.

The marina is administered by the LaSalle Park Marina Association who present yearly audited statements to the City of Burlington (the legal owner of the facility).

FOREGROUND

The rationale for choosing a floating tire breakwater at LaSalle Park in Burlington, Ontario, fits the pattern of minimal fetch distances, poor seabed foundation and site with a partial deep-water location. These factors combined to economically eliminate a fixed breakwater structure. The breakwater and 219-slip dock facility was installed in the April/May period of 1981 at an overall cost of approximately $660,000. The breakwater itself was fabricated by Bermingham Construction Ltd. for $270,000. Modules were assembled in Hamilton and trucked less than 16 km to a lagoon on Hamilton Harbour for mat assembly during the late winter period of 1981.

From the owners' point of view, site installation of the breakwater took place on time with no community disruption.

Performance of the Goodyear design breakwater can be evaluated in numerous ways.

Structural Maintenance

Visual surface inspection is performed twice yearly. After three full years of service and an exceptional April 1984 storm, the anchors, mooring chains, and attachment points showed very little discernible wear.

Housekeeping Maintenance

As the need arises, perhaps twice a year, plus the odd occasion for a localized problem, college students are employed to clean the breakwater of debris.

This debris typically has minimal visibility from the Marina walkways but can be of some concern if motoring or sailing close to the breakwater.

In addition, there have been no complaints regarding odours resulting from fish, weed, etc. decaying within the FTB.

Man-Made Visibility

The early season natural colouration and shore background do not lend themselves to enhance the visibility of the breakwater. In addition, the relatively low elevation of the night lighting is not easily seen.

This lack of visibility may be accentuated by shore-side lighting so that reasonably late at night, the breakwater appears to blend in with the shore. On the positive side, no official complaints have been forwarded to the Marina Committee - perhaps a case of "local knowledge" being sufficient.

Performance

This naturally is the prime criterion that must be satisfied prior to addressing any other concerns. While a lengthy dissertation extolling the virtues of the FTB design and its wave attenuating power can be made, the best summary is that the 219 owners are very satisfied with the unit's performance. The location of the facility with relatively short fetches, it is felt, virtually guarantees success provided safe engineering standards are adhered to.

Storage

What do you do with an FTB in the off season? The main criterion here must be to avoid damage by floating or pack ice.

Common sense would say err on the safe side - if there is any chance at all of ice damage, the FTB should be towed to a sheltered location. As an alternative, it could perhaps be pulled to shore if the risk of silting up the bottom cord of the FTB were not judged a problem.

In the LaSalle Park case, a local firm, International Harvester Corporation, has loaned the facility the use of a commercial sheltered slip face through the off-season period. At a cost of roughly $18,000, the FTB is dismantled and towed (by its erector) approximately three kilometres to shelter and returned in the spring. It is thought that the towing cost is easily justified when weighed against the potential cost of a spring break-up of floating pack ice doing substantial damage to the FTB.

To summarize, the decision to build an FTB with four years of experience now behind us has been the correct one. This technology can be endorsed for similar applications.

FIELD ASSESSMENT OF FLOATING TIRE BREAKWATER

Craig T. Bishop

Abstract

A field monitoring program of a Goodyear floating tire breakwater (FTB) was undertaken at La Salle Park, Burlington, Ontario during 1981 and 1982. Incident and transmitted waves were measured with underwater pressure transducers. The resulting wave height transmission data compares favourably with previous results from model studies. Mooring loads on some anchor lines were measured with two electronic and four mechanical gauges. The resulting peak load data, corresponding to incident wave heights up to 0.65 m, is in good agreement with previous results from prototype-scale model studies.

Introduction

Floating Tire Breakwaters (FTBs) originated in 1963 and are used mainly to provide wave protection at limited-fetch locations. Until recently, design information was only available from two-dimensional model tests. A large FTB of the Goodyear design, comprising 35,000 car tires, was constructed in Burlington, Ontario, in the spring of 1981. Its proximity to the National Water Research Institute (NWRI) provided an excellent opportunity to collect prototype performance data. Accordingly, a field monitoring program was initiated to measure wave transmission and mooring force characteristics. The resulting prototype design data is presented.

Site Description

La Salle Park is located on the north shore of Hamilton Harbour, at the western end of Lake Ontario. A location map, also showing bathymetry and fetches, is shown in Figure 1. The prevailing wind direction is from the southwest, especially during the May to October boating season. Strong winds also blow from the east and northeast directions. The modest fetches at La Salle Park (less than 4.5 km) restrict typical significant wave heights and periods to less than 0.75 m and 3 s, respectively, while extreme values are less than 1.25 m and 4 s, respectively. Currents in the harbour near La Salle Park are negligible.

The moderate wave climate and relatively large water depths of 7 m or more make the FTB a practical wave protection alternative for the marina at this site. A conventional bottom-resting breakwater would be prohibitively expensive for a marina here. An FTB of the Goodyear design was assembled and installed in the Spring of 1981 (Figure 2).

The Goodyear design (Candle and Piper 1974) assembles basic modules, which consist of 18 tires in a 3-2-3-2-3-2-3 arrangement, into a flexible breakwater mat that is one layer of tires thick (Figure 3). The La Salle Park FTB uses conveyor belting to bind the tires together to form a module, and to interconnect the modules. The FTB mat is moored with steel chains to concrete gravity anchors. Construction details and costs for the La Salle Park FTB can be found in Bishop and Gallant (1981). State-of-the-art construction practices and materials are discussed in Bishop et al. (1983). Performance of the breakwater to date has been fully satisfactory. There have been no maintenance requirements during the first three years.

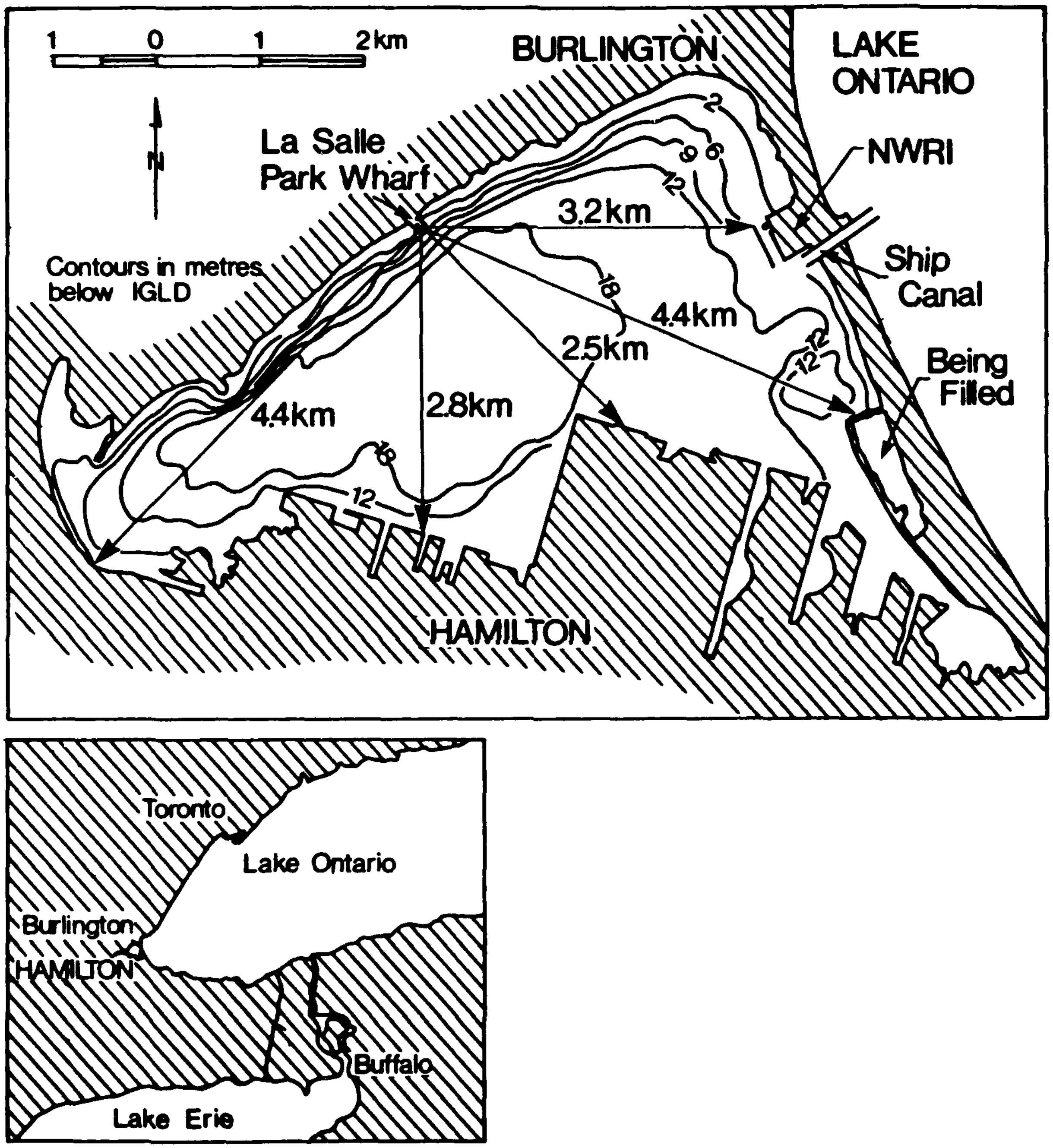

Figure 1. Location of La Salle Park

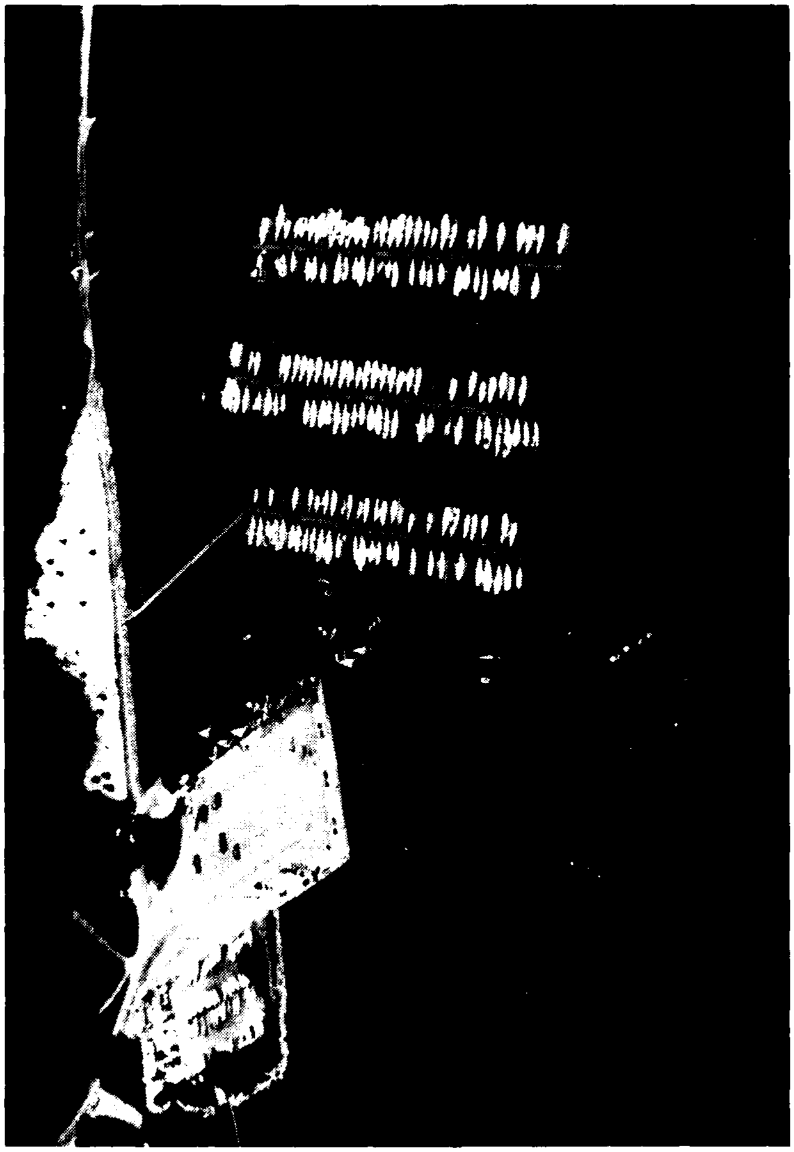

Figure 2. Aerial view of FTB at
La Salle Park Marina

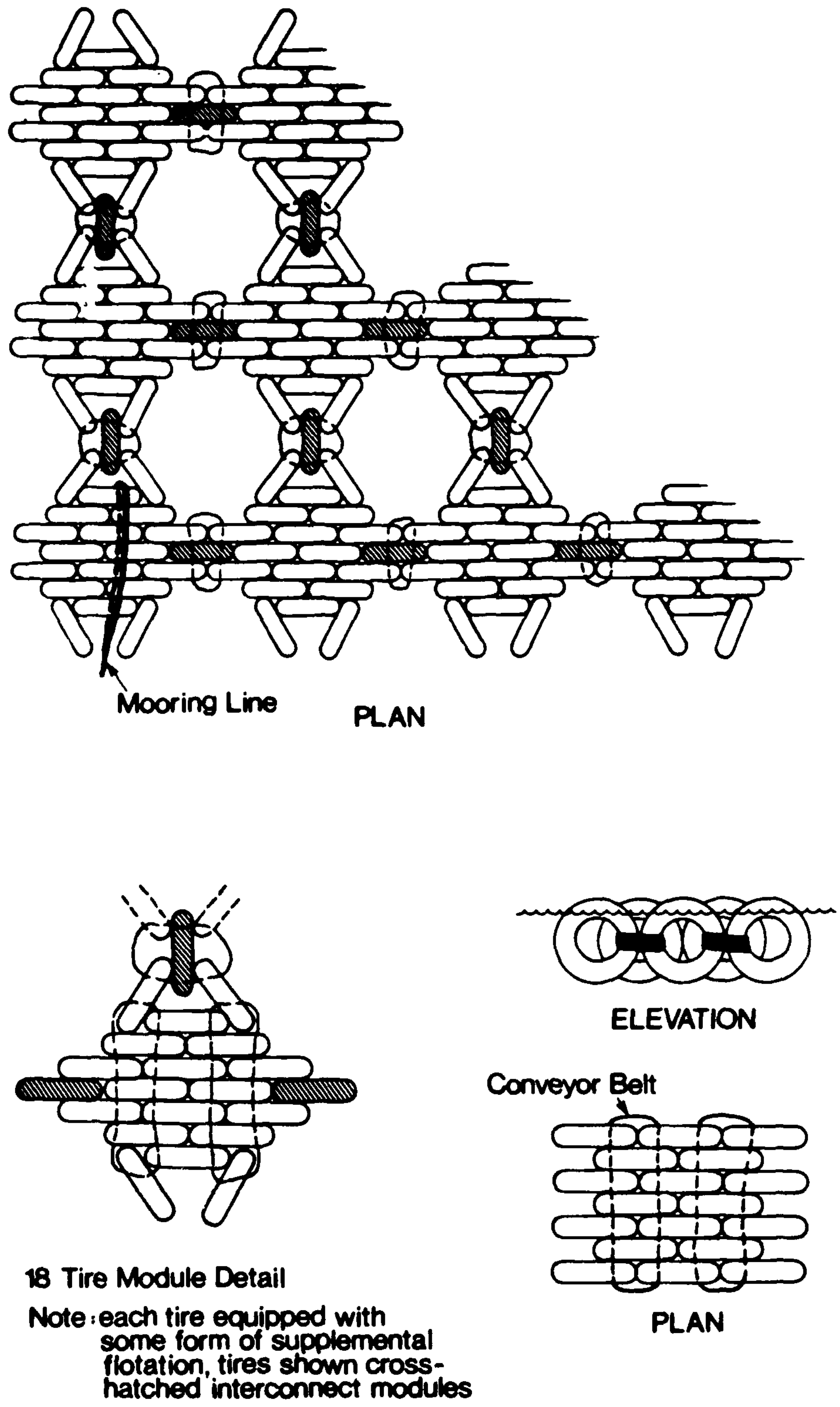

Figure 3. Detailed arrangement of tires in a Goodyear FTB

Design Information

A coastal engineer charged with designing an FTB has two main concerns requiring design data:

1. For a given incident wave height or wave energy spectrum, what will the transmitted wave height or wave energy spectrum be after propagating through the FTB?
2. For a given incident wave height or wave energy spectrum, how big will the mooring loads be?

Other concerns include the effect of ice on the FTB and its mooring system, the drag force on the FTB due to currents (Bishop 1981), and continued flotation of the breakwater (Bishop 1982).

An earlier Goodyear FTB field monitoring program was undertaken in Narragansett Bay, Rhode Island (Kowalski and Candle 1976) but no useful design information was ever published. The Goodyear FTB design information that does exist is the result of model tests conducted in wave flumes, some at prototype scale.

Instrumentation

Waves were measured with four pressure transducers (Viatran Corporation, Model 218), two on each side of the 64 x 9 module (129 m x 19 m) FTB test section (Figure 4). The pressure transducers were

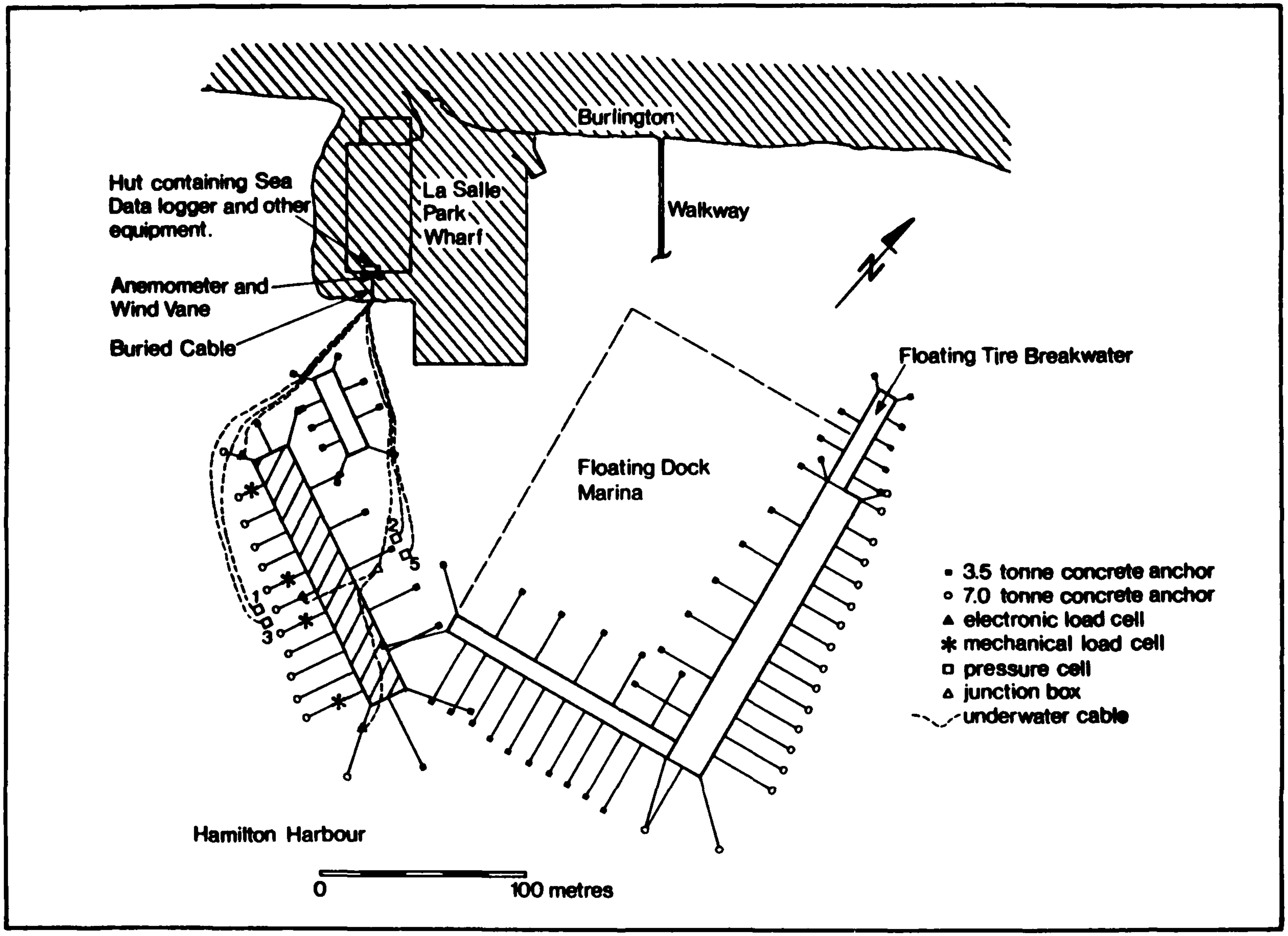

Figure 4. Layout of Instrumentation for La Salle Park Field Monitoring Study

mounted on vertical steel pipes (8 cm diameters) that had been driven into the harbour bottom. The depth of submergence of the transducers was approximately 1.06 m below International Great Lakes Datum (IGLD). The depth of water at the seaward transducer locations was 7.2 m below IGLD, and 6.6 m below IGLD at the leeward locations. During the course of the study, the mean water level varied from 35 to 70 cm above IGLD.

The pressure transducers were calibrated in a static test in the NWRI Calibration Lab. Changes between pre- and post-season calibrations were less than one percent.

It was intended to measure the mean incident wave direction using the two seaward transducers as done by Bruno et al. (1980). However, the separation between the two transducers as installed in the field was 6.4 m, and this was much larger than the specified separation of 3.5 m. Accordingly, the directional results suffered from spatial aliasing and were not used.

Mooring loads were measured with two electronic load cells (manufactured by Sensotec Inc.) and four mechanical "scratch" gauges. The centre mooring line on the seaward side was equipped with a 4,000-lb (17,800-N) electronic load cell, mounted on the chain mooring line about 2 m below the mean water level. The northwest corner mooring line was equipped with a 2,500-lb (11,100-N) electronic load cell, mounted about 2 m below mean water level. The water depths at the two locations were approximately 6.7 and 3.1 m below IGLD, respectively. The ratio of the length of mooring line to the water depth was measured to be approximately 4, except at the northwest corner where it was 5.4. A third electronic load cell for the southwest corner mooring line was installed but did not work.

Wind velocity data was obtained from a cup anemometer and vane installed on a tower on La Salle Park Wharf (Figure 4) at an elevation of 10 m above mean water. The anemometer was calibrated in NWRI's towing tank for speeds up to 6 m/s. The difference between pre- and post-season calibrations was -2.6 percent. The post-season value was used. The compass was calibrated on the tower with readings taken by pointing the vane at known reference locations around the harbour. Bearings were then determined accurately from a map.

The pressure, load and wind sensors were connected to a 12-channel Sea Data logger via a custom built control unit (Valdmanis and Savile 1984). The control unit activated the logger whenever the wind speed and direction met pre-set conditions. This limited recording observations to significant events. A nine-minute sample of data would be collected at 2 Hz, followed by a 51-minute gap. At the beginning of the next hour, the control unit would check the wind conditions to determine whether to start collecting another sample.

In order to improve the resolution of the data gathering system, a duplicate set of the pressure signals with the means removed was amplified 21.8 times and stored along with the other data on cassettes by the Sea Data logger (Valdmanis and Savile 1984).

Wave Pressure to Wave Height Transfer Function

According to linear theory for gravity waves, a subsurface wave pressure head fluctuation, H_p, can be related to the surface wave height, H, by

$$[1] \qquad H = H_p \frac{\cosh kh}{\cosh k(h+z)}$$

where k is the wave number $2\pi/L$, L is the wavelength in water depth, h, and z is the depth of submergence of the pressure transducer, measured upward from the still water level. The term $(\cosh k(h+z)/\cosh kh)$ is known as the pressure response factor, K_p.

An empirical correction factor, N, has been introduced to Equation 1 by many investigators:

$$[2] \qquad H = N \cdot H_p \frac{\cosh kh}{\cosh k(h+z)}$$

A relation for N was determined from prototype scale tests conducted in the 103 m long wind-wave flume of the National Water Research Institute. These tests are reported elsewhere (Bishop 1984). Several empirical relations for N versus $|z|/L$ are shown in Figure 5.

The measured pressure head fluctuations were analyzed using fast Fourier transform techniques. Then the power spectral components, $S_s(f)$, of the water surface elevation were related to the power spectral components of the subsurface pressure head variation, $S_p(f)$, by

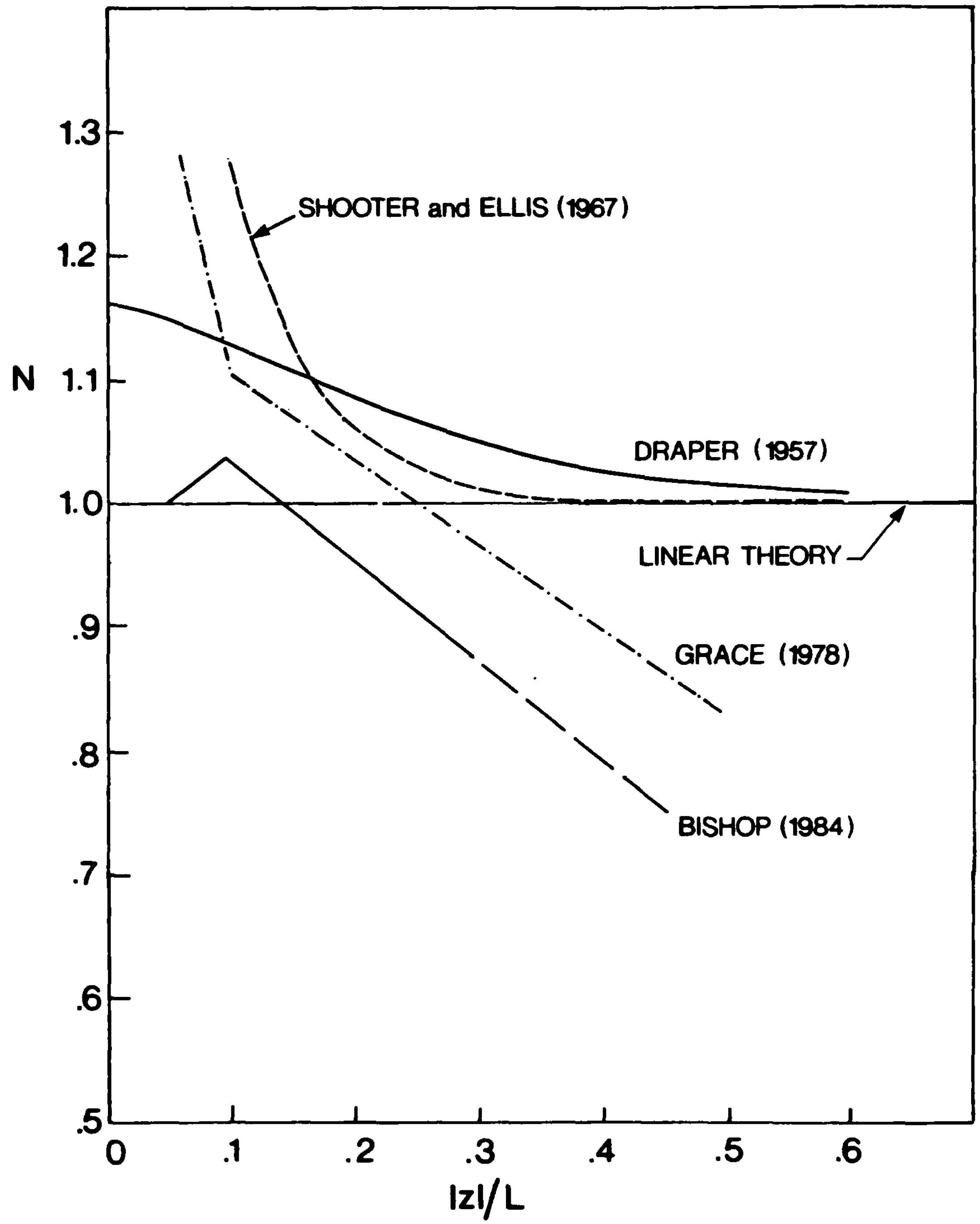

Figure 5. Empirical relations for correction factor N for transfer function from wave pressure to wave height

$$[3] \qquad S_s(f) = \left(\frac{N(f)}{K_p(f)}\right)^2 \cdot S_p(f)$$

using values for N(f) from Bishop (1984).

Wave Transmission

Mooring load and amplified pressure signals for the largest recorded event are shown in Figure 6. Dimensional analysis (Harms et al. 1981) has shown that the transmission coefficient C_t, where C_t is the ratio of transmitted to incident wave heights (H_t/H_i), can be expressed as

$$[4] \qquad C_t = \psi(L/B,\ H/L,\ D_t/h,\ B/D_t)$$

For the La Salle Park FTB, $B/D_t = 29.5$ and $D_t/h \simeq 0.085$ at the pressure transducer locations. Model tests of Goodyear FTB's (Harms and Bender 1978) showed that wave transmission is insensitive to the B/D_t parameter or the D_t/h parameter for $D_t/h \leq 0.32$. Values of H_c/L_p were typically 0.04 to 0.08.

Wave transmission results are given in terms of transmission coefficients, $C_t(f)$, versus the ratio of wavelength, L(f), to breakwater beam, B, where

$$[5] \qquad C_t(f) = \left[\frac{S_{st}(f)}{S_{si}(f)}\right]^{1/2}$$

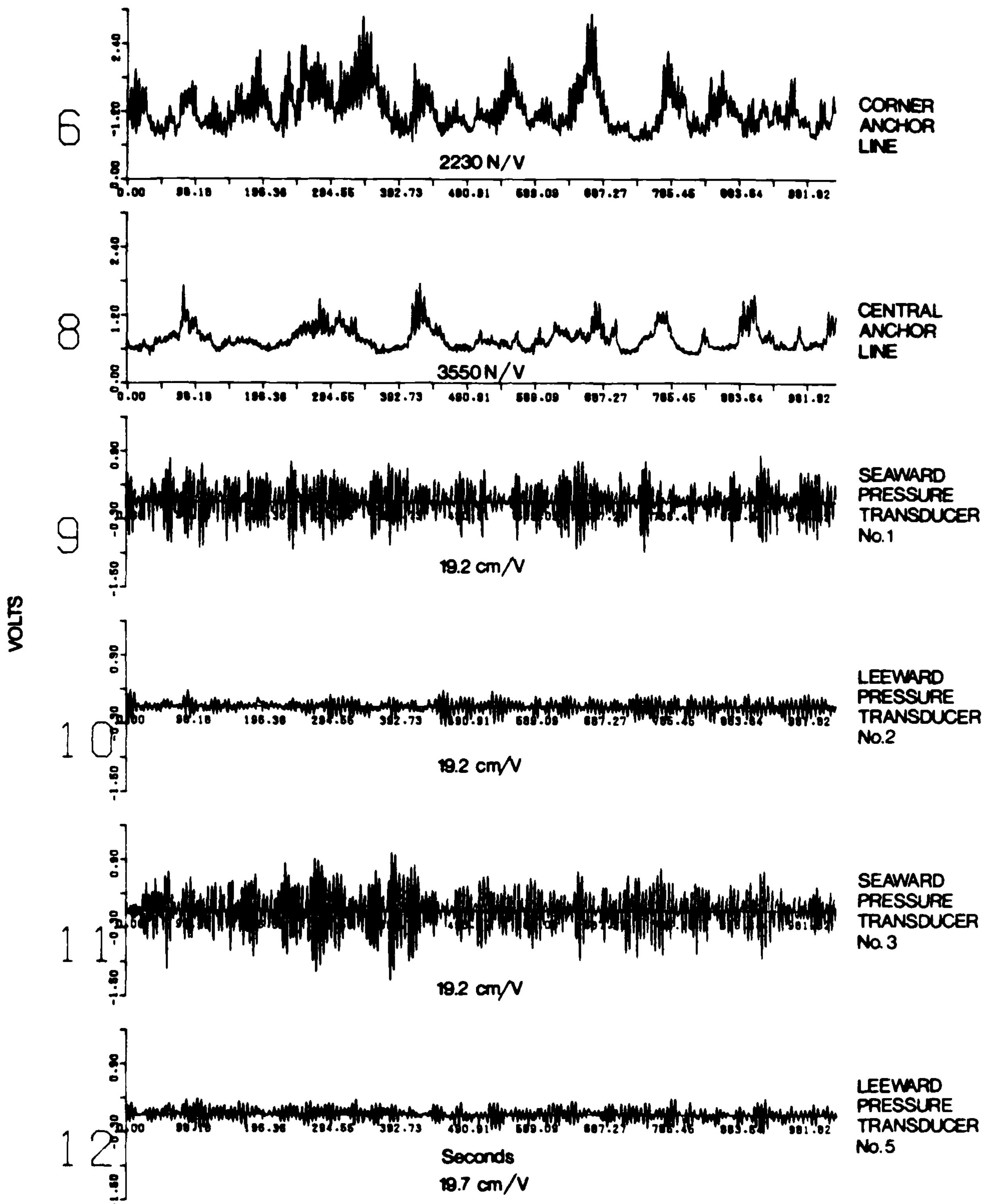

Figure 6. Mooring load and amplified pressure signals for the largest recorded event (82/11/12, 1117 hours)

and $S_{st}(f)$ is the average of the two leeward gauges (transmitted waves) and $S_{si}(f)$ is the average of the two seaward gauges (incident waves). It should be noted that values of C_t for any given frequency are independent of the correction factor N(f). Figure 7 shows transmission results for $S_i(f)/S_i(f_p) > 0.10$ and $f_p < 0.67$ Hz and the corresponding second-order regression curve. There is good data coverage for $0.2 \leq L/B \leq 0.8$. This range has been extended in Figure 8 by plotting results for the two values of frequency (at 0.04-Hz intervals) for each record that are just smaller than the smallest frequency meeting the criterion $S_i(f)/S_i(f_p) > 0.10$. The corresponding second-order regression curve is also shown. This provides good data coverage for $0.8 \leq L/B \leq 1.4$.

The data plotted in Figures 7 and 8 is from 118 records obtained between October 8 and November 13, 1982. Characteristic wave heights vary from 12 to 66 cm with peak frequencies from 0.32 Hz to 0.64 Hz.

The data in Figures 7 and 8 has been combined in Figure 9. The curve through the data is the curve from Figure 7 for $0.2 \leq L/B \leq 0.6$, from Figure 8 for $1.0 \leq L/B \leq 2.2$, and a transition by eye for $0.6 \leq L/B \leq 1.0$.

Some of the scatter in results is probably due to variability in the direction of the incident waves. Under oblique attack, the effective beam of the FTB is increased but this has not been taken into account. A constant value of B = 18.9 m was used to determine values of L/B.

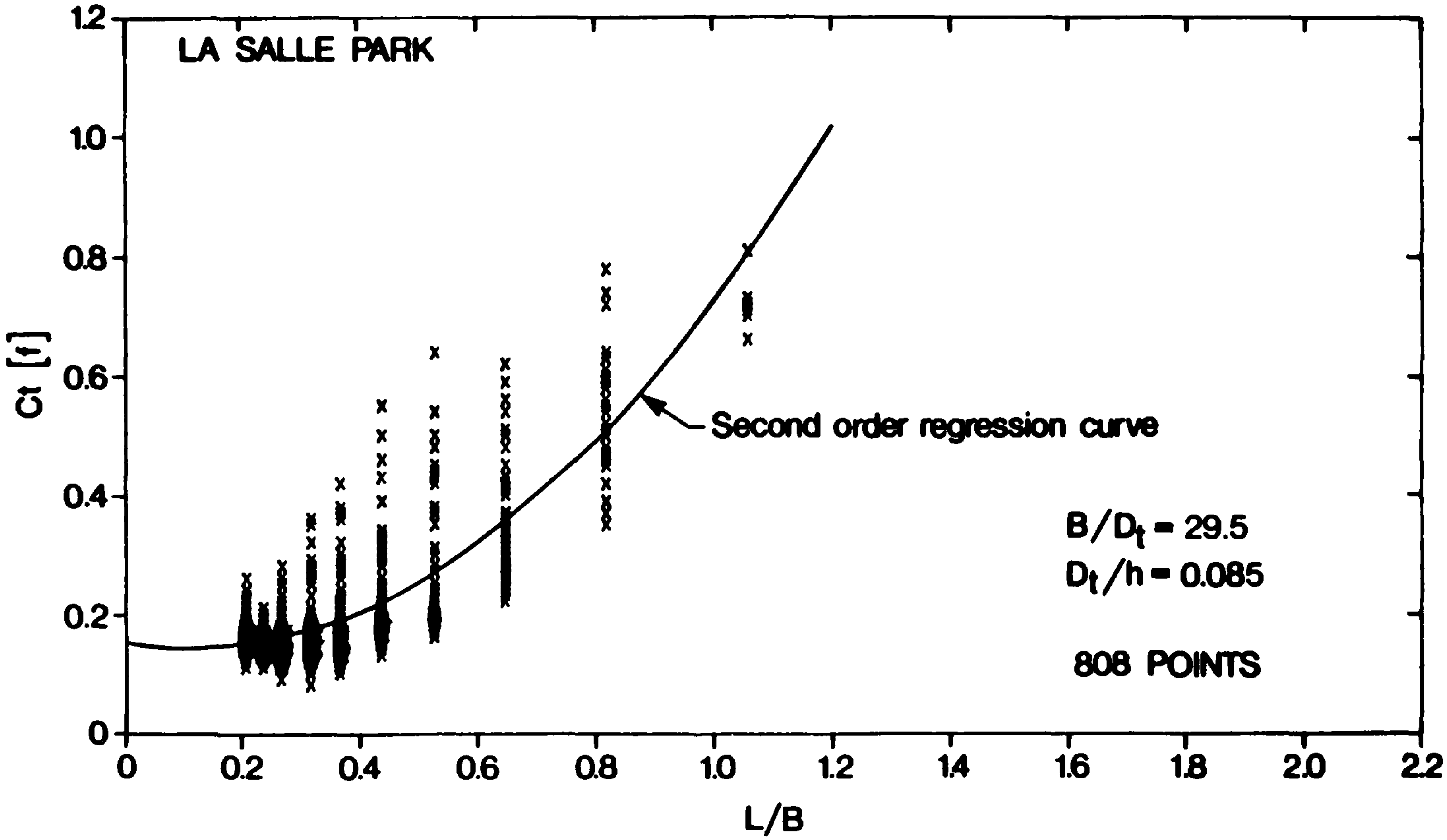

Figure 7. Wave transmission results for $S_i(f)/S_i(f_p) \geq 0.10$ and $f_p < 0.67$ Hz

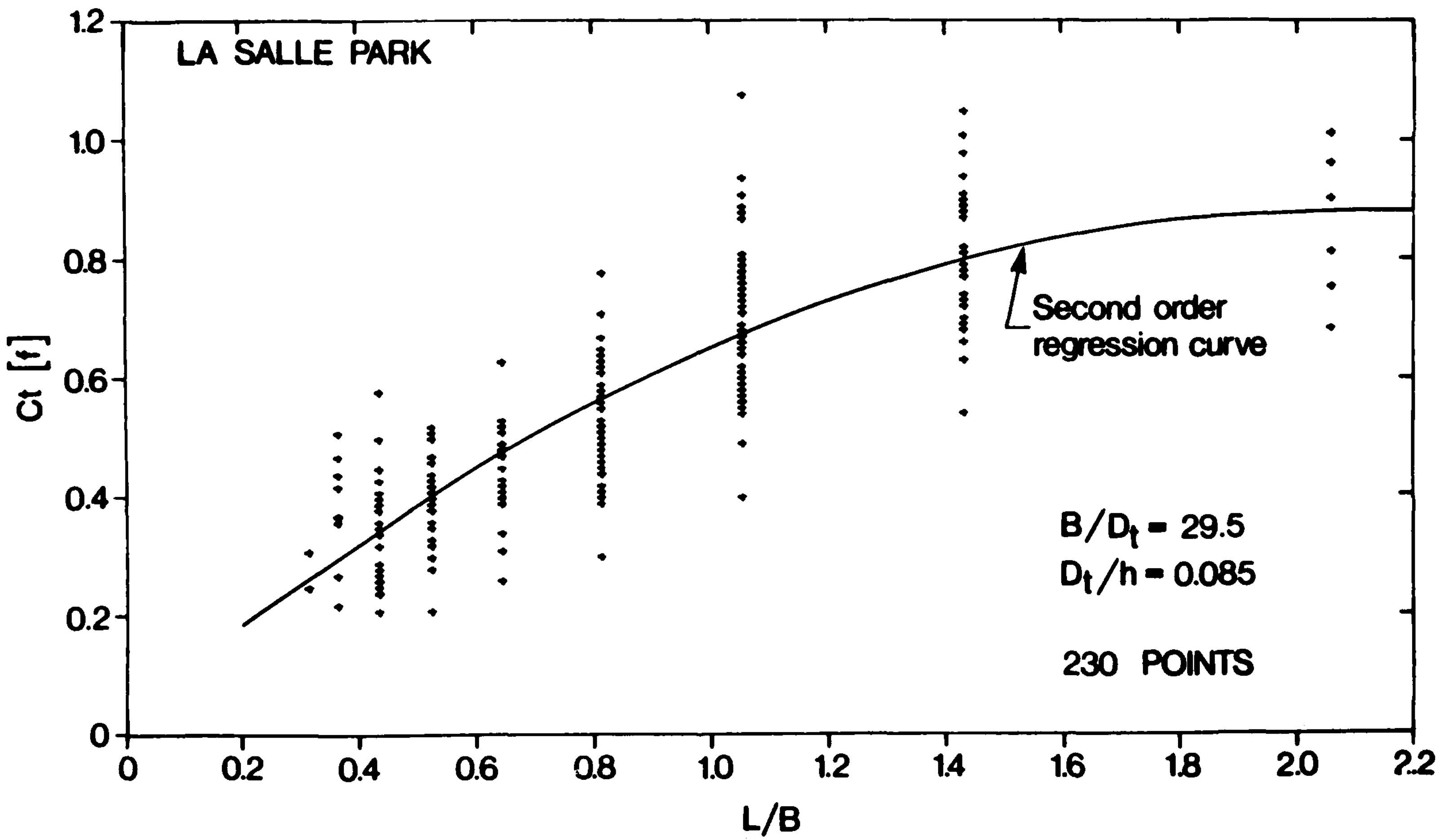

Figure 8. Wave transmission results for $S_i(f)/S_i(f_p) < 0.10$ and $f_p < 0.67$ Hz

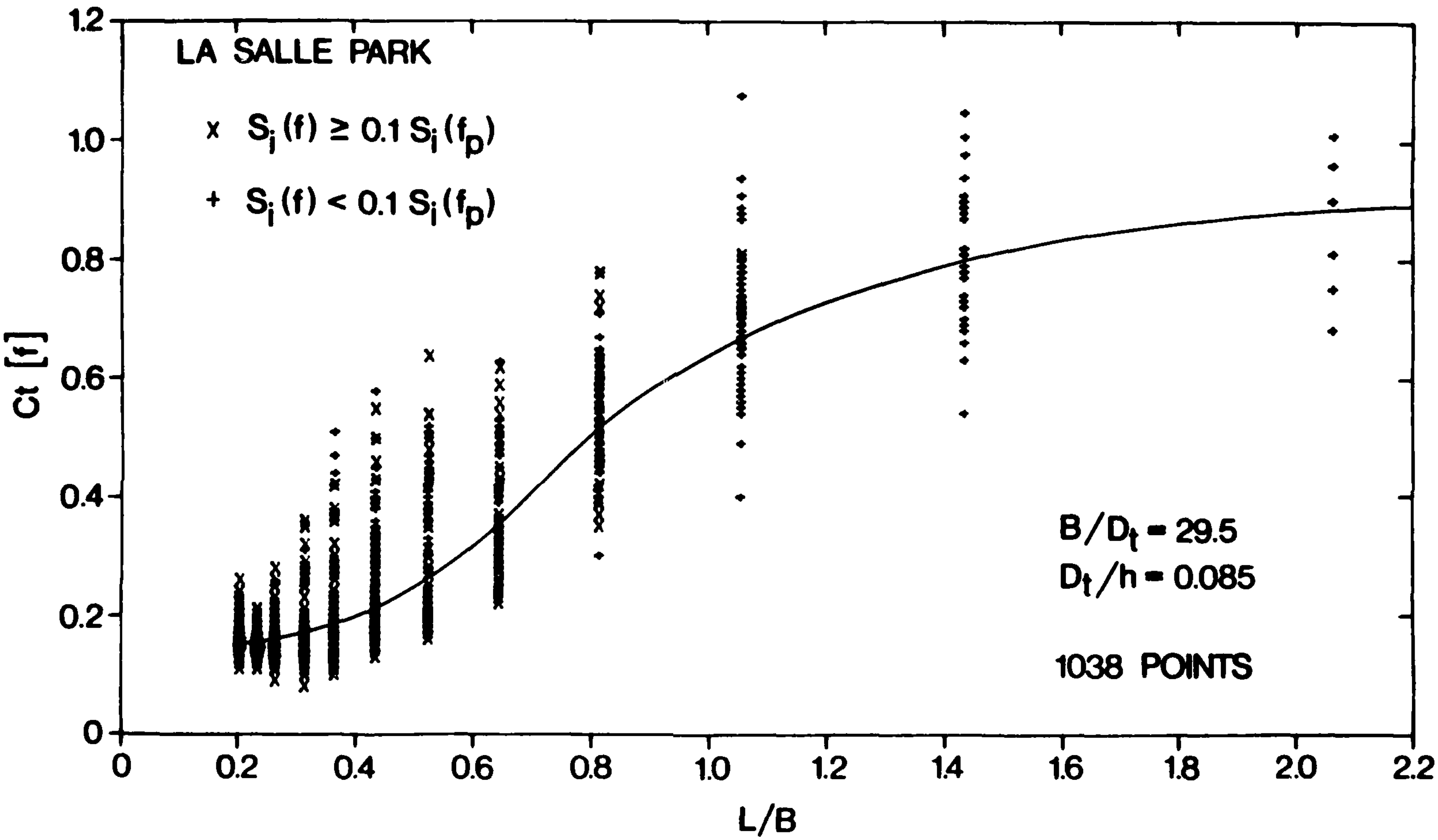

Figure 9. Wave transmission results from 118 records obtained between October 8 and November 12, 1982, at La Salle Park

Comparison With Model Results

Prototype-scale wave transmission tests of Goodyear FTB's were conducted by Giles and Sorensen (1978) with car tires of 64 cm diameter using monoperiodic waves with heights up to 1.4 m. The tests were done on two different beam widths, four and six modules at two water depths, 2 and 4 m. Their results are referred to as the CERC results in Figure 10.

Model-scale tests of Goodyear FTB's were conducted by Nelson (1978) using monoperiodic waves and tires of 15 cm diameter. The tests were done on three different beam widths, three, four and six modules at two water depths, 46 and 84 cm. Results for the six-module beam tests agree well with the CERC six-module results and these data sets have been plotted in Figure 11. Only those points with wave steepnesses H/L in the range 0.02 - 0.06 are included. The results are easily distinguishable because the CERC data is for $L/B \geq 0.81$ and the Nelson data is for $L/B \leq 0.82$. The curve through the data is from second-order regression, modified slightly by eye for $L/B > 2.0$.

Model-scale tests of Goodyear FTB's were conducted by Harms and Bender (1978) using mostly monoperiodic waves and tires of 8.4 and 15 cm diameter. The tests were done on four different beam widths, two, four, eight and twelve modules at water depths from 31 to 120 cm. Their results are referred to as the Harms results in Figure 10.

Model-scale tests of Goodyear FTB's were conducted by McGregor (1978) using pseudo-random waves and tires of 15 cm diameter. The tests

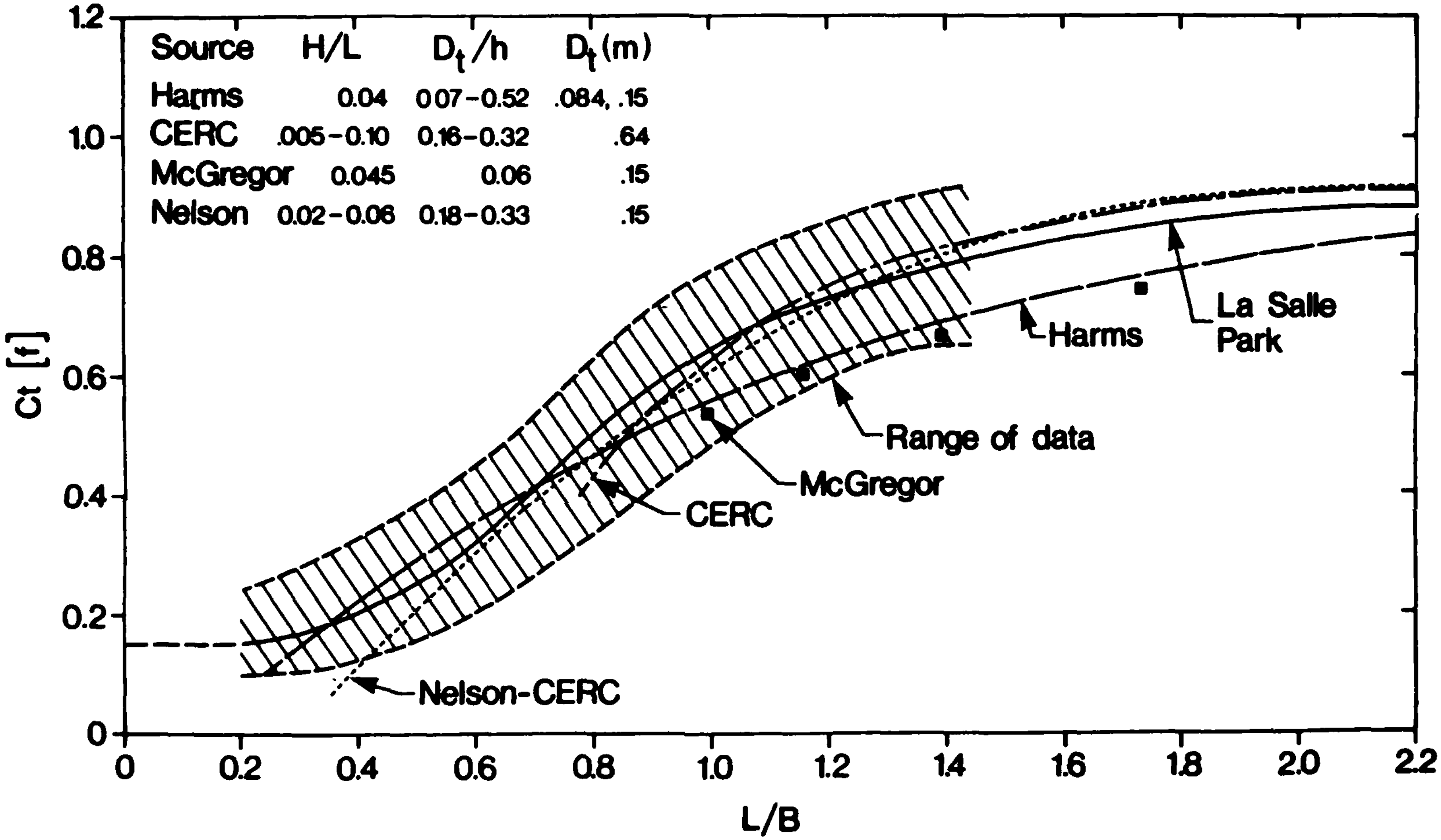

Figure 10. Comparison of wave transmission curves

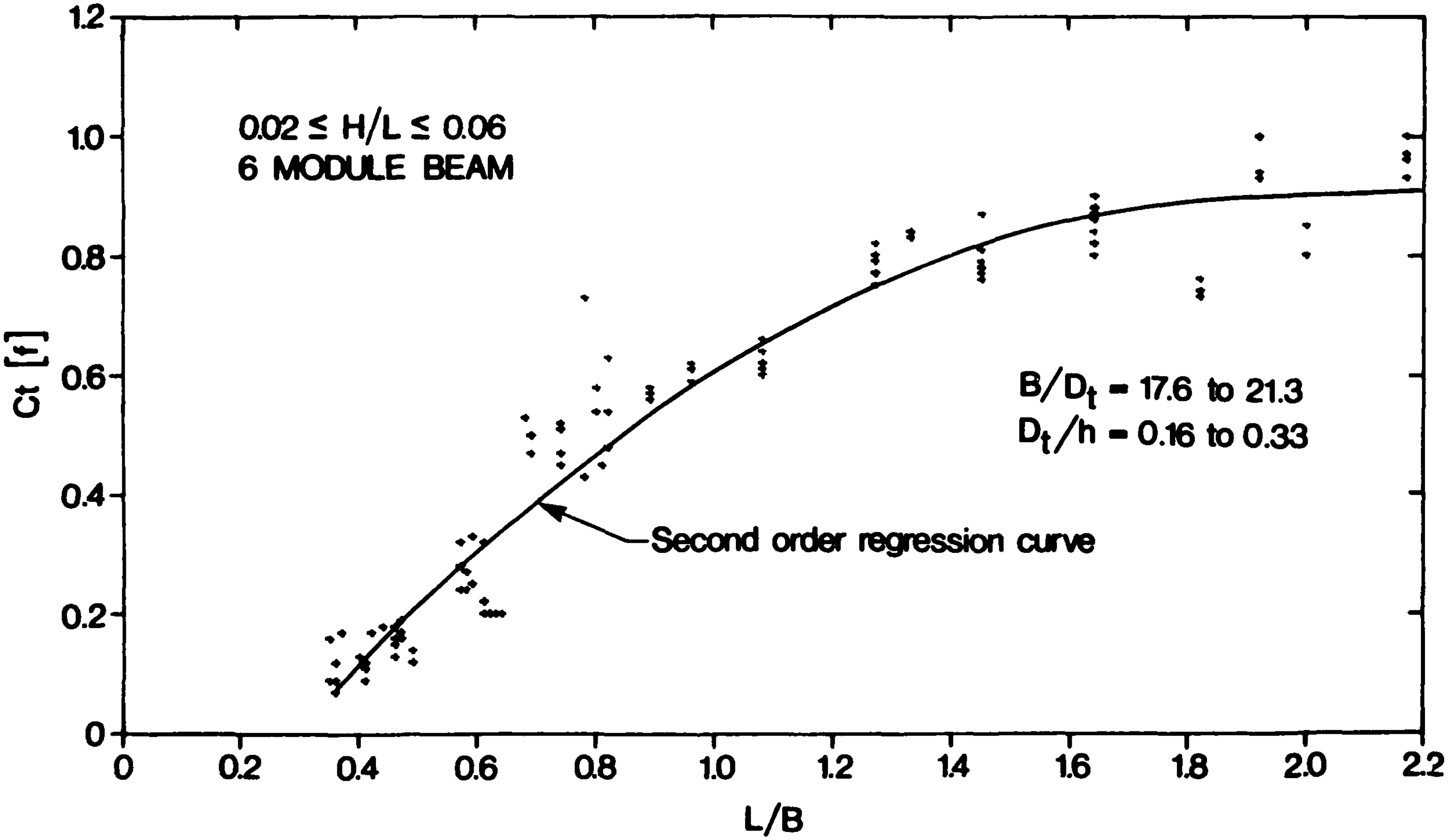

Figure 11. Wave transmission results of Nelson (1978) and Giles and Sorensen (1978)

were done on six different beam widths, 2, 3, 4, 5, 6 and 7 modules at a constant water depth of 240 cm. Results were presented graphically in the form of transmission coefficients versus frequency for each beam width (McGregor 1978, Figure 7). All tests were run with the same incident wave spectrum with a peak frequency of 0.67 Hz. Values of C_t versus L_p/B have been obtained by measurement from McGregor's Figure 7. Results agree very well with those of Harms and are shown in Figure 10. Unfortunately, there is no data for $L_p/B < 0.99$.

As seen in Figure 10, the results of the present field study agree quite closely with earlier model test results. For practical purposes, the most important part of Figure 10 is for values of C_t less than 0.5. In this range the Harms curve shows the best agreement with the field results. For values of C_t larger than 0.4, the Harms and McGregor results underpredict C_t.

The field results indicate a levelling-off or residual value of C_t of approximately 0.15, while the model results tend towards zero for small values of L/B. This may be attributable to viscous scale effects causing more attenuation in the model than in prototype. It may also be due to reflected and diffracted wave energy contributions in the field. Unfortunately the prototype-scale CERC model tests do not include data for values of L/B less than 0.8.

Application

Wave energy spectra for the largest recorded wave height event are shown in Figure 12. For a known incident spectrum the transmitted spectrum can be predicted using values of C_t from Figure 10. Using the La Salle Park curve, this has been done for pressure transducers 3 and 5 in Figure 4; results are provided in Table 1. The predicted transmitted characteristic wave height is 0.193 m while the value calculated from the pressure measurements is 0.184 m, giving an overprediction of 4.9 percent.

A simpler approach to predicting the transmitted wave height would be to use a single value of C_t corresponding to the peak frequency. For the example in Table 1, f_p = 0.36 Hz giving C_t = 0.355. The predicted transmitted wave height would be 0.638 x 0.355 = 0.226 m, giving an overprediction of 25 percent. In general, the simpler approach will be less accurate than the spectral approach. Whenever the incident spectrum is multi-peaked, only the spectral prediction method should be used.

For practical purposes, a breakwater is seldom required unless wave attenuation of 50 percent or more is needed. From Figure 10 it can be seen that to obtain $C_t < 0.5$ the ratio L/B must be less than 0.85. Therefore, a rule of thumb for Goodyear FTB's would be that the beam must be at least 1.2 times the design wavelength. For another type of FTB, the Pipe-Tire floating breakwater (Harms et al. 1981), a comparable

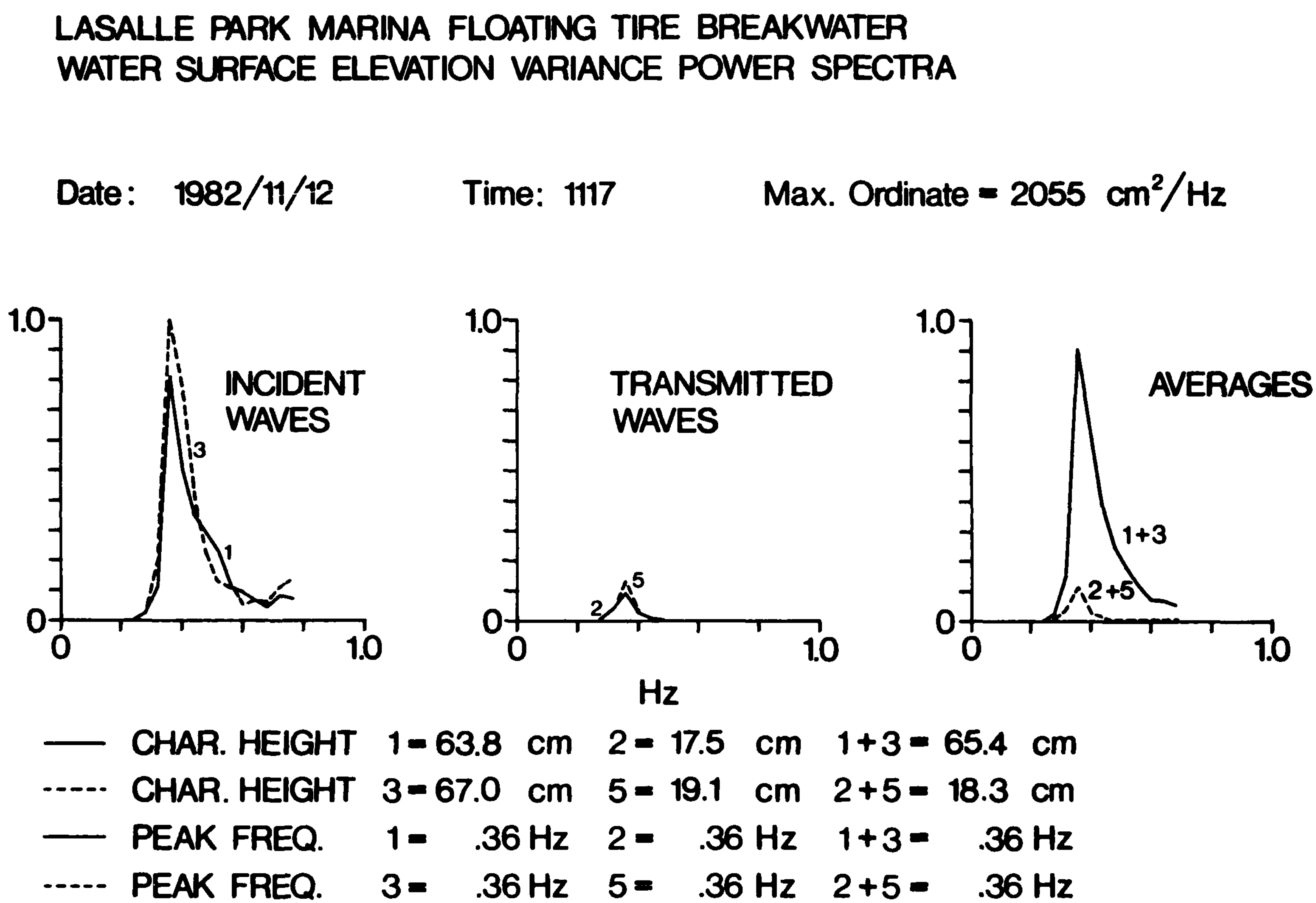

Figure 12. Wave energy spectra for the largest recorded event (82/11/12, 1117 hours)

TABLE 1. Comparison of Transmitted Wave Energy Spectral Values (1982/11/12, 1117 hours)

(1) freq (Hz)	(2) $\frac{L}{B}$	(3) $S_i(f)$ (cm^2/Hz)	(4)* $S_t(f)$ (cm^2/Hz)	(5)* C_t	(6)* $C_t^2 \cdot S_i(f)$ (cm^2/Hz)
.24	1.43	3.5	2.3	.795	2.2
.28	1.05	46.3	24.4	.675	21.1
.32	.81	424.6	83.9	.515	112.6
.36	.64	2054.8	273.2	.355	259.0
.40	.52	1581.1	78.0	.260	106.9
.44	.43	870.5	23.5	.215	40.2
.48	.36	457.0	11.2	.185	15.6
.52	.31	242.0	8.2	.175	7.4
.56	.26	256.1	5.5	.165	7.0
.60	.23	122.9	4.6	.155	2.7
.64	.20	163.4	4.2	.150	3.7
.68	.18	143.7	7.5	.150	3.2
	H_c(m)*:	.638	.184		.193

(4) Spectral values calculated from measured pressure fluctuations on leeward side.

(5) From Figure 10

(6) Predicted spectral values from (3) and (5)

(7) The values of H_c differ slightly from those in Table 4 due to a simplified manual method of computation here.

rule of thumb would be that the beam must be at least 0.8 times the design wavelength.

Mooring Loads - Empirical

Mooring load signals from the largest recorded wave height event are shown in Figure 6. It can be seen that the mooring load fluctuates with the passage of each wave. There is a well-defined minimum load on each gauge during a record, and local maxima which appear to be correlated with wave groups.

Dimensional analysis of wave-induced mooring loads (Harms et al. 1981) has shown that

$$[6] \qquad F_d = \phi(L/D_t,\ H/D_t,\ D_t/h,\ B/D_t)$$

where F_d is the dimensionless peak mooring load, D_t is the outside tire diameter (approximately 64 cm) and

$$[7] \qquad F_d = \frac{F_{max}\cos\theta}{\ell\ \rho g D_t^{\,2}}$$

where F_{max} is the maximum measured load (Newtons) at a gauge during a record

ρ density of fresh water in kg/m^3

g gravitational acceleration (m/sec^2)

ℓ is the length in metres of breakwater frontage restrained by the mooring line (10.72 m for the central line, 5.36 m for the corner line).

θ is the angle between the mooring line and a perpendicular to the front face of the FTB. (0 degrees for the central line, 45 degrees for the corner line)

The formulation of Equation 6 neglects current or ice-induced mooring loads; it is appropriate for the La Salle Park FTB during the boating season.

Model tests of Goodyear FTB's (Harms and Bender 1978) and of Pipe-Tire floating breakwaters (Harms et al. 1981) revealed that F_d does not vary substantially with B/D_t. Mooring loads increase with increasing values of L/D_t, H/D_t and D_t/h.

Preliminary analysis of the dimensionless parameters F_d versus H_c/D_t showed that the use of tires with diameters larger than 0.64 m would result in the prediction of smaller mooring loads for the same incident wave height. This disagrees with expectations. More data is needed to quantify the effect of tire diameter on mooring loads. Accordingly, the analysis of mooring loads has been done dimensionally.

The dominant variable affecting mooring loads at the La Salle Park FTB is H_c. There are 65 records in which $H_c \geq 30$ cm (see Tables 2-4). For these records, the dimensional peak mooring loads per unit length $(F_{max}\cos\theta)/\ell$ have been plotted against H_c in Figure 13.

TABLE 2. Summary Data Table for Mooring Force Results When

$H_c \geq 30$ cm

Date	Time (hr/min)	T_p (s)	L_p (m)	H_c (cm)	F_{max}/ℓ central line (N/m)	$F_{max}\cos 45^\circ/\ell$ corner line (N/m)
Oct. 20	7/7	1.92	5.75	36.4	52.6	(72.5)*
	9/8	2.08	6.77	39.1	64.8	(85.4)
	10/8	2.27	8.06	54.3	166.0	(223.2)
	11/7	2.50	9.75	50.0	225.2	255.6
	12/7	2.27	8.06	49.2	152.3	389.1
	13/8	2.08	6.77	33.8	75.3	98.4
	14/8	2.08	6.77	36.9	113.4	201.7
	15/8	2.27	8.06	44.1	161.2	367.7
	16/8	2.78	12.0	48.6	159.6	374.8
	17/8	2.78	12.0	49.0	192.8	435.9
	18/8	2.08	6.77	37.5	93.2	207.5
	19/8	2.50	9.75	40.0	106.1	316.7
	20/8	2.50	9.75	42.1	123.1	285.7
	21/8	2.27	8.06	39.9	116.7	322.4
	22/8	2.50	9.75	45.1	140.9	356.8
	23/8	2.50	9.75	46.2	123.9	380.6
Oct. 21	0/8	2.27	8.06	30.8	(277.0)	213.9
	1/8	2.50	9.75	36.1	108.5	295.1
	2/8	2.50	9.75	38.4	69.6	193.9
	3/8	2.50	9.75	34.4	72.1	196.7
	4/8	2.27	8.06	35.1	82.6	201.7
	5/7	2.27	8.06	30.2	51.8	121.4

* Brackets signify an outlying point.

TABLE 3. Summary Data Table for Mooring Force Results When $H_c \geq 30$ cm

Date	Time (hr/min)	T_p (s)	L_p (m)	H_c (cm)	F_{max}/ℓ central line (N/m)	$F_{max}\cos 45^\circ/\ell$ corner line (N/m)
Nov. 5	11/30	2.50	9.75	37.3	79.3	129.9
	12/30	2.27	8.06	32.3	64.0	133.6
	14/30	2.50	9.75	33.8	57.5	150.1
	15/31	2.50	9.75	41.9	85.8	257.0
	16/31	2.27	8.06	33.0	61.6	137.2
	18/31	2.27	8.06	33.0	72.1	162.9
	19/31	2.08	6.77	31.5	60.8	155.8
	20/31	2.27	8.06	36.5	70.5	139.3
	21/31	2.50	9.75	37.3	93.2	207.5
	23/31	2.50	9.75	37.3	85.8	213.3
Nov. 6	0/31	2.08	6.77	37.6	74.5	183.8
	1/31	2.27	8.06	38.7	72.1	219.0
	2/31	2.27	8.06	45.1	90.7	213.9
	3/31	2.50	9.75	44.5	99.7	321.7
	4/31	2.27	8.06	35.5	77.0	150.8
	5/31	2.08	6.77	35.3	69.6	135.8
	6/31	1.92	5.75	31.7	44.6	99.8
	7/31	2.08	6.77	32.1	52.6	105.6
	8/31	2.08	6.77	34.9	72.1	133.6
	9/31	2.08	6.77	36.0	68.8	139.3
	10/30	2.27	8.06	32.4	68.8	173.8
	11/33	2.08	6.77	31.2	53.4	109.9
	12/33	2.27	8.06	36.2	72.9	178.7
	13/33	2.27	8.06	38.1	69.6	147.1
	14/33	1.92	5.75	33.6	60.8	117.8
	15/33	2.27	8.06	41.2	73.7	218.3

TABLE 4. Summary Data Table for Mooring Force Results When $H_c \geq 30$ cm

Date	Time (hr/min)	T_p (s)	L_p (m)	H_c (cm)	F_{max}/ℓ central line (N/m)	$F_{max} \cos 45^\circ/\ell$ corner line (N/m)
Nov. 12	0/11	1.92	5.75	30.2	47.8	(268.5)*
	2/13	1.92	5.75	32.3	60.8	114.1
	7/17	2.08	6.77	42.4	195.2	220.4
	8/17	2.27	8.06	46.4	237.3	336.7
	9/17	2.50	9.75	57.5	290.0	503.3
	10/17	2.50	9.75	55.2	321.6	812.1
	11/17	2.78	12.0	65.4	504.6	835.1
	12/17	2.27	8.06	44.7	214.7	355.4
	13/17	2.50	9.75	42.4	222.7	479.6
	14/17	2.08	6.77	41.1	179.0	(601.7)
	16/17	2.78	12.0	54.1	353.1	657.0
	17/17	2.78	12.0	59.8	406.6	545.4
	18/17	2.78	12.0	42.4	131.2	414.3
	19/17	3.13	15.2	35.3	81.0	188.8
	20/17	2.50	9.75	43.9	154.7	319.5
	21/17	2.27	8.06	30.7	46.9	108.5
	22/19	2.27	8.06	30.2	42.1	99.1

* Brackets signify an outlying point.

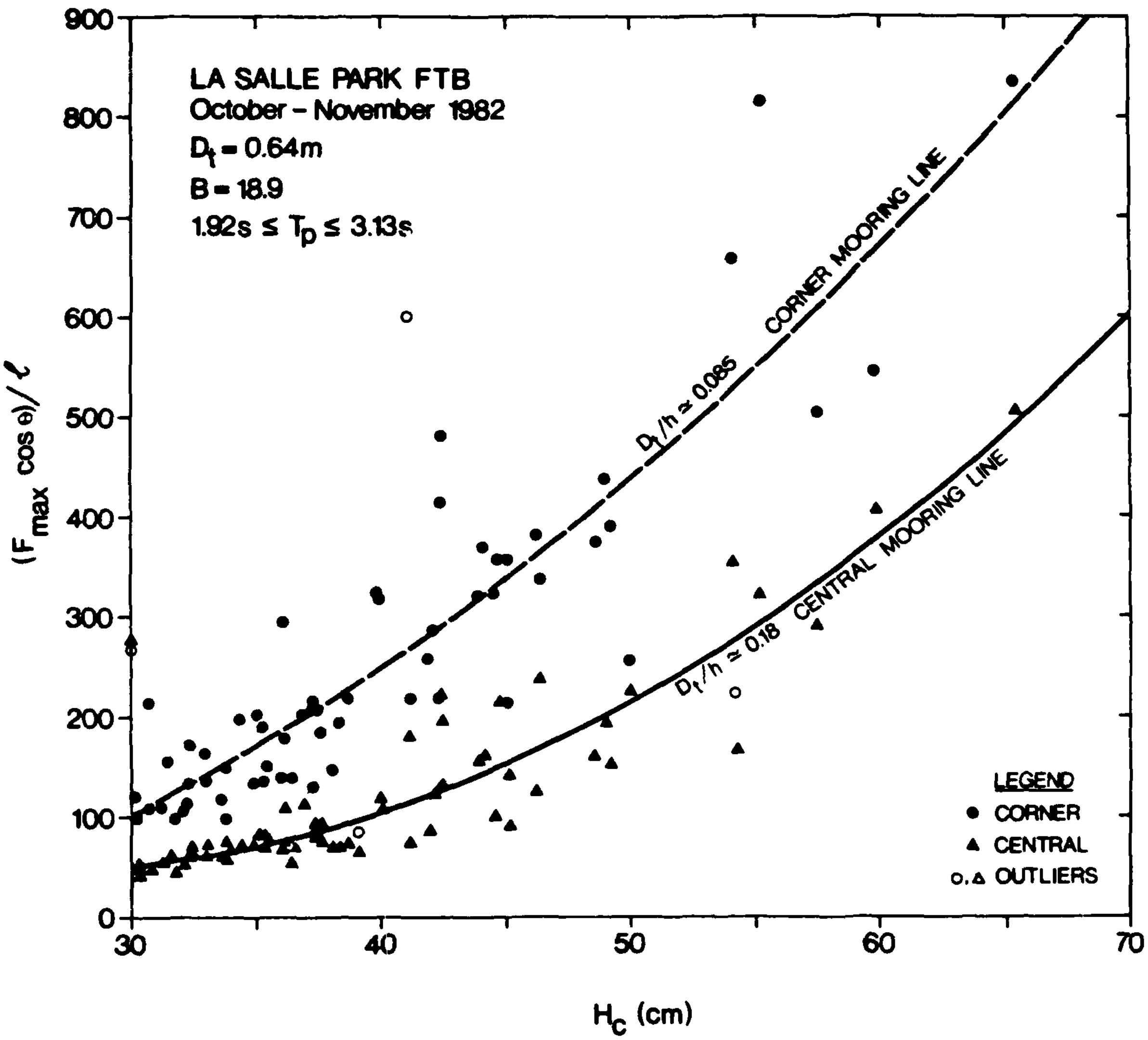

Figure 13. Dimensional plot of peak mooring load versus characteristic wave height data

After removing several outlying points from the data set, second-order regression curves were determined and are also shown in Figure 13.* Some of the scatter in results is probably due to L_p varying from 5.75 m to 15.2 m. However, there is insufficient data at overlapping values of H_c to determine a relation similar to that between F_d and L_p/D_t as done for Pipe-Tire floating breakwaters in Harms et al. (1981).

Results from the 6-module-beam two-dimensional prototype-scale tests by Giles and Sorensen (1978) in 4 m of water are compared with the La Salle Park results in Figure 14. For the Giles and Sorensen (1978) data, the height H of regular waves has been substituted for H_c. Agreement is surprisingly good. A second-order regression analysis of the 64 field test points and 39 model test points gives

[8] $$(F_{max} \cos\theta)/\ell = -346 + 8.76\ H_c + 0.0798\ (H_c)^2$$

where $(F_{max} \cos\theta)/\ell$ is in Newtons per metre length and H_c is in centimetres. The corresponding value of the square of the correlation coefficient is 0.96. Equation 8 should only be used for values of $H_c > 40$ cm. It is very similar to the relation proposed by Harms and

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* A plot of $(F_{max} \cos\theta)/\ell$ versus H_c where H_c was calculated according to linear wave theory (i.e., N = 1.0) showed almost no difference in the regression curve over the range of data.

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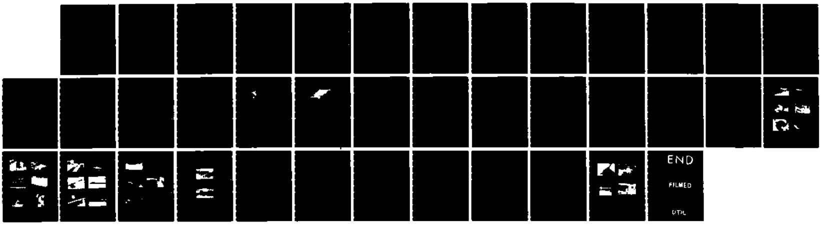

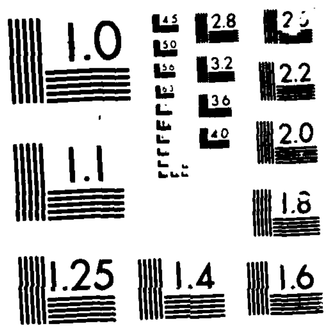

MICROCOPY RESOLUTION TEST CHART

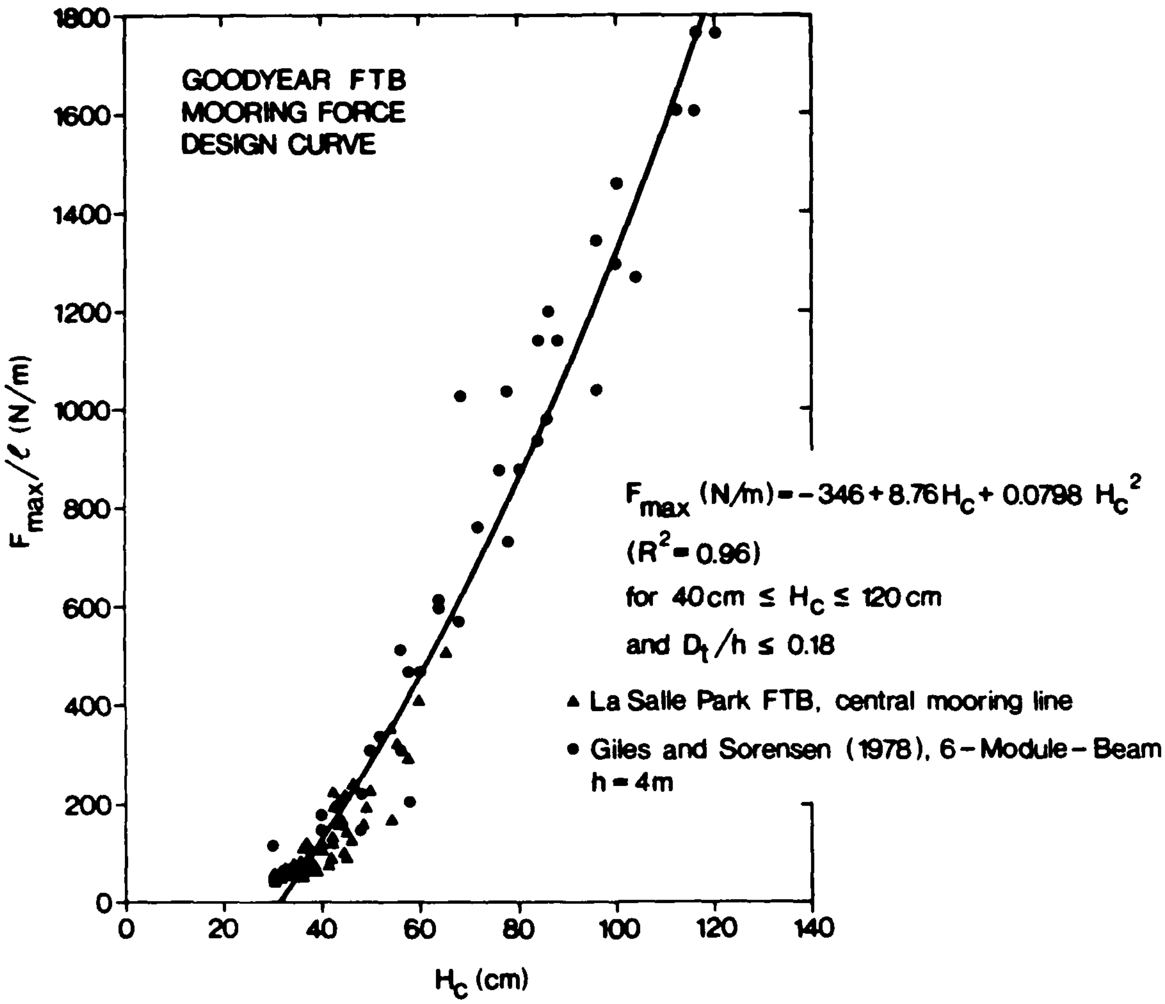

Figure 14. La Salle Park peak mooring load data from central mooring line and 6-module-beam data from Giles and Sorensen (1978)

Westerink (1980) from an analysis of the 6-module-beam data of Giles and Sorensen (1978) in 4 m of water which gave $F_{max}/\ell = .140\ (H_c)^2$.

A striking feature of Figure 13 is that the mooring loads on the corner line ($D_t/h \approx 0.18$) are significantly greater than those at the central line ($D_t/h \approx 0.085$). Prototype-scale model tests of Pipe-Tire floating breakwaters (Harms and Westerink 1980) showed a large increase in mooring loads when D_t/h changed from 0.22 to 0.51. Prototype-scale model tests of Goodyear FTB's (Giles and Sorensen 1978) showed a slight decrease in mooring loads when D_t/h changed from 0.16 to 0.32. This latter trend, however, disagrees with the results of other model studies (Harms 1979) and with theoretical expectations. At La Salle Park, the increase in D_t/h from 0.085 to 0.18 is not expected to cause a large increase in mooring loads. A more likely reason for the increase in mooring loads from central to corner mooring lines is that waves diffract around the corner of the breakwater, essentially doubling the frontage restrained by the corner line. Clearly more data is needed on the influence of relative draft D_t/h on mooring forces. Meanwhile, for design purposes, it is suggested that the mooring load (in a direction perpendicular to the FTB length) of the corner line be estimated as twice the central mooring line load.

Mooring Loads - Analytical

The preceding empirical approach can be compared with an analytical method. A floating body which reflects or dissipates wave energy is subject to a mean horizontal force, F. The existence of a horizontal momentum flux, or radiation stress, has been demonstrated experimentally by Longuet-Higgins (1977). For non-breaking waves of low amplitude (obeying linear wave theory), the mean horizontal force per unit length has been shown by Longuet-Higgins (1977) by conservation of momentum to be

$$[9] \qquad F = \frac{\rho g}{4} (a_i^2 + a_r^2 - a_t^2)(1 + \frac{2kh}{\sinh 2kh})$$

where ρ = density of water

g = gravitational acceleration

a_i = the amplitude of the incident wave

a_r = the amplitude of the reflected wave

a_t = the amplitude of the transmitted wave

k = $2\pi/L$

L = wavelength

h = water depth

Floating tire breakwaters characteristically dissipate wave energy through internal friction rather than reflection. Therefore, as a first approximation, F has been calculated by assuming $a_r = 0$. The wave amplitude is assumed to be half the wave height. For the water depths and wavelengths present at La Salle Park, the factor (1 + 2kh/sinh kh) equals unity. In Figure 15, the predicted loads (for a 5-module

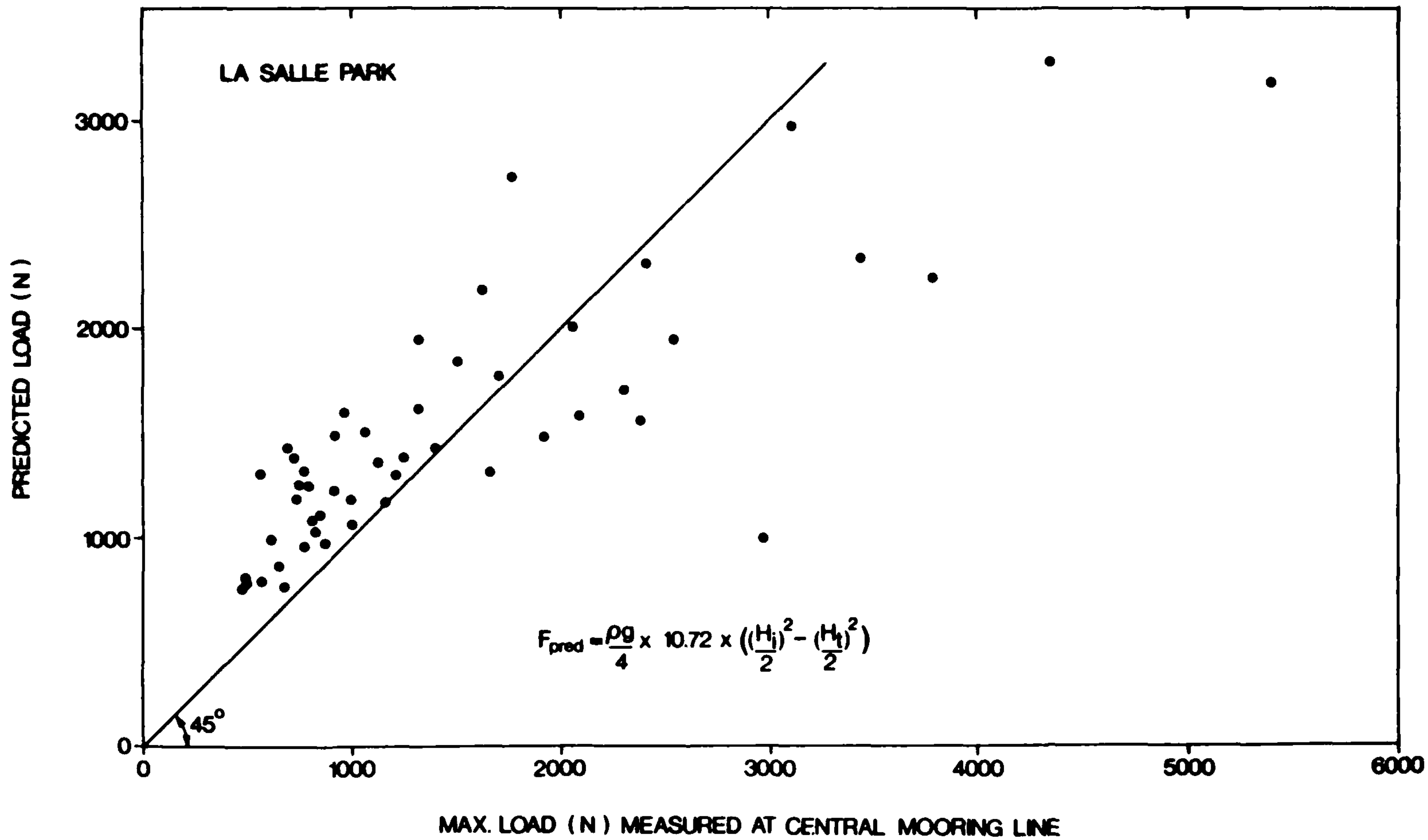

Figure 15. Comparison of measured peak mooring loads to predictions using relation of Longuet-Higgins (1977)

frontage of 10.72 m) are compared to the peak loads measured at the central mooring line. Equation (9) tends to overpredict for loads less than 2000 N and to underpredict for larger loads. It should not be used for design purposes, contrary to some evidence presented in Galvin and Giles (1979) which gave $F = F_{max}/2$. This lack of agreement can be attributed to the following reasons:

- The theory predicts a mean load in non-breaking waves but steep and breaking waves were present at La Salle Park. Furthermore, the comparison of mean loads estimated by Equation (9) is made with the peak measured loads (a comparison of F to $F_{max}/2$ is also unsatisfactory).
- The theory is valid for sinusoidal waves. In irregular waves, the wave amplitude has been approximated by one-half the characteristic wave height.
- The peak prototype mooring loads are dependent on the elasticity of the mooring lines and on the dynamic interaction between the waves and the structure. Wave grouping and the structure's natural period of oscillation will affect the peak mooring loads, while the mean horizontal load is essentially independent of wave-structure dynamics and mooring line elasticity.

Mechanical Load Gauge

A mechanical load gauge was installed on each of four windward anchor chains (Figure 4). The load gauges produce scratches on brass disks that rotate as the scratch is being made. After retrieving the disks at the end of the field season the scratches were measured using a microscope. This provided estimates of the largest loads but did not give the load-time history. The gauges were designed for a maximum load of 5000 lbs (22250 N). They were calibrated in the lab and showed a linear relationship between the load and the length of the scratch up to 22250 N.

The gauges were deployed September 24 - November 12, 1981 and June 15 - November 15, 1982. The largest measured loads were much smaller than the design load of 22250 N, and therefore, the resolution of the scratches was sometimes difficult. The maximum estimated loads (N ± 20 percent) for gauges 1 to 4 for 1981 and 1982 respectively were:

	1	2	3	4
1981	4900	3400	3700	3900
1982	-	5900	4400	5400

These estimates compare well with the maximum loads measured in 1982 with the electronic load cells: 5400 N at the central anchor chain between gauges 2 and 3, and 6300 N at the corner anchor chain beside gauge 4. These loads were probably induced by characteristic wave heights of 65 cm or less.

Storm of April 30, 1984

A severe storm occurred over the Great Lakes on this date. A fishing boat sank near the end of Long Point in Lake Erie, taking three lives. Several sailboats moored at offshore buoys beside the La Salle Park Marina broke their mooring lines and sunk or were badly damaged. One of these breakaways became grounded on the 9-module—wide southwest-facing section of FTB; the boat safely rode out the storm without damage to itself or the FTB.

Although the FTB was not equipped with measuring instrumentation during this storm, its performance was observed under these extreme wave conditions. Environment Canada wind measurements at Hamilton Airport, located 14 km south of La Salle Park, recorded a peak southwest gust of 30.9 m/s at 1555 hours, with a corresponding one-minute average speed of 21.6 m/s. At the L.B. Pearson (Toronto) International Airport, the peak of the storm occurred at 1422 hours with a southwest gust of 27.8 m/s and a one-minute average speed of 19.6 m/s. Using the average of these two one-minute speeds, 20.6 m/s, the resulting hindcast wave conditions at La Salle Park are H_c = 1.0 m and T_p = 3.5 s.

The FTB successfully rode out the storm without any apparent damage. Minor damage occurred to the floating docks in two locations. The FTB mooring system had been designed for waves of the magnitude and period hindcast for this storm. However, the transmitted characteristic wave heights were not expected to meet the standard of being less than 0.3 m.

The transmitted wave height at the peak of the storm has been estimated by obtaining a value of C_t from Figure 10 for L/B corresponding to T_p = 3.5 s; the resulting value of H_t is 0.66 m. Visual estimates of the transmitted wave height at the peak of the storm were 0.6 - 0.9 m.

An estimate of the peak mooring load can be obtained by using Equation 8 for H_c = 1.0; the resulting peak mooring load on a central mooring line is 14240 N or 1330 N/m.

Conclusions

The Goodyear-design floating tire breakwater at La Salle Park Marina has performed successfully from its installation in May 1981. It survived extreme wave conditions estimated at H_c = 1.0 m and T_p = 3.5 s with no damage, during a storm on April 30, 1984. It appears that an FTB of this type can be designed with confidence using the prototype results in this report and field-proven construction guidelines reported elsewhere (Bishop et al. 1983).

An 129 m x 19 m section of FTB was monitored during parts of 1981 and 1982. Wave transmission characteristics were determined by measuring incident and transmitted waves with underwater pressure transducers. The wave transmission results (Figure 10) are in close agreement with earlier results from model tests.

Mooring load characteristics were determined by measuring the loads exerted on several anchor lines using electronical and mechanical gauges. For the central anchor line the peak mooring loads per unit length were found to be in good agreement with those measured in earlier prototype-scale model tests (Figure 14). The peak loads measured on the corner anchor line were found to be significantly greater than those measured at the central anchor line.

Acknowledgements

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LIST OF SYMBOLS

a_i	amplitude of the incident wave
a_r	amplitude of the reflected wave
a_t	amplitude of the transmitted wave
B	beam width of FTB
C_t	transmission coefficient = H_t/H_i
D_t	tire diameter
f_p	frequency corresponding to the peak of the wave energy spectrum
f	frequency
FTB	floating tire breakwater
F	mean horizontal force per unit length
F_d	dimensionless peak mooring load
F_{max}	maximum measured load during a record
g	gravitational acceleration
h	water depth
H	wave height
H_c	characteristic wave height = four times the standard deviation of the water surface elevation record
H_i	incident wave height
H_p	wave pressure head
H_t	transmitted wave height
IGLD	International Great Lakes Datum
k	$2\pi/L$
K_p	pressure response factor
L	wavelength

L_p wavelength corresponding to the frequency at the peak of the wave energy spectrum

ℓ length of breakwater frontage

N empirical correction factor for pressure records

$S_i(f)$ water surface variance spectral component of incident waves

$S_t(f)$ water surface variance spectral component of transmitted waves

$S_s(f)$ water surface variance spectral component

$S_p(f)$ wave pressure head variance spectral component

T_p wave period = $1/f_p$

z depth of submergence of pressure transducer

ρ density of fresh water

θ angle between the mooring line and a perpendicular to the front face of the FTB

FLOATING BREAKWATER PROTOTYPE TEST PROGRAM

Eric Nelson

ABSTRACT

Due to increased interest in the use of floating breakwaters to provide wave protection, the US Army Corps of Engineers initiated the Floating Breakwater Prototype Test Program in February 1981. The program, which utilizes two types of breakwaters--a concrete box and a pipe-tire mat--was designed to answer several important engineering questions which include the following: determining the most efficient breakwater for a particular wave climate, predicting the forces that act upon structures and anchoring systems, determining the optimum construction materials, and providing a low-cost means of connecting or fendering the individual breakwater modules. After construction and mooring at an exposed site in Puget Sound, the breakwaters were monitored relative to performance and structural response, and the results are being consolidated to aid designers of future floating breakwaters.

INTRODUCTION

In February 1981, the US Army Corps of Engineers (USACE) initiated a 3-1/2-year prototype test program to establish design criteria for floating breakwater applications in semiprotected coastal waters, lakes, and reservoirs. The test was designed not only to obtain field information on construction methods and materials, connector systems, and maintenance problems but also to measure wave transmission characteristics, anchor loads, and structural forces. Program planning, engineering, and design work were completed in September 1981, and construction and placement were completed in August 1982. Monitoring and data collection were concluded in January 1984. The Office of the Chief of Engineers (OCE) had overall program responsibility, which included funding of the total program and reviewing and approving all major actions and reports. Guidance regarding site selection, breakwater design, and monitoring was provided by the Floating Breakwater Prototype Test Working Group comprised of representatives from OCE, the US Army Engineer Waterways Experiment Station (WES), the Coastal Engineering Research Center (CERC) (now at WES), the Seattle District (NPS), and the North Pacific Division (NPD). The Seattle District had primary responsibility for carrying out all major facets of the program except data analysis, which is the responsibility of CERC.

The breakwater test site was in Puget Sound off West Point at Seattle, Washington (Figure 1). The site was in an exposed location, assuring that, within the period available for testing, wave conditions would approximate design waves normally associated with sites currently considered suitable for floating breakwaters. Water depth at the site varied between 40 and 50 ft at mean lower low water (MLLW), and bottom materials consisted of gravel and sand. The diurnal tide range at the site was 11.3 ft, and the extreme range was 19.4 ft.

The prototype structures that were built and monitored were of two types: a concrete box design (Figure 2) and a pipe-tire mat design (Figure 3). The concrete breakwater was composed of two 75-ft-long units, each 16 ft wide and 5 ft deep (draft of 3.5 ft). The pipe-tire breakwater was composed of nine 16-in.-diameter steel pipes and 1,650 truck tires fastened together with conveyor belting to form a structure that was 45 ft wide and 100 ft long.

DESIGN AND CONSTRUCTION

The concrete structure design was based on field and design experience from numerous floating structures now in use, available model test data, and detailed structural analysis of similar structures (Adee, et al., 1976; Carver, 1979; Davidson, 1971; and Hales, 1981). The pipe-tire mat breakwater was based on a sea grant-funded design by Professor Volker Harms (Harms and Westerink, 1980) and modified based on local site conditions and personal discussion with Professor Harms. Other types of floating breakwaters, such as log bundles and twin pontoons, or A-frames, were considered; but either high construction costs, lack of broad applicability, or overall test program budget limited testing to the box-type concrete float and the pipe-tire mat structures. Based on available design information, the breakwaters were sized to provide acceptable wave attenuation under conditions typical of sites where the future use of floating breakwaters is anticipated (i.e., H_s = 2 to 4 ft,

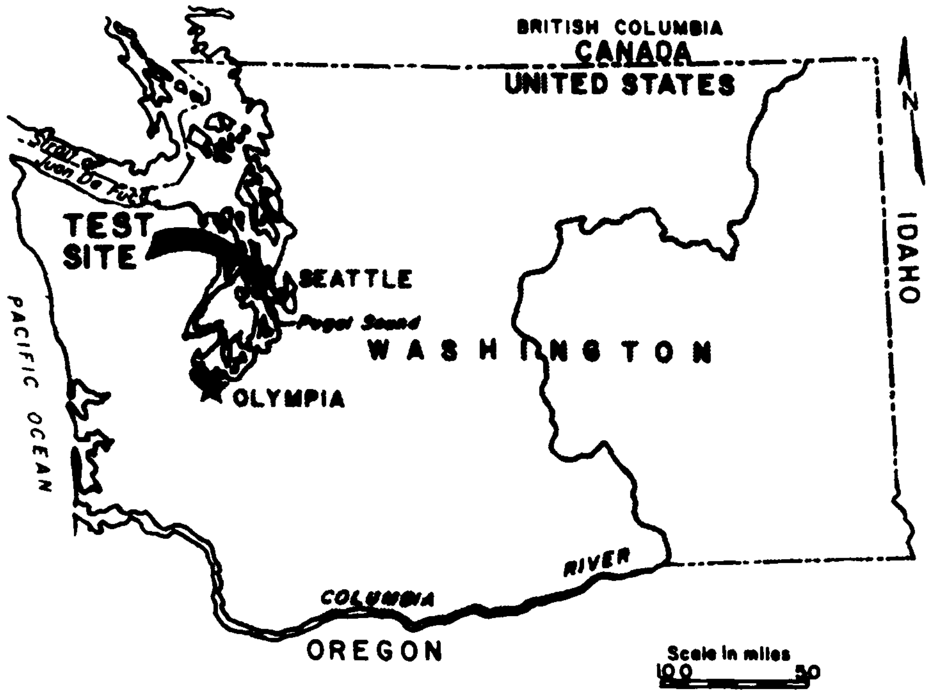

FIGURE 1. VICINITY MAP

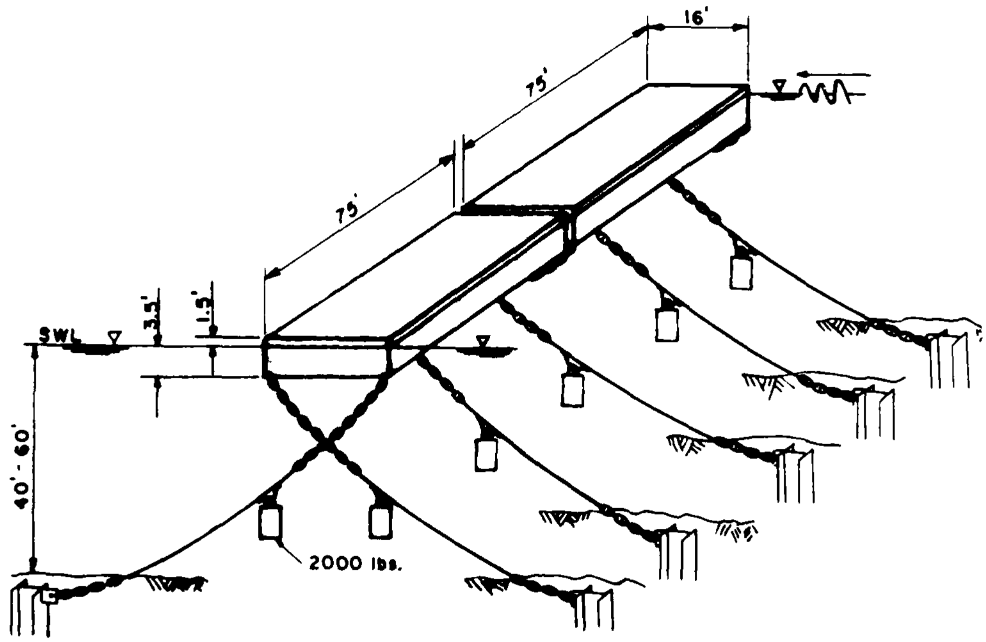

FIGURE 2. CONCRETE BREAKWATER (NOT TO SCALE)

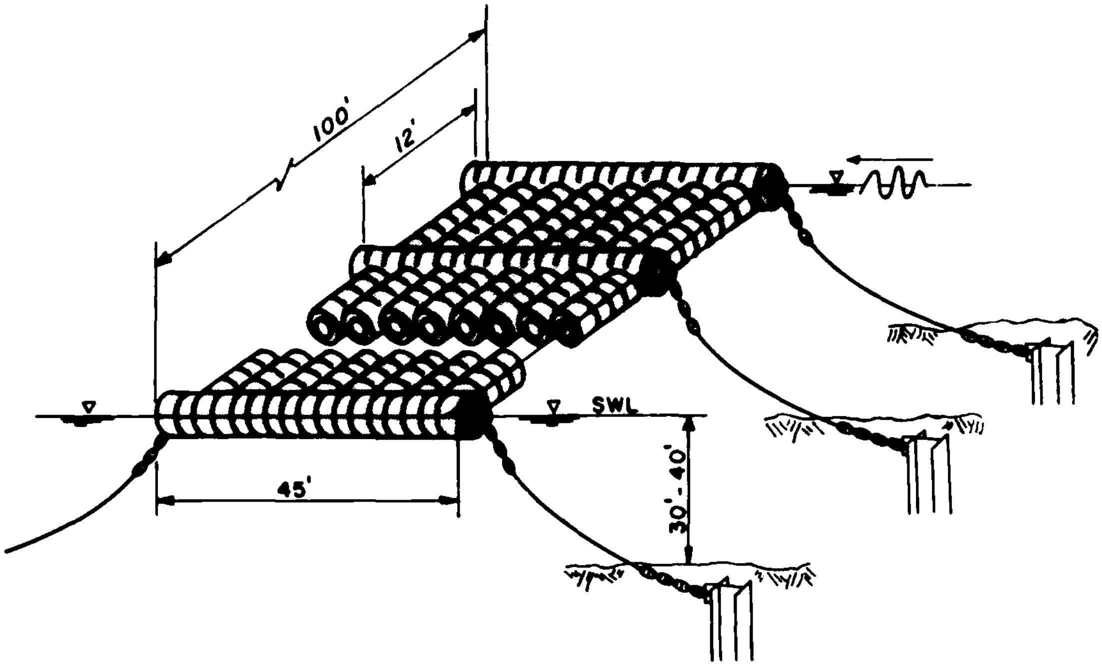

FIGURE 3. PIPE-TIRE BREAKWATER
(NOT TO SCALE)

T = 2 to 4 sec). However, the structures and anchor systems were designed to withstand the maximum wave predicted for the West Point site (H_s = 6 ft, T = 5 sec).

Pipe-Tire Breakwater Construction

The tire breakwater was assembled one bay at a time on a construction platform located adjacent to a waterway. As each bay was completed, the breakwater was moved (one bay at a time) into the waterway (Photograph 1). Construction of the breakwater closely followed the sequence described by Harms. The tires were brought to the assembly platform (Photograph 2) where they were arranged as shown in Figure 4. The matrix of 1,650 truck tires depended on the loops of 5-1/2-in.-wide, 3-ply conveyor belting for structural integrity. A special tool fabricated from a car jack was used to tension the belting (Photograph 3) before the loop ends were joined together with five 1/2-in.-diameter by 2-in.-long nylon bolts. The ends of the bolt thread were melted with a welding torch to prevent the nuts from working off the bolts. After 12 rows of 11 tires had been fastened together, additional tires were forced into the open spaces ("free" tire spaces). The breakwater was then ready to have a

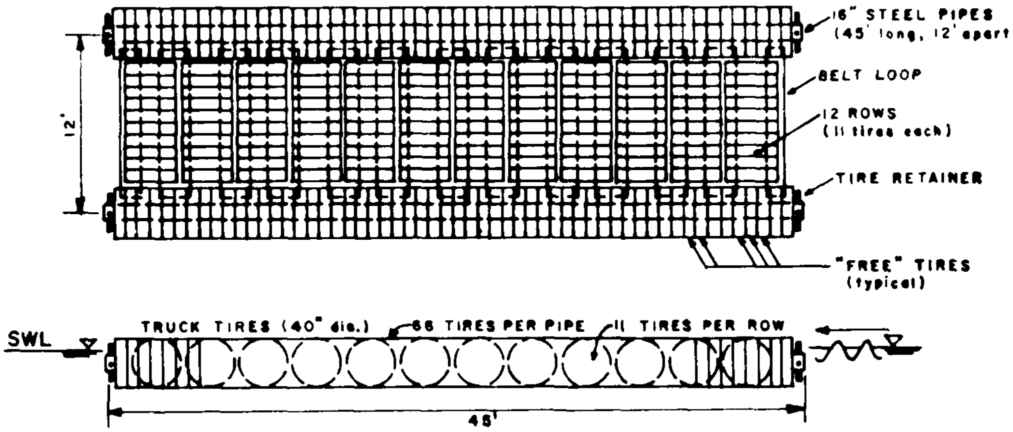

FIGURE 4. PIPE-TIRE BREAKWATER MODULE
(NOT TO SCALE)

pipe inserted into the beam-wise row of tires. Because the tires were not perfectly aligned, a "nose cone" was placed on the end of the pipe. The pipe was moved into place with a large overhead crane and was shoved through the row of tires with a forklift (Photograph 4). A tight structure was produced by compressing one additional tire onto each end of the pipe before the keeper pipes were installed (Photograph 5). This procedure brought the total number of tires on each pipe to 66. The completed bay was dragged into the adjacent waterway by using the overhead crane and a small tugboat (Photograph 6). This process was repeated for each of the eight bays (nine pipes). After construction procedures had been perfected, assembly time for each bay was approximately 8 hours for two men. Adding the free tires, inserting the pipe, and moving the completed bay off the assembly platform required an additional two men and took approximately 4 hours. Construction time was considerably reduced by the use of heavy equipment and the special tools fabricated by the contractor.

Concrete Breakwater Construction

The two 75-ft-long concrete breakwater units were cast in Bellingham, Washington. Work on these units began with the erection of steel forms. Welded wire fabric (3/8-in.-diameter) was then placed on the sides, ends, and bottom of the breakwater, with the top left open to allow placement of styrofoam blocks during the casting process. All small pieces of reinforcing steel were epoxy coated, and the larger welded wire parts were galvanized for corrosion protection. Prior to casting, 16 rebar strain gages were fastened into the deck, sides, bottom, and corners as part of the monitoring system. The concrete pour began at dawn; by sunrise the 4-3/4-in.-thick bottom had been completed. The styrofoam blocks that served as the interior forms were then dropped into place (Photograph 7). Wood two-by-fours and PVC pipe were used as spacers to keep the reinforcing steel located properly between the foam and the forms. Steel beams were placed across the deck; then wedges were hammered in between these beams and the foam to keep the foam from floating up as the sides of the float were poured. After the sides of the floats had been poured to within 1 ft of the deck surface, the spacers and steel holddown beams were removed, leaving friction to keep the foam from rising out of the forms. The deck reinforcing steel was placed, and the final stage of the pour was begun (Photograph 8). Pouring and finishing of the deck completed the casting process (Photograph 9). Test samples of concrete were taken throughout the pour. The concrete weight varied between 131 and 134 pcf, with an average 7-day strength of 4,000 to 5,000 psi and a 28-day strength of 5,000 to 6,000 psi. After the concrete had cured for 7 days, each of the 10 cables composing the six post-tensioning tendons was tensioned to 25,000 lb (Photograph 10).

On May 28, 1982, the 140-ton units were lifted from the casting area and lowered into the waterway (Photograph 11). The longitudinal strain gages in the lower center edges of the B-float were monitored during the launching. A maximum strain of 1,700 microstrains was recorded, indicating that loads were about two-thirds of the yield strength of the reinforcing steel. After both units were launched, they were joined end-to-end with two flexible connectors (Photograph 12) and towed approximately 90 miles south to the West Point test site.

Anchoring

The concrete breakwater was anchored in place by ten 30-ft-long steel H-piles (HP 14 by 102) (Photograph 13) embedded their full length. The pilings were driven using a Vulcan 010 hammer with a 10,000-lb ram weight and an 8,000-lb mandrel (Photograph 14). A special fitting was attached to the mandrel to hold the piling in proper alignment while it was being driven. Anchor lines consisted of 1-3/8-in.-diameter galvanized bridge rope with 15 to 30 ft of 1-1/4-in. stud link chain at each end. Anchor line lengths were sized to provide a minimum slope of 1 vertical to 4.5 horizontal. A 2,000-lb concrete clump weight was attached near the upper end of each anchor line. The purpose of this design was to produce a more even anchor line tension over the full range of tides and thereby to reduce the horizontal excursions of the breakwater, particularly at lower tide elevations. Initial anchor line tensions were 5,000 ± 1,000 lb. Four months prior to the termination of the field test, the clump weights were removed. During this 4-month period, the effects of this clump weight removal on float motions, anchor forces, and wave attenuation were monitored.

The pipe-tire breakwater was anchored alongside the concrete breakwater (Photograph 15) with ten 20-ft-long steel H-piles (HP 12 by 53). Anchor lines, which consisted of 1-1/4-in.-diameter, three-strand, nylon rope with 10 ft of 3/4-in. stud link chain at each end, were attached to both ends of each pipe. Minimum slope for these anchor lines was about 1 vertical to 4 horizontal. The center and end H-piles had one anchor line each, while the remaining four anchor piles were attached to three anchor lines apiece. The four end pilings were offset at an outward angle to counteract the opposing longitudinal component of force from the adjacent anchor lines.

TEST CONDITIONS

The prototype breakwater test site at West Point was selected for its exposed location. This choice proved to be more than adequate for providing the desired wave conditions. During the 16-month test period more than 20 storms moved through Puget Sound. One storm brought winds in excess of 60 knots and generated waves over 4 ft high. But most often storm winds were in the 20- to 40-knot range with wave heights between 2 and 3.5 ft (Photograph 16). Access to the breakwater was difficult when winds exceeded 10 knots; 15-knot winds made working conditions potentially hazardous.

Advantage was taken of calm periods to make repairs and to conduct additional tests. Four boat wake tests and an anchor line stiffness (pull) test were conducted at various points in the program. For two of the boat wake tests, 41-ft Coast Guard cutters were used to generate waves (Photograph 17). The other two tests used large (75-ft and 110-ft) tugboats. Boat-generated waves were in the 2- to 3-ft range. For the anchor stiffness test, a 4,000-hp tugboat was used to pull on the breakwater with varying loads, while surveying instruments measured displacements, and load cells in the anchor lines monitored anchor forces (Photograph 18). This test was conducted to obtain simultaneous measurements of breakwater lateral displacement and the resisting anchor force, properites of the anchor system that affect overall float motions and internal loads.

OBSERVATIONS OF PERFORMANCE AND DURABILITY

Visual comparisons of incident and transmitted wave height indicated that, under all observed wave conditions, the pipe-tire and the concrete breakwaters provided an adequate and very similar degree of wave protection for both wind waves and boat wakes (Photograph 19). Readily apparent was the fact that the concrete breakwater reflected the wave energy, but the pipe-tire breakwater dissipated it through viscous damping. As a result of wave reflection, the windward side of the concrete breakwater was always noticeably rougher than the windward side of the pipe-tire breakwater (Photograph 20).

Overtopping of the concrete breakwater by waves was quite pronounced (Photograph 21). Sheet flow 3 to 4 in. deep was common. As a result, a lush crop of algae thrived on the deck of the structure, making the surface treacherously slippery. The actual freeboard of the concrete breakwaters was about 13 in., 4 to 5 in. less than anticipated in the original design. The reduced freeboard undoubtedly contributed to the amount of overtopping.

The relatively high tension in the anchor lines of the concrete breakwater (5,000 lb with the 2,000-lb clump weights and 1,500 lb without the clump weights) appeared to minimize the lateral travel of the floats even during low tides and fast tidal current flows (2 knots). Lateral displacements were estimated to be less than 2 ft even when the clump weights were removed.

Lateral displacement of the pipe-tire breakwater did not appear excessive (about 5 ft), but tidal currents running at a 45° angle to the anchor lines tended to carry the pipe-tire breakwater in a longitudinal direction to the near end of the concrete breakwater, a distance of about 30 ft.

Water leakage into the hollow end compartments of the concrete breakwater was a serious problem throughout the test. Primary leak points were the "watertight" access hatches and the 2-in.-diameter post-tensioning bolt holes that were used when making the rigid connections between the two floats. Because calculations indicated that the breakwater could sink if the end compartments filled, emergency pumping operations were carried out on several occasions. Eventually, reworking the hatch covers and filling the bolt holes with sealant reduced the leakage rate to manageable levels.

One of the major goals of the test program was to investigate various methods of connecting (or fendering) the two 140-ton floats. Several different connection methods were tested: rigidly bolting the units together, using three types of flexible connectors, and disconnecting completely (with fendering). Both the rigid connection and the fendering (Photograph 22) were successful. None of the flexible connector designs survived their test period undamaged, although considerable progress was made toward a viable flexible connection design.

Upon completion of the field test, diver inspections of the anchor lines and the concrete floats were made. No significant damage, wear, or cracking was found on the floats. The galvanized steel anchor lines were visibly corroded, and the shackles used to attach the clump weights to the anchor lines were worn; otherwise the anchor line hardware, including the chain, was found to be in excellent condition.

For nearly a year, the pipe-tire breakwater proved to be remarkably durable. Except for minor repairs to the keeper pipes, it withstood the winter storms of 1982 without any maintenance (Photograph 23). But in June 1983, almost a year to the day after the pipe-tire breakwater was installed, the first problem of any consequence developed. After a minor storm, routine inspection revealed that one of the longitudinal pipes had broken (Photograph 24). Further scrutiny revealed that the 45-ft pipe had been fabricated from a 40-ft section and a 5-ft section. A poor weld between the two sections had finally failed because of a combination of corrosion and fatigue, allowing the two pipe sections to pull out of the tires. One month later, when a second pipe failed in exactly the same manner, a decision was made to terminate testing of the pipe-tire breakwater. The pipe-tire breakwater anchor lines were inspected during the removal process, and no major problems were found in either the nylon anchor lines or the connecting hardware. After the breakwater was removed, it was eventually reinstalled at a private marina in southern Puget Sound. Monitoring of the long-term durability of this unit is planned.

While the Floating Breakwater Prototype Test Program was under way, two projects using floating breakwaters were designed and constructed by NPS. In 1983, a 600-ft-long breakwater was constructed for the 800-boat East Bay Marina at Olympia, Washington (Photograph 25). A year later, another floating breakwater, 1,600 ft long, was anchored at Friday Harbor, Washington (Photograph 26).

As originally planned, the prototype test breakwater was refurbished and incorporated into the Friday Harbor Project. Throughout the test program, information obtained from the construction and operation of the prototype breakwater was used to refine the East Bay and Friday Harbor designs. Preliminary prototype test data were used to confirm float sizing. Construction specifications were broadened to allow the use of either lightweight or standard weight concrete, with appropriate adjustments in float draft. Details of the East Bay connector system were changed to reduce maintenance, and the Friday Harbor fender system is a direct spinoff of the one developed during the prototype testing.

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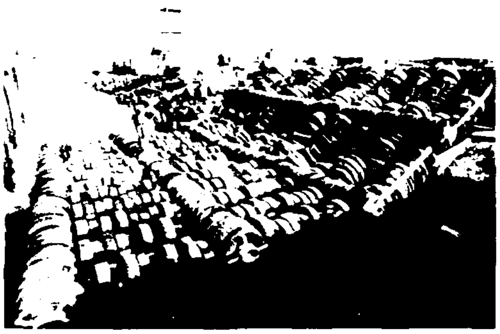

PHOTO 1. PIPE-TIRE BREAKWATER BEING ASSEMBLED (FOUR MODULES HAVE BEEN COMPLETED)

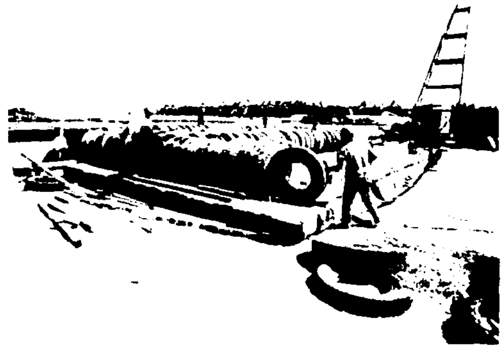

PHOTO 2. ASSEMBLY AREA (AS EACH MODULE IS COMPLETED IT IS MOVED INTO THE WATERWAY)

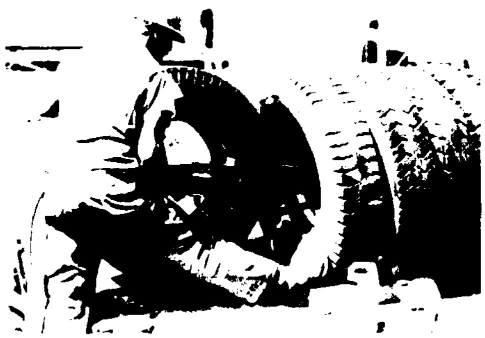

PHOTO 3. TENSIONING OF BELTING USING A MODIFIED CAR JACK

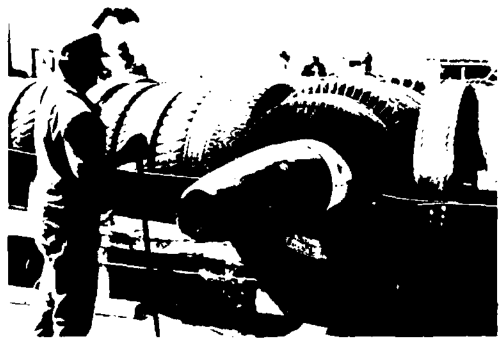

PHOTO 4. STEEL PIPE BEING SHOVED THROUGH TIRES (TIRES AROUND PIPES WERE NOT FOAMED)

PHOTO 5. KEEPER PIPES BEING SECURED (WELDING OF KEEPERS IS REQUIRED TO PREVENT LOOSENING)

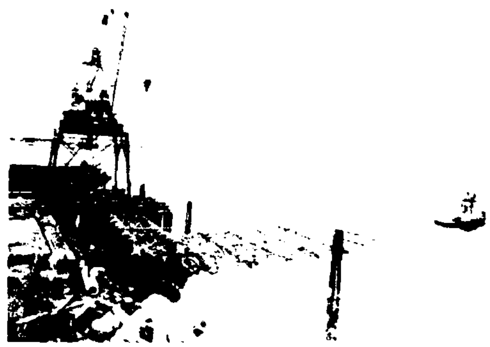

PHOTO 6. LAUNCHING OF PIPE-TIRE BREAKWATER

PHOTO 7. CONCRETE BREAKWATER POUR (PLACEMENT OF INTERNAL FOAM BLOCKS)

PHOTO 8. POURING SIDES AND INTERNAL WALLS

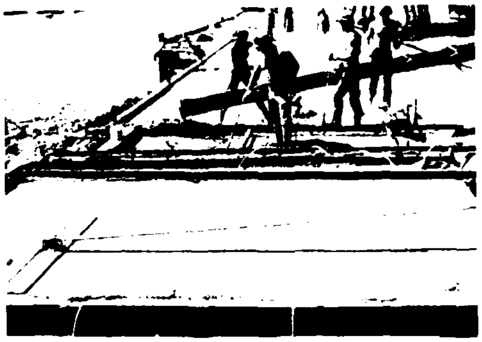

PHOTO 9. POURING AND LEVELING DECK

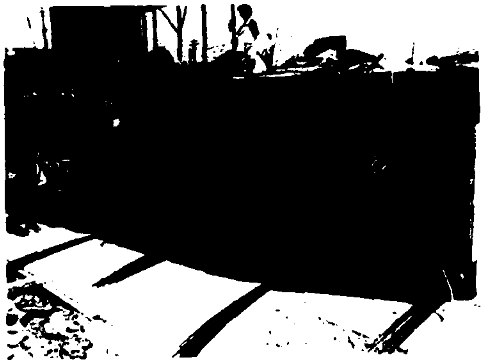

PHOTO 10. POST-TENSIONING OF CONCRETE UNITS

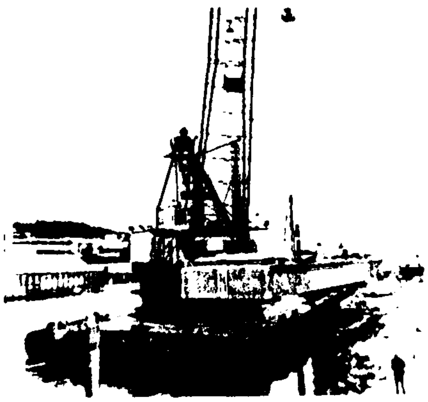

PHOTO 11. LAUNCHING OF CONCRETE BREAKWATER

PHOTO 12. JOINING UNITS WITH FLEXIBLE CONNECTORS

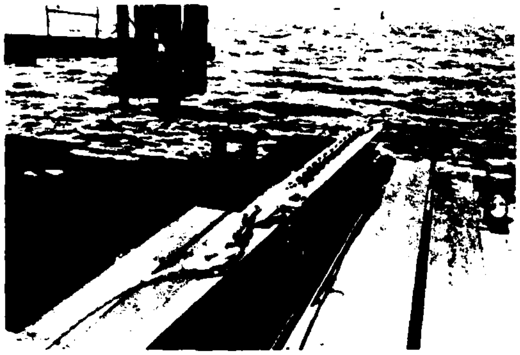

PHOTO 13. H-PILE WITH CHAIN AND STEEL ROPE ATTACHED (NOTE ANCHOR FORCE CELL IN CHAIN)

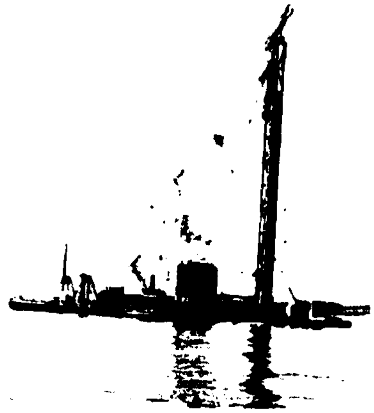

PHOTO 14. ANCHOR PILES BEING DRIVEN AT TEST SITE

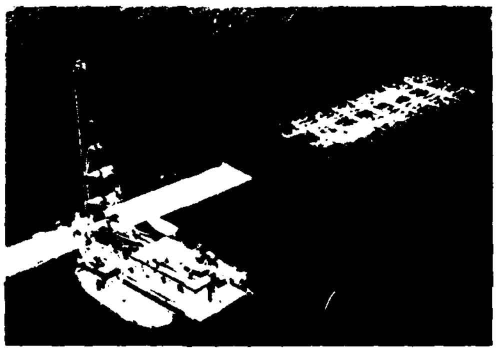

PHOTO 15. FINAL ANCHORING OF BREAKWATERS AT TEST SITE

PHOTO 16. WAVES REFLECTING FROM THE CONCRETE BREAKWATER (SENDING SPRAY 20 FT INTO THE AIR)

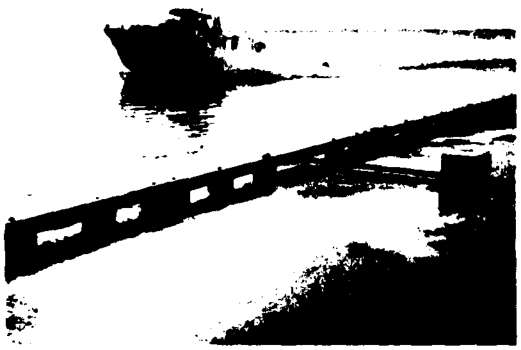

PHOTO 17. 41-FT COAST GUARD CUTTER PASSING THE BREAKWATERS (DURING A BOAT WAKE TEST)

PHOTO 18. 4,000-HP TUGBOAT PULLING CONCRETE BREAKWATER TO DETERMINE ANCHOR LINE STIFFNESS

PHOTO 19. BOTH BREAKWATERS PROVIDING GOOD PROTECTION FROM STORM WAVES

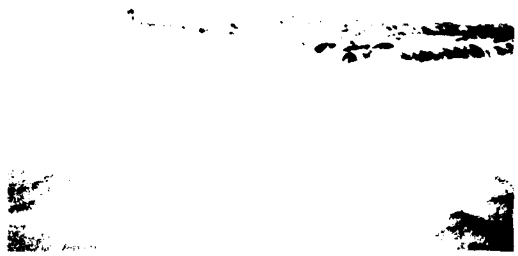

PHOTO 20. REFLECTING WAVES OBVIOUS ON WINDWARD SIDE OF CONCRETE FLOAT

PHOTO 21. 1.5-FT WAVES OVERTOPPING THE BREAKWATERS (JOINT BETWEEN RIGIDLY CONNECTED UNITS IS VISIBLE)

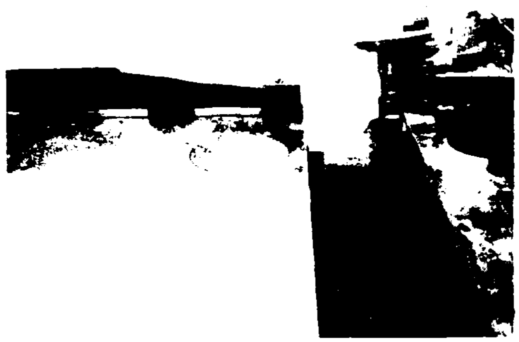

PHOTO 22. CONCRETE UNITS IN DISCONNECTED AND FENDERED CONFIGURATION

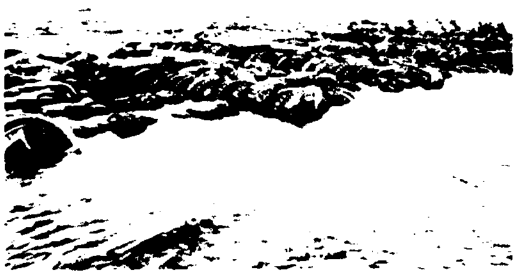

PHOTO 23. PIPE-TIRE BREAKWATER AFTER HAVING WEATHERED NUMEROUS STORMS

PHOTO 24. AFTER BREAKING, LONGITUDINAL PIPE PULLS OUT OF TIRES

PHOTO 25. THE 16-FT-WIDE BY 600-FT-LONG EAST BAY BREAKWATER MOORED WITH PILINGS

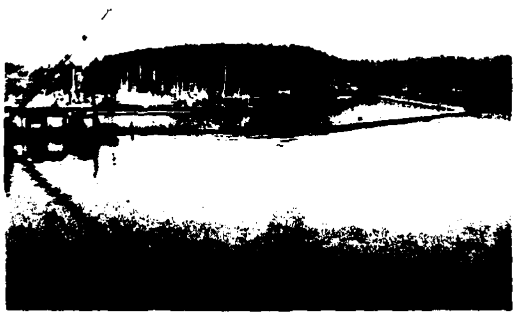

PHOTO 26. TEST UNITS NOW PART OF THE FLOATING BREAKWATER AT FRIDAY HARBOR, WASHINGTON

DATA RESULTS, FLOATING BREAKWATER
PROTOTYPE TEST PROGRAM

Laurie L. Broderick

INTRODUCTION

The monitoring program for the prototype test was conducted by the Civil Engineering Department of the University of Washington under contract with the US Army Corps of Engineers. The purpose of the monitoring program was to collect data that would serve as a basis for establishing and evaluating the fundamental behavior of the two breakwater types under study. The University designed a system to measure and record pertinent environmental and structural variables that are involved in the design and mathematical modeling of the test breakwaters and similar structures. The parameters that were measured included incident and transmitted waves, wind speed and direction, anchor line forces, stresses in the concrete units, relative float motion, rotational and linear accelerations, pressure distribution on the concrete breakwater, water and air temperatures, and tidal current data.

"Off the shelf" transducers for measuring many of the parameters were not available. A major effort was required to design and fabricate anchor force load cells (Photograph 1), wave measuring spar buoys, a relative motion sensor (Photograph 2), pressure sensor housings, and embedment strain gages. By the end of the monitoring program, approximately 60 transducers had been installed in and around the breakwater. Over 3 miles of underwater electrical cable was required to feed signals to the data acquisition system that was housed on the concrete breakwater (Photograph 3). Using large lead-acid batteries for power, the system was completely self-contained. In addition to the input transducers, the system included a microprocessor-controlled data logger and special purpose signal conditioning electronics, which were designed and built by the University (Photograph 4). The data acquisition system was programmed to sample selected transducers for 1 min on an hourly basis. When either wind speed, current speed, anchor force, or significant wave height exceeded a preset threshold value, an 8-min record of all transducers was made at a sampling rate of 4 Hz. The microprocessor was capable of a limited amount of data processing, including calculations of maximum, minimum, mean, and standard deviation of selected channels of transducer data. After each data tape was retrieved from the breakwater, it was processed at the University. Selected statistics and data plots were analyzed to determine whether all critical components of the data acquisition system were operating properly. When problems were detected, repairs were made as soon as the breakwater was safely accessible. Keeping this complicated and extensive system operational in such a hostile environment proved to be a challenging enterprise. Salt water flooded instrumentation, waves and tidal currents broke transducers and tore out electrical leads, and logs, fish nets, and other debris caused damage continuously. Despite these difficulties in the 16 months of data collection, 130 data tapes were recorded, representing approximately one-quarter billion measurements. After initial processing at the University, the data were transferred to CERC for detailed analysis.

DATA ANALYSIS

Analysis of the data has been initiated, with the major effort being directed toward the transmission characteristics and anchor forces of the breakwaters. These two parameters are being looked at initially because they appear to be key factors in the effort to optimize the cost effectiveness of floating breakwater design. Other parameters, i.e., the internal concrete strains and wave pressures, have been checked to ensure the reliability of the data; but detailed analysis has not been initiated.

Figures 1 and 2 are wave transmission characteristics and mooring forces, respectively, for the concrete breakwater. The data plotted in Figures 1 and 2 constitute a partial data set for the 150-ft pontoon with clump weights on the anchor lines, one of the configurations tested for the concrete breakwater. In Figure 1 the prototype data are plotted versus a laboratory curve of a model of a 16-ft-wide pontoon (Carver, 1979). From Figure 1 the prototype wave transmission data seem to follow the laboratory trend. The mooring line loads shown in Figure 2 are much lower than calculated using simple wave force

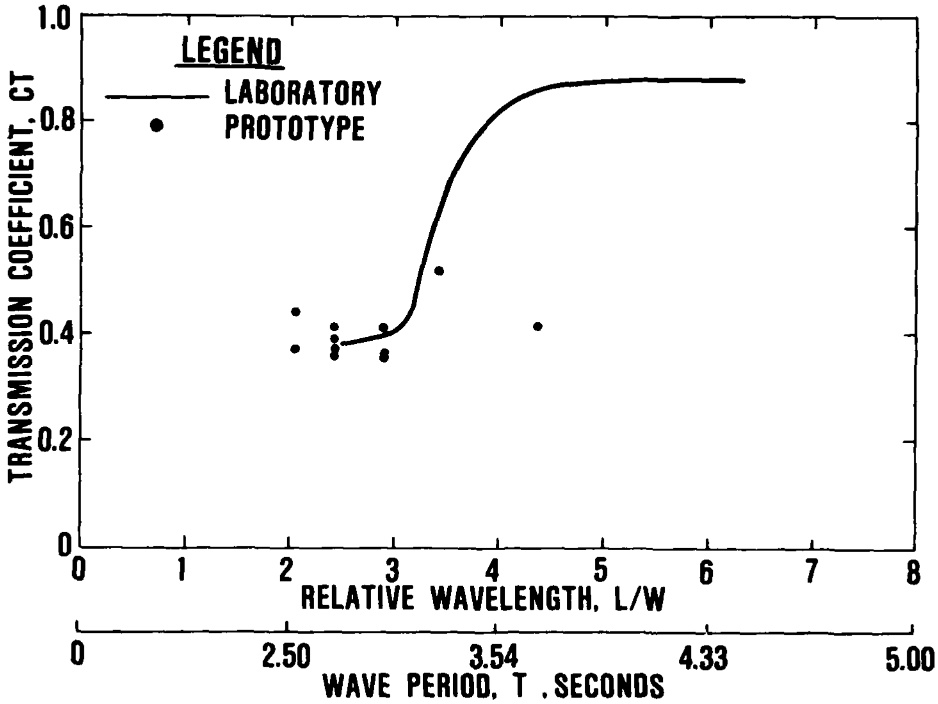

FIGURE 1. WAVE TRANSMISSION FOR CONCRETE BREAK-WATER (150-FT PONTOON WITH CLUMP WEIGHTS)

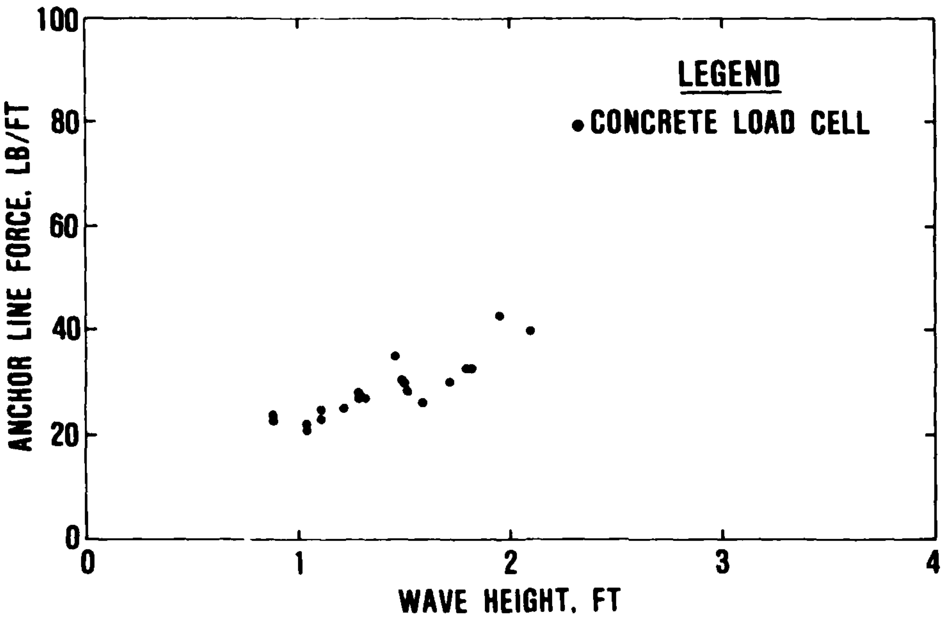

FIGURE 2. MOORING LOADS FOR CONCRETE BREAK-WATER (150-FT PONTOON WITH CLUMP WEIGHTS)

analysis. This was definitely shown in the design of the anchor force load cells, which for the concrete breakwater were designed for a maximum load of 50,000 lb (approximately 1,670 lb/ft of breakwater) which is more than forty times larger than the loads experienced by the breakwater.

Figures 3 and 4 show the wave transmission characteristics and the mooring line loads, respectively, for the pipe-tire breakwater. In Figure 3, the prototype wave attenuation does not appear to be as effective as the model data predicted (Harms and Westerink, 1980). There are several possible explanations for this discrepancy between the prototype and the model data such as relative depth effects, long period wave energy, background noise, and diffraction around the breakwater. Figure 4 presents a plot of the mooring loads versus wave height for the pipe-tire breakwater. The prototype data show that the mooring loads are less than predicted. The laboratory data show mooring loads increasing with wave heights; whereas the prototype data are nearly constant for any given wave height. The model data used in Figures 3 and 4, the best available for comparison, are based on two-dimensional laboratory studies conducted using prototype materials (Harms and Westerink, 1980). When mooring loads experienced by the tire breakwater and the concrete breakwater are compared on a per linear foot of breakwater basis, the tire breakwater has on the average larger loads for wave heights 2 ft or smaller.

These are only preliminary results for the prototype breakwaters, and a detailed analysis of the data is currently under way.

Future projects utilizing floating breakwaters (Section 107 studies for Oak Harbor, Washington, and Juneau and Saxman, Alaska, are presently under way) will benefit greatly from the test data, and even more cost-effective and lower maintenance designs are anticipated.

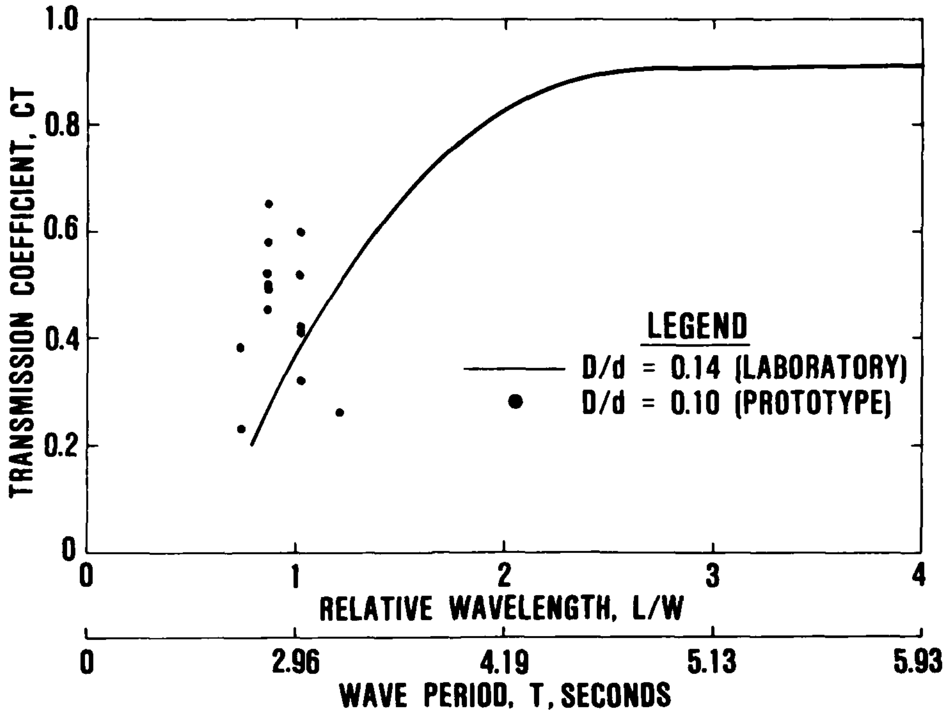

FIGURE 3. WAVE TRANSMISSION FOR PIPE-TIRE BREAKWATER

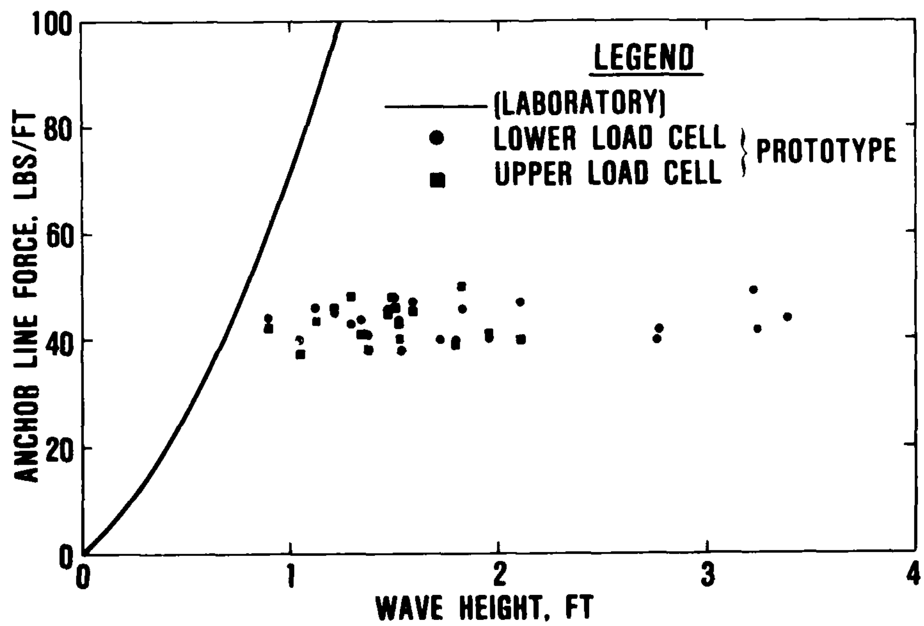

FIGURE 4. MOORING LOADS FOR PIPE-TIRE BREAKWATER

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HARMS, V. W., AND WESTERINK, J. J. 1980. "Wave Transmission and Mooring-Force Characteristics of Pipe-Tire Floating Breakwaters," Report LBL-11778, Lawrence Berkeley Laboratory, University of California, Berkeley, Calif.

PHOTO 1. UPPER LOAD CELL IN ANCHOR LINE

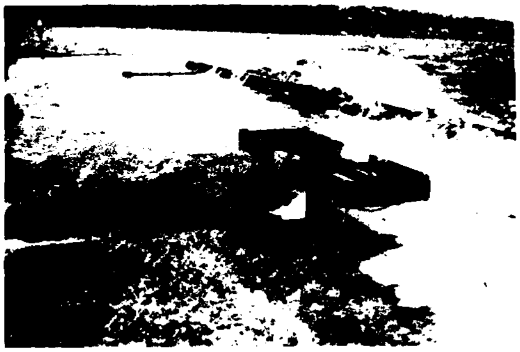

PHOTO 2. RELATIVE MOTION SENSOR IN USE DURING TEST OF FLEXIBLE CONNECTOR

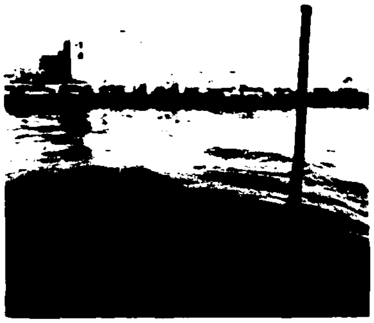

PHOTO 3. DECKHOUSE PROTECTING EQUIPMENT FROM ELEMENTS (NOTE WAVE BUOY IN FOREGROUND)

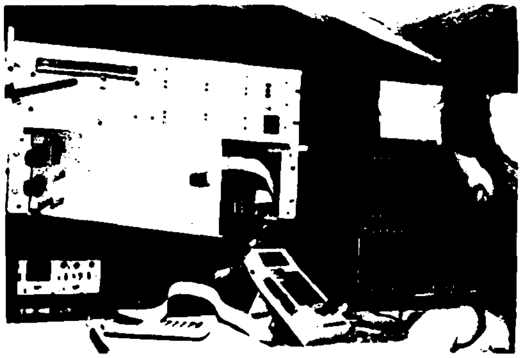

PHOTO 4. TWO HERMETICALLY SEALED CASES CONTAINING THE ON-BOARD COMPUTER

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