University of Washington
Department of Civil and Environmental Engineering

REVIEW OF FLOATING BREAKWATER FOR BAR POINT HARBOR, KETCHIKAN, ALASKA

E. P. Richey
B. H. Adee

Water Resources Series
Technical Report No. 43
June 1975

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Review of Proposed Floating Breakwater

for

Bar Point Harbor, Ketchikan, Alaska

by

Eugene P. Richey and Bruce H. Adee

June 1975

Technical Report No. 43

Prepared for

Department of the Army
Alaska District, Corps of Engineers
P.O. Box 7002
Anchorage, Alaska 99510

ACKNOWLEDGEMENT

The review reported herein was authorized by Purchase Order No. NPASU-75-772, issued by the District Engineer, Alaska District, Corps of Engineers, PO Box 7002, Anchorage, Alaska 99510, dated 21 March 1975, to Professor E.P. Richey, Department of Civil Engineering, c/o University of Washington, Seattle, Washington 98195.

The work to be performed is contained in the following Scope of Work.

SCOPE OF WORK

Evaluation and Report
Concrete Module Floating Breakwater
for Bar Point Harbor Extension
Ketchikan, Alaska

1. Conduct a literature search, map studies, and computer analysis leading to preparation of a brief report for a proposed floating breakwater at Bar Point Harbor, Ketchikan, Alaska.

2. The structure type to be reported on will be as designed by the State of Alaska and presently installed at Sitka, Tenakee and Whitter, or incremental size alterations thereof.

3. The structure will be restrained by a chain and anchor mooring system as presently used by the State of Alaska.

4. Data to be furnished by the Corps of Engineers includes fetch lengths and direction, the area wind spectrum, significant wave heights and periods for design purposes, wave attenuation desired within the enclosure, available mapping of the area including proposed project, hydrographic data, expected foundation conditions, aerial photographs, design data on existing rock rubble mound breakwaters, size and number of vessels expected to use the harbor and tentative State design of mooring facilities.

5. Report required not later than 1 June shall include but not be limited to the following:

a. Design anchor forces for significant wave and maximum wave including defined size of maximum wave that might break the structure loose from its moorings.

b. Analysis of anchor forces for the maximum wave with respect to duration.

c. At what wave stage will overtopping occur, and what type of wave will be created inside the breakwater when overtopping occurs?

d. Can significant wave height for the maximum and lesser periods be reduced to less than one foot, and if not, what is the allowable height within the harbor, taking into account craft size and orientation of mooring as proposed?

e. Wave attenuation that can be expected from design waves on present structural cross sectional width of 21 feet plus similar analyses of the effect of increasing the section by incremental addition of 7-1/2 feet and 15 feet of width to 28-1/2 and 36-foot widths respectively.

f. How will long period waves react with breakwater and what will be the in-harbor effect?

g. What are expected life spans for breakwater components including concrete units, rubber buffers, anchors, anchor chain, and reinforcing? Each unit must have a rationale for design to enable a prediction of annual or incremental maintenance to be expected.

h. Recommendations as to structural design and favored project dimensions for Bar Point Harbor extension with rationale for the recommendations, and wave attenuation to be expected.

i. Results and recommendations of the study may be shown in the form of charts or graphs, particularly wave height reduction for incident wave height and period.

j. Any limitations to use of a floating breakwater at Bar Point Harbor, and in particular, if the breakwater will be affected by loss of mass in the anchorage system due to aging, i.e., will it still function effectively?

k. Should any derivation from present State of Alaska design be considered, and if so, what and why?

l. Any limitations to use of a floating breakwater at Bar Point Harbor. In particular, will the breakwater responses be affected significantly by increasing or decreasing the mass of the anchorage system?

m. Summary of design recommendations for a floating breakwater at Bar Point Harbor.

Some of the analyses and data used as background for this report were drawn from general studies on floating breakwaters sponsored by the National Oceanic and Atmospheric Administration as administered by the Washington Sea Grant Program (Tenakee Springs and Sitka), and by the Corps of Engineers, Coastal Engineering Research Center (Friday Harbor). Reports on these studies are still in the early draft stages, so that specific references are premature, but reliance on them is hereby acknowledged.

REVIEW OF PROPOSED FLOATING BREAKWATER FOR BAR POINT HARBOR, KETCHIKAN, ALASKA

Site Discussion

Bar Point Harbor, Ketchikan, Alaska lies on the northeast shore of Tongass Narrows, a fjord oriented on a SE-NW bearing as shown on the accompanying Plate 20, reproduced from a report on the initial Bar Point Basin. The bordering mountains guide the approach for strong winds to be up or down the channel, with a secondary approach from the south. Pennock Island initially confines the fetch from the southeast to two channels about a half-mile wide, to within about 1.5 miles from the site, where the full channel width is about a mile at the end of the island, and reduces to less than a half mile at the site. There is an opening through the hills to the south, and a fetch distance of about one mile from that direction. Toward the NW, Tongass Narrows is about one half mile wide for about 2-3 miles, where it widens on the approach to Ward Cove. Water depths reach 100 feet quite close to shore, so any waves influencing the site of proposed breakwater can be considered to be in the deep water range.

In the absence of site wave records, wave conditions have to be predicted from fetch-speed graphs. Some subjective assumptions have to be made to arrive at design values for the speeds and fetches. The strongest recorded wind is 45 mph from the southeast, lasting for 4 hours.* Short term speeds of at least 50 mph can be expected. The channel is narrow, and geometric fetches need to be reduced accordingly. An effective fetch of one nautical mile and a wind speed of 50 knots yield a significant wave height and period of 3.15 feet and 3.45 seconds, according to Figures 3-13 and 3-36, Shore Protection Manual, Volume 1.

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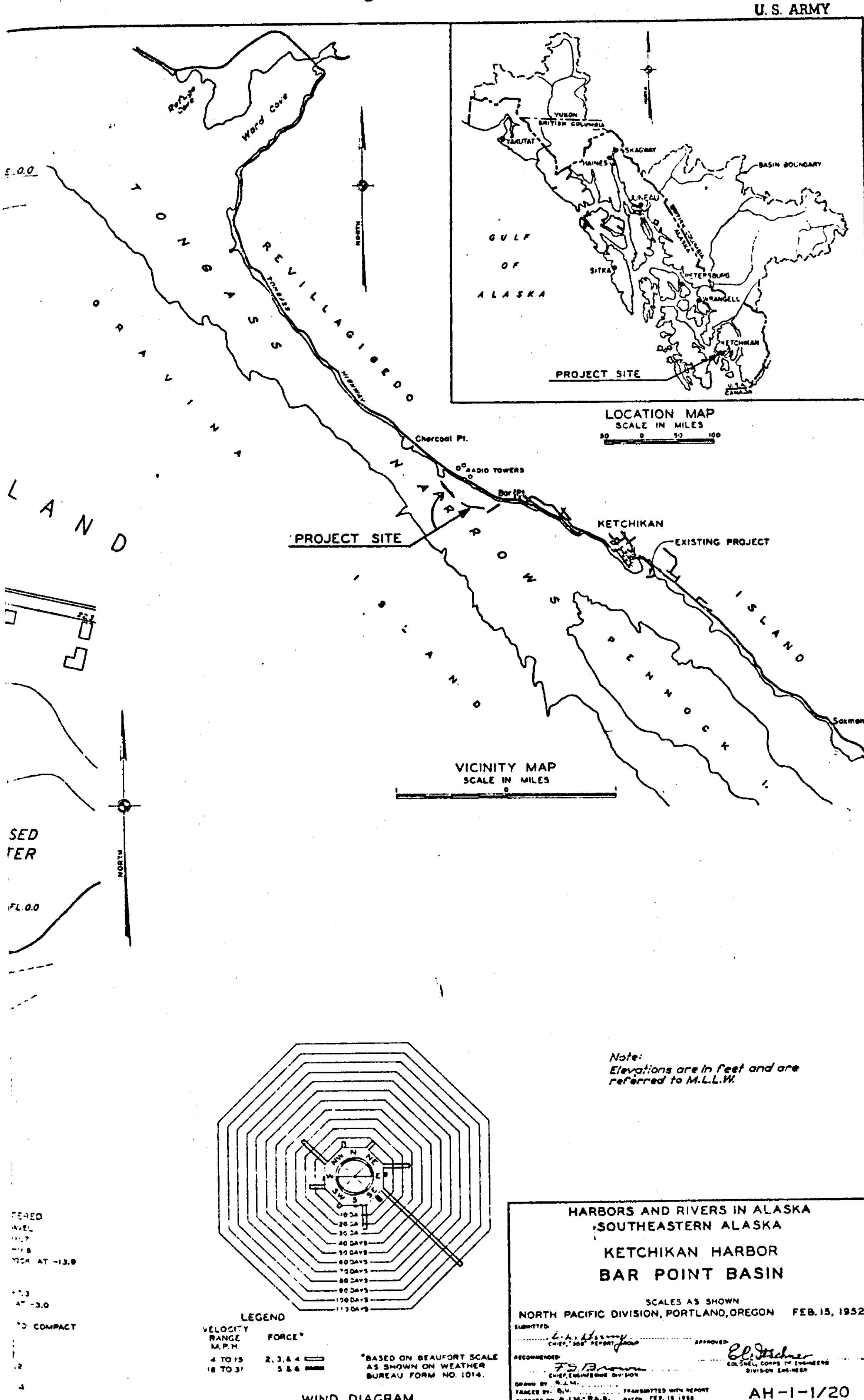
* Reconnaissance Report, Bar Point Harbor Extension, submitted as per NPAEN-PR-R letter of 24 April 1974.

U. S. ARMY



HARBORS AND RIVERS IN ALASKA
SOUTHEASTERN ALASKA

KETCHIKAN HARBOR

BAR POINT BASIN

SCALES AS SHOWN

NORTH PACIFIC DIVISION, PORTLAND, OREGON FEB. 15, 1952

SUBMITTED: CHIEF, 308 REPORT GROUP

RECOMMENDED: F.S. Brown, CHIEF, ENGINEERING DIVISION

APPROVED: COLONEL, CORPS OF ENGINEERS, DIVISION ENGINEER

TRANSMITTED WITH REPORT DATED FEB. 15, 1952

AH-1-1/20

PLATE 20

A wave spectrum provides additional information about the composition of wind waves. Bretschneider* has developed a procedure for computing wave spectra when given the significant wave height, period and duration of wind. The short fetches involved in the current application allow the steady-state case (fully arisen) to develop in less than an hour. Spectra for the 50-knot wind and fetches of 0.5 and 1.0 nautical miles appear as Figures 1 and 2, and these become the design wave spectra for the proposed Bar Harbor Floating Breakwater.

The tides at Ketchikan are diurnal and have the following extreme and mean values:

Highest Tide (est.)	19.5 feet
Mean Higher High Water	15.4
Mean High Water	13.9
Mean Tide	8.0
Mean Low Water	1.5
Mean Lower Low (datum)	0.0
Lowest Tide (est.)	-5.0

Anchor Forces

The Scope of Work items 5a, b, and parts of 5j and 5l refer to anchor forces from different but closely related perspectives. Before responding to these points, a discussion of anchor forces in general is in order, for recent data of field installations in the wind-wave environment show that anchor forces are quite low under certain anchoring conditions, and theoretical developments provide plausible explanations for the modest forces encountered.

The magnitude of anchor forces is as yet a parameter which has to be determined by measurement. In the usual laboratory-scale study, a relatively short section of a model breakwater is subjected to monotonic waves and the parameters of interest are then measured. Similarity criteria are assumed

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*"Wave Variability and Wave Spectra for Wind Generated Gravity Waves," Beach Erosion Board Technical Memorandum No. 118, August 1959.

satisfied by Froude's Law. Anchor forces scaled up from such tests are apt to be unrealistically large for (1) the elasticity and restraint conditions of the anchor system are not simulated, and are inordinately stiff in the model, (2) the model is usually short with respect to the crest lengths of the incident wave, and therefore receives the wave over its full length, and (3) the regular, monotonic waves can force the breakwater to translate to the end of its tether, taking up all slack in the anchor system, at which time high forces develop.

In the natural random wind wave environment, theprobability is very low that a series of waves would strike the full length of a floating breakwater to develop conditions (2) and (3) above to cause anchor forces comparable to the model results "under certain anchor conditions" mentioned earlier.

The arguments being presented here apply to the cases where the floating breakwater is anchored by lines of significant length (length to depth ratio of order 5:1), and not to cases where units are closely coupled to pilings by short, relatively stiff, inelastic rings or collars. Field data on anchor forces is available (reports in progress) on floating breakwaters at Tenakee Springs and Sitka, Alaska and Friday Harbor, Washington. Design constants for these sites are:

Site	Anchor System	Initial Tension lbs	Spring Constant lbs/ft per ft of breakwater
Tenakee	Chain	1200	0.7
Sitka	Chain	5000	1.5
Friday Habor	Nylon line-chain	--	1.0

It becomes apparent that the breakwater must move appreciably and stretch the anchor system before large forces will develop. At Tenakee, for example, where the chain is lying along the bottom, there is a great deal of damping introduced as chain is picked up and dropped back to the bottom with change in tide and wave loading on the breakwater, with little need for actual elongation of the chain to accommodate breakwater motion.

Sutko and Haden (1974) reported on experiments showing that sway (these authors used "surge" as the motion in the direction of the wave) was the dominant component; Adee and Martin (1974) arrived at similar conclusions for B/L ratios greater than 0.3 from theoretical considerations. Even if the breakwater is fixed, there is some energy transmitted beneath it. The actual displacements (in the sway direction) of a floating breakwater in a wind wave exposure appear to be small, with only modest anchor forces developing, due in part to the fact that the waves do not approach with long crests on the beam.

Anchor forces measured on the floating breakwaters at Tenakee Springs during the period September 1973 to August 1974, at Sitka from August 1974 to May 1975, and at Friday Harbor December 1974 to May 1975, are summarized on Table 1. The largest force measured was 7146 pounds for a 60-foot module at Tenakee, about 6% of the weight of the structure.

Similar experience, i.e., low anchor forces, are noted from other sources. An A-frame floating breakwater installed at Lund, British Columbia in 1964 is anchored with chain weighing 10 pounds per foot and has performed without incident to this date. It has been replaced recently under a routine maintenance plan with chain of the same type and weight. Harris (1974, p. 223) remarks that "the mooring forces...were, as expected, relatively low at less than 2% of the deadweight of the structure."

Thus, it appears that wave forces on a floating breakwater anchored "elastically" in a wind wave environment are damped through the random nature of the loading, short crests not on the beam, displacements of the structure, and the energy-absorbing characteristics of the anchor system itself. The peak wave energy at Tenakee, Sitka, Friday Harbor, and the proposed Ketchikan site occurs at a frequency of about 0.3 Hz, which is very much higher than the anchor system, so a coupling between the waves and breakwater motion that could lead to the large forces predicted by some model studies just does not develop. A plot of the natural sway periods for the Tenakee breakwater is given as Figure 3. It should be noted that the sway periods are very long compared to the periods of incident wind waves at the site. The longer the structure relative to the crest length of the incident waves, the lower the force reaching the anchor lines. With the general discussion of anchor forces as a background, the specific points in the Scope of Work can be discussed in sequence.

5a and b. Design anchor forces...for maximum waves...and with respect to duration.

Although the foregoing discussion concludes that anchor forces will not be large, the very conservative attitude toward dimensioning the anchor lines, as done in the installations mentioned, should continue until more field experience is acquired to reinforce the basis for a significant reduction in anchor line size. The chain as used at Tenakee was proof-tested to 115,000 pounds (Miller, 1974); certainly this is ultraconservative; the chain was selected on the basis of relative economics of a used chain. Quite possibly a smaller chain ordered specifically for the job would have been more expensive. For the Bar Harbor site, a reduction in proof strength to 75,000 pounds still could be considered a very conservative design level.

No loss of mass due to aging (5j, 5l) to affect the function of the anchor system is foreseen during the design life of the structure. The system has considerable reserve strength. The anchor system of the newly rebuilt City

Float (Ketchikan) reportedly was "in good shape" after many years of operation.

The responses of the breakwater (51) as anchored in the manner under discussion are affected very little by even large increases in the spring constants. The heave and sway hydrostatic restoring forces are very large; even large increases in the sway spring constants still would leave the natural frequency outside range of periods in the incident waves.

In summary, the anchor system is a very important component of the floating breakwater installation. However, the anchor chain of the type used at Tenakee and Sitka and the lengths necessary at the proposed site provide a linkage to the bottom-fix (pile, concrete block, etc.) that is compliant; as a result, large forces just do not develop from the wind wave loading on the floating breakwater.

5c. Wave overtopping.

The Alaska-type breakwater has a freeboard of about 16 inches (Miller 1974) so waves of 2-1/2 foot height likely will overtop the outer section, spill into the 15-foot cavity between sections, where the energy will be expended in dissipative motion and some regeneration (transmission). The wave that would overtop the entire breakwater is difficult to dimension, for the breakwater would tend to ride the surface of the extreme wave.

5d.

The design height and period are 3.15 feet and 3.45 seconds. For this case the transmission coefficient would be about 0.5 for the on-beam wave (Figure 4), yielding a transmitted wave height of 1.6 feet. However, the breakwater is located parallel to the direction of wave advance, and the effective transmission coefficient will be considerably less. The transmission coefficient depends upon the angle of wave attack as well as the usual variables, but this parameter has not been investigated very thoroughly. Anticipated reductions should place the transmission coefficients between the free and fixed positions. The effect of attack angle was treated by Stramandi (1974) who dealt with a field study of ship generated waves on a floating breakwater at Friday Harbor, Washington, and reported that the transmitted wave height was reduced by nearly an order of magnitude when the incident wave struck the breakwater at an angle of 15-30°. This facet is discussed further under 5f, but the relative orientation of the design incident wind waves and floating breakwater results in a transmitted wave height of less than one foot.

5e. Attenuation changes due to structural width changes.

The analytical model for breakwater response characteristics (Adee and Martin 1974) has been used to estimate the effect of varying the spacing between the sides of the breakwater on transmission coefficients. The calculated breakwater transmission coefficient for widths of 6, 11, 15 and 26 feet are shown in Figures 5, 6, 7 and 8. A plot of transmission coefficient for the actual 21-foot dimension is included in these figures for comparison. The relative insensitivity of C_T to width changes it not too surprising when one recalls that the surge motion plays the dominant role in wave transmission, and just altering the spacing between the two pontoons does not alter the masses involved so the period is rather conservative, down to the spacing where the mass of water "trapped" between the two pontoons would be effectively reduced, a limit that would have to be ascertained experimentally, but likely would become significant for spacings less than 6-8 feet, i.e., about equal to the combined width of the two pontoons.

There is an important function of the space between the two pontoons that is not picked up by the linear computer model, viz., that of an energy sink for waves passing over the seaward pontoon. Forces impinging upon the breakwater are not only lower, but also must be damped out in place and time by the very nonlinear action resulting from the wave passing over the outer pontoon. In view of the two lower limits, added mass and energy sink, a clear distance between the pontoons should not be reduced to less than about 10 feet without detailed examination, and cost justification.

5f. Long period waves

The floating breakwater is quite transparent to long period waves. Unlike the Sitka site, the Ketchikan site is completely shielded from ocean swell, but is parallel to a major shipping route for vessels ranging in size from the fishing boat, tug, barge, cargo vessel, through the Alaskan ferry and cruise ship, and wakes from these sources will impinge upon the proposed breakwater.

The basic pattern of waves from moving sources (ships) has been defined on theoretical grounds by Kelvin, Havelock, et al., as reviewed by Sorensen (1967). The ship generates a set of waves (Figure 10) at the bow and one at

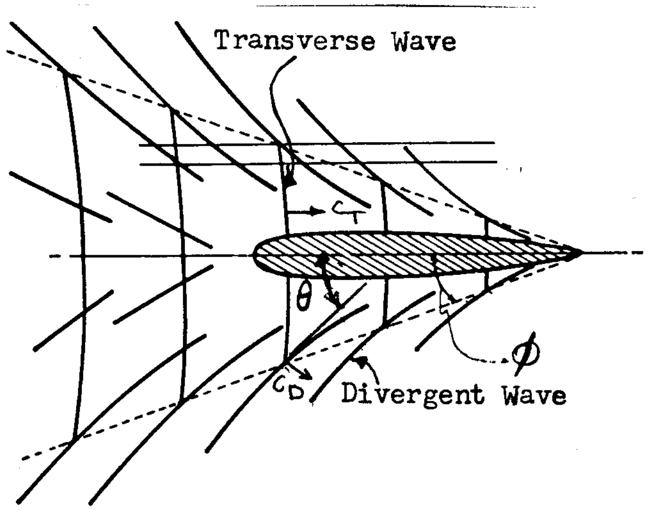

FIG. 10 TYPICAL PATTERN OF WAVE CRESTS GENERATED BY A SHIP MOVING IN DEEP WATER

the stern, which is usually lower than the bow set. Each set includes a series of transverse waves traveling in the direction of the ship, and a series of diverging waves that travel obliquely to the sailing line. The wave lengths are expressed as

$$L_T = 2\ \pi/g\ V_s^{\ 2}$$

$$L_D = 2\ \pi/g\ V_s^{\ 2}\ \cos^2\theta$$

for the transverse and diverging waves, respectively. V_s is the ship speed, ϕ is the angle between the sailing line and locus of cusps, and is 19°-28' in deep water. θ is the angle a line normal to crest of the divergent wave makes with the sailing line.

Sorensen measured wave heights as a function of time and distance from the sailing line for waves created by vessels of different sizes. His results for four vessels are reproduced here as Figure 16. The half-period T/2 is the time from a crest to the next trough as measured on the height-time chart. Sorensen comments that "The large tankers and cargo ships that use the estuary operate at low speeds (typically 5 or 6 knots) and do not generate very high waves. The waves observed from these ships were consistently less than 1 ft. high. Most of the measurements were therefore taken on the wakes of the smaller ships that operate at higher speeds and generate higher waves." Thus Sorensen's work fortunately provides some information on characteristics of vessel wakes, i.e., height vs. speed, wave lengths, and general pattern, which is useful to potential wake problems at Ketchikan.

The response of a floating breakwater to wake from a vessel was investigated by Stramandi (1974). A Coast Guard cutter in the 82-foot class was directed past the breakwater at selected speeds (up to 14 knots) and directions so that the vessel wake would arrive at the breakwater essentially parallel to the structure in one set, and at an angle of about 25 degrees in another set of runs. Instruments to record the incident, the transmitted waves, and accelerations (in heave, roll and sway) were set up to record the breakwater responses. There was a very marked reduction in wave transmission when the incident waves arrived at the structure on an angled position rather than on-beam. The transmission coefficients C_T computed from the experimental data are shown on Figure 12 as they depend upon the ratio of structure width B to wave length L.

The work of Sorensen on ship wake and Stramandi on breakwater response can be combined to assess the problem of ship wake in the case of the Bar Point Harbor site. The distance from the proposed breakwater to the channel centerline is about 600 feet, so the data obtained by Sorensen are in a comparable range. If the vessels stay below about 8 knots, then wave heights exceeding one foot would be exceptional; the waves will strike the breakwater at an appreciable angle, so the transmission coefficient of 0.3 or less would be appropriate. Therefore, the wave transmitted would be less than the specified upper limit of one foot. If the vessels run by the breakwater at excessive speeds and too close, then their wake would be very apparent behind the breakwater. Under reasonable operating conditions, the vessel wake likely will be noticeable within the marina, but should not cause any problems.

5g. Expected life spans

The breakwaters at Tenakee Springs and Sitka provide the only information on the longevity of a complete breakwater of the type proposed for Bar Harbor, although the materials in the components have been in use in the marine environment for a long time. No particular problems have appeared during 2-1/2 years of operation at Tenakee. Some spalling has taken place, but this seems to have been caused from mishandling before final installation. In a few places, reinforcing steel appears on or near the surface, likely the result of casting errors. The connections between modules is one of the more difficult components to design. Some of the rubber bumpers used in earlier designs took a permanent set. This design has been modified, and more field experience needed to see if further refinements can be achieved.

The concrete used in the breakwater has been used extensively in marina floats and no time-dependent deterioration patterns have been reported. Long-term performance records or case histories on structures similar to the proposed one do not exist, so the forecast for "life expectancy" does not have a firm basis. However, the individual record of the components and short-term record of the Tenakee breakwater suggest that a 20-year life span would be in order.

5h. Project Dimensions

The recommended breakwater layout is identified on Figure 13 as "Revised Proposal". Some of the reasons for the new arrangement are more readily shown on the large-scale (1 inch to 50 feet) condition surveys. These maps should be consulted for planning purposes. The topography on the northerly end of the marina appears to lend itself to a fixed breakwater extending out to about the -20 feet contour, the minimum navigation depth. The fixed structure here would eliminate the floating breakwater-to-land connection that is difficult to accomplish where the tidal range (24 feet) is so extreme as at the Bar Harbor site. The length of the fixed breakwater would be about 200 feet; a section much longer than this would encounter excessive water depths. The main floating breakwater was moved shoreward from the "Corps Proposal" alignment in order to form an entrance (150 feet wide) facing the narrow, low-energy, cross-channel direction. The 120-foot detached floating breakwater at the southern end has been retained as an essential protection for that entrance.

With the configuration shown, waves in excess of one foot are not expected inside the proposed marina area. The anchor line arrangement on the long breakwater, in particular, should be planned to resist longitudinal displacement due to tidal currents and wind stress.

5j,k,l. Limitations or design changes

The proposed breakwater section is considered to be appropriate for the site. The exposure is less severe than those at Sitka and Tenakee Springs. The breakwater width could be changed, but the performance characteristics are not very sensitive to modest width changes, as already discussed, if the displaced water volume remains the same. There is little to gain from the performance standpoint by altering the breakwater width. If significant economies would result from reducing the width by 5 feet or so, there would be no sigificant reduction in performance capabilities. A contribution to field experience could be made by specifying that the detached 120-foot unit at the southerly entrance be designed with a narrow width, and its performance compared to the Tenakee-type structure. The points in 5j and 5l relating to the anchor system have been discussed under the broader "Anchor Forces" section.

5m. Summary

The Alaska-type breakwater is an appropriate one for the proposed Bar Point Harbor extension. The site quite well suited to a floating breakwater installation for it is parallel to a deep narrow channel so the major waves will move along the face of the breakwater; some shielding is provided by the fixed breakwater on the southeast, and a landform on the northwesterly fringe.

General Comments

In the summary above, the statement was made that the Alaska-type breakwater was "an appropriate" choice for the Bar Point Harbor extension, as proposed in the Scope of Work. Now that several floating breakwaters are in operation, experiences already in hand have contributed toward the resolution of some of the anticipated problems, and have led to several design modifications. This same progressive sequence should continue until the designs become as straightforward as for any other structure in the marine setting. In other words, at some other site in the near future, a breakwater of different section might be more suitable than the Alaska-type.

The breakwater "design" should consider the total system, from layout, fabrication, transportation and final installation. Conflicts can easily arise between the final functional performance of a breakwater and the various steps to be taken to get the structure on site. In Alaska, high transportation costs and limited erection equipment may tend to dominate a given design; this dominance must be questioned continuously. For instance, the modular length of 60 feet is fixed by the available maximum length of post tensioning rods. Can tendons be used instead? Connections between modules are expensive and not yet optimized. Experience is showing that longer units tend to dampen peak forces and motions, so any fabrication constraint on module size needs to be scrutinized.

Theoretical work is showing that the water volume (mass) displaced by a given breakwater section is the dominant factor in the performance, rather than the shape of the cross section. When this analysis is applied to the Alaska-type breakwater, the two sections of the catamaran merge into a single, rectangular hull. The design for a rectangular section for a given site, of course, would have to be assessed by going through the fabrication, transportation and installation economics.

The conclusion that the displaced water volume is far more important than breakwater shape has another ramification in the materials used for constructing the breakwater, viz., no premium should be placed on using lightweight concrete. Mixing and placing standards are easier to maintain with regular concrete, and it has a long history of successful performance in salt water.

Very careful quality control must be maintained in the fabrication of the concrete units, and in subsequent handling. Periodic inspections should be carried out, not only for maintenance purposes but also to acquire information for design modifications.

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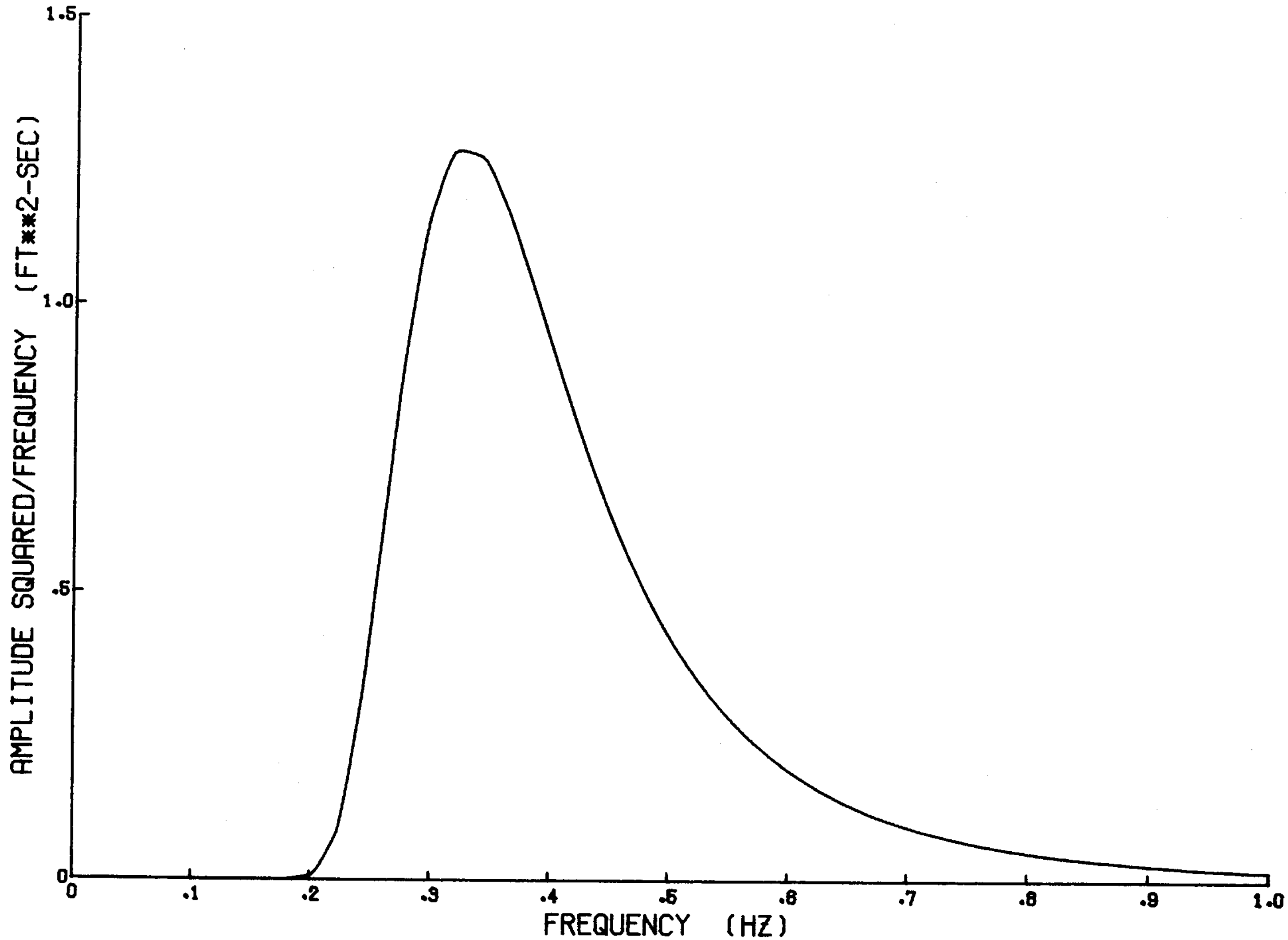


FIGURE 1. PREDICTED WAVE SPECTRUM
(FETCH = 0.5 STATUTE MILES, WIND SPEED = 50 M.P.H.)

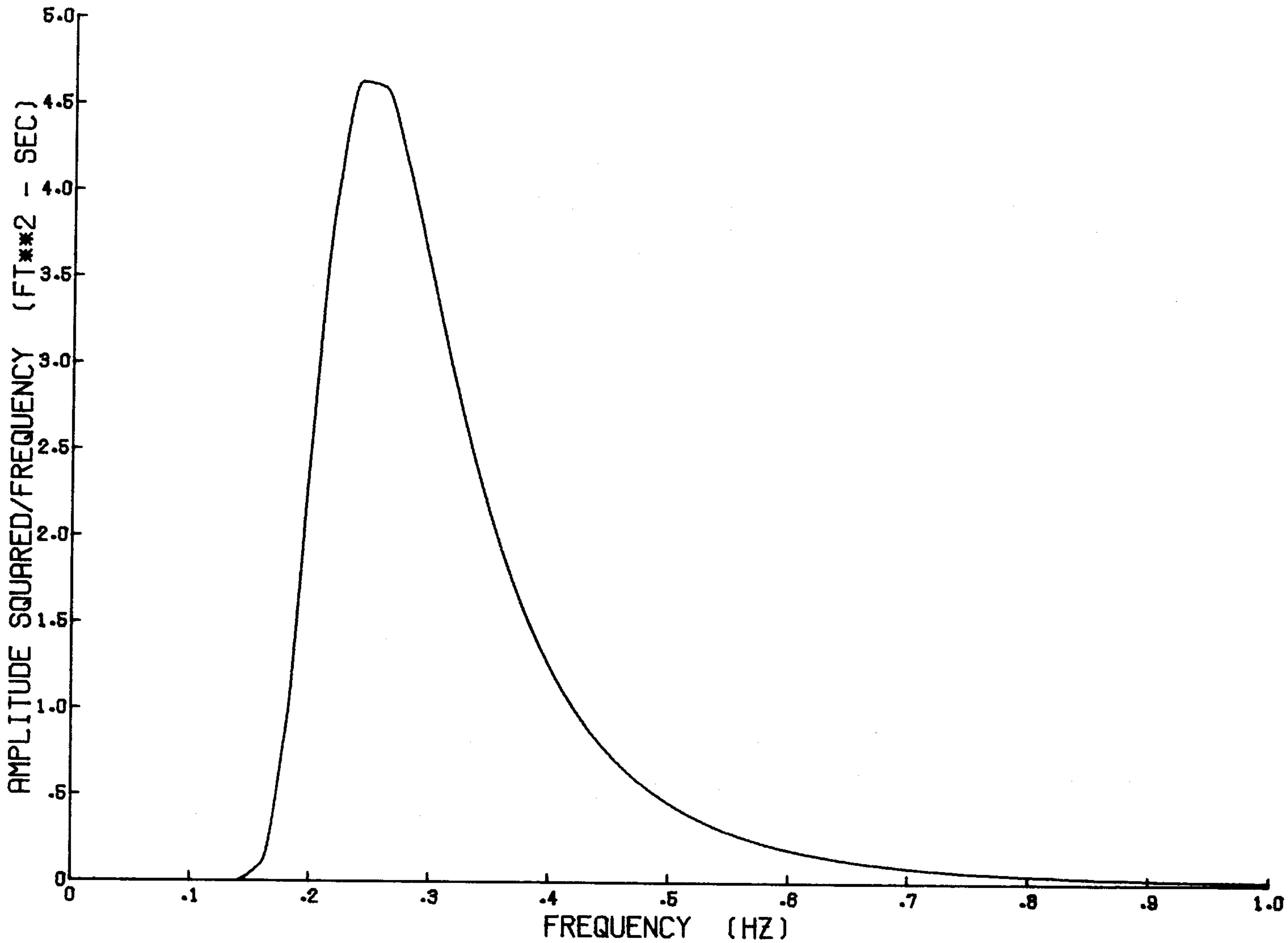


FIGURE 2. PREDICTED WAVE SPECTRUM
(FETCH = 1.0 NAUT. MILES, WIND SPEED = 50 KTS.)

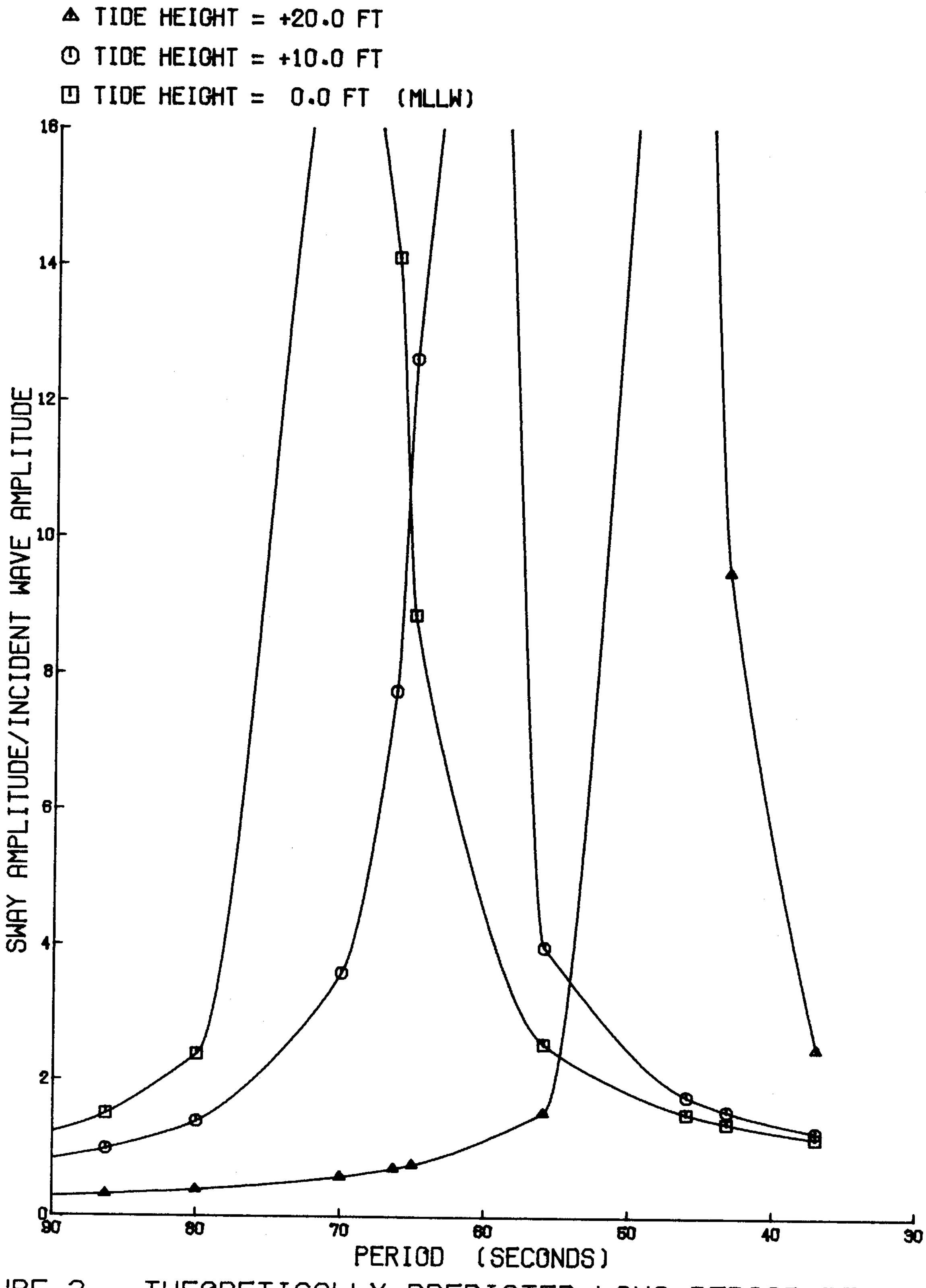


FIGURE 3. THEORETICALLY PREDICTED LONG PERIOD RESPONSE OF ALASKA-TYPE BREAKWATER TENAKEE, ALASKA

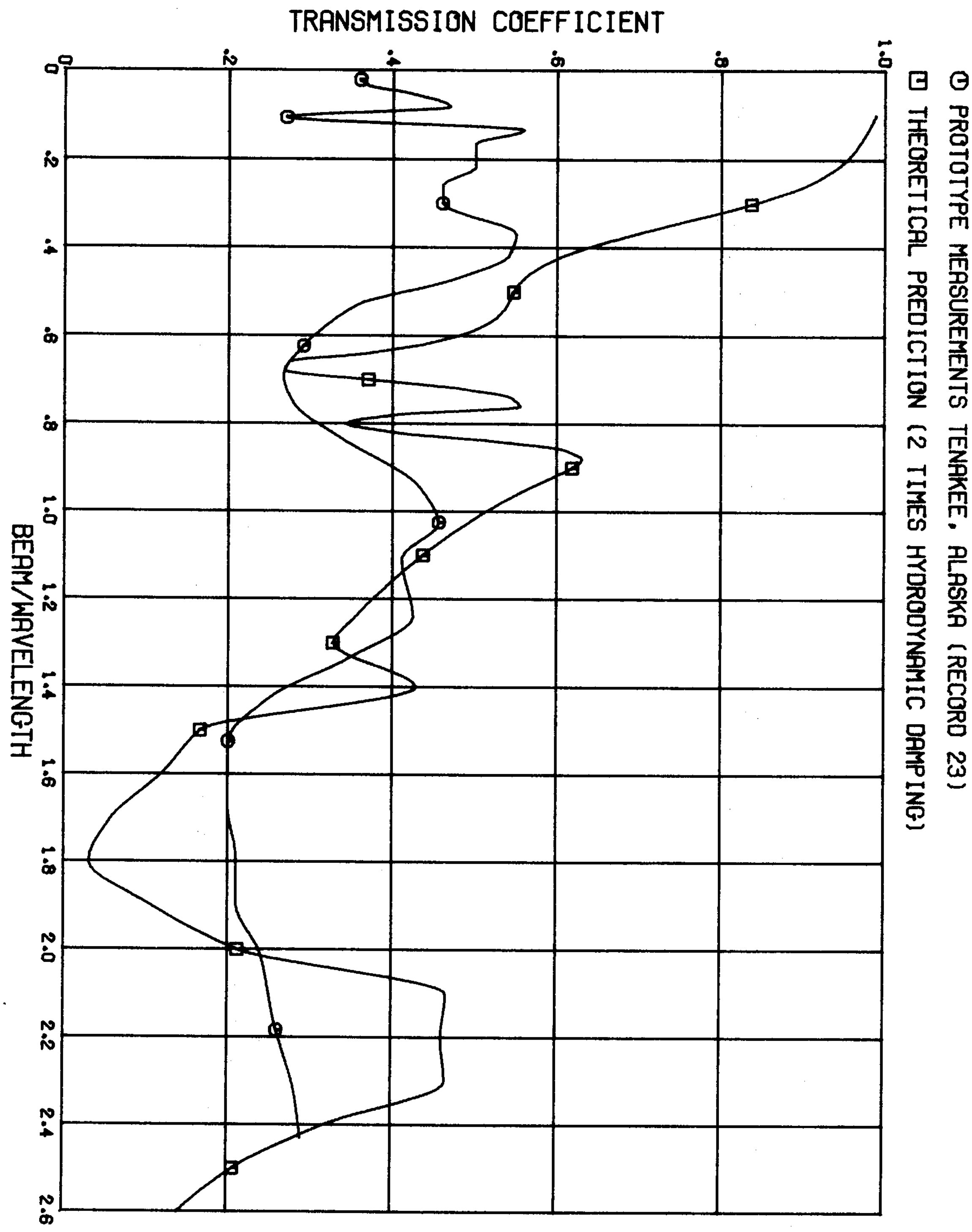


FIGURE 4. THEORETICALLY PREDICTED AND MEASURED TRANSMISSION COEFFICIENT TENAKEE, ALASKA

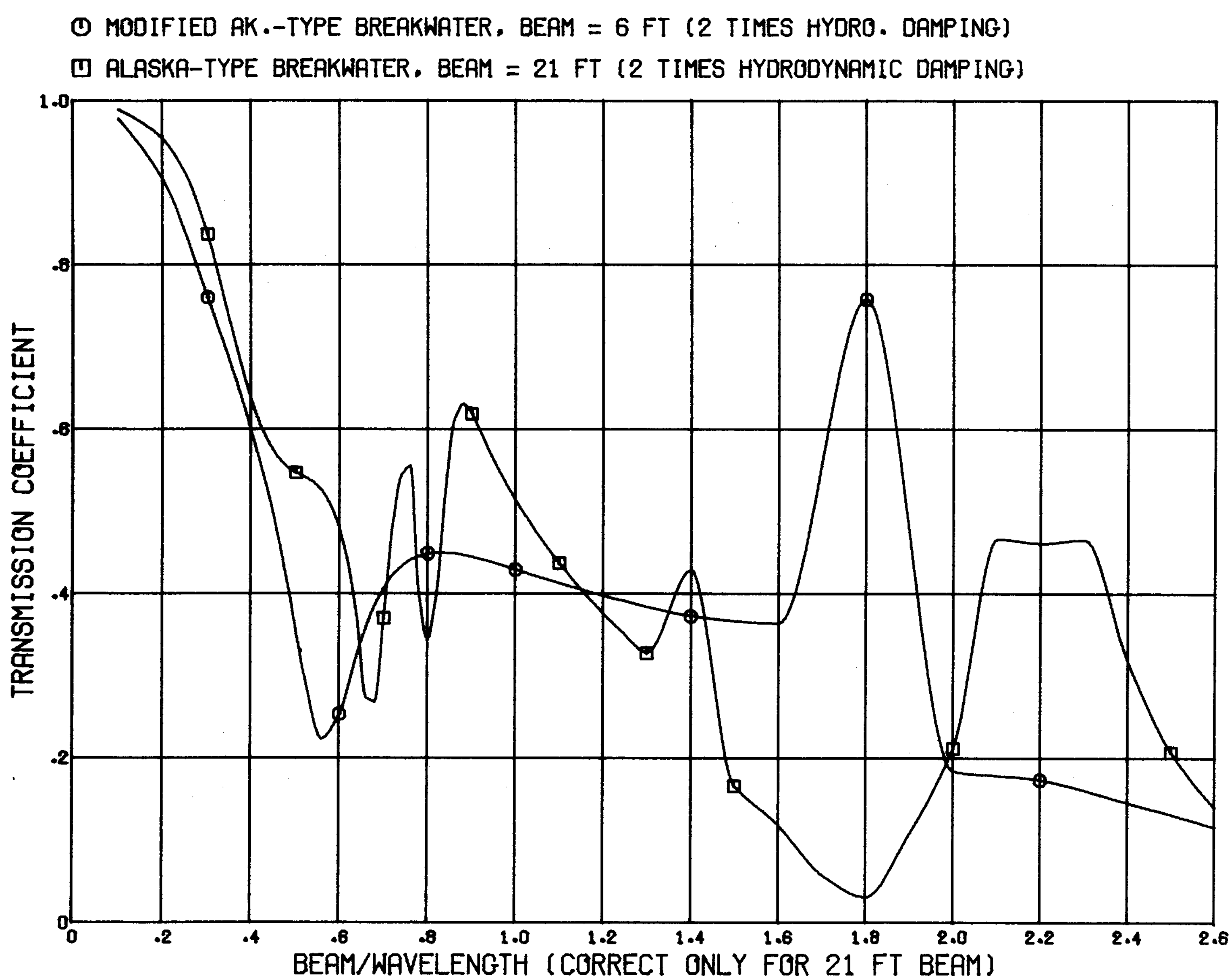


FIGURE 5. COMPARISON OF THEORETICALLY PREDICTED TRANSMISSION BETWEEN ACTUAL ALASKA-TYPE BREAKWATER AND MODIFIED FORM (BEAM = 6 FT)

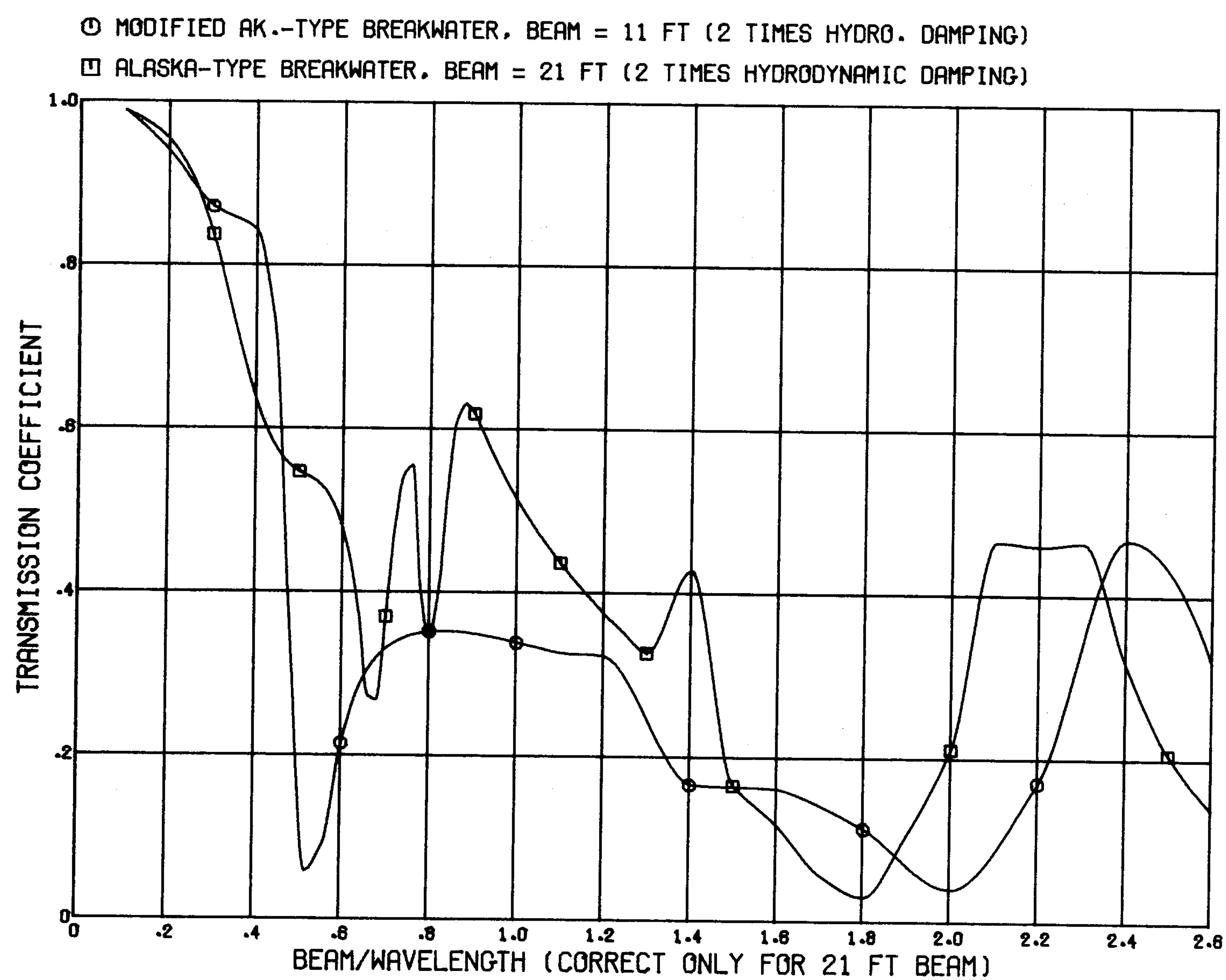


FIGURE 6. COMPARISON OF THEORETICALLY PREDICTED TRANSMISSION BETWEEN ACTUAL ALASKA-TYPE BREAKWATER AND MODIFIED FORM (BEAM = 11 FT)

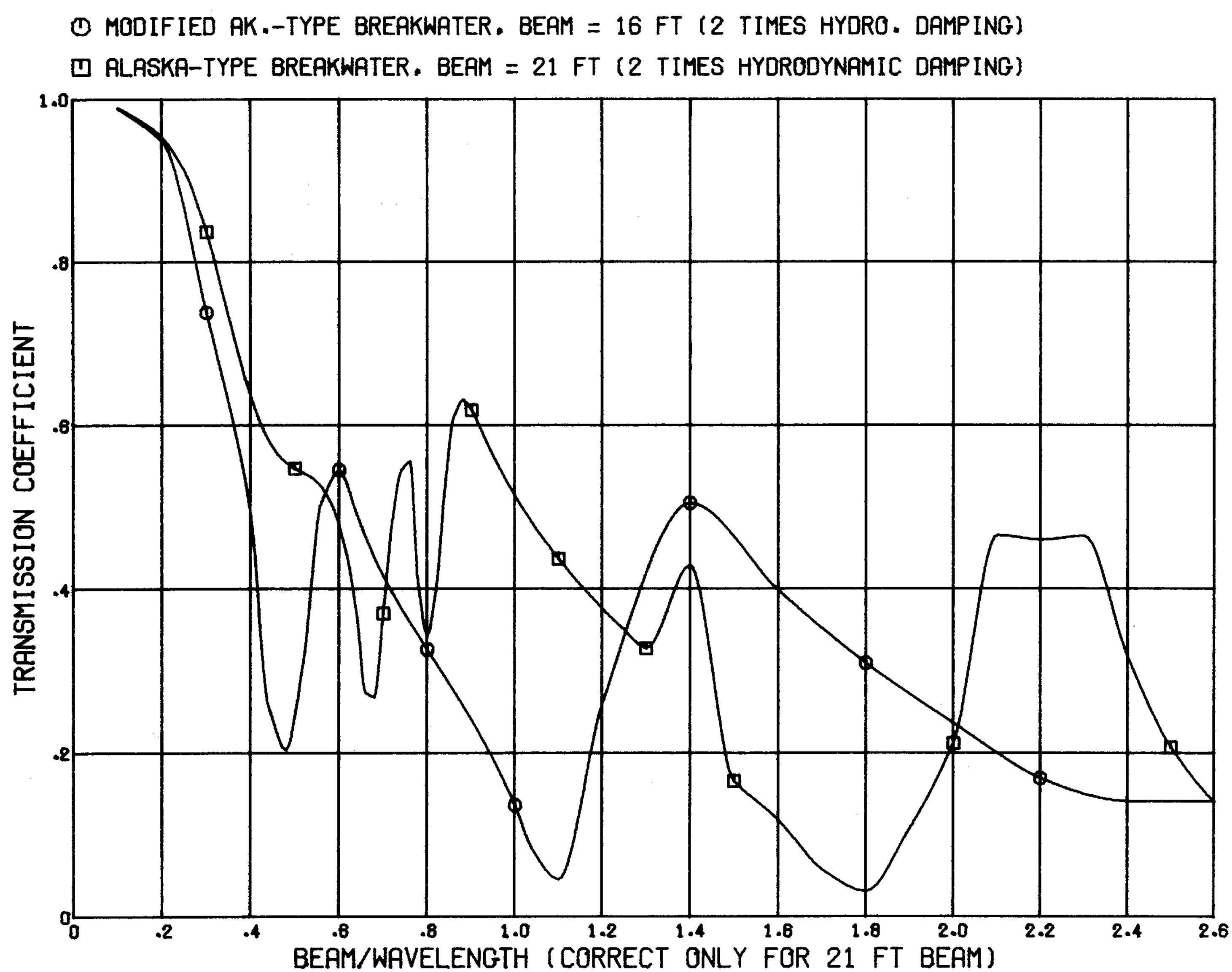


FIGURE 7. COMPARISON OF THEORETICALLY PREDICTED TRANSMISSION BETWEEN ACTUAL ALASKA-TYPE BREAKWATER AND MODIFIED FORM (BEAM = 16 FT)

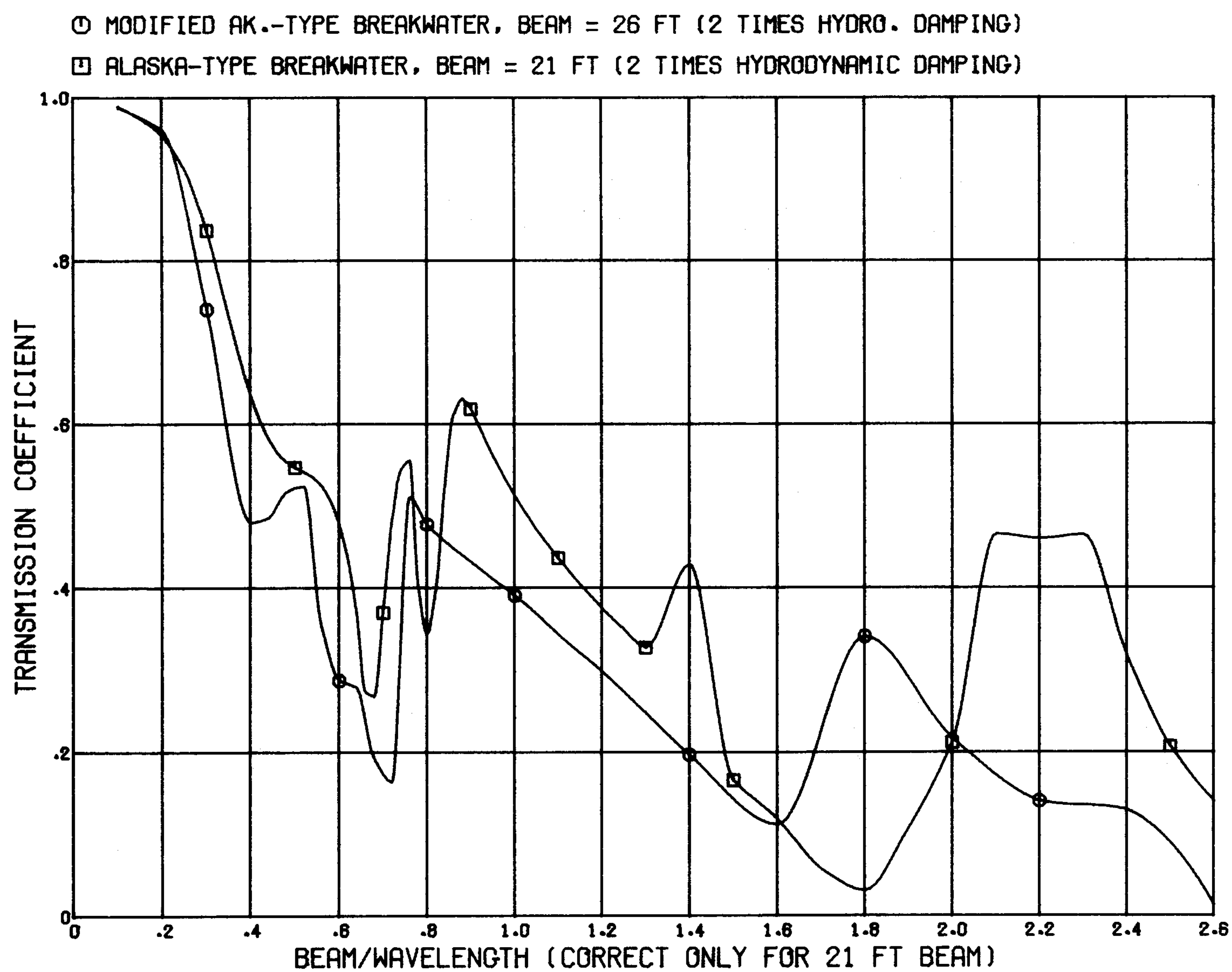
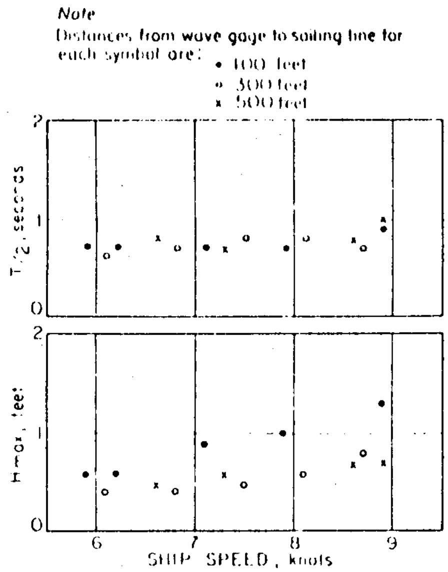
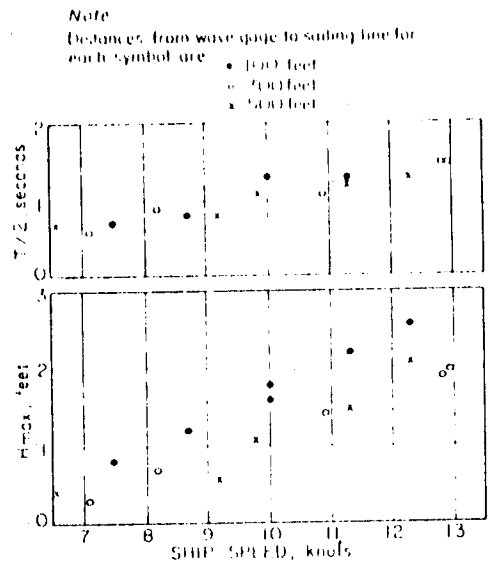


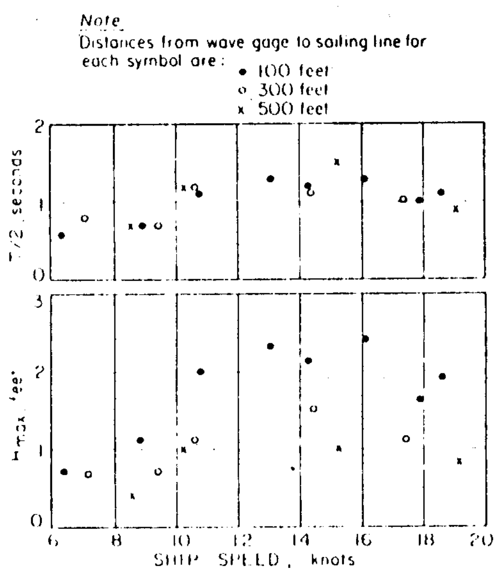
FIGURE 8. COMPARISON OF THEORETICALLY PREDICTED TRANSMISSION BETWEEN ACTUAL ALASKA-TYPE BREAKWATER AND MODIFIED FORM (BEAM = 26 FT)



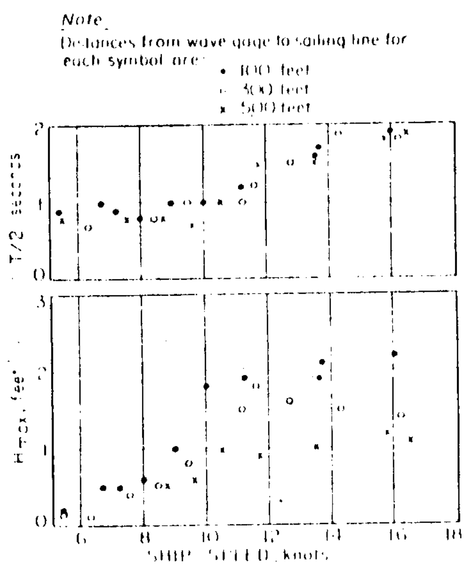
—WAVE HALF-PERIOD AND MAXIMUM HEIGHT AS A FUNCTION OF SHIP SPEED FOR THE U. S. ARMY CORPS OF ENGINEERS TUG "MERRYFIELD"



—WAVE HALF-PERIOD AND MAXIMUM HEIGHT AS A FUNCTION OF SHIP SPEED FOR CITY OF OAKLAND FIRE BOAT

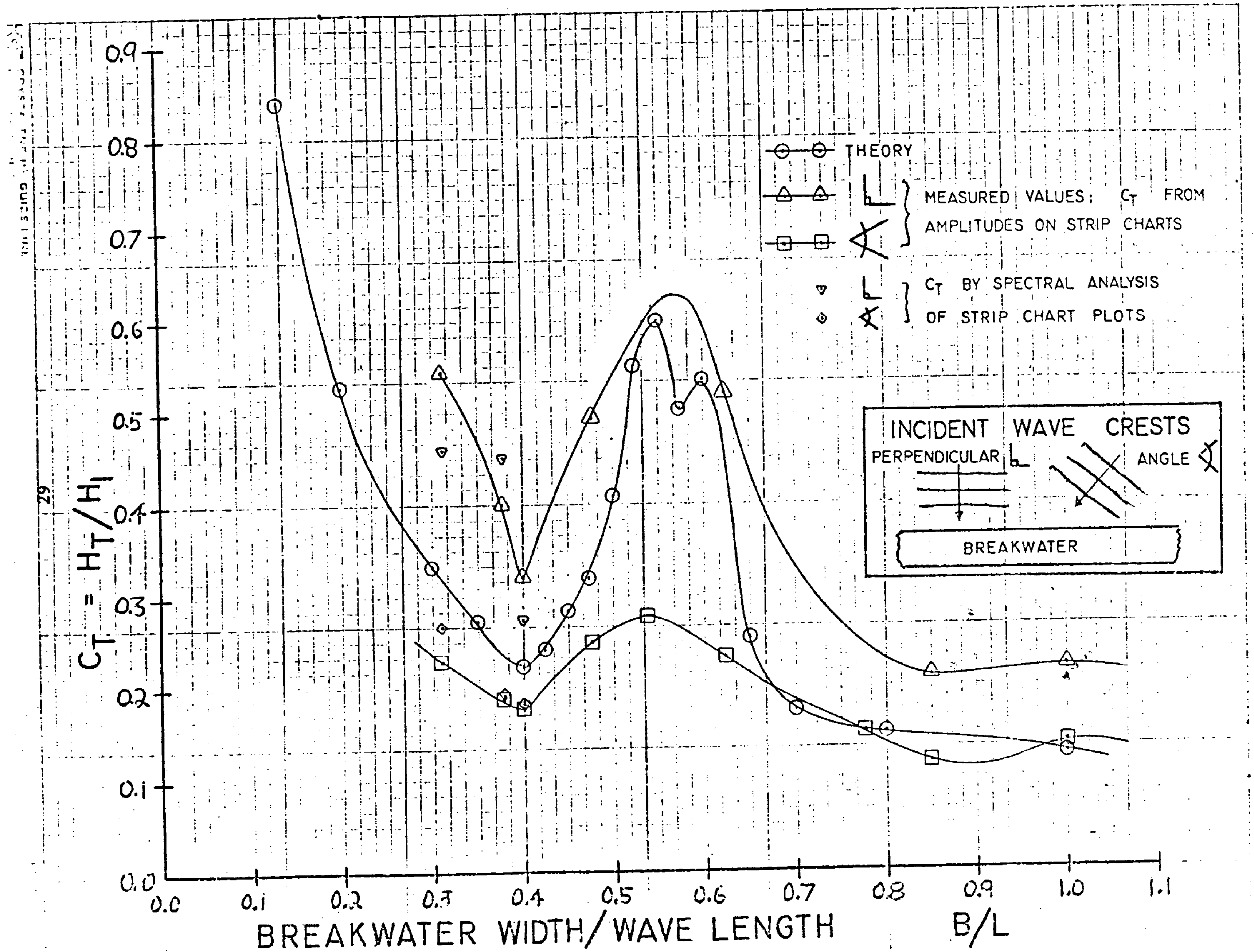


—WAVE HALF-PERIOD AND MAXIMUM HEIGHT AS A FUNCTION OF SHIP SPEED FOR A 40-FT U. S. COAST GUARD CUTTER



—WAVE HALF-PERIOD AND MAXIMUM HEIGHT AS A FUNCTION OF SHIP SPEED FOR THE FISHING BOAT "MISS DRAGNET"

Figure 11. Ship Generated Waves



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$C_T = H_T/H_I$
THEORY
MEASURED VALUES; C_T FROM AMPLITUDES ON STRIP CHARTS
C_T BY SPECTRAL ANALYSIS OF STRIP CHART PLOTS
INCIDENT WAVE CRESTS
PERPENDICULAR
ANGLE
BREAKWATER
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
BREAKWATER WIDTH/WAVE LENGTH
B/L

FIGURE 12

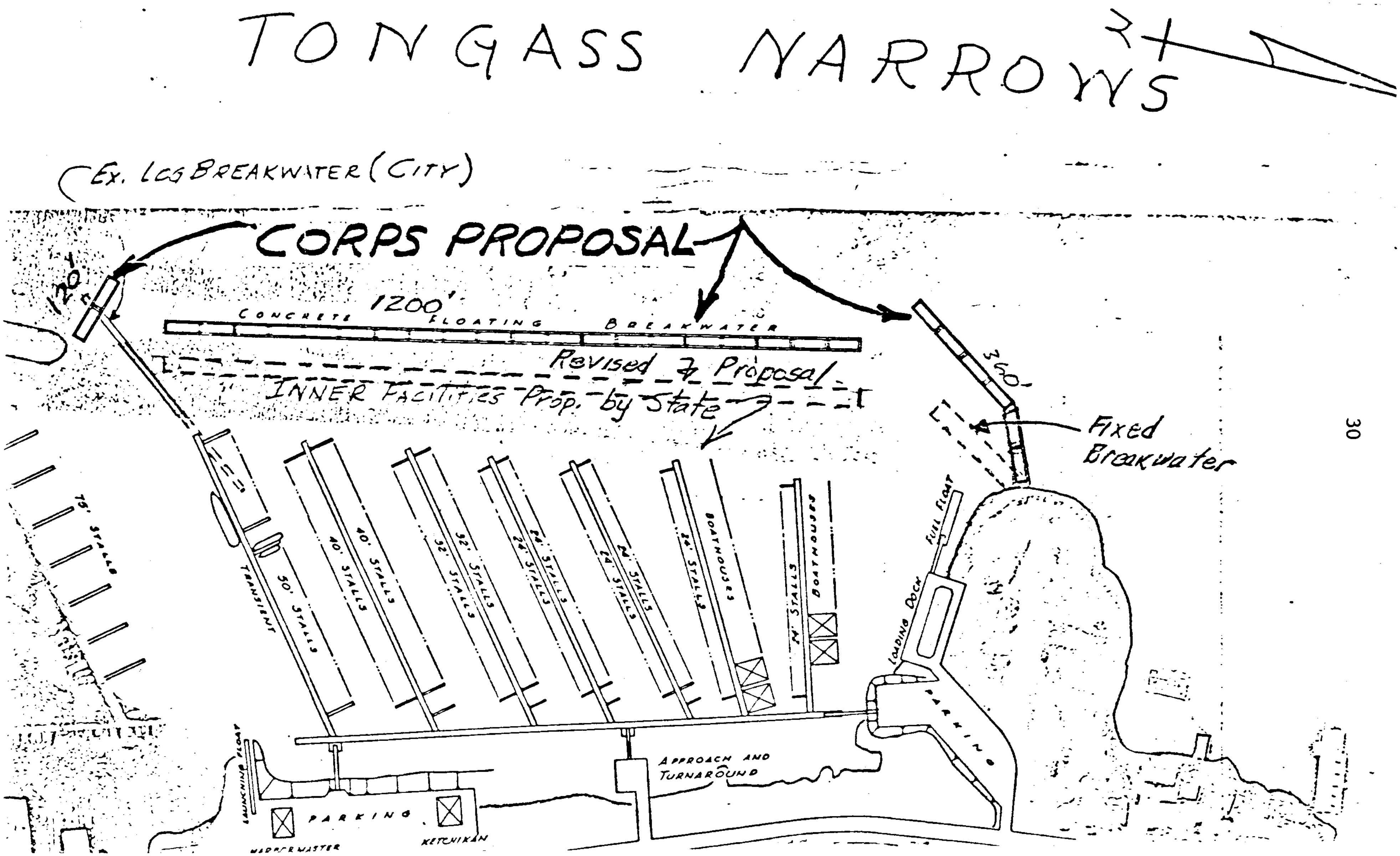


Figure 13. Revised Proposal

Table 1

Anchor Force Data
Force > 500 lbs or U > 15 mph

SK	Sitka
TK	Tenakee
FH	Friday Harbor

Tape	Rec No	L_1 lbs	L_2 lbs	U mph	Az deg	η_1 ft	η_2 ft	η_3 ft	η_T ft
SK 7	7	53	144	16.2	118	0.48	0.77	-	0.76
1/21/75	8	91	389	18.0	185	1.60	1.32	-	1.15
to	9	113	564	13.9	166	1.60	1.53	-	1.30
3/7/75	10	130	609	12.2	139	1.53	1.74	-	1.15
	11	92	193	20.3	241	2.16	2.17	-	0.89
	13	185	750	15.9	244	2.37	2.30	-	1.55
	14	38	126	15.7	162	1.67	1.74	-	0.78
SK 6	1	55	136	16.2	229	1.75	1.25	-	0.78
1/3/75	3	94	361	15.8	231	1.68	1.54	-	0.80
to	5	128	247	15.5	266	2.03	1.75	-	0.87
1/21/75	7	72	133	20.7	258	1.87	2.16	-	1.01
	8	55	97	15.5	302	1.67	1.32	-	0.64
	9	108	159	16.0	315	1.87	1.61	-	0.75
	10	98	136	15.3	320	1.60	1.60	-	0.64
	16	69	294	20.7	93	0.98	1.25	-	1.02
	17	96	526	21.7	99	0.83	1.26	-	0.89
	18	144	1784	21.7	110	0.98	1.11	-	0.84
	19	166	1799	21.6	108	0.90	1.32	-	1.00
	20	105	526	18.3	115	1.25	1.46	-	1.29
	21	101	252	18.0	124	1.74	2.03	-	1.54
	22	96	193	20.6	116	1.81	2.02	-	2.04
	23	55	108	19.1	163	1.46	1.46	-	1.10
	24	60	103	17.1	166	1.45	0.94	-	1.15
	25	38	94	16.1	121	0.97	1.04	-	0.86
	28	126	1029	18.6	166	1.67	1.54	-	1.34
	29	174	1422	14.7	173	1.74	1.67	-	1.32

Tape	Rec No	L_1 lbs	L_2 lbs	U mph	Az deg	η_1 ft	η_2 ft	η_3 ft	η_r ft
SK6	30	367	2672	17.3	175.0	1.88	1.88	-	1.65
	31	345	1790	19.8	175.5	2.72	2.92	-	2.26
cont.	32	182	623	16.6	191.8	3.00	2.86	-	2.40
SK5	5	339	902	15.6	103	7.11	7.11	-	6.70
11/25/74	6	91	288	16.0	146	3.07	3.01	-	2.59
to	7	116	238	19.3	182	2.51	2.37	-	2.87
1/3/75	8	127	297	18.9	163	2.51	2.44	-	2.19
	12	155	926	14.3	174	4.32	4.39	-	3.76
	13	177	846	14.6	155	4.46	4.67	-	4.30
SK4	2	47	89	15.8	155	0.96	1.04	0.77	0.91
11/13/74	3	50	171	18.2	173	1.53	1.46	1.18	1.03
to	4	49	149	18.1	164	1.60	1.60	1.39	1.11
11/25/74	5	63	291	18.1	168	1.74	2.02	1.60	1.46
	6	91	514	18.5	171	1.95	1.94	1.67	1.53
	7	162	1275	14.0	179	1.61	1.60	1.47	1.45
	8	235	1900	15.9	202	1.53	1.81	1.39	1.19
	10	127	261	16.2	275	2.64	2.16	2.78	1.20
	11	549	5486	11.0	291	1.95	2.16	2.23	1.27
	12	229	1167	3.1	180	2.02	1.81	2.16	1.37
	14	94	168	15.9	256	1.89	1.82	3.26	1.18
	16	94	97	18.7	302	1.88	2.02	2.72	0.93
	17	83	147	17.0	278	2.09	2.02	4.74	1.19
	18	149	333	15.7	247	2.23	1.95	2.93	1.26
	19	180	585	17.4	280	2.31	2.16	2.58	1.12
	20	182	767	12.4	275	1.88	1.82	2.10	0.98
	21	146	247	18.0	248	2.44	2.51	2.02	1.18
SK2									
8/20/74	9	1510	3166	6.5	286	4.56	4.56	16.25	5.07
8/28/74									

Tape	Rec No	L_o lbs	L_i lbs	U mph	Az deg	η_i ft	η_r ft	η_T ft
TK 9 2/21/74 to 4/5/74	1-31	Data below selection criteria of: Force - (Max + Mi) > 500 lbs. Wind speed > 15 mph						
TK 8 2/13/74 to 2/21/74	1-14	Data below selection criteria						
TK 7 12/17/73 to 2/13/74	1-28	Data below selection criteria						
TK 5 11/16/73 to 12/11/73	1-4	Data below selection criteria						
TK 4 10/5/73 to 11/16/73	1	7146	4308	7.8	207	1.47	1.63	1.21
	2-18	Data below selection criteria						
TK 3 9/6/73 to 10/5/73	1-6	Data below selection criteria						

Friday Harbor

	Rec No	U mph	Az deg	NW lbs	SW lbs	NE lbs	SE lbs	η_1 ft	η_2 ft	η_i ft	η_T ft	Tape
FH 13	1	20.8	171	208	474	70	200	0.60	0.57	0.94	1.18	FH 13
4/8/75	2	20.6	136	134	444	62	182	0.56	0.52	0.67	0.97	4/8/75
to	3	20.7	137	170	458	76	212	0.68	0.61	1.02	1.39	to
5/3/75	4	22.4	122	166	478	92	296	0.86	0.78	1.28	1.66	5/3/75
	5	19.9	81	158	310	78	176	0.68	0.66	0.94	1.35	Force >
	6	19.6	151	124	240	72	140	0.50	0.45	1.00	1.43	500 lbs
	7	22.8	124	210	578	98	316	0.58	0.61	1.07	1.06	U > 15mph
	8	24.9	126	198	684	86	338	0.49	0.53	1.02	1.30	
FH 12	3	18.1	105	106	208	74	128	0.38	0.40	0.90	1.10	FH 10
3/20/75	4	21.3	104	142	296	94	170	0.39	0.46	1.18	1.35	3/20/75
to	5	20.6	35	126	248	68	146	0.34	0.35	1.03	113	to
4/8/75	6	18.8	16	100	179	50	100	0.25	0.27	0.95	1.15	4/8/75
	7	18.4	18	128	236	82	158	0.22	0.24	0.77	0.97	
	8	22.1	17	156	326	94	204	0.29	0.28	0.97	1.15	force >
	9	19.2	88	122	226	72	154	0.28	0.30	0.92	1.05	500 lbs U > 15 mph
	10	24.5	19	224	472	115	261	0.46	0.47	1.13	1.34	
	11	27.6	54	196	504	104	277	0.62	0.72	1.23	1.33	
	12	25.2	15	150	440	78	276	0.65	0.60	1.18	1.36	
	13	20.7	9	120	308	50	166	0.59	0.60	0.87	1.15	
	14	20.1	9	124	294	44	140	0.48	0.50	0.81	0.92	
	15	20.1	319	216	268	207	109	0.48	0.44	0.63	0.64	
	16	20.8	290	346	356	166	124	1.10	0.90	0.43	0.44	
	17	15.7	143	109	258	66	136	0.27	0.28	0.74	0.86	
	18	15.7	143	111	278	56	132	0.19	0.20	0.51	0.73	
FH 11	5	20.3	52	150	404	59	202	0.58	0.55	0.79	1.25	FH 11
3/1/75	6	21.1	39	122	386	56	186	0.64	0.57	0.84	1.02	3/1/75
to	9	22.8	51	176	526	86	304	0.36	0.37	1.23	1.18	
3/20/75												to
												3/20/75
												Force > 500
												U > 20 mph

	Rec No	U mph	AZ deg	NW lbs	SW lbs	NE lbs	SE lbs	ft	ft	ft	ft	Tape
FH 11	10	23.4	46	162	430	84	263	0.61	0.62	1.17	1.23	FH11 cont'd
	11	238	91	168	424	96	262	1.16	1.13	1.15	1.38	
	12	25.0	92	228	491	136	309	1.08	1.17	1.36	1.68	Force > 500 lbs
	13	21.9	80	214	430	148	282	1.06	1.08	1.38	1.71	
	14	21.6	57	232	522	118	274	0.89	0.77	1.48	1.71	U > 20 mph
FH 10 2/9/75 to 2/28/75	Data below selection criteria of: Force (Max + Min) > 500 lbs Wind speed > 20 mph											FH 10 2/9/75 to 2/28/75
FH 9	11	21.7	17	120	340	52	448	0.69	0.61	1.38	1.79	FH 9
1/22/75	12	22.3	14	123	436	52	544	0.59	0.57	1.51	1.61	1/22/75
to	13	20.2	13	96	336	44	440	0.31	0.37	1.20	1.49	to
2/9/75	14	21.2	19	108	456	52	588	0.38	0.43	1.51	1.44	2/9/75
	15	20.1	7	124	352	52	448	0.48	0.47	1.20	1.15	Force >
	23	20.3	81	148	384	91	584	0.41	0.37	1.30	1.77	500 lbs
	25	20.0	160	108	268	64	334	0.47	0.54	1.33	1.54	U > 20 mph
FH 8	3	20.2	165	108	524	60	676	0.49	0.53	1.15	1.49	FH 8
1/8/75	4	20.1	177	120	860	72	1208	0.40	0.30	1.05	1.46	1/8/75
to												to
1/22/75												1/22/75
FH 7	4	21.0	184		504	80	208	0.64	0.83	1.30	5.01	FH 7
12/30/74	7	23.9	151		472	88	352	0.58		1.70	4.30	12/30/74
to	8	22.8	163		508	80	316	0.58		1.92	4.56	to
1/8/75	9	21.7	162		608	84	268	0.58	1.09	1.51	6.42	1/8/75
	10	21.2	172	88	632	120	256		1.15	1.58	5.91	
	11	20.3	171	143	452	116	232		0.83	1.28	4.56	
	16	20.5	155		568	92	208		1.03	1.10		