CHAPTER 159

FLOATING BREAKWATER PERFORMANCE

by

Bruce H. Adee*

INTRODUCTION

The Pacific Northwestern United States contains large areas of protected waters with abundant recreational boating opportunities. The area also supports many commercial fishermen who use small boats in their fishing operations. As a result, there is a large demand for sheltered moorage for all these vessels. Traditionally, this demand has been accommodated by constructing rubble-mound breakwaters for marina protection. At present, most of the sites where rubble-mound breakwater construction is economically feasible have been used. Conditions at many of the remaining areas for marina development are unsuitable for traditional techniques of marina construction. In general, the cost is too great because the water is too deep, or the environmental degradation resulting from marina development is unacceptable. To satisfy the demand for moorage, while at the same time overcoming the other restrictions, floating breakwaters have been employed at many new marina facilities.

In order to optimize the configuration of floating breakwaters and to overcome the problems which have been encountered with their use, the University of Washington has undertaken a continuing program of research. The aim of this research has been to monitor the performance of existing breakwaters and to develop a theoretical model to predict performance. Using the theoretical model supplemented with appropriate model-scale tests, a series of parametric variations will be tested to determine the effects of these variations on breakwater performance.

At present, several comparisons of the theory with model tests and full-scale performance have been reported by Adee (1975a, 1975b, 1976). This report is a continuation of this effort incorporating data obtained at the Friday Harbor, Washington floating breakwater.

FLOATING BREAKWATER OPERATION

A floating breakwater is illustrated in Figure 1. An incident wave approaches the breakwater. Part of the energy contained in the incident wave is reflected, part passes beneath the breakwater, and some is lost through dissipation. Another part of the incident wave energy excites the motions of the breakwater. These motions are restrained by the mooring system. The oscillating breakwater in turn generates waves which travel away from the breakwater in the direction of the reflected and transmitted waves. The total transmitted wave is the sum of the component which passes beneath the breakwater and the components generated by the breakwater

* Associate Professor, Department of Mechanical Engineering, University of Washington, Seattle, Washington

motions. The total reflected wave is composed similarly.

To assess the performance of a floating breakwater one single parameter which has been widely used is the transmission coefficient. This is found by dividing the transmitted wave height by the incident wave height. In conducting field experiments or in developing theoretical models the variables affecting performance which need to be measured include:

(1) Total transmitted and reflected waves (in theoretical predictions the individual components should be predicted).

(2) Wave forces on the breakwater.

(3) Motions of the breakwater.

(4) Forces on the mooring lines.

FIELD MEASUREMENTS

From the outset, obtaining data on the field performance of floating breakwaters was an important component of the research program. A suite of instruments designed to record breakwater performance data was designed and installed at a floating breakwater in Friday Harbor, Washington.

The breakwater at Friday Harbor forms an L shape with the shorter leg extending from a fixed dock connected to shore. The shorter leg is 227 feet and the longer leg 627 feet. The topography at the site offers relatively good protection to the marina and breakwater. Prevailing southwest winds approach almost parallel to the neighboring shore perpendicular to the short leg. The fetch is about one mile in this direction. The most serious exposure is in the northeast direction through a channel affording about a 1.7 mile fetch. Although storms with winds from this direction are not common, a few severe storms of this type may be expected during a Winter storm season. The layout of the breakwater and marina are shown in Figure 2.

Although the original plan was to instrument the longer leg of the breakwater, it became necessary to alter plans and place the instruments in a position to monitor the shorter leg. Several large barges were tied to the longer leg to prevent a recurrence of damage which had occurred in previous severe storms with winds from the northeast.

Figure 2 also shows the instrument locations. Included in the instrument suite were:

(1) Incident wave measuring buoy.

(2) Wave buoy located in incident and reflected wave field.

(3) Two transmitted wave measuring staffs.

(4) Four load cells in the anchor lines.

(5) One horizontally mounted accelerometer.

(6) Two vertical accelerometers mounted near the seaward and shoreward sides of the breakwater.

The horizontal accelerometer provided surge acceleration directly while the average of the vertical accelerometers and the difference yielded heave and roll accelerations, respectively.

A more detailed description of the equipment is provided by Christensen and Richey (1976).

THE FRIDAY HARBOR BREAKWATER

The Friday Harbor floating breakwater is constructed quite differently from other floating breakwaters. This breakwater has a continuous structure whereas most other floating breakwaters have been constructed using discrete modules connected together.

Figure 3 shows a cross section of the Friday Harbor breakwater. The stringers provide continuous lengthwise support for the decking. The breakwater pontoons are made from a centrifugally molded polyolefin. Each pontoon is about 10 feet long and 5 feet wide but very irregular in shape. A view of the breakwater under construction without decking is given in Figure 4. Ballast is required to insure that the breakwater floats at the design water level. This is provided by 1.5 feet of water in each pontoon.

The breakwater is held in position by mooring lines on the seaward and shoreward side at about 50 foot intervals. The mooring line is chain extending about 45 feet below the breakwater. The next portion of each mooring line is double-braided nylon rope followed by another section of chain which connects to piling driven into the bottom.

Further information on this breakwater may be found in Adee (1975b).

THEORY

When one considers the myriad possible breakwater configurations which have been proposed to date and the different conditions which prevail at each potential breakwater site, the number of required model tests and the attendant expense of selecting a configuration becomes very large. To avoid this expense and also to permit parametric studies aimed at obtaining optimum breakwater configurations, a theoretical model was developed. The goal was to theoretically predict the performance which could be measured in laboratory studies or at prototype installations.

The initial restriction imposed on the theoretical model was to consider only two-dimensional conditions. Under this restriction the breakwater is assumed to be very long in one direction with long-crested waves approaching so that their crests are parallel to the long axis of the breakwater. At most breakwaters where the wave climate results from wind-generated waves, this condition would rarely be approached. However, experiments performed using a boat wake to generate incident waves on the beam and at an angle to a breakwater indicate larger breakwater motions and larger transmitted waves when the incident wave crests approach parallel to the long axis of the breakwater. As a design tool, a two-dimensional theory provides information on the worst conditions which might be expected to occur. In addition, the information available from extensive two-dimensional wave-channel experiments provide the data needed to test the theoretical model.

The approach used here has been to employ the techniques which naval architects have developed to deal with ship-motion problems. Mathematically, the hydrodynamic equations are formulated in terms of a boundary-value problem for the velocity potential. Solution of this complete problem is presently impossible because the free-surface boundary condition is nonlinear. An approximate solution may be obtained if restrictions are imposed on the boundary-value problem, and the procedure of linearization is applied. The restrictions limit the applicability of the solution to cases of small incident wave amplitude and small motion response of the breakwater.

Once the equations have been linearized, the performance of the breakwater may be obtained. The calculation procedure is illustrated in the block diagram of Figure 5.

Results obtained using the theory are in good agreement with laboratory and field data (Adee, 1975b, 1975c, 1976). The theory also provides an indication of the influence of fixed-body transmission, and of sway, heave and roll motions on the transmission coefficient at varying values of the beam to wavelength ratio.

RESULTS FROM FRIDAY HARBOR BREAKWATER

The instruments were placed at the Friday Harbor breakwater and a great deal of data was obtained during the Winter season of 1975. While no extreme storm event occurred during the time of observation, there were many occurrences of storms with mean wind speeds on the order of 20 miles per hour. It is interesting to note that when the transmission coefficient is plotted as a function of frequency the results are very consistent.

Because of the great similarity of the results, one record (FH 7-8) was selected for presentation. In this case the wind was nearly perpendicular to the short leg of the breakwater and the average wind speed was 22.9 miles per hour. The average tidal elevation was 5.3 feet above mean lower low water.

The measured and theoretically predicted transmission coefficient as a function of frequency is shown in Figure 6.

The field data was high-pass filtered with a cutoff frequency of 0.05 Hertz in order to remove the influence of tidal variations or wave buoy motions. After initial processing the data were directly transformed using fast Fourier transformation procedures and smoothed by averaging adjacent raw spectral components. The complete details of data analysis are contained in Adee, Richey and Christensen (1976).

Extensive comparisons between theory and experiment have shown that the hydrodynamic theory is excellent so long as roll motions are small. In the frequency regions where the theory predicts higher roll motions the transmission coefficient may be in error. This is because nonlinear damping is an important factor in determining roll motion. Nonlinear damping is not included in the theory but may be artificially approximated. Experience has shown that by arbitrarily doubling the calculated hydrodynamic damping, better agreement is produced. Damping has been doubled for the theoretical prediction presented in Figure 6.

One advantage of the theory is that it doesn't simply produce a transmission coefficient, but produces sufficient information to deterine what factors have an effect on the wave transmission. For the Friday Harbor floating breakwater as for other floating breakwaters the very low frequency waves are unaffected by the structure's presence yielding a transmission coefficient of nearly unity. The first trough in ths transmission coefficient at about 0.3 Hertz results from heave-and roll-generated waves cancelling the fixed-body wave transmission. This transmission coefficient is well below the transmission coefficient which would be obtained with the breakwater rigidly restrained and only fixed-body transmission waves passing through. As frequency increases, there is a peak at about 0.38. At this point, the heave-generated wave has almost vanished, and the fixed-body transmission is also small. The larger predicted transmission coefficient is primarily the result of a roll-generated wave with a smaller component resulting from sway motion. The next trough at 0.43 occurs as the heave motion-generated wave increases and cancels the roll and sway motion-generated components. The fixed-body transmission is very small at 0.43. As frequency increases above 0.43 the transmitted wave is almost totally a result of the sway motion of the breakwater.

Another result of great interest to the designer is the force in the mooring lines. In presenting this data a mooring force coefficient is used which is defined as the amplitude of the force oscillation divided by the incident wave amplitude times the weight per unit length of the breakwater.

The mooring-force coefficient for the seaward mooring line of the Friday Harbor breakwater is shown in Figure 7. Here again, the field data has been high pass filtered to eliminate tidal effects and also a low frequency spike which occurs in the mooring-force spectrum. The theoretical prediction is based on computing the spring constants for the three degrees of freedom, multiplying these by the motions and summing force components. From the designers standpoint, the theory predicts the trends accurately and the overprediction at the peak would add to the margin of safety.

The main conclusion which should be reached from these results is that it is possible to measure the performance of floating breakwaters in the field and that the theory which has been developed predicts the trends of the data and can play a very useful role in design.

PROBLEM OF COMPARISON

The floating breakwater at Friday Harbor, Washington represents one type of breakwater which provides protection by reflecting the energy contained in the incident wave. Other, more compliant breakwaters have been proposed which provide protection by dissipating this energy or by setting up waves which "interfere" with the incident wave. Still other proposed breakwaters attempt to reduce the energy in the incident wave by forcing it to break over some obstacle. Because these concepts are quite different and because few have been tested at prototype scale, a rational comparison of performance is quite difficult with the data presently available. Clearly, from a users point of view, the breakwater offering the best performance for the least cost would be the most attractive.

To present the performance of various types of floating breakwaters in terms of performance per dollar is very difficult. There has been a great variation in the cost of the floating breakwaters constructed to date, even among those of the same type. Besides, with the diversity of materials available and the rapid fluctuations in their prices which has recently taken place, such information would rapidly become obsolete.

In the course of the study of floating breakwaters at the University of Washington, we have often used beam divided by wavelength as the parameter which characterizes the size of the breakwater. This seems to work well so long as the discussion is centered on breakwaters which protect primarily by reflection. When different types such as the reflecting and tethered float breakwater are to be compared using beam to wavelength is inadequate.

An alternative procedure which seems to have merit is to use the square root of the underwater volume per unit length divided by the wavelength as the independent variable. If we are to ever be able to draw fair general comparisons among proposed floating breakwaters,a consistent scheme for presenting performance data should be developed.

NONLINEAR BEHAVIOR

Figure 8 shows a recorded time history of the mooring forces measured at the Tenakee, Alaska floating breakwater. Looking at this figure one can observe an oscillation with a period of about 60 seconds superimposed on the expected shorter period oscillations.

The linear theoretical model permits the system to respond only at the frequency of the incident wave. In order to explain the presence of these long-period oscillations, nonlinearities must be included in the analysis. To perform a mathematically complete analysis including all nonlinear effects is beyond the present state of the art. However, in the case of the floating breakwater, one can show that if two incident waves are considered and second-order terms are retained, then an exciting force is present at the difference between the frequencies of the incident waves. Normally, this small exciting force would have little effect. Since the structure is only lightly restrained in sway, the natural period is very long for sway motion. The existence of a small exciting force at the sway natural frequency could explain the large oscillation in mooring force.

Because the mooring lines are critical to floating breakwater survival in extreme storm conditions, further research effort on the long-period oscillations is justified.

ACKNOWLEDGEMENT

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REFERENCES

Adee, B.H., "Analysis of Floating Breakwater Performance," Proceedings of the Symposium on Modeling Techniques, San Francisco, Calif., 3-5 September 1975a.

Adee, B.H., "Floating Breakwater: An Idea Whose Time Has Returned," IEEE-MTS Annual Meeting, Ocean '75, San Diego, Calif., September 1975b.

Adee, B.H., "Floating Breakwater Mooring Forces," Ocean Engineering Mechanics, Am. Soc. of Mechanical Engineers, New York, 1975c.

Adee, B.H., "A Review of Developments and Problems in Using Floating Breakwaters," Offshore Technology Conference, Houston, Texas, May 1976.

Adee, B.H., Richey, Ep., Christensen, D.R., "Floating Breakwater Field Assessment Program, Friday Harbor, Washington," Final Contract Report submitted to U.S. Army Corps of Engineers Coastal Engineering Research Center, July 1976.

Christensen, D.R., Richey, E.P., "Prototype Performance Characteristics of Two Floating Breakwaters," Offshore Technology Conference, Houston, Texas, May 1976.

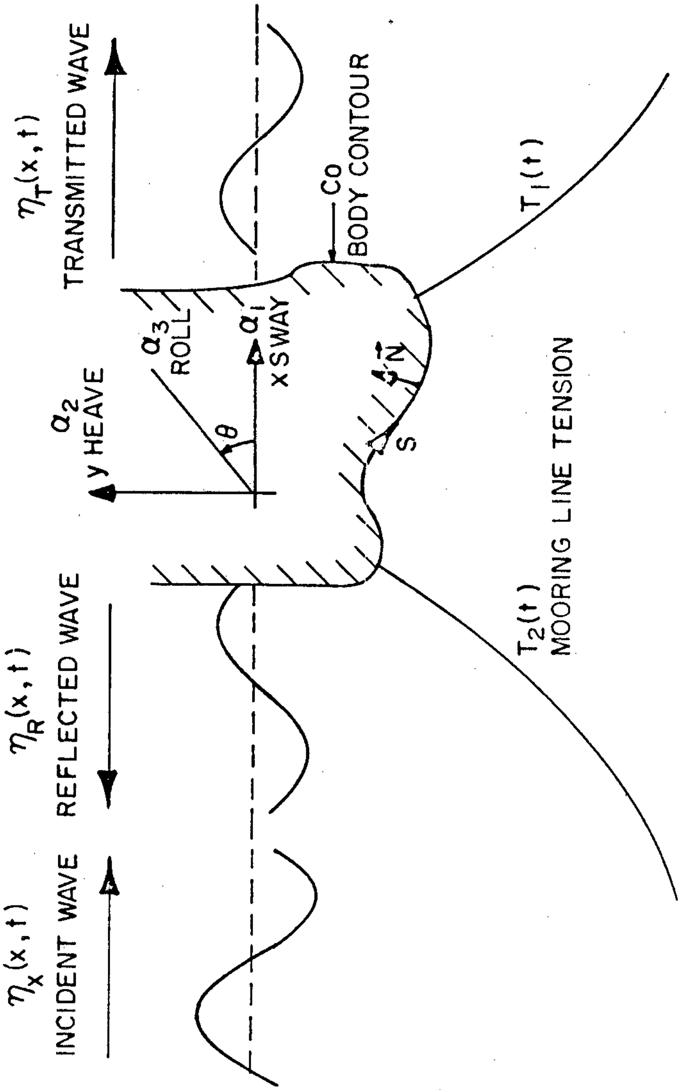

Figure 1. A two-dimensional floating breakwater.

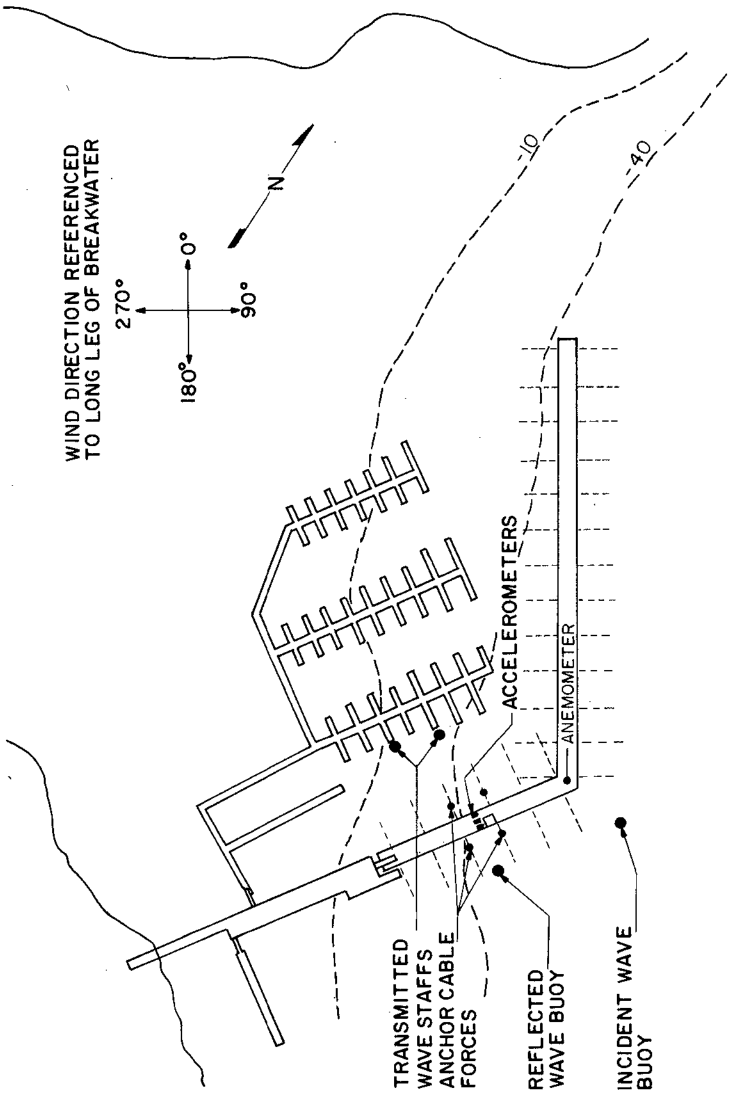

Figure 2. Instrumentation location plan, Friday Harbor breakwater.

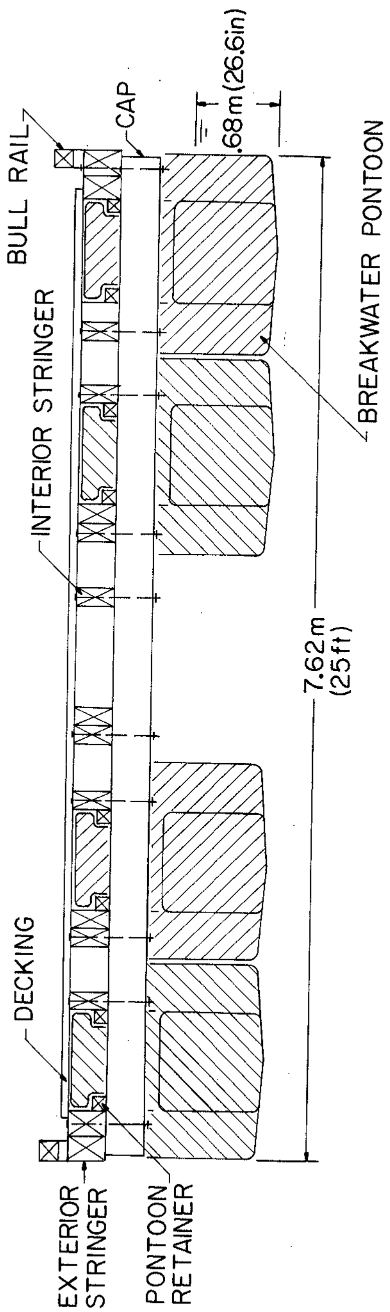

Figure 3. Cross section of Friday Harbor breakwater.

Figure 4. Friday Harbor breakwater before installation of decking.

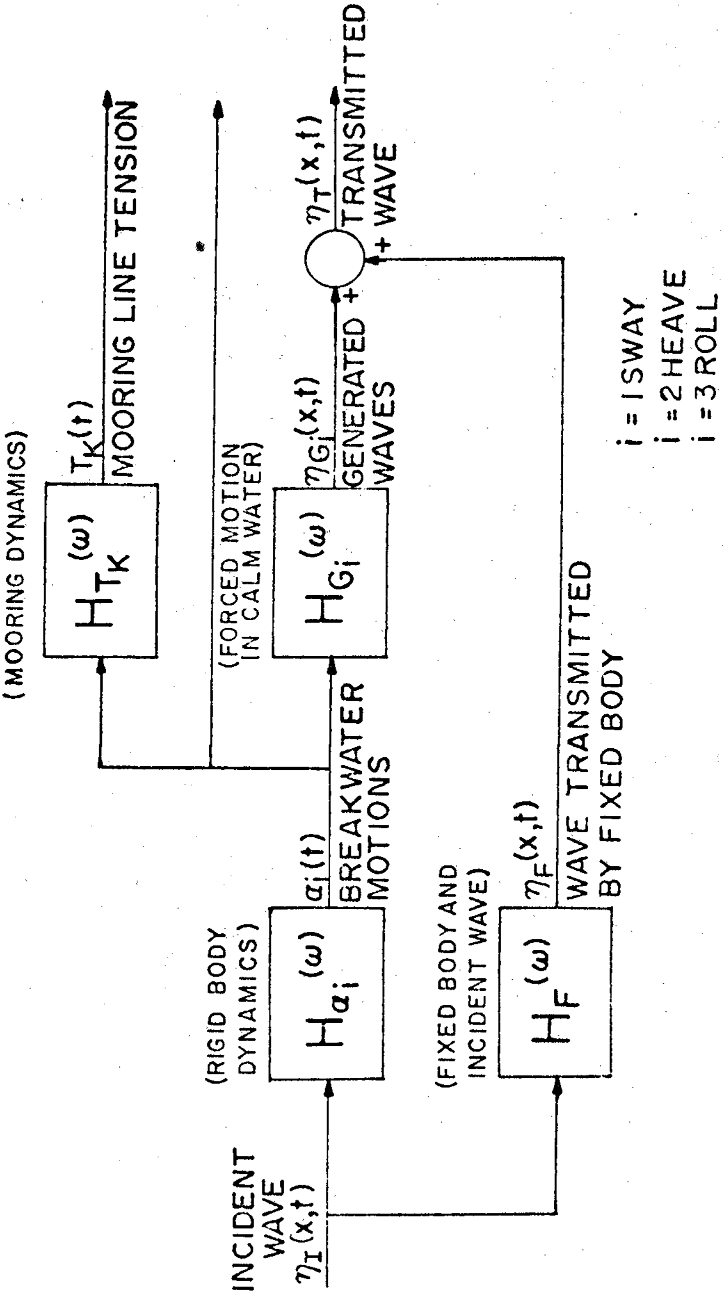

Figure 5. Linear system representation of a floating breakwater.

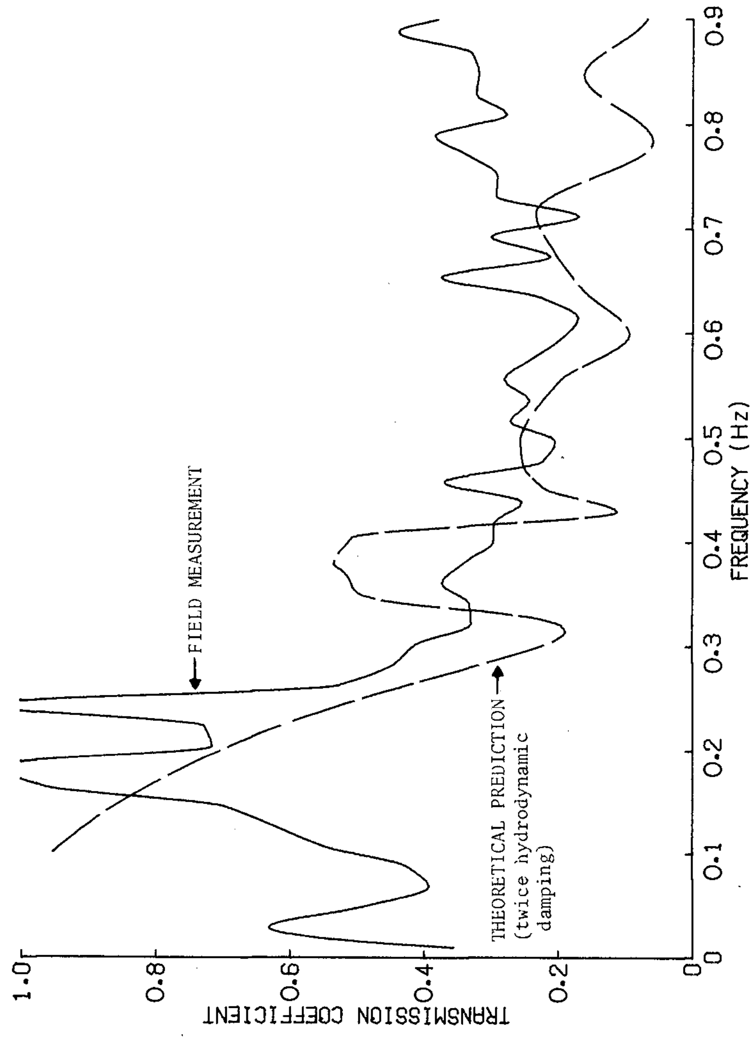

Figure 6. Transmission coefficient for Friday Harbor breakwater (record FH 7-8).

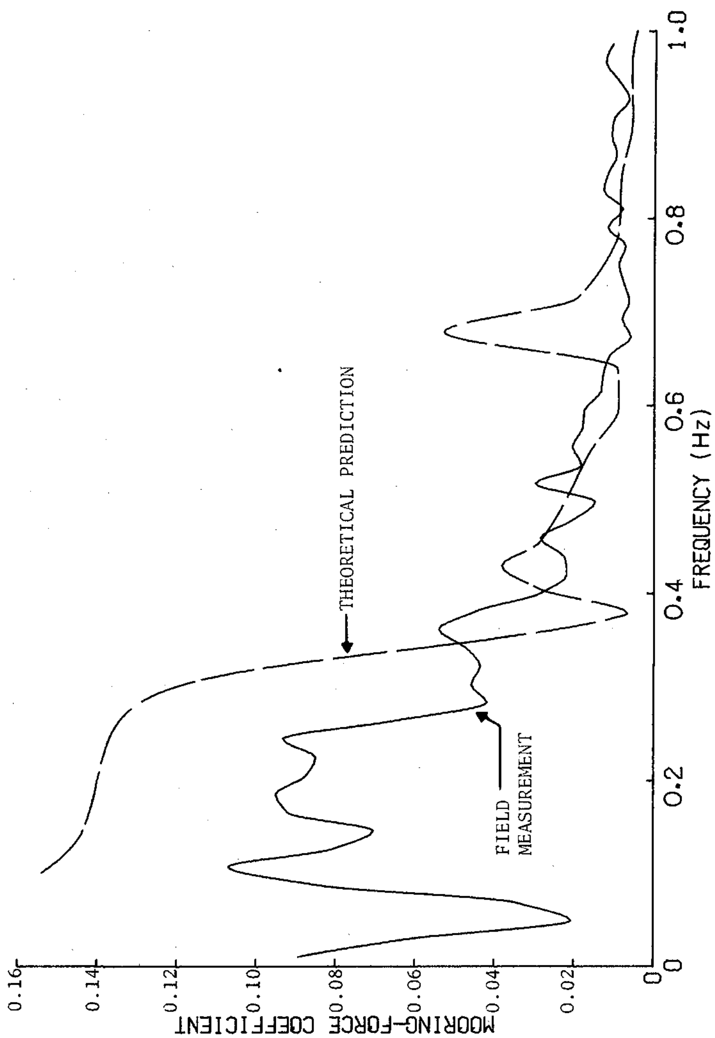

Figure 7. Seaward mooring line mooring-force coefficient, Friday Harbor breakwater (record FH 7-8).

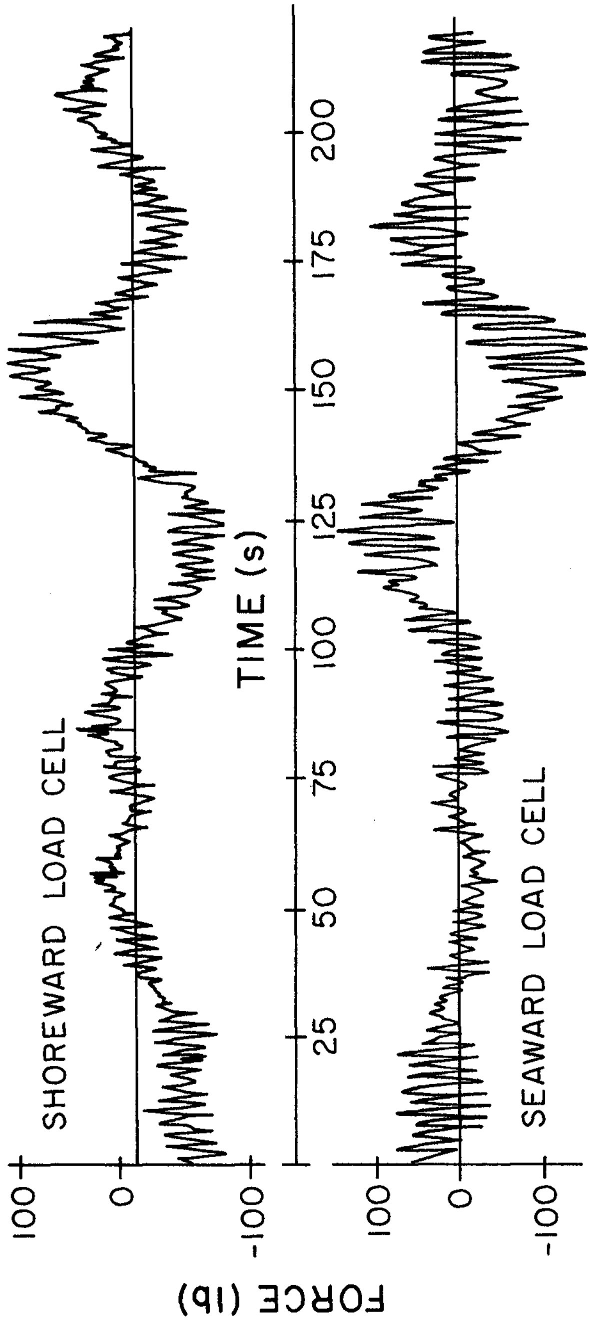

Figure 8. Time history of mooring line load cells, Tenakee breakwater (record TK 7-23).