

Application of Physical Model in Long Wave Studies for The Port of Long Beach

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INTRODUCTION

The increase in container shipping demand has lead to rapid expansion of container terminal facilities. The Port of Long Beach have expanded their operations by landfills in areas more exposed to waves in less protected areas of the harbors. At the same time, container ships have been increasing in size and more rapid cycle time of cargo transfers by container cranes have demanded tranquil berths to minimize vessel motions. The availability of tranquil water and the need for faster crane cycle times have been in conflict.

The Port of Long Beach constructed a container terminal near the entrance to the harbor in 1992 for Maersk shipping lines. The 2,300 ft wharf is backed by over 100 acre of terminal and gate area and has four post panamax size container cranes. The terminal operates with a trucking and rail facility. Immediately after construction of the terminal in 1992, the first ships of over 900-ft size experienced excessive ship motions. These motions produced a surge measured up to 10 ft with periods on the order of one minute. Sway motions were about 20 to 40 seconds, and when coupled with the surge caused damage to fenders, represented a safety issue by mooring line breakage, and substantially reduced container crane productivity.

This paper summarizes the use of physical model studies in the design of a breakwater to attenuate vessel surge motions at Pier J berths to acceptable levels. In assessing the performance of a breakwater configuration, two different criteria were considered. The

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first criterion was based on comparing the long wave energy in Pier J with a proposed breakwater arrangement in place to the wave energy at existing conditions. This criterion was used to quantify the improvement in wave conditions in Pier J and hence to compare the performance of different alternatives. The second criterion was based on comparing the long waves at Pier J with those at the South East Basin at the Port of Long Beach, at where container ship operations had not experienced major ship motion. The long wave attenuation criterion selected for the Pier J Breakwater design was therefore set to match or be below the existing wave conditions within South East Basin.

EXPERIMENTAL PROGRAM

Model Description

The effectiveness of the Pier J Breakwater in reducing the long wave in Pier J was tested at the US Army Engineer Waterways Experiment Station (WES) Los Angeles and Long Beach Harbors (LA/LB) model. The LA/LB model was originally constructed to conditions in the early 1970's and has been periodically updated to account for changes in the LA/LB Harbors. The model has a vertical scale of 1:100 and a horizontal scale of 1:400. The model shoreline extends from 2 miles northwest of Point Fermin to Huntington Beach, and reproduces the Pacific Ocean bathymetry seaward of the harbor out to the -300 ft MLLW contour. The total model area covers about 44,000 ft², which represents 253 sq. miles in prototype.

A wave generator composed of 13 individual segments, each independently controlled by a computer, was located at the far end of the wave basin. Details of the generator design and modes of operation can be found in Outlaw et al. (1997). A sketch of the physical model basin, wave generators and offshore wave gages is shown in Figure 1.

Breakwater Configurations

Seventeen different breakwater configurations were tested. These configurations are shown in Figure 2, and represent modifications from the original "J6" configuration identified in a prior study by Sargent and Thomas (1995) as effective in reducing the long wave energy at Pier J.

A total of twenty-three sets of tests were conducted. These include the seventeen different configurations, two tests for the existing (base) conditions, and four additional tests for construction phasing (J20, J21, J22 and J23).

Detailed descriptions of each breakwater configuration are not provided herein. However, the rationale in selecting these different test configurations is summarized as follows:

1. Compare the performance of the breakwaters with a rectangular layout (J6 and J8) with those breakwaters with a triangular layout (J9 and J11);
2. Optimize the performance of the rectangular layout by varying the length of the breakwaters (J6, J8, and J12 through J19);
3. Test the importance of the permeability of the breakwaters (J6, J15 and J19) in reducing the long wave energy in Pier J; and
4. Identify the importance of different long wave attenuation mechanisms such as blocking the incident wave (O1), enhancing the separation losses (P1, O1 and J18), and reducing the trapped long wave energy (J11).

Test Conditions

Both monochromatic waves and random wave spectra were tested. Eleven wave periods were selected for most of the monochromatic wave tests which included 151.5, 128.3, 110.3, 99.0, 80.2, 72.3, 60.2, 47.8, 41.9, 37.2 and 32.7 seconds. These wave periods were chosen based on the response of the basin during an initial test with a uniform random wave. Some of the test configurations shown in Figure 2 (BS2, J10, J11, N1, O1 and P1) were tested with only four wave periods (151.5, 128.3, 110.3 and 37.2 seconds). The final configuration J19 was tested with five additional wave periods (160.0, 141.1, 120.0, 106.0 and 91.0 seconds), which results in a total of sixteen periods tested.

Ten wave gages were used for data collection. These included five in Pier J, two in the South East Basin, one at the Queen's Gate entrance, and two offshore gages (one near Platform Edith). The gage locations and their designated numbers are shown in Figure 3. For the final test for J19, an additional gage was placed near the entrance to the Pier J. Wave gages were also deployed in other locations in the Port of Long Beach and Port of Los Angeles to investigate whether proposed modifications would exacerbate any existing surge conditions outside the Pier J project site.

Data Analysis

The monochromatic wave test results revealed that the incident wave conditions measured at a gage near Platform Edith location are subject to multiple wave reflections within the model basin. Reflected waves from the breakwaters, reflected waves from other model boundaries, and re-reflected waves from the wave machine contaminated the wave record at Platform Edith after a short time.

An example time series of recorded waves at four different gage locations is shown in Figure 4. In the figure, Gage 16 is at Platform Edith; Gage 42 is at the Queen's Gate entrance; Gage 81 is near the end of Pier J; and Gage 29 is in the South East Basin. This

example record shows that it takes about 5 seconds for the waves to reach Platform Edith and about another 25 seconds for the waves to travel from Edith to Queen's Gate. This means that it takes about 50 seconds for the reflected waves from the Federal Breakwaters to reach Edith. In another 10 seconds, the reflected waves will travel to the wave generator and be re-reflected to Edith. The effect of these reflected and re-reflected waves to the wave record at Edith is clearly shown in the figure.

In calculating the wave amplification factor – the ratio of the measured wave height at a specified location to that at Edith, only the uncontaminated (before wave reflection affects the Edith reading) wave record was used in the calculation.

The test with the uniform spectrum, which requires a long wave record for spectral analysis, is inherently contaminated and therefore not suitable in defining wave amplifications. In this study, the optimized breakwater configuration was therefore chosen based on the results of the monochromatic wave tests. The spectral wave results were used only for studying the general response of the basin over a range of wave periods.

MODEL RESULTS

In general, the monochromatic wave tests showed that for similar total breakwater lengths, the rectangular layout is more efficient in attenuating the long waves than the triangular layout. For the rectangular layout, the longer the breakwater segments the better the performance. In addition, the permeability of the breakwater was found to be an important factor in determining the performance of the breakwaters. The less permeable breakwater cross section performs better than the more permeable sections.

Due to the large number of tests and large amount of analyzed data, only the most relevant and important test results are presented here. These results were chosen to illustrate and elaborate the general conclusions stated above. In addition, only measurements at Gages 81 (located near the end of Pier J, which usually shows the greatest long wave amplification within Pier J, are shown. However, wave measurements at all gages were analyzed and their results were evaluated in determining the best breakwater configurations.

Effect of Permeability

The amplification factors measured at Gage 81 for configurations J6 and MI are shown in Figures 5. The two test configurations used identical breakwater layouts. While J6 has permeable breakwater cross-sections, MI has impermeable breakwater sections. The results showed that in general, the impermeable breakwater performs better in attenuating the long waves. Data taken at other gage locations showed the same general trend.

Since the breakwater permeability was found to be an important factor in the performance of the breakwaters, proper modeling of long wave transmission through a breakwater in a distorted scale model was further evaluated in a two-dimensional flume. The model stone size providing the best match of permeability of the prototype design (determined from a 1:30 undistorted scale flume model test) was specified for use in the final test with Configuration J19.

Effect of Breakwater Length

The length of the breakwater segments for the rectangular layout was found to be important. In general, wave amplifications in Pier J were found to be less for the breakwater configurations with longer segments. However, this improvement in performance is less sensitive to the length of the breakwater segments running in the north-south direction (i.e., parallel to the Pier J entrance) compared to the lengths of the breakwater segments extending eastward from the Pier J Berth (i.e. parallel to the berthing slips). In the following discussions, the average length of the two north-south breakwater segments is designated as L_1 , while the average length for the two east-west sections is designated as L_2 . A definition sketch of L_1 and L_2 is shown on the last configuration in Figure 2.

Effect of L_1

The amplification factors measured at Gage 81 for configurations J08 and J15 are shown in Figure 6. These two configurations have roughly the same L_2 of about 600 feet but L_1 differs by about 200 feet. The results show that J08 with longer L_1 of 1,000 feet has slightly less amplification factors compared to those for J15 with L_1 of about 800 feet. However, the differences in the amplification factors are in general very small.

Effect of L_2

Amplification factors at Gages 81 configurations J12, J14, J15 and J17 are shown in Figure 7. For these four tests, the shortest L_2 is about 370 feet (J12) and the longest L_2 is about 965 feet (J17). Note that these four test configurations do not have the same L_1 , the latter ranges between 600 to 800 feet. As discussed above, the length L_1 does have some effect on long wave attenuation in Pier J, but not to a great extent.

In Figure 7, the dot-dash line connects the amplification factors for J12, which has the shortest L_2 of 370 feet. The solid line represents results for J17, which has the longest L_2 of 965 feet. The results show that there is a great difference in the amplification factors between these two configurations. In most of the tested wave periods, J17 has amplification factors of only about half or less of those amplification factors for J12.

The effects of L_2 on long wave attenuation at Pier J were further examined by comparing their performance relative to the existing condition (base case) for five critical wave periods. These include three longer periods of 151.5, 128.3 and 110.3 seconds which are important for ship surge motions; and two shorter periods of 41.9 and 37.2 seconds which are important for ship sway motions.

Figure 8 plots the amplification factors relative to the base case versus the length of the east-west breakwater segment L_2 at Gage 81. The amplification factors are taken from test results for breakwater configurations J12, J15, J14 and J17; which have different L_2 of 370, 600, 810 and 965 feet, respectively. Except for the longest period of 151.5 seconds, all the four configurations resulted in substantial reduction in wave amplification factors compare to the existing conditions. There is also a general trend of reduced amplifications with the increase in L_2 . The reductions in the amplification factors are substantial when the breakwater length L_2 extends from 360 to 600 feet. When the breakwater extends beyond 600 feet, the amplification factors reduce less rapidly and seem to level off when the L_2 approaches about 1,000 feet.

Separation Loss

Exploratory tests were conducted by visual observations for a few selected wave periods for configurations P1 and O1. These tests were designed to determine whether enhancement of the separation losses would have measurable impact on surge. The results of these very basic tests, however, did not support the importance of the separation losses in attenuating the long waves in Pier J. After J17 was chosen for the final test, a full test with all the eleven wave periods was conducted to further examine the importance of separation losses. The test was conducted with configuration J18, which has similar layout as J17. The only difference between J17 and J18 is that while J17 has the traditional sloping breakwater head sections, J18 has vertical sheet piles installed at the breakwater head sections leading to the Pier J basin. These vertical sheet piles for J18 were intended to increase the flow separation at the basin entrance and hence should have induced greater separation loss compare to J17.

Figure 9 compares the amplification factors at Gage 81 for J17 and J18. The methodology and results did not indicate that it would be warranted to investigate alternatives based on increasing separation losses.

FINAL TEST WITH J19

After reviewing all the results, it was determined that J17 had the best performance among all the configurations tested. A final test was therefore conducted with Configuration J19, which was a modification of J17. This final configuration J19 differs from J17 in two major aspects. First, the lengths of the breakwater segments were

extended to the maximum allowable for the site as limited by dredging and ship maneuvering room. Second, a less permeable breakwater cross-section was specified.

The performance of J19 was compared to J17 in Figure 10. This figure shows the wave amplification factors measured at Gages 81 for J17 and J19. The results show that the less permeable J19 breakwater did result in smaller wave amplifications at Gage 81. Similar results were found for other gage locations.

As mentioned earlier, the criterion for long wave attenuation at Pier J is set to be the same or less long wave energy compared to those long wave energy at the South East Basin. The wave amplification factors measured at Pier J with the final test configuration J19 in place are therefore compared with those amplification factors measured at the South East Basin. These comparisons are shown in Figure 11. In the figure, solid symbols denote wave amplification factors measured in Pier J (Gages 81, 82, 85, 53 and 54), while open symbols are used to show measured results in the South East Basin (Gages 29 and 30). The wave amplification factors at Gage 81 for existing condition (base case) are also shown in the figure for comparison.

In general, with the J19 breakwater configuration in place, wave amplification factors at Pier J are comparable to those at the South East Basin. For the shorter wave periods between 30 to 70 seconds, the amplification factors at Pier J are close to those at the South East Basin. For the longer wave periods of between 90 to 130 seconds, waves at Pier J are slightly higher than those at the South East Basin. However, these wave amplifications at Pier J already represent reduction by a factor 1/2 to 1/3 compared with existing conditions. Even longer wave periods, of between 140 and 160 seconds, waves amplifications at Pier J are in general smaller than those at the South East Basin.

SUMMARY

In summary, although configuration J19 does not completely meet the criterion of reducing the long waves in Pier J to be the same as or lesser than the wave conditions at the South East Basin, it is the most effective among all the tested configurations and also represents substantial improvement over existing conditions. Hence, the J19 Breakwater configuration was selected. The Pier J layout with the J19 Breakwater (hatched) is shown in Figure 12.

REFERENCES

Outlaw D.G., Durham, D.L., Chatham, C.E., and Whalin, R. W. (1977), "Los Angeles and Long Beach Harbors' Model Study: Report 4, Model Design," Technical Report H-75-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sargent F.E., and Thomas, L.J. (1995), "Port of Long Beach Pier J Slip Study – Draft Report," US Army Corps of Engineers Waterways Experiment Station Tech. Report CERC-95-X.

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APPENDIX – CONVESION FACTORS

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	Meters
mile	1.6093	Kilometers
acre	0.4047	Hectares

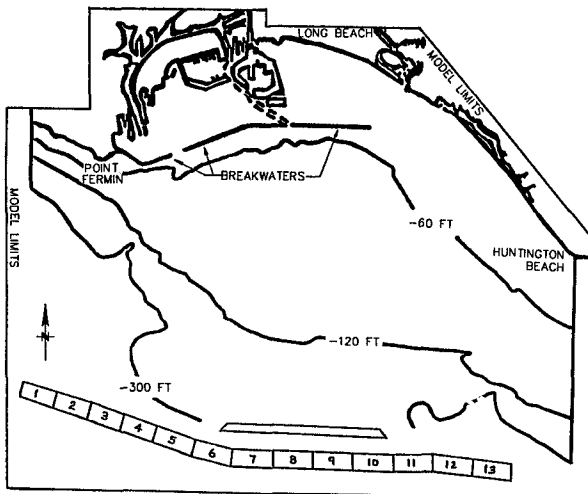


Figure 1: Physical Model Layout

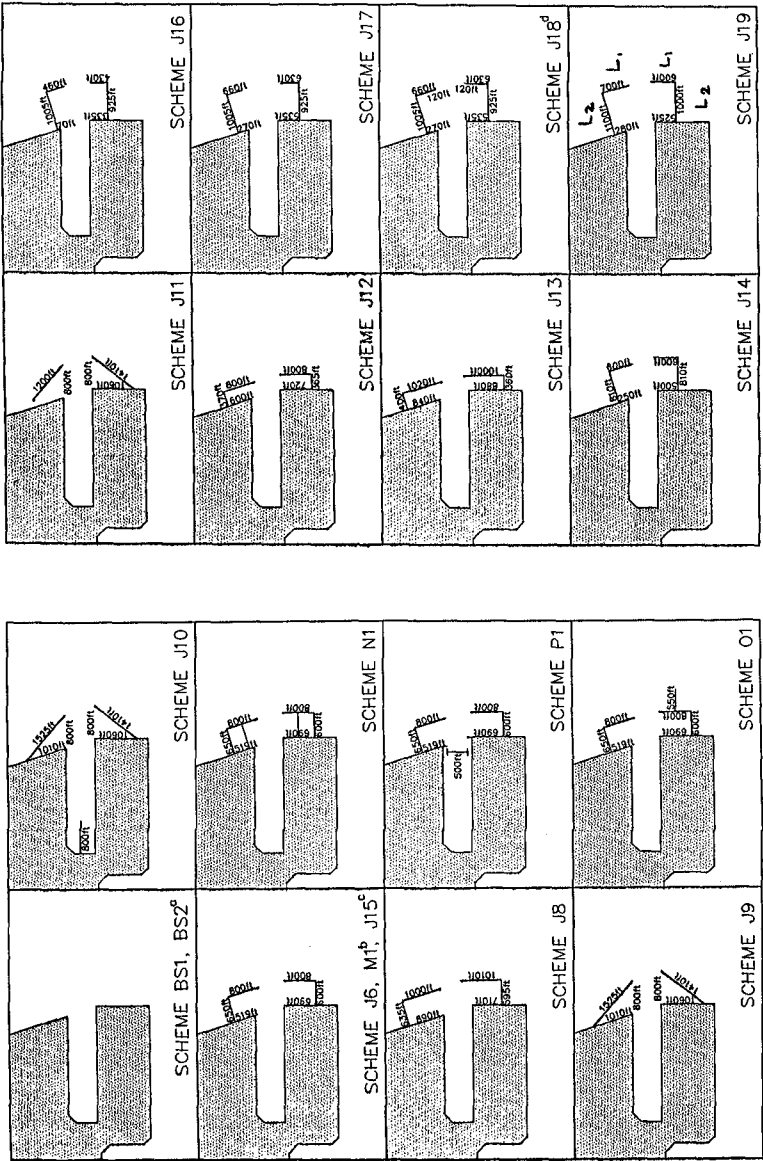


Figure 2: Schematics of Different Breakwater Configurations

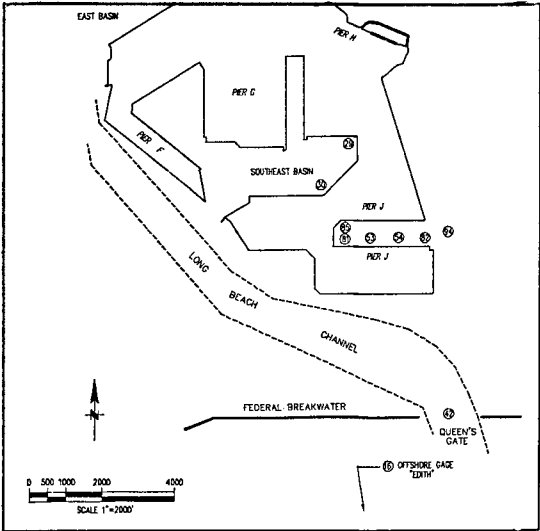


Figure 3: Gage Locations

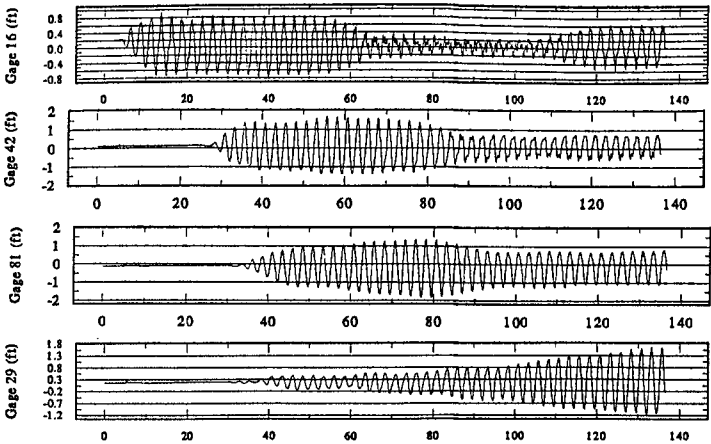


Figure 4: Example Water Surface Elevation Time History

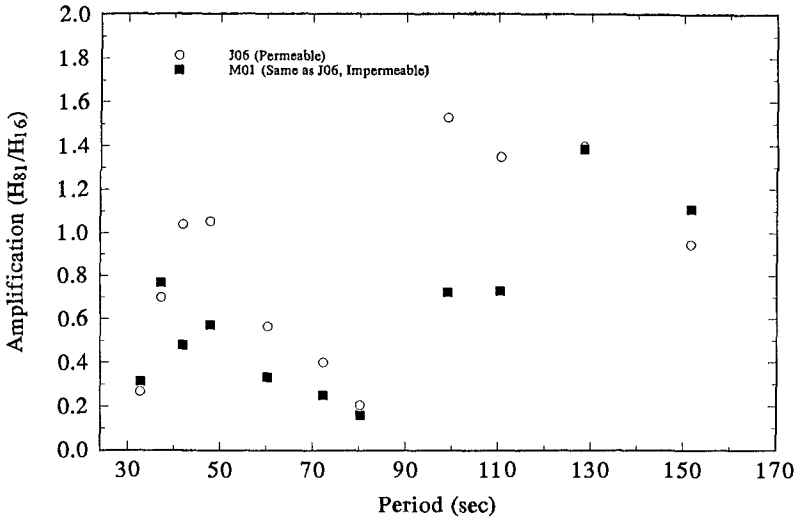


Figure 5: Effect of Breakwater Permeability on Long Wave Attenuation

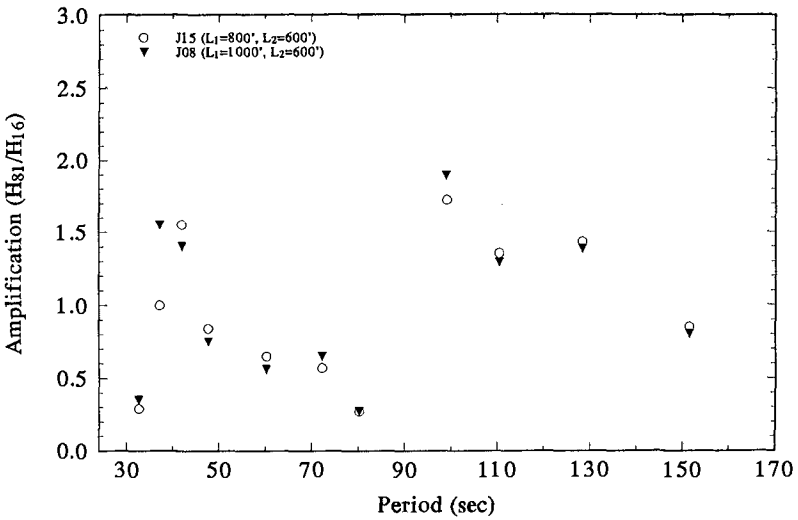


Figure 6: Effect of Length L_1 on Long Wave Attenuation

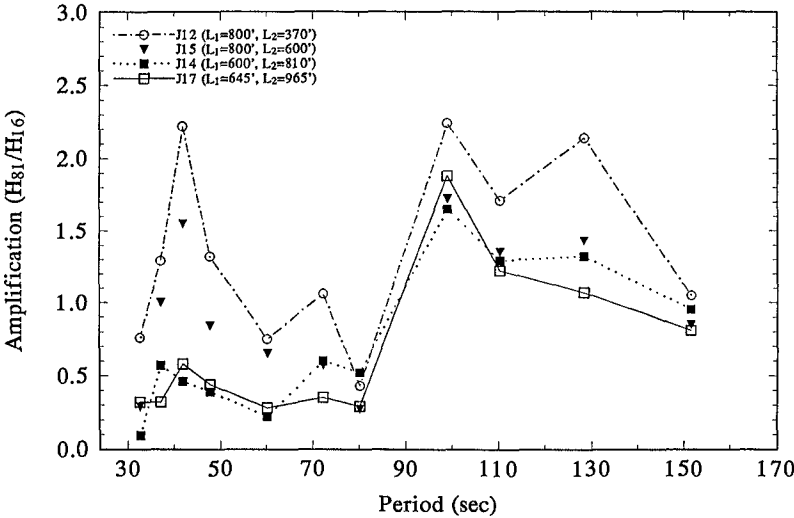


Figure 7: Effect of Length L_2 on Long Wave Attenuation

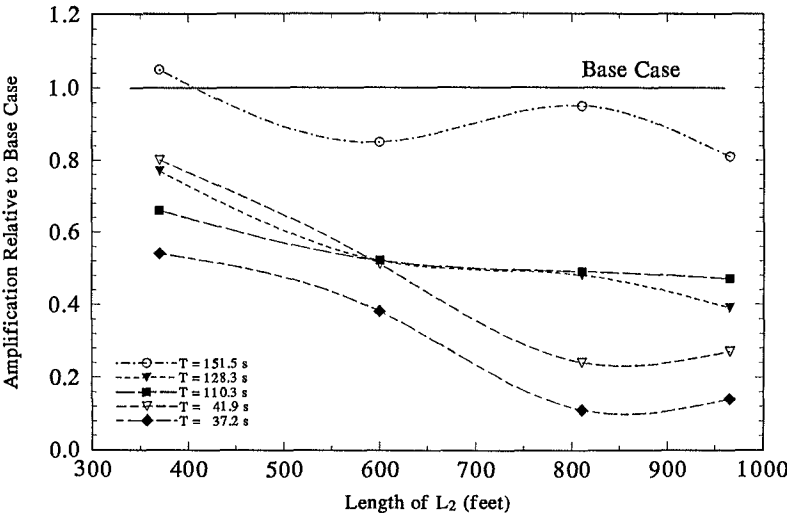


Figure 8: Effect of Length L_2 on Long Wave Attenuation for Five Critical Periods

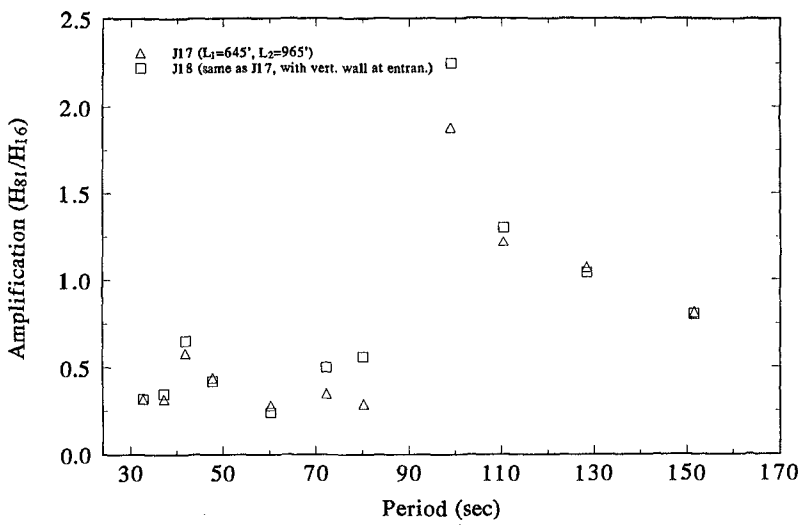


Figure 9: Effect of Enhanced Separation on Long Wave Attenuation

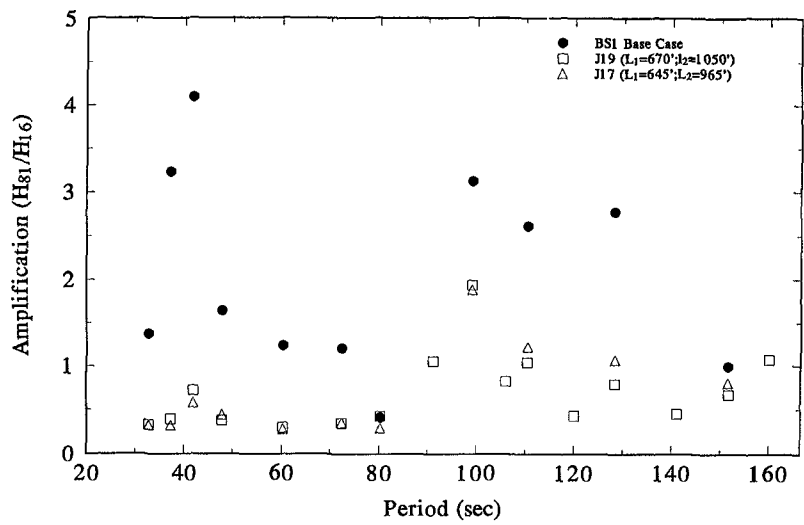


Figure 10: Comparison between J19 and J17 with the Base Case

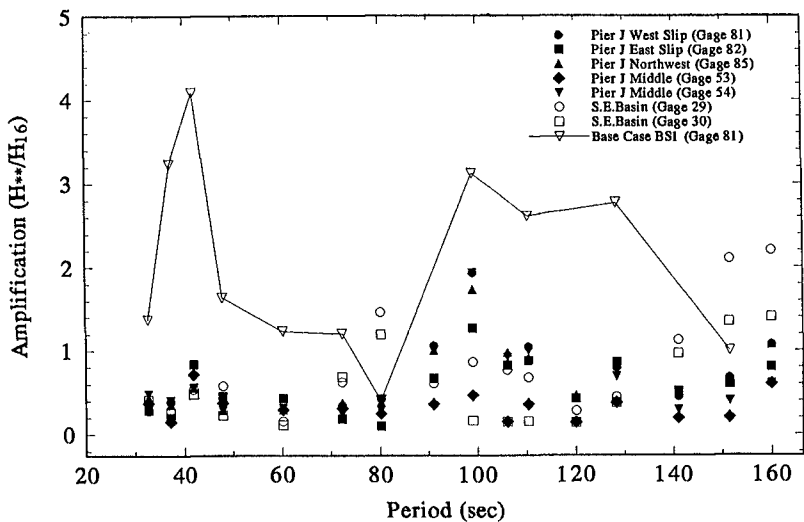


Figure 11: Comparison between J19 and the South East Basin

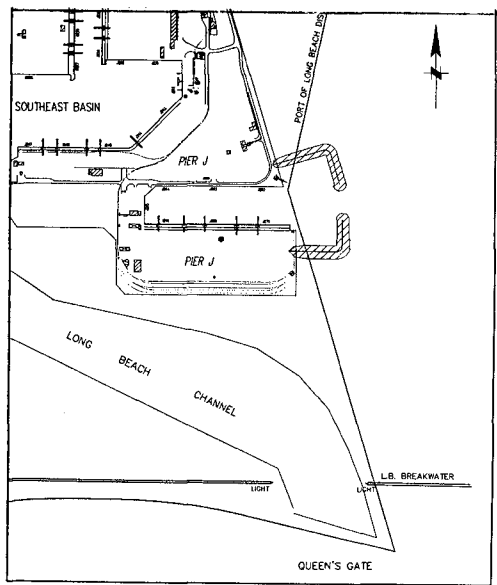


Figure 12: Selected J19 Breakwater (Hatched) to Reduce Surge Motion