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September 1994

US Army Corps
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Wave Response of Proposed Improvement Plan 6 to the Small Boat Harbor at Maalaea, Maui, Hawaii

by Edward F. Thompson, Lori L. Hadley

Prepared for U.S. Army Engineer Division, Pacific Ocean

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Final report

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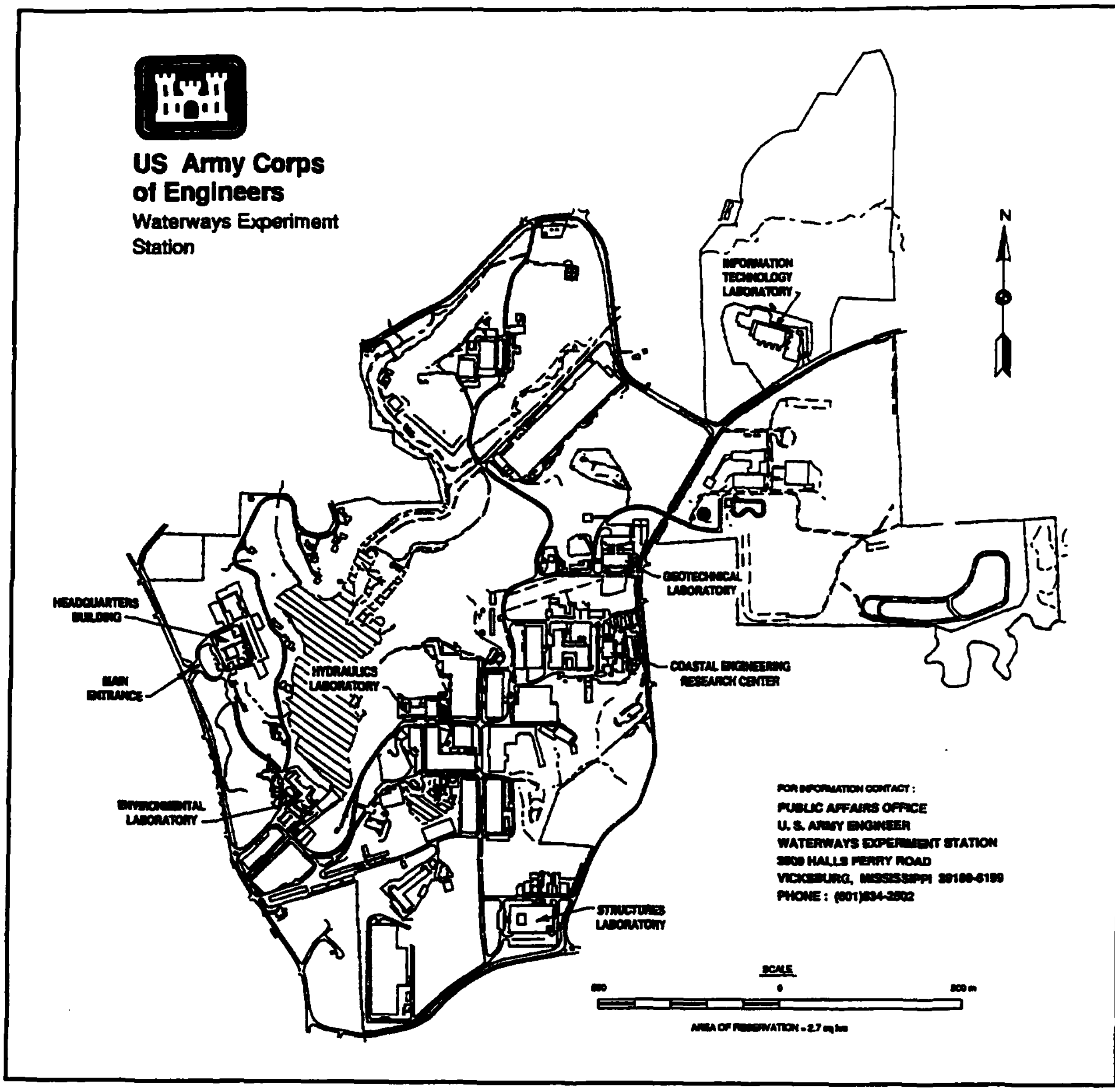

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Preface

This study was authorized by the U.S. Army Engineer Division, Pacific Ocean (POD), and was conducted by personnel of the Coastal Oceanography Branch (COB), Research Division (RD), Coastal Engineering Research Center (CERC), of the U.S. Army Engineer Waterways Experiment Station (WES). The study was conducted during the period April through May 1994. Mr. Stanley Boc, POD, oversaw progress of the study.

This report was prepared by Dr. Edward F. Thompson, Hydraulic Engineer, COB; and Ms. Lori L. Hadley, Hydraulic Engineer, COB. The work was performed under the direct supervision of Dr. Martin C. Miller, Chief, COB, and Mr. H. Lee Butler, Chief, RD, and under the general supervision of Mr. Charles C. Calhoun, Jr., Assistant Director, CERC, and Dr. James R. Houston, Director, CERC.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (U.S. statute)	1.6093	kilometers
nautical miles	1.852	kilometers

1 Introduction

Background

At the request of the U.S. Army Engineer Division, Pacific Ocean (POD), a numerical model wave response study of propòsed improvement Plan 6 to Maalaea small boat harbor was conducted by the U.S. Army Engineer Waterways Experiment Station's (USAEWES) Coastal Engineering Research Center (CERC). The study was conducted as an extension of an earlier study to assess the wave response of various alternative modification plans for the harbor (Lillycrop et al. 1993). This report is focussed on the suggested alternative Plan 6 for modifying the existing harbor. Plan 6 was not considered in the earlier study. Information provided in the earlier report is referenced in this report but generally not repeated. Thus, for example, detailed descriptions of the existing harbor and the numerical model must be obtained from the report by Lillycrop et al. (1993).

Study Location

Maalaea small boat harbor is located on the southwest coast of the island of Maui, HI, the second largest island in the Hawaiian chain. The harbor is approximately 7 miles[1] south of the County seat in Wailuku and approximately 8 miles south of the commercial and business center of Kahului (Figure 1).

Harbor space on Maui is much in demand. Maalaea small boat harbor contains 93 berths. Wave energy penetrates inside the harbor sufficiently often and with enough energy that the harbor is regarded as having a "surge" problem. A larger, more protected small boat harbor at Maalaea would help satisfy the demand for tranquil berthing space.

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

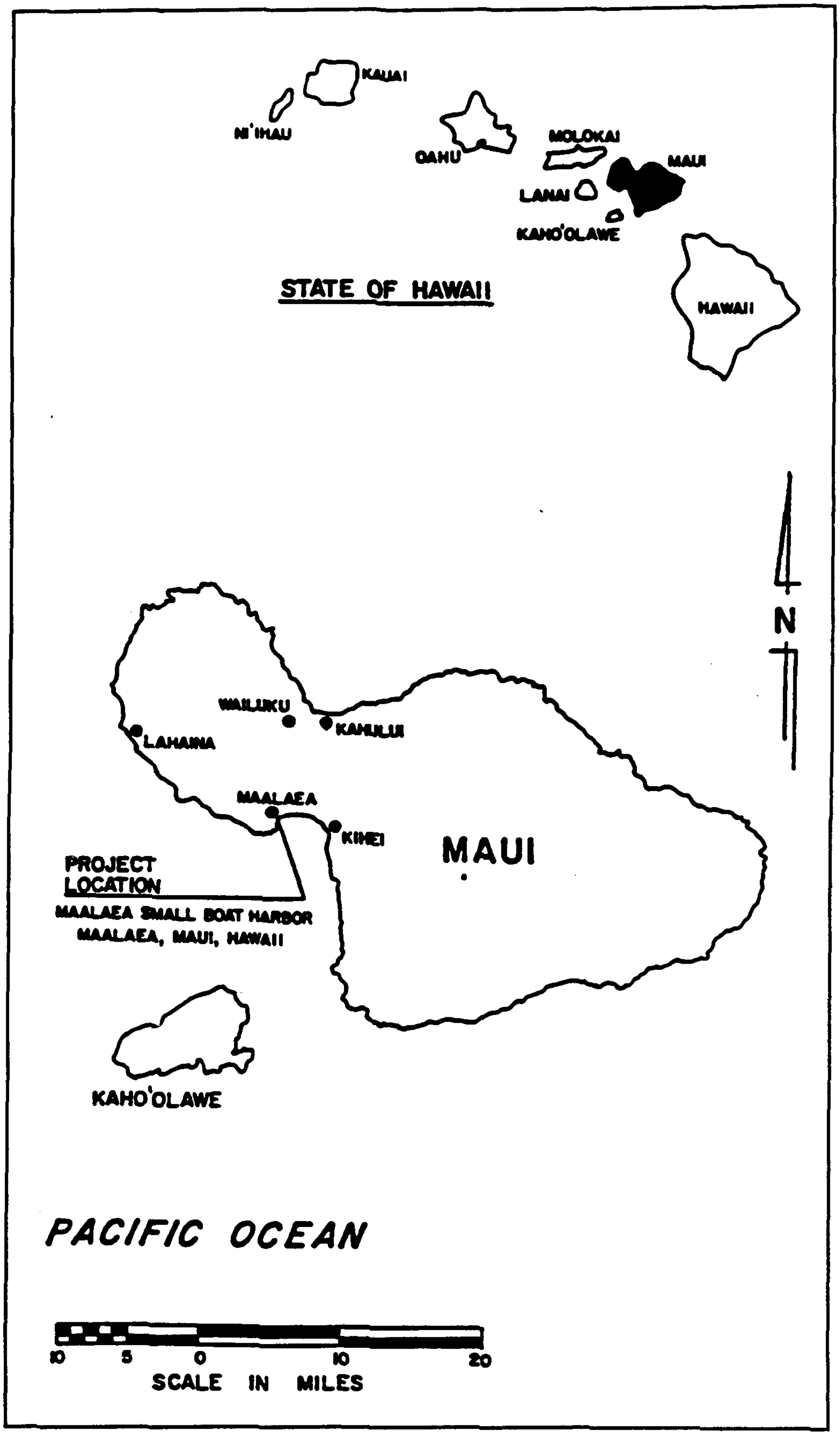

Figure 1. Study location

The shoreline of Maalaea Bay is part of an isthmus connecting two inactive volcanos which form west and east Maui. The shoreline is characterized by a long narrow coral-sand beach. The area is also known among surfers as the Maalaea Pipeline because of an infrequent, but world class breaking wave condition. Maalaea Harbor is located at the extreme west end of this beach. Several lesser surfing spots are also located near the harbor. There is concern that changes at Maalaea small boat harbor may impact nearby surfing areas.

The existing harbor configuration is shown in Figure 2. Plan 6 (Figure 3) would provide a more protected harbor area without new structures *exterior* to the existing harbor. Its disadvantages include lack of needed new mooring space and a possibly difficult entrance channel section confined between two rock-faced structures. Plan 6 includes the following improvements:

a. Addition of a 95-ft-wide, 500-ft-long mole extending from the east end of the existing south breakwater into the harbor.

b. A 610-ft-long entrance channel, varying in width from 150 to 200 ft, and varying in depth from 12 to 15 ft (not shown in Figure 3).

c. A 570-ft-long interior revetment varying in width from 50 to 170 ft.

Study objectives of Headquarters, U.S. Army Corps of Engineers (HQUSACE) and POD were to test the proposed harbor design improvements against the criteria that wind wave and swell wave heights not exceed 1 ft in berthing areas and 2 ft in the entrance and access channels and turning basin more than approximately 10 percent of the time per year. Another objective was to assess the potential for harbor oscillations in Plan 6 relative to the existing harbor. To accomplish these objectives, the HARBD numerical harbor wave response model (Chen and Houston 1987) developed at CERC was used.

Modeling Approach

Both numerical and physical modeling were originally considered for study of alternative modifications to Maalaea small boat harbor. As discussed by Lillycrop et al. (1993), the numerical modeling approach was chosen to assess the variety of proposed alternatives. Assumptions inherent in the numerical modeling approach are as follows:

a. No wave transmission or overtopping of structures.

b. Structure crest elevations will not be tested or optimized.

c. No wave-wave or wave-current interaction.

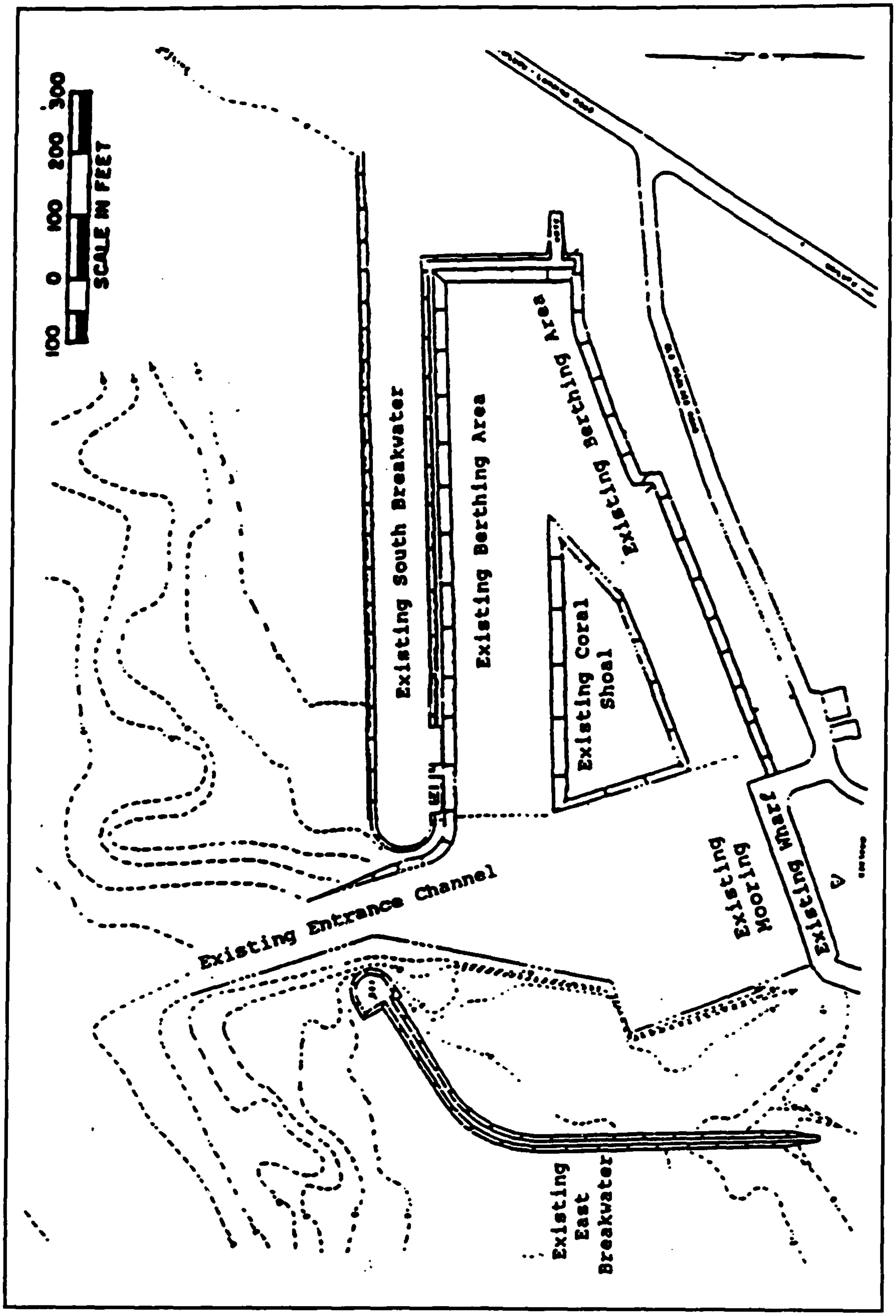

Figure 2. Existing plan

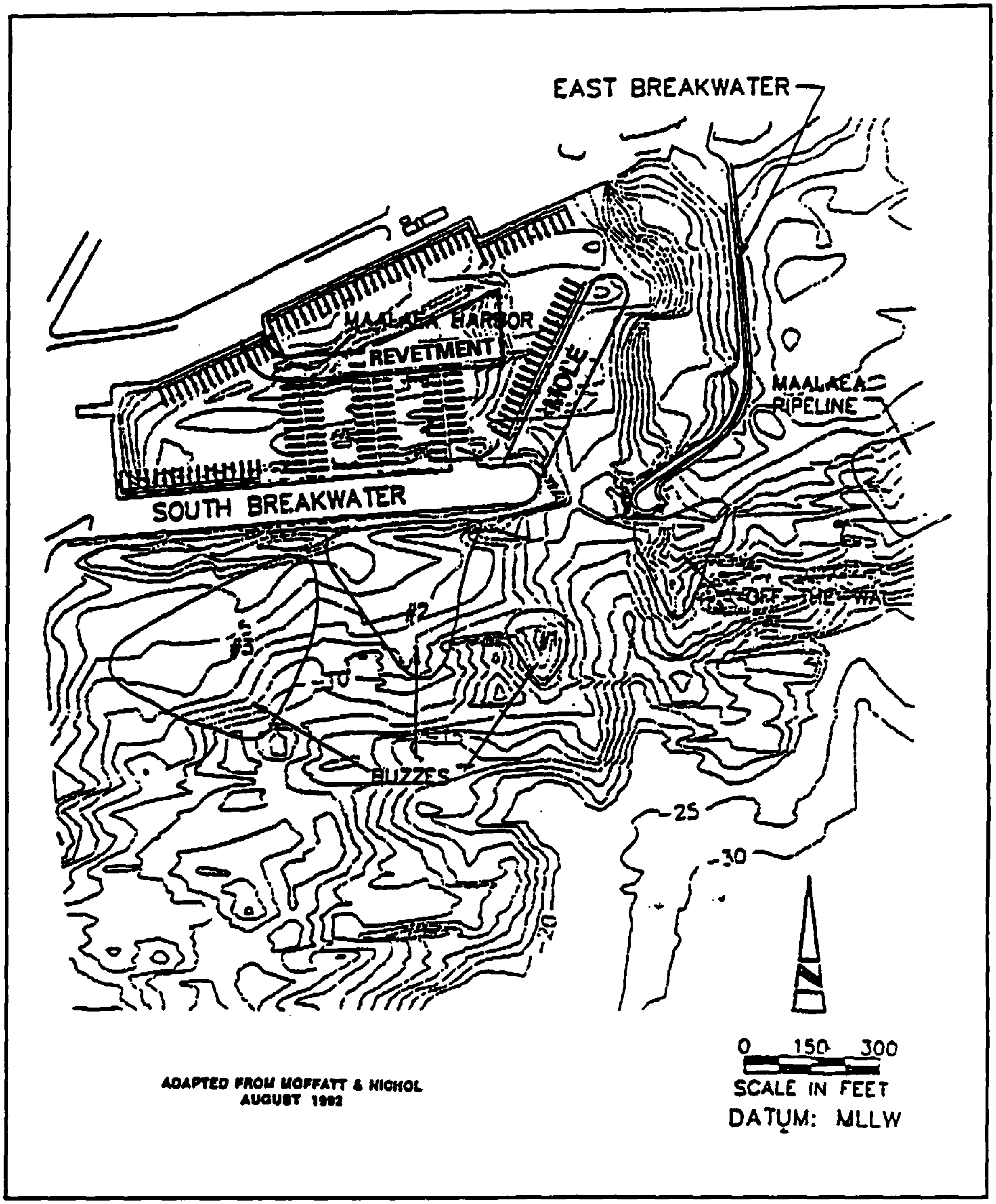

Figure 3. Proposed Plan 6

d. No wave breaking effects.

e. Diffraction around the structure ends is represented by diffraction around a blunt vertical wall with specified reflection coefficient.

f. Energy losses at constricted entrances are not explicitly included.

Within the limits of the assumptions, the numerical modeling approach can be expected to give a reasonable assessment of the proposed plans.

The procedures used to develop incident wind wave and swell information for the harbor response model are described by Lillycrop et al. (1993). The HARBD model and finite element grid used are briefly presented in Chapter 2. Results for wind waves and swell are given in Chapter 3. Harbor oscillation results for both the existing harbor and Plan 6 are given in Chapter 4. Conclusions are summarized in Chapter 5.

2 Numerical Model

The numerical model HARBD is a steady state hybrid element model (Chen and Houston 1987, Chen 1986, Lillycrop 1993). The model is described in the earlier report on Maalaea small boat harbor (Lillycrop et al. 1993). An overview of the model and its applications is also available in Thompson and Hadley (1994).

A finite element grid was developed to represent Plan 6 by modifying the grid used previously for the existing harbor (Figure 4). The new mole and interior revetted area were added and bathymetry was modified to give a 15-ft-deep entrance channel. The channel depth transitions to 12 ft near the existing wharf. Grid characteristics are summarized in Table 1. The grid manipulation software was developed by Turner and Baptista (1993).

Table 1
Grid Size, Plan 6

Item	Size
Numer of Elements	6,747
Number of Nodes	3,603
Number of Solid Boundary Nodes	353
Number of Semicircle Boundary Nodes	105
Length of Typical Element, ft	20

Reflection coefficients along solid boundaries are the same as those used previously for the existing harbor for the boundaries common to both plans. Reflection coefficients along the new boundaries introduced in Plan 6 were estimated as 0.5 along the new mole and 0.35 along the interior revetment (Figure 5). Other parameter values used in the model are summarized in Table 2.

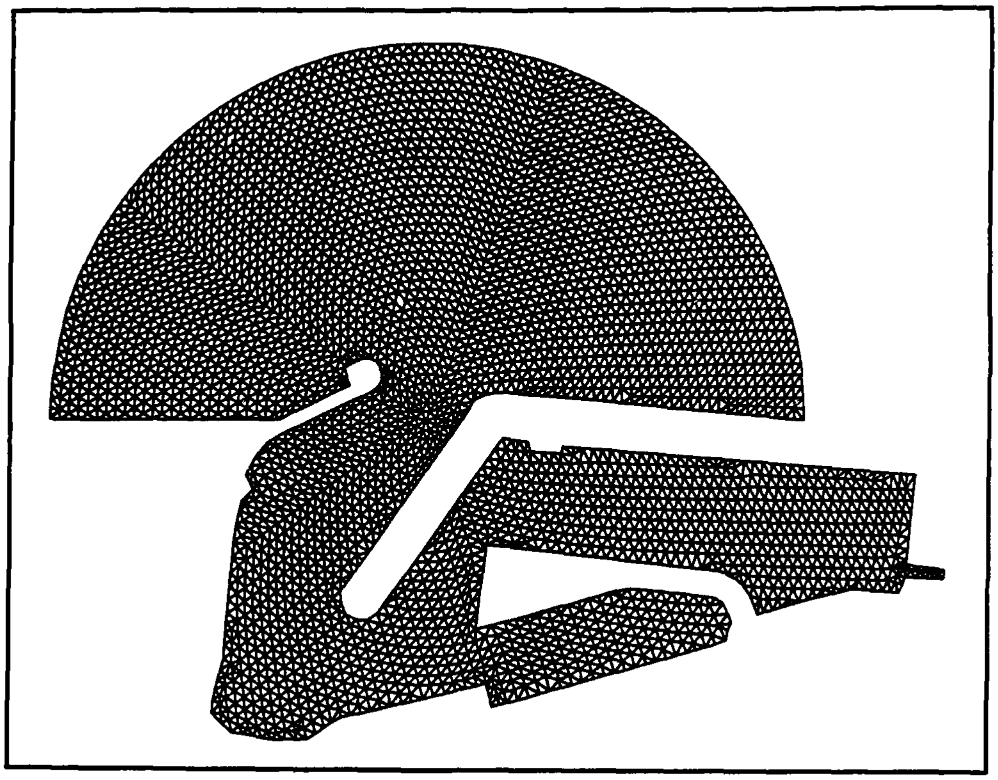

Figure 4. Finite element grid for Plan 6

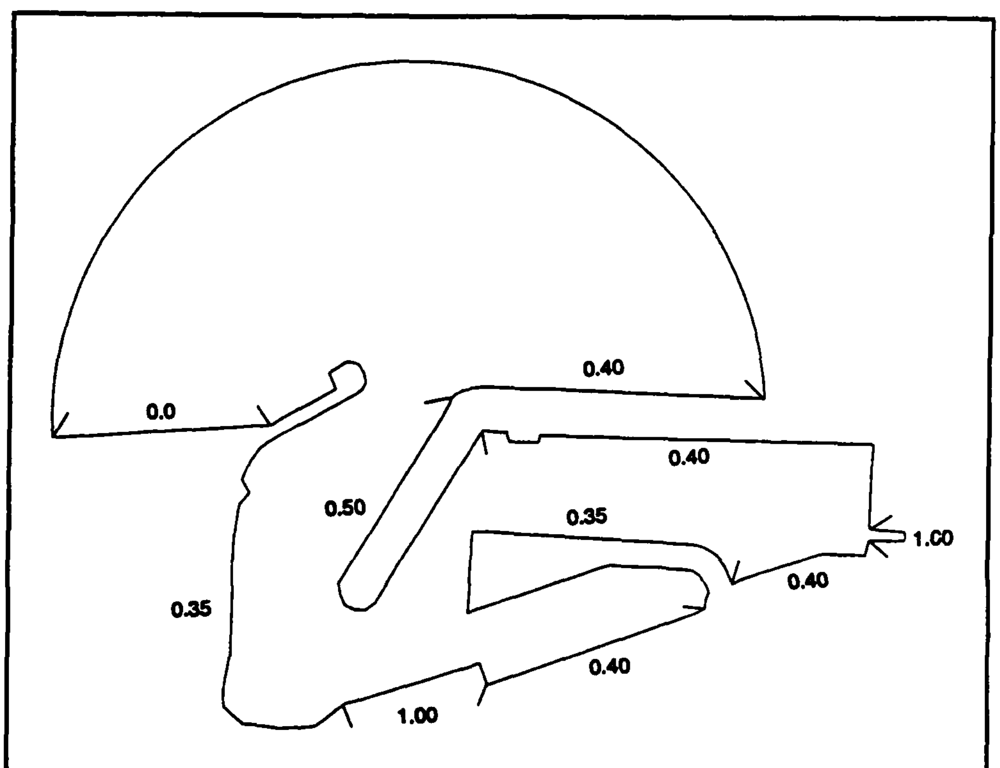

Figure 5. Boundary reflection coefficients for Plan 6

Table 2
Parameter Values Used in HARBD, Plan 6

Parameter	Value	
	Wind Waves and Swell	Harbor Oscillations
Bottom friction, β	0.0	0.0
Coastline reflection, $K_{r,coast}$	0.1	1.0
Depth in infinite region, h_{far}	25 ft	25 ft

Different parameters are used for the harbor oscillation tests. The reflection coefficient was set to 1.0 for all boundaries, since long waves generally reflect very well from a coastal boundary. Long waves are more affected by bottom friction than short waves, so a value of bottom friction β greater than zero is appropriate. However a default β of zero was used in these tests in which relative differences between the existing harbor and Plan 6 are the primary concern.

3 Harbor Response to Wind Waves and Swell

To establish the wave climate incident to Maalaea Harbor, a total of 187 deepwater wave height, period, and direction combinations were input to the SHALWV model (Lillycrop et al. 1993). The SHALWV grid extended beyond the island of Kahoolawe. It allowed estimates of sheltering and shallow-water effects on waves between the deepwater, open ocean south of Kahoolawe and the Maalaea Harbor area. To determine wave heights in Maalaea Harbor, the SHALWV wave heights near the harbor (in the vicinity of the seaward boundary of the HARBD grid) were multiplied with the HARBD amplification factors corresponding to each deepwater condition. The 187 wave height, period, and direction combinations were tested for Plan 6. All simulations were run on the WES CRAY Y-MP supercomputing facilities.

Output "basins" were selected for each plan tested to determine wave response throughout the harbor. A basin is a small cluster of elements over which the HARBD response is averaged to give a more representative output. Eighteen output basin locations were selected for Plan 6. The locations, selected by CERC and POD, are shown in Figure 6. Since the wave height criteria which must be satisfied are different for channel areas than for berthing areas, the basins are designated by area (Table 3). The HARBD amplification factors at these basins for each deepwater wave condition were saved and tabulated (Appendix A).

Table 3
Designation of Output Basin Areas, Plan 6

Area	Basin Numbers
Channel	1-6
Berthing	7-18

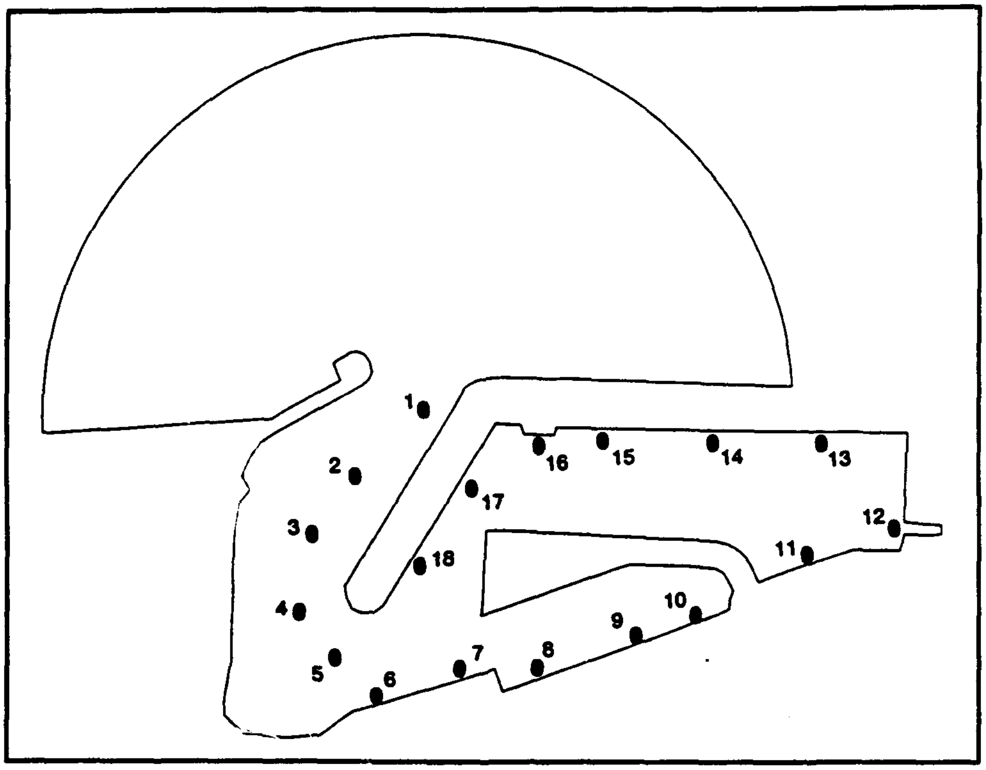

Figure 6. Output basin locations for Plan 6

The percent occurrence of wave heights exceeding 1 ft in the berthing areas and 2 ft in the entrance and access channels and turning basin were calculated for Plan 6. The procedure is identical to that used by Lillycrop et al. (1993).

Table 4 is a tabulation of the HARBD-SHALWV wave heights initially exceeding the HQUSACE criteria for each deepwater wave direction. The table shows that wave heights initially exceeding the maximum 1-ft criterion in berthing areas (basins 7 through 18) did not occur for deepwater incident wave heights of less than 9 ft. Wave heights exceeding the 2 ft maximum criterion in the entrance channel (basins 1-6) resulted from 9-, 13-, and 15-sec waves from the 225-deg direction and 17-sec waves from the 180-deg direction. These waves occurred at the harbor entrance in basin 1.

Table 4
HARBD-SHALWV Wave Heights Exceeding HQUSACE Criteria, Plan 6

Deepwater Direction (deg az.)	Deepwater Period (sec)	Height (ft)	Deepwater Height (ft)	HARBD Amp. Factor	SHALWV Height (ft)	Basin Number
			1-ft Criterion			
135.0	*					
157.5	*					
180.0	*					
202.5	*					
225.0	*					
247.5	*					
270.0	*					
			2-ft Criterion			
135.0	*					
157.5	*					
180.0	17	2.04	3.8	1.22	1.68	1
202.5	*					
225.0	9 13 15	2.01 2.31 2.02	4.7 7.0 6.9	1.27 1.13 1.07	1.58 2.04 1.89	1 1 1
247.5	*					
270.0	*					

*Deepwater wave heights between 1-9 ft do not exceed HQUSACE criteria for this condition.

The percent occurrence of wave heights exceeding the maximum 1-ft and 2-ft criteria was calculated using the percent occurrence tables of deepwater conditions and HARBD-SHALWV wave height results. These results are given in Tables 5 and 6 and illustrated in Figure 7. Although wave breaking was not taken into account in the tables, the higher wave heights may break over the reef, thus reducing wave heights in the harbor. In evaluating the percent occurrence results, it is apparent that waves approaching from the southeast (135.0- and 157.0-deg) directions are insignificant in comparison to waves approaching from south to west (180.0- to 270.0-deg) directions.

The percentage of wave heights exceeding the maximum 1-ft and 2-ft criteria for the existing condition and Plans 1, 2, 3, 1a, 1b, and 6 are summarized in Table 7 along with the HQUSACE criteria. These values are somewhat conservative since they represent basins with the largest wave

Table 5
Percent Occurrence of Wave Height Versus Direction, Plan 6 - Wave Heights Exceeding 1 ft in Berthing Areas

Deepwater Wave Height, ft	Deepwater Wave Direction (deg azimuth)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
3.01-4.00								0.00
4.01-5.00								0.00
5.01-6.00								0.00
6.01-7.00								0.00
7.01-8.00								0.00
8.01-9.00								0.00
9.01+						1.25	0.65	1.90
TOTAL	0.00	0.00	0.00	0.00	0.00	1.25	0.65	1.90

Table 6
Percent Occurrence of Wave Height Versus Direction, Plan 6 - Wave Heights Exceeding 2 ft in Channel

Deepwater Wave Height, ft	Deepwater Wave Direction (deg azimuth)							
	135.0	157.5	180.0	202.5	225.0	247.5	270.0	Total
3.01-4.00			0.05					0.05
4.01-5.00					0.36			0.36
5.01-6.00			0.02		0.49			0.51
6.01-7.00					0.57			0.57
7.01-8.00			0.01		2.25			2.26
8.01-9.00					1.88			1.88
9.01+						1.25	0.65	1.90
TOTAL	0.00	0.00	0.08	0.00	5.54	1.25	0.65	7.52

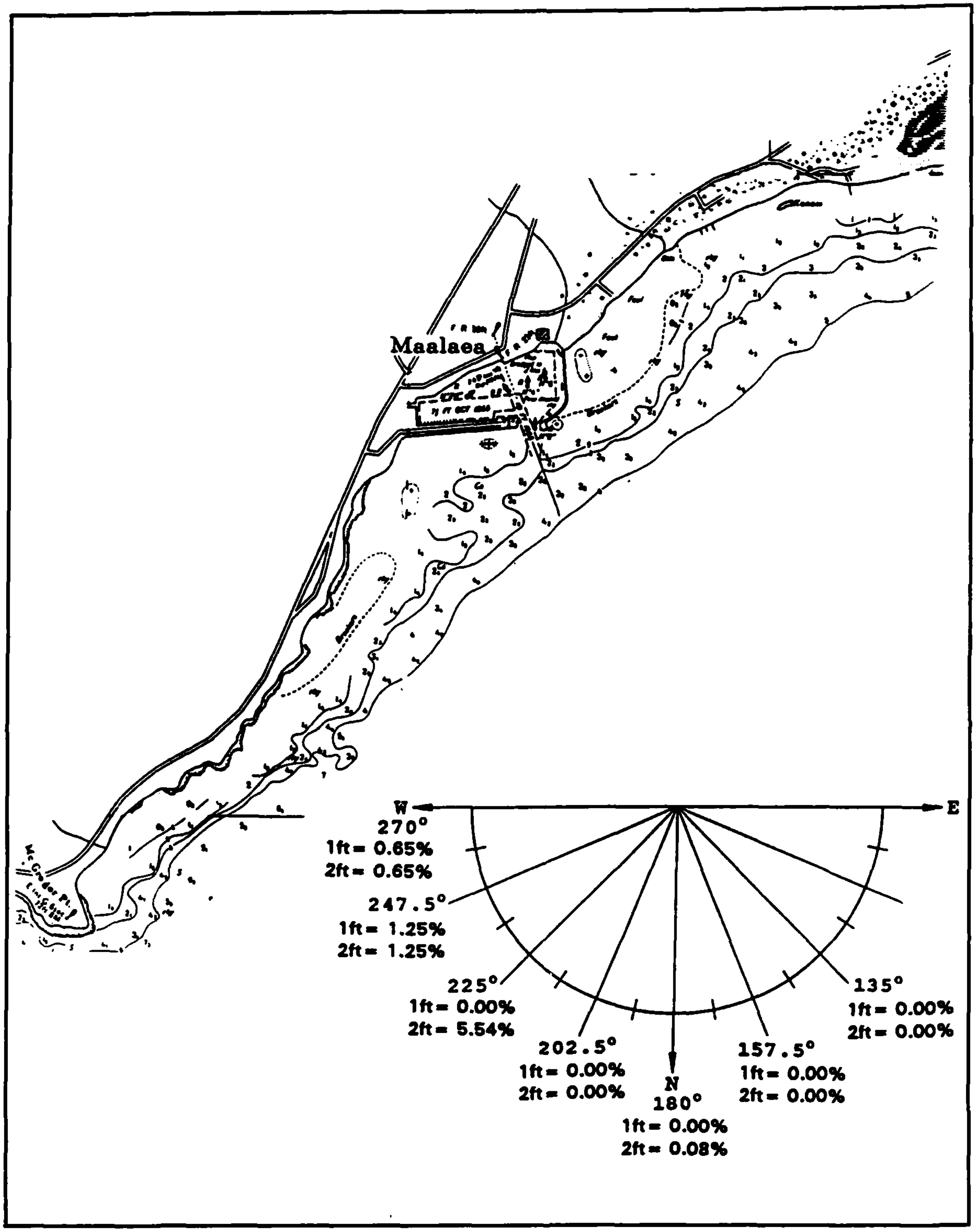

Figure 7. Percent occurrence of wave heights exceeding HQUSACE criteria, Plan 6

heights occurring in the harbor for each deepwater wave condition. Plan 6 satisfies the HQUSACE criteria for providing adequate protection in the channel and berthing areas.

Table 7
Summary of Percent Occurrence of Wave Heights

Location	Percent of Time Criterion Is Exceeded							
	HQUSACE Criterion	Existing	Plan 1	Plan 2	Plan 3	Plan 1a	Plan 1b	Plan 6
Berthing areas (1 ft criterion)	< 10.0	21.4	6.1	17.7	2.0	10.0	18.9	1.9
Entrance Channel (2-ft criterion)	< 10.0	9.6	2.0	11.3	2.0	5.0	4.9	7.5

Although Plan 6 is acceptable relative to the usual protection criteria, it may result in unusually hazardous navigation conditions in the confined portion of the channel located between the east breakwater and the proposed new mole. Table 7 indicates the likelihood of encountering wave heights in the channel which exceed the HQUSACE threshold criterion. More detailed information about the distribution of wave height conditions above the threshold in Plan 6 is given in Figure 8. For example, the figure indicates that one percent of the time wave heights at some point in the channel will exceed about 3.3 ft. These conditions are characteristic of output basin 1. More protected areas would generally experience lower wave conditions.

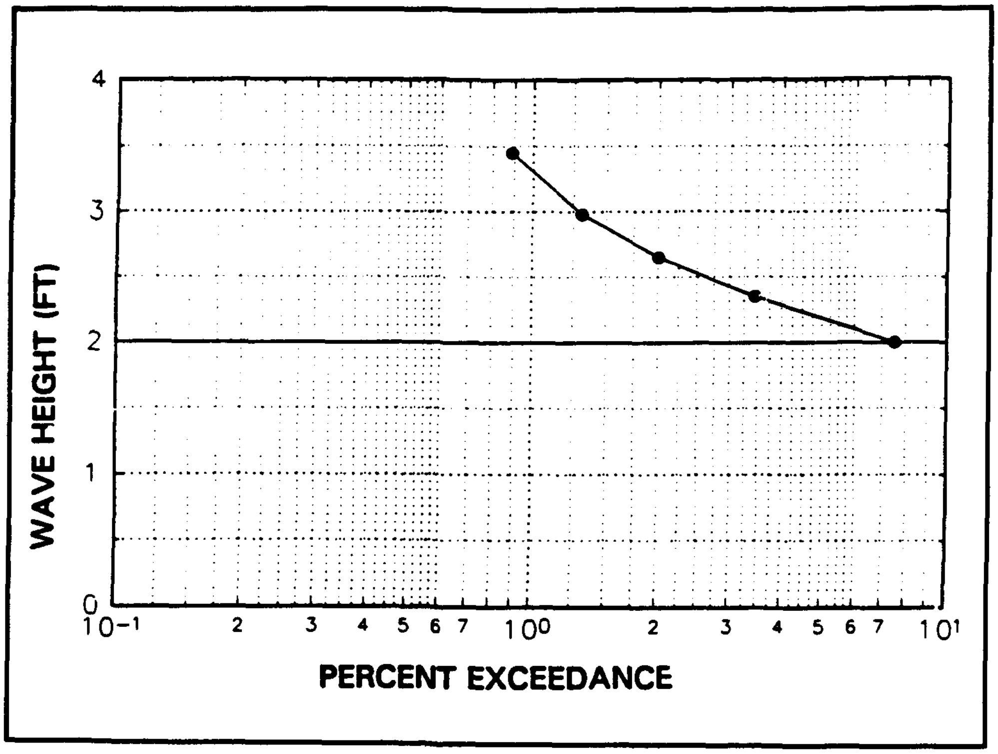

Figure 8. Cumulative distribution of wave heights exceeding HQUSACE criterion in channel, Plan 6

4 Harbor Oscillations

The HARBD numerical model was run for both Plan 6 and the existing plan to investigate the harbor response to wave periods characteristic of harbor oscillations. These tests were included because the "surge" problem reported in the existing harbor may arise in part from a resonant response to long-period wave energy impacting the harbor. Harbor oscillations were not considered in the earlier study by Lillycrop et al. (1993).

Incident long wave conditions consisted of wave periods ranging from 20 sec to 180 sec approaching the harbor from directly offshore (central approach direction relative to the HARBD seaward boundary). The increment between successive periods tested, based on frequency, was 0.00020 Hz for the shorter periods to 0.00007 Hz for most of the longer periods.

Amplification factors for Plan 6 and the existing harbor plan are shown by basin in Appendix B. It is important to note that the basin numbers in Appendix B for the existing harbor match the locations shown in Figure 6. Coincident basin locations for the existing harbor and Plan 6 allowed a more straighforward comparison of oscillation characteristics of the two harbor configurations.

Relative to harbor oscillations, the principal difference between Plan 6 and the existing harbor appears to be the addition of new "corner" areas in Plan 6. The corner just west of basin 10 and the corner between basins 16 and 17 both appear to act as antinodes for a number of different resonant oscillation modes, as evidenced by the high amplification factor peaks in Appendix B. Figure 9 shows the oscillation pattern for one Plan 6 resonant mode causing a strong response at basins 12, 14, 16, and 17. Similarly, Figure 10 shows a case with strong response at basins 8 and 10. Both of the potentially troublesome new corner areas may be desired for berthing facilities. Basin 12, which is an active antinode in the existing harbor, appears to be comparably active in Plan 6, though the resonant frequencies are different.

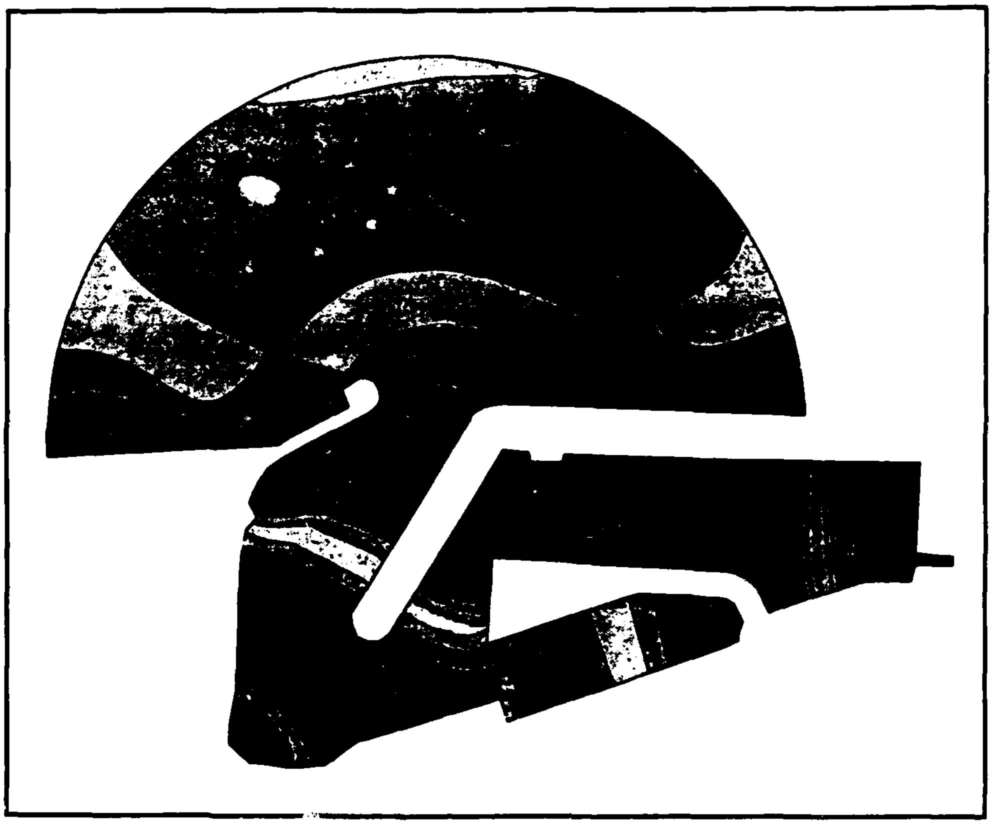

Figure 9. Oscillation pattern for Plan 6, 52.4-sec period (0.01910-Hz frequency); darker areas indicate higher amplification

The amplification factors shown in Appendix B should be viewed as conservatively high for several reasons. The wave reflection coefficient at all solid boundaries was taken as 1.0. Energy losses through a constricted entrance are not explicitly included in the HARBD model (Thompson et al. 1993). Finally, the east breakwater is represented as a solid barrier; but for harbor oscillation wave periods, significant energy may be transmitted through it.

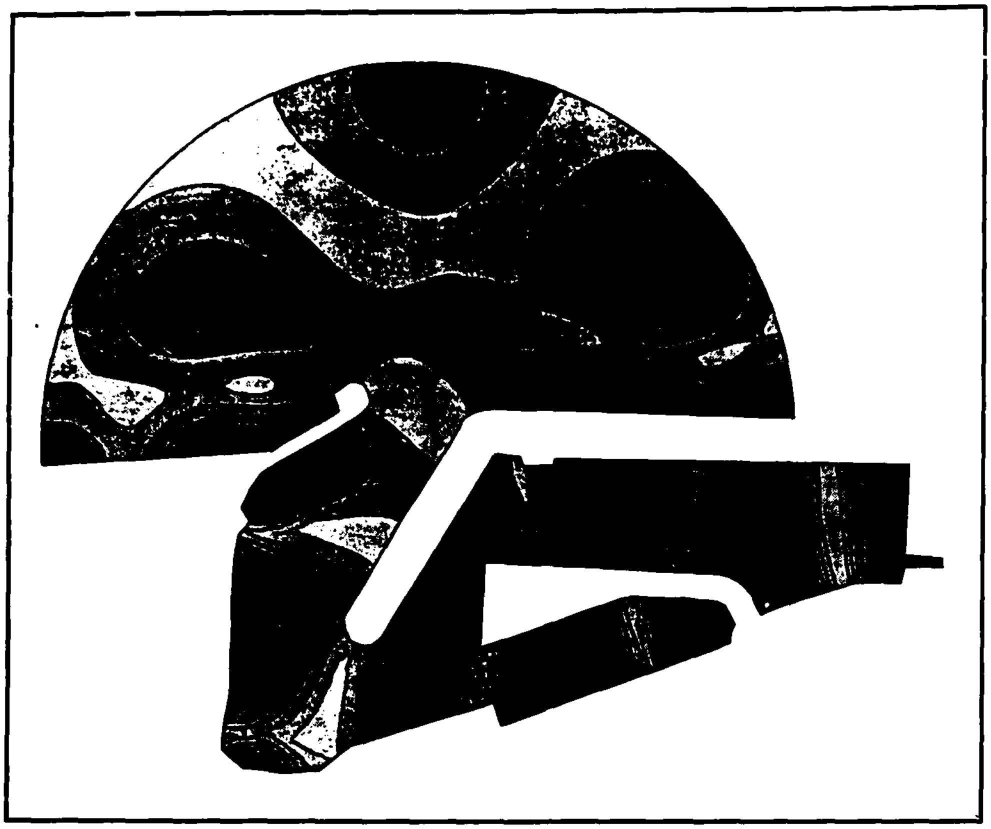

Figure 10. Oscillation pattern for Plan 6, 40.5-sec period (0.02470-Hz frequency); darker areas indicate higher amplification

5 Conclusions

The numerical model studies and results described in this report should be seen in light of the following considerations:

a. Deepwater wave estimates are based on measurements in the Monitoring of Completed Coastal Projects Program collected at Barbers Point, Oahu. Availability of incident wave data at the Maalaea Harbor vicinity would significantly improve the validity of the overall results.

b. Reflection coefficients were estimated as described by Lillycrop et al. (1993). Research in this area continues at CERC for better guidance.

c. The following assumptions were made in the implementation of the HARBD numerical model used in this study. The model does not consider wave transmission through the breakwater, overtopping of structures, and wave breaking effects in the entrance channel; structure crest elevations were not tested or optimized; currents and nonlinear effects were neglected; and diffraction around the structure ends was represented by diffraction around a blunt vertical wall with specified reflection coefficients. If wave transmission through the breakwater and overtopping of structures did occur in the harbor, the increased energy could result in larger wave heights than predicted. The presence of wave currents and breaking would increase hazardous navigation; however, wave breaking would reduce the energy in the harbor and result in lower wave heights than predicted. The primary effects which must be considered within a harbor such as Maalaea are wave refraction, diffraction, and dissipation effects for which the model has been well verified.

d. Energy losses for long-period (harbor oscillation) waves passing through a constricted entrance were not explicitly modeled.

e. The HARBD model uses monochromatic waves only.

Based on the results of this study, the following conclusions were reached:

a. Plan 6 is satisfactory in providing the harbor with adequate protection from the incident wind wave and swell climate.

b. Navigation during high wave conditions is potentially more hazardous in Plan 6 relative to other plans because much of the entrance channel is confined between two rock-faced structures.

c. Plan 6 can potentially lead to a significant increase in the amplitude of harbor oscillations by:

(1) Creating more confined corners (which can act as antinodes) in desired berthing areas.

(2) Creating a new solid, impermeable, eastern boundary for the harbor basin. In the existing harbor, the permeable east breakwater serves as the eastern boundary of the harbor basin.

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Appendix A
HARBD Wave Amplification Factors, Wind Waves and Swell

Table A1
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 135.0 deg

Basin	Deepwater Wave Period, sec					
	9	11	13	15	17	20
1	1.30	0.94	0.51	1.26	0.15	1.07
2	0.98	0.65	0.45	0.71	0.12	0.63
3	0.60	0.35	0.35	0.43	0.07	0.55
4	0.56	0.47	0.22	0.30	0.04	0.23
5	0.34	0.38	0.18	0.14	0.01	0.07
6	0.28	0.22	0.15	0.17	0.01	0.11
7	0.09	0.12	0.16	0.19	0.02	0.01
8	0.10	0.05	0.07	0.10	0.01	0.02
9	0.04	0.04	0.05	0.07	0.01	0.01
10	0.02	0.03	0.03	0.04	*	0.01
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	*	0.01	0.01	*	0.01
14	0.01	0.01	0.02	0.01	*	0.01
15	0.01	0.02	0.02	0.02	*	0.01
16	0.01	0.02	0.03	0.02	*	0.02
17	0.08	0.07	0.12	0.11	0.01	0.04
18	0.08	0.07	0.12	0.11	0.01	0.04

*Wave amplification factor is below significance for tabulation.

Table A2
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 157.5 deg

Basin	Deepwater Wave Period, sec					
	9	11	13	15	17	20
1	0.27	1.06	0.44	1.35	0.76	1.00
2	0.50	0.68	0.40	0.68	0.43	0.57
3	0.25	0.37	0.33	0.44	0.28	0.40
4	0.24	0.52	0.20	0.30	0.18	0.21
5	0.16	0.40	0.16	0.16	0.06	0.04
6	0.13	0.25	0.12	0.18	0.07	0.05
7	0.03	0.14	0.13	0.19	0.11	0.07
8	0.04	0.06	0.06	0.10	0.06	0.05
9	0.02	0.04	0.04	0.06	0.04	0.02
10	0.01	0.03	0.03	0.04	0.02	0.01
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	0.01	0.01	0.01	*	*
14	*	0.02	0.01	0.01	*	0.01
15	*	0.03	0.02	0.02	*	0.01
16	0.01	0.04	0.03	0.03	*	0.01
17	0.04	0.09	0.10	0.12	0.04	0.03
18	0.04	0.09	0.10	0.12	0.04	0.03

*Wave amplification factor is below significance for tabulation.

Table A3
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 180.0 deg

Basin	Deepwater Wave Period, sec					
	9	11	13	15	17	20
1	0.36	0.42	0.14	1.02	1.22	0.20
2	0.11	0.30	0.15	0.53	0.60	0.12
3	0.08	0.22	0.10	0.37	0.39	0.08
4	0.08	0.18	0.08	0.25	0.28	0.04
5	0.06	0.14	0.06	0.16	0.13	0.01
6	0.03	0.09	0.05	0.16	0.15	0.01
7	0.01	0.07	0.05	0.17	0.18	0.02
8	0.01	0.03	0.03	0.08	0.10	0.01
9	0.01	0.02	0.02	0.05	0.06	0.01
10	*	0.01	0.01	0.03	0.03	*
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	*	*	0.01	0.01	*
14	*	0.01	0.01	0.01	0.01	*
15	*	0.01	0.01	0.02	0.02	*
16	*	0.02	0.01	0.03	0.02	*
17	0.01	0.04	0.04	0.11	0.10	0.01
18	0.01	0.04	0.04	0.11	0.10	0.01

*Wave amplification factor is below significance for tabulation.

Table A4
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 202.5 deg

	Deepwater Wave Period, sec					
Basin	**9**	**11**	**13**	**15**	**17**	**20**
1	0.35	0.68	0.61	0.60	1.12	0.32
2	0.15	0.48	0.27	0.39	0.48	0.21
3	0.06	0.41	0.23	0.25	0.33	0.13
4	0.08	0.36	0.09	0.18	0.23	0.08
5	0.08	0.28	0.04	0.13	0.11	0.02
6	0.06	0.18	0.03	0.13	0.13	0.01
7	0.03	0.17	0.04	0.13	0.15	0.03
8	0.01	0.08	0.02	0.06	0.08	0.02
9	0.01	0.05	0.01	0.04	0.05	0.01
10	0.01	0.03	0.01	0.02	0.03	0.01
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	0.01	*	0.01	*	*
14	*	0.02	*	0.01	0.01	*
15	*	0.03	0.01	0.02	0.01	*
16	0.01	0.04	0.01	0.02	0.02	*
17	0.02	0.11	0.03	0.09	0.08	0.01
18	0.02	0.11	0.03	0.09	0.08	0.01

*Wave amplification factor is below significance for tabulation.

Table A5
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 225.0 deg

Basin	Deepwater Wave Period, sec					
	9	11	13	15	17	20
1	1.27	0.72	0.89	1.07	0.95	0.91
2	0.27	0.27	0.44	0.42	0.44	0.47
3	0.23	0.27	0.41	0.39	0.29	0.42
4	0.35	0.23	0.21	0.20	0.21	0.18
5	0.30	0.19	0.15	0.14	0.10	0.05
6	0.19	0.12	0.13	0.12	0.11	0.08
7	0.05	0.12	0.14	0.13	0.13	0.01
8	0.03	0.05	0.07	0.06	0.07	0.01
9	0.03	0.03	0.04	0.04	0.04	0.01
10	0.02	0.02	0.03	0.03	0.03	*
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	*0.01*	*0.01*	*0.01*	*	*
14	*	0.01	0.01	0.01	0.01	0.01
15	0.01	0.02	0.02	0.02	0.01	0.01
16	0.01	0.03	0.03	0.02	0.01	0.01
17	0.04	0.07	0.10	0.09	0.07	0.03
18	0.04	0.07	0.10	0.09	0.07	0.03

*Wave amplification factor is below significance for tabulation.

Table A6
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 247.5 deg

	Deepwater Wave Period, sec					
Basin	9	11	13	15	17	20
1	1.02	0.70	1.15	0.76	0.81	0.96
2	0.42	0.45	0.46	0.37	0.40	0.51
3	0.26	0.39	0.42	0.25	0.26	0.45
4	0.39	0.26	0.22	0.18	0.15	0.19
5	0.31	0.21	0.16	0.08	0.03	0.05
6	0.18	0.15	0.14	0.10	0.02	0.09
7	0.09	0.16	0.15	0.11	0.07	0.01
8	0.04	0.08	0.07	0.06	0.05	0.01
9	0.03	0.05	0.05	0.04	0.02	0.01
10	0.02	0.03	0.03	0.02	0.01	*
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	0.01	0.01	*	*	*
14	0.01	0.02	0.01	0.01	*	0.01
15	0.01	0.03	0.02	0.01	*	0.01
16	0.01	0.04	0.03	0.01	*	0.01
17	0.05	0.11	0.10	0.06	0.02	0.03
18	0.05	0.11	0.10	0.06	0.02	0.03

*Wave amplification factor is below significance for tabulation.

Table A7
HARBD Wave Amplification Factors
Plan 6, Deepwater Wave Direction = 270.0 deg

	Deepwater Wave Period, sec					
Basin	9	11	13	15	17	20
1	1.07	0.88	1.15	0.76	0.81	0.96
2	0.42	0.49	0.46	0.37	0.40	0.52
3	0.26	0.44	0.42	0.25	0.26	0.46
4	0.29	0.28	0.22	0.18	0.15	0.19
5	0.22	0.24	0.16	0.08	0.03	0.05
6	0.18	0.18	0.13	0.10	0.02	0.09
7	0.08	0.19	0.15	0.11	0.07	0.01
8	0.04	0.09	0.07	0.06	0.05	0.01
9	0.03	0.06	0.05	0.04	0.02	0.01
10	0.02	0.04	0.03	0.02	0.01	*
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	0.01	0.01	*	*	*
14	0.01	0.02	0.01	0.01	*	0.01
15	0.01	0.03	0.02	0.01	*	0.01
16	0.01	0.04	0.03	0.01	*	0.01
17	0.05	0.14	0.10	0.06	0.02	0.03
18	0.05	0.14	0.10	0.06	0.02	0.03

*Wave amplification factor is below significance for tabulation.

Appendix B
HARBD Wave Amplification Factors, Harbor Oscillations

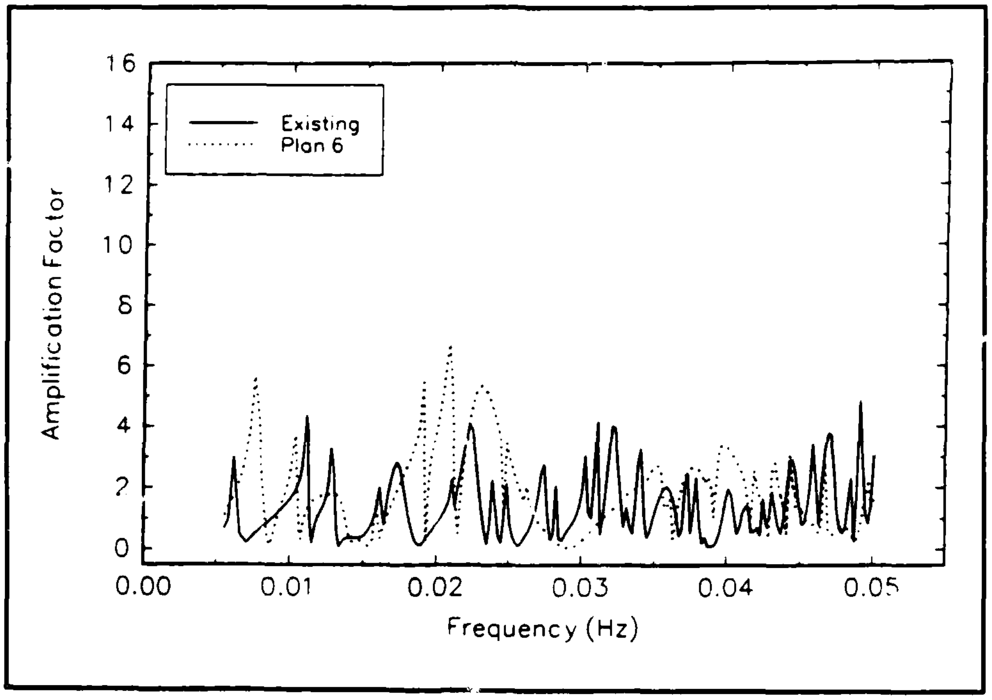

Figure B1. Wave amplification factor, basin 1

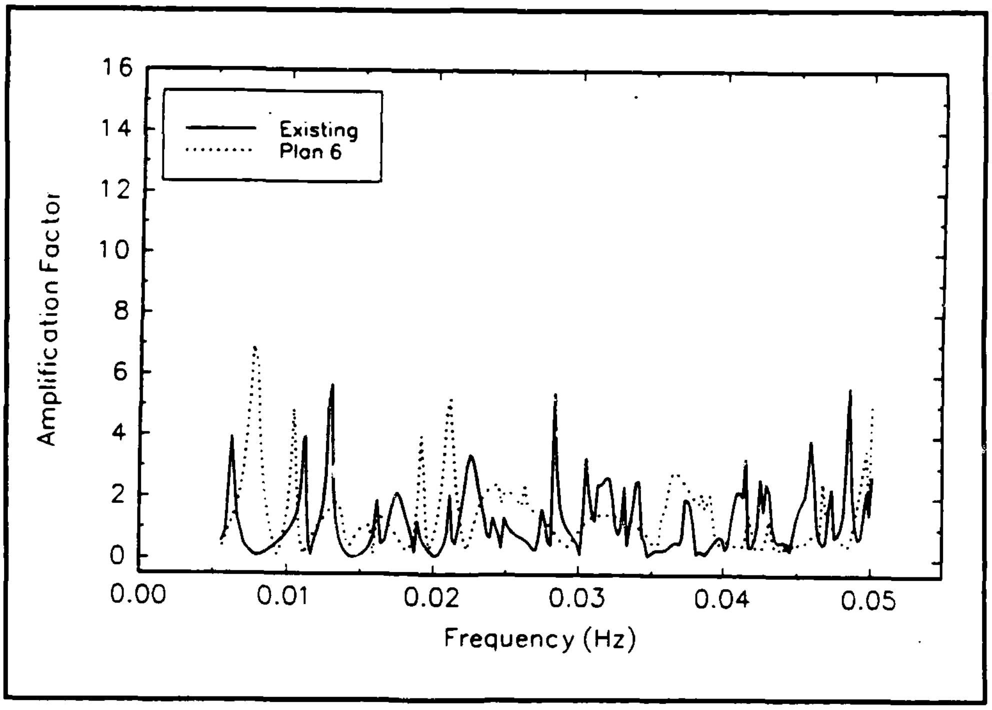

Figure B2. Wave amplification factor, basin 2

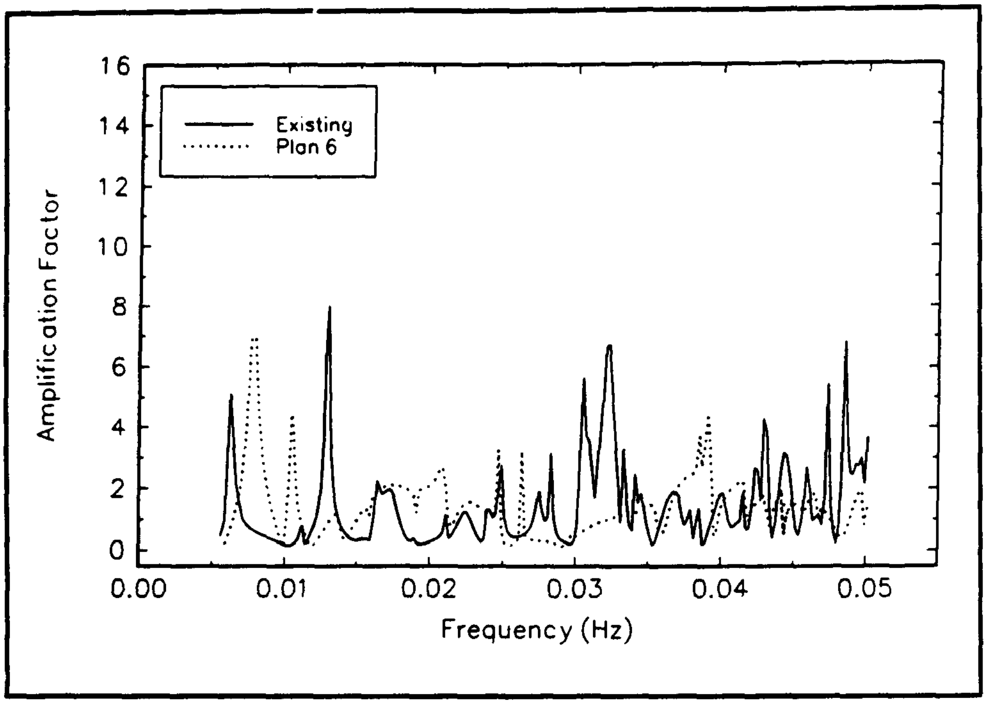

Figure B3. Wave amplification factor, basin 3

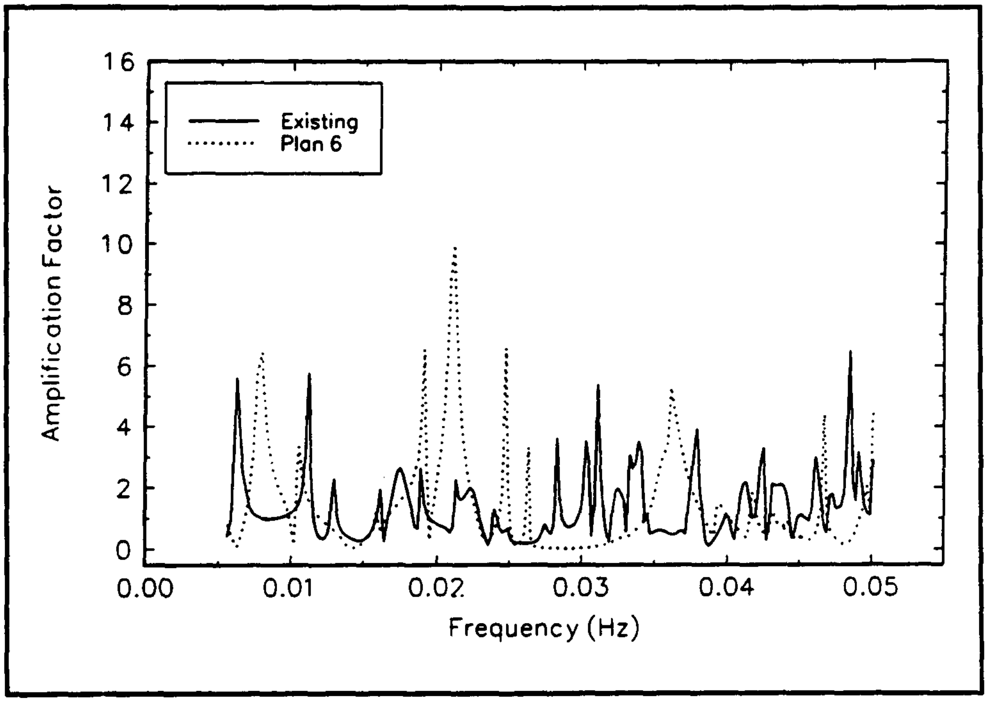

Figure B4. Wave amplification factor, basin 4

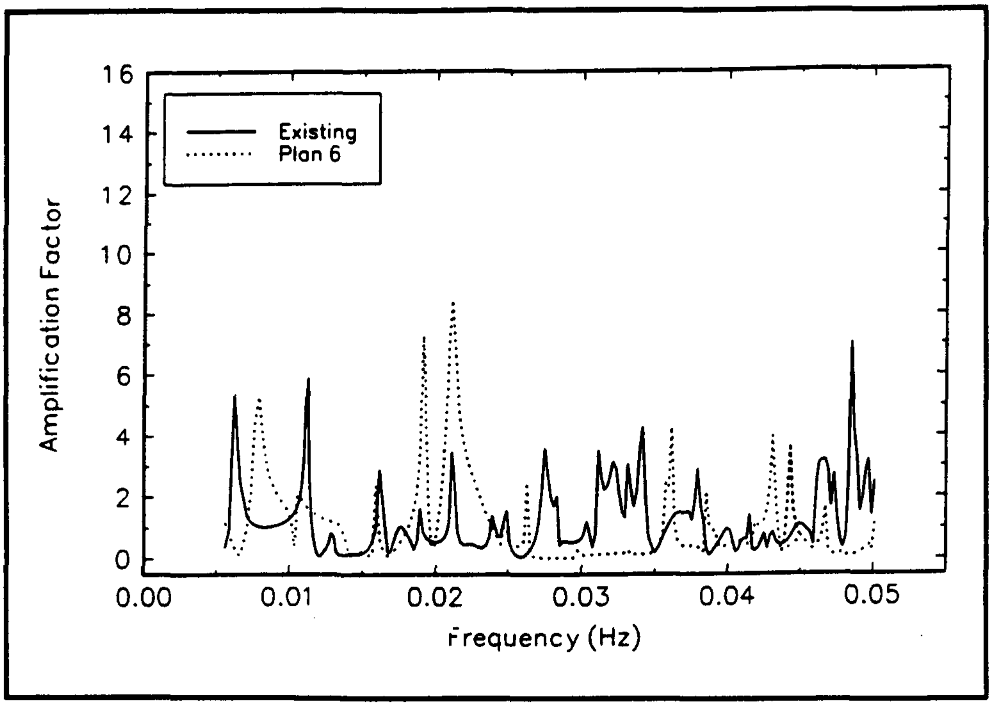

Figure B5. Wave amplification factor, basin 5

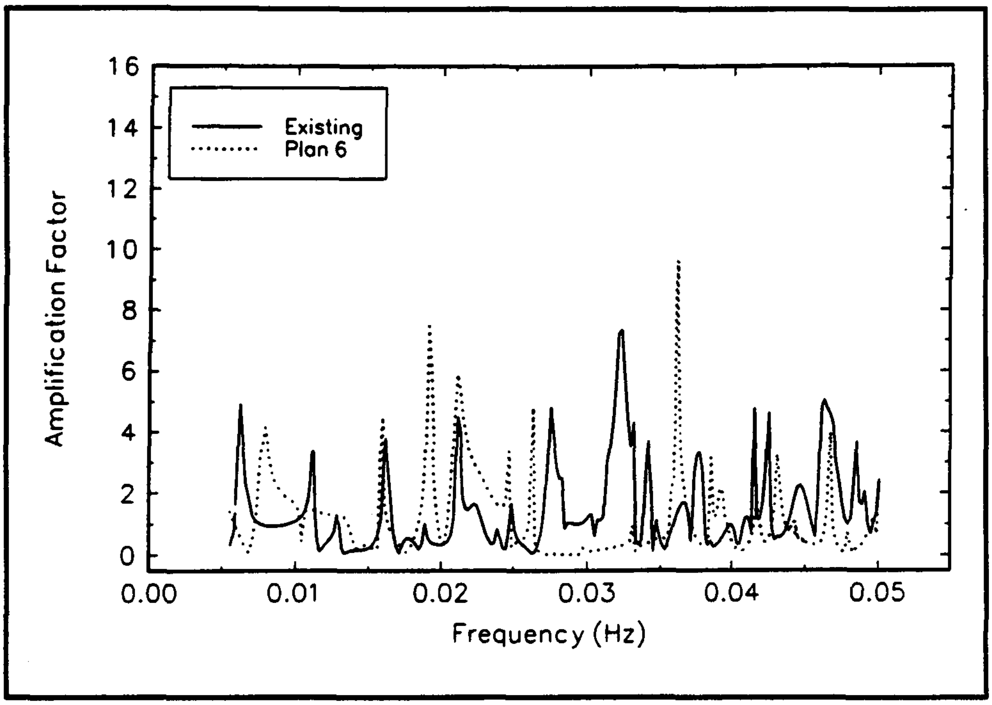

Figure B6. Wave amplification factor, basin 6

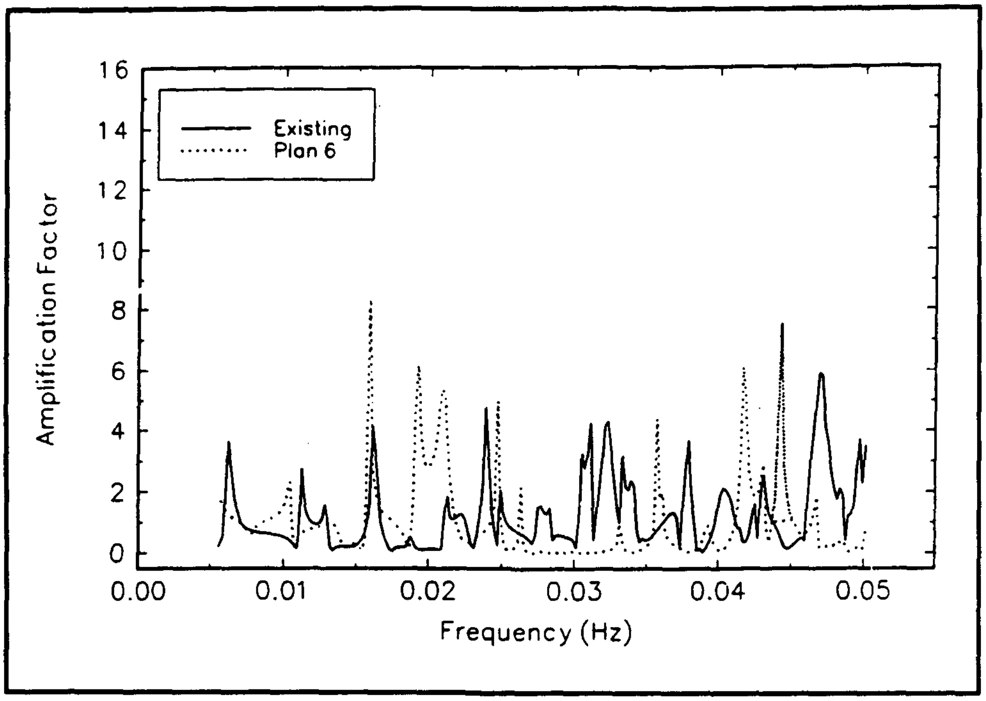

Figure B7. Wave amplification factor, basin 7

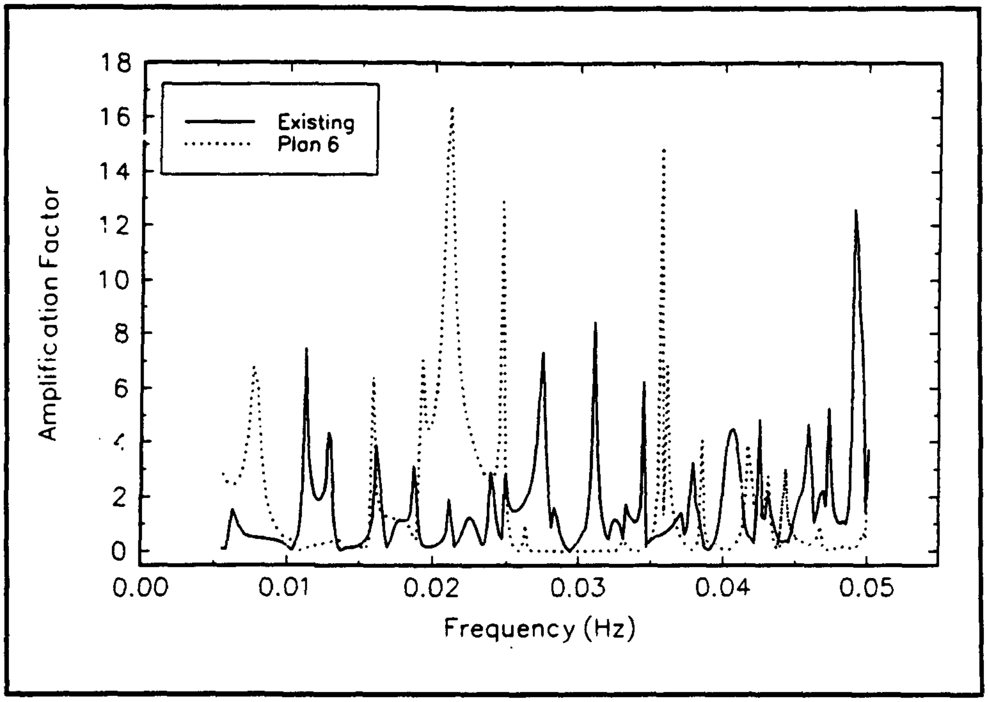

Figure B8. Wave amplification factor, basin 8

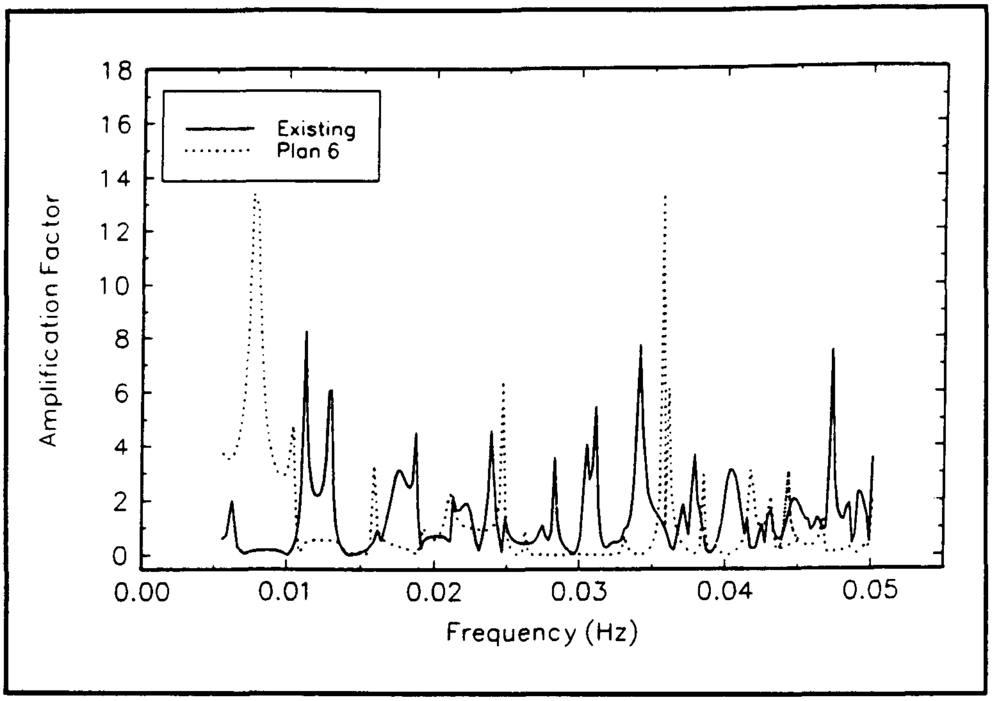

Figure B9. Wave amplification factor, basin 9

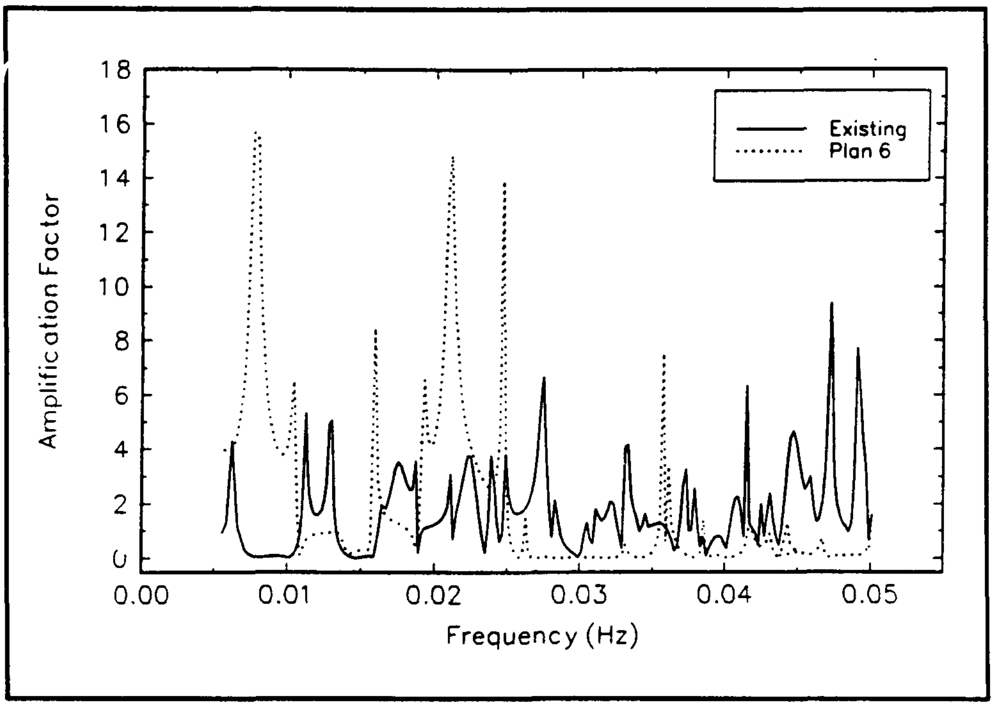

Figure B10. Wave amplification factor, basin 10

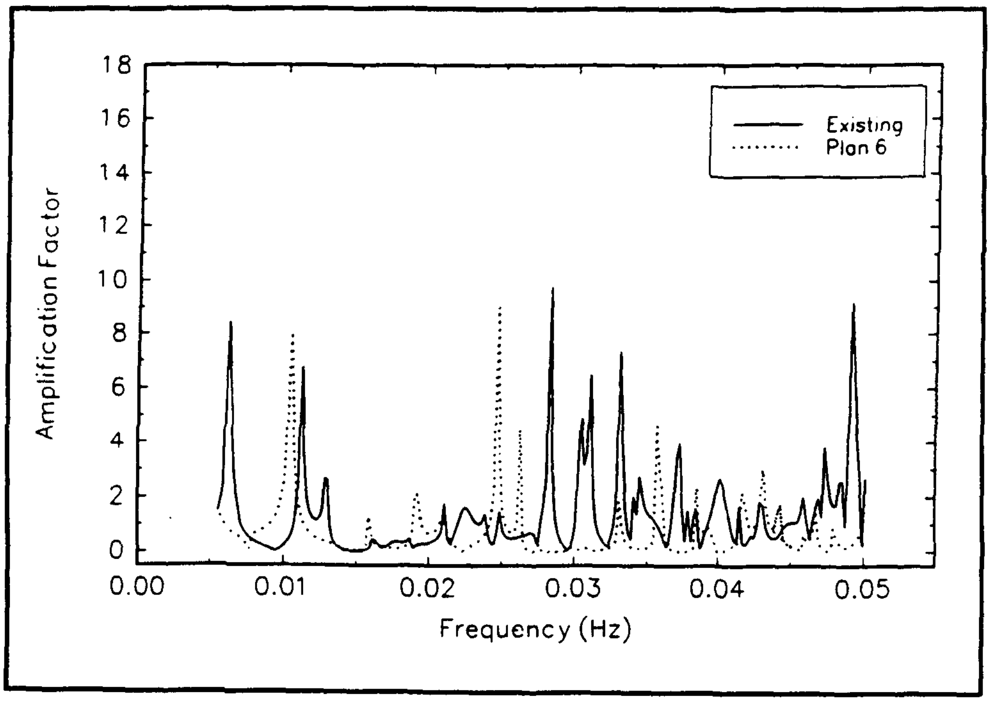

Figure B11. Wave amplification factor, basin 11

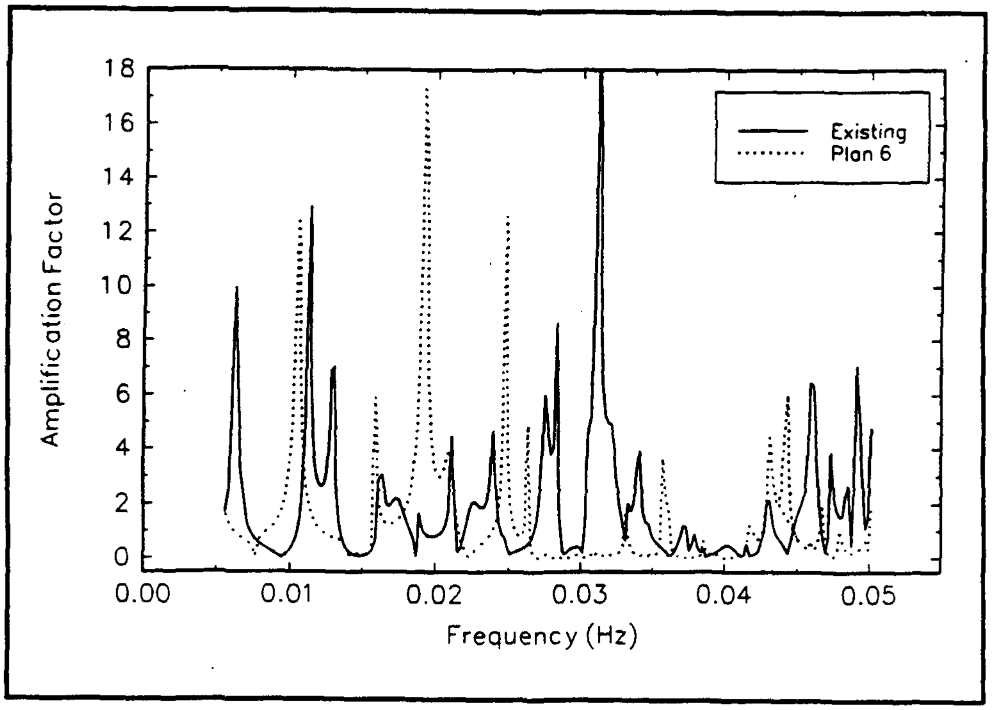

Figure B12. Wave amplification factor, basin 12

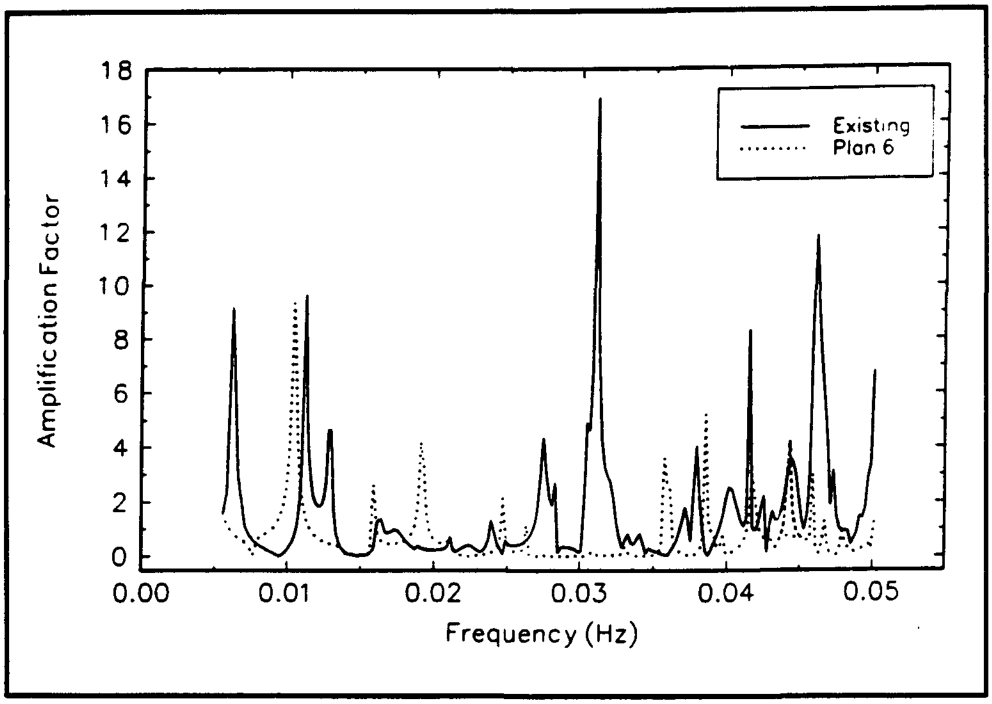

Figure B13. Wave amplification factor, basin 13

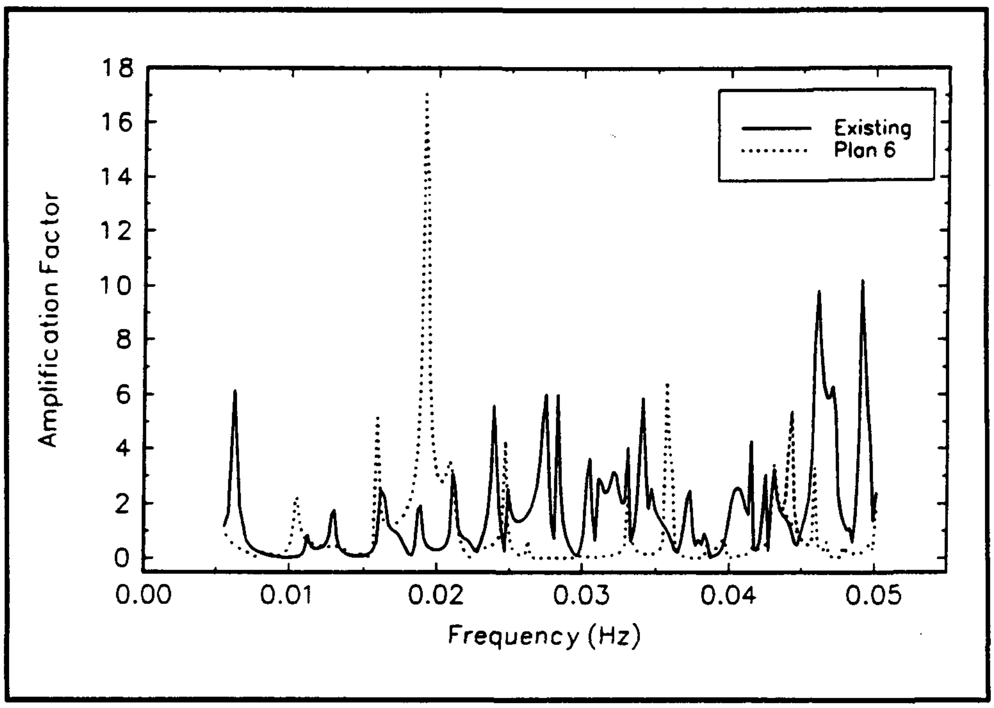

Figure B14. Wave amplification factor, basin 14

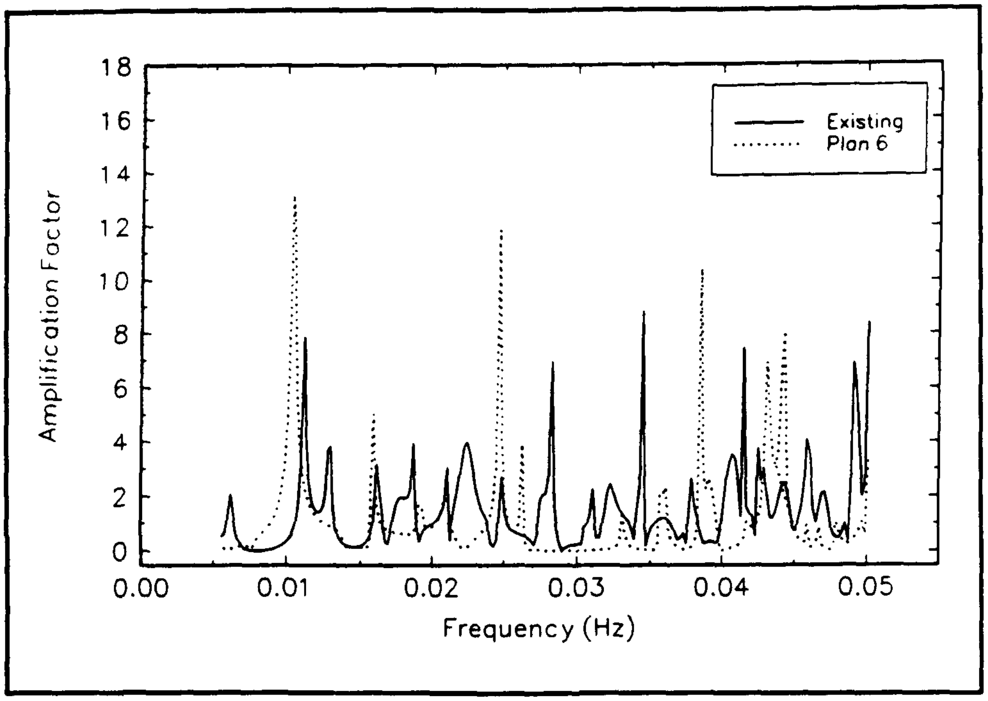

Figure B15. Wave amplification factor, basin 15

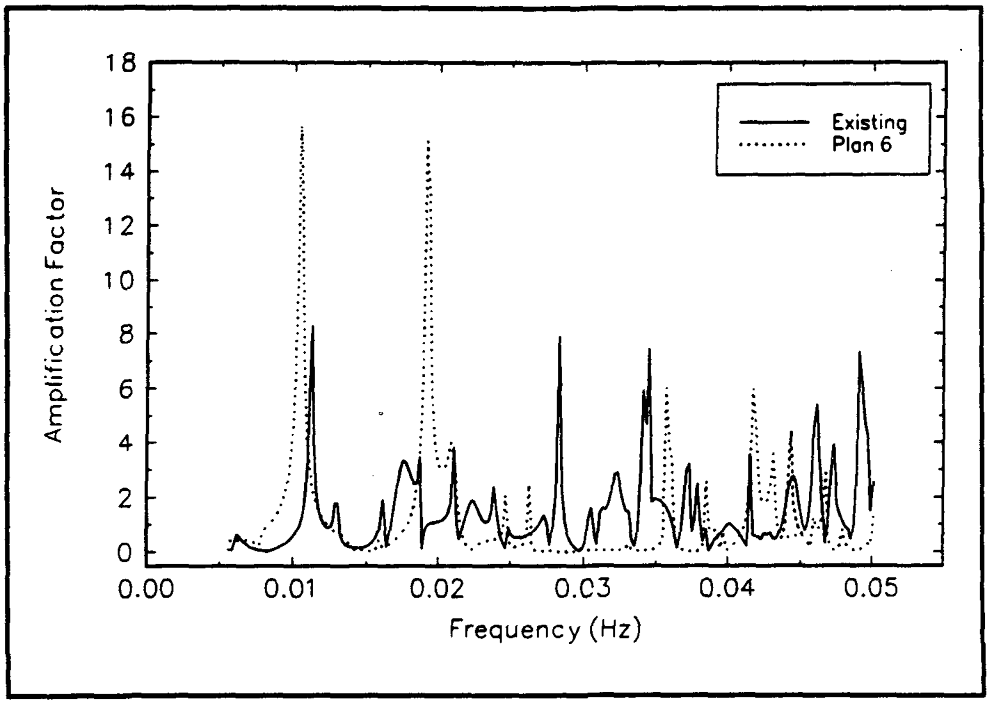

Figure B16. Wave amplification factor, basin 16

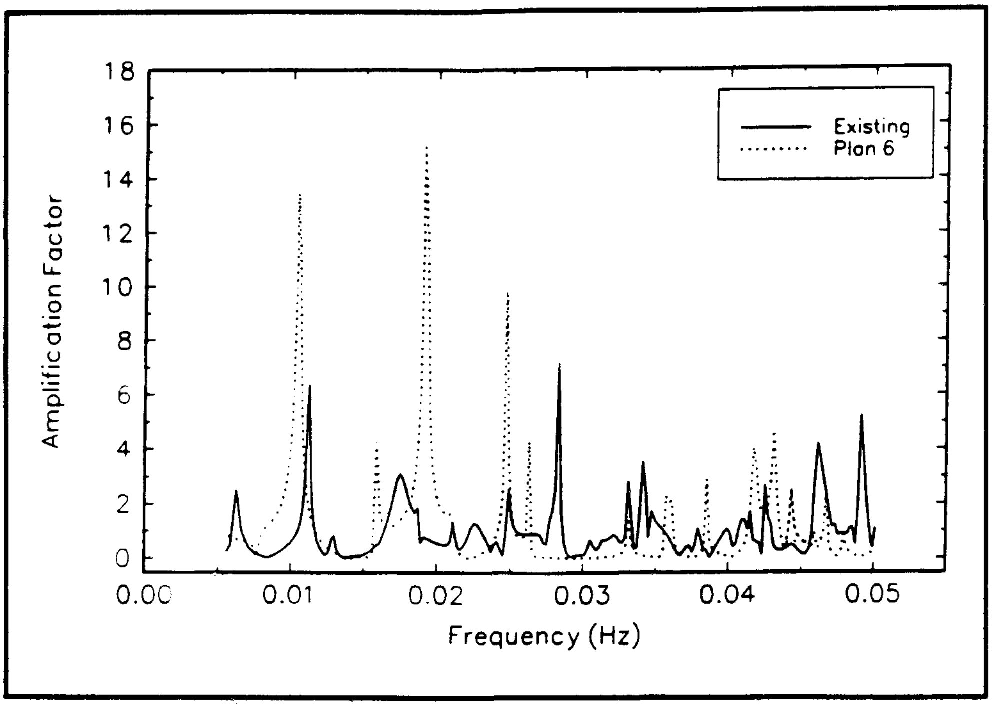

Figure B17. Wave amplification factor, basin 17

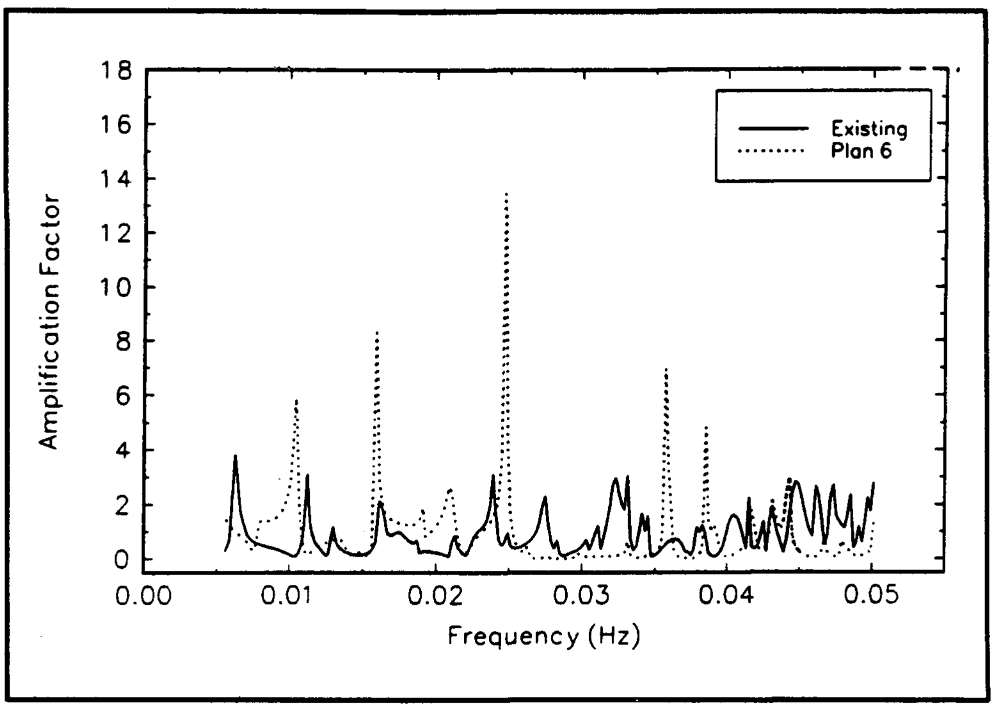

Figure B18. Wave amplification factor, basin 18

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Army Engineer Division, Pacific Ocean (CEPOD) requested that the U.S. Army Engineer Waterways Experiment Station numerically study the wave response of proposed improvement Plan 6 to the small boat harbor at Maalaea, Maui, Hawaii. The study is an extension of an earlier study to assess the wave response of the existing harbor and five other proposed modification plans. Wave periods tested ranged from 9 sec to 180 sec, encompassing wind waves and swell conditions and harbor oscillations. Since harbor oscillations were not investigated in the earlier study, the existing harbor was included in this study.

The results of this study show that Plan 6 provides the harbor with adequate protection from the incident wind wave and swell climate. Navigation during high wave conditions is potentially hazardous in Plan 6 relative to the other plans because much of the entrance channel is confined between two rock-faced structures. Plan 6 can potentially lead to a significant increase in the amplitude of harbor oscillations.

14. SUBJECT TERMS

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Harbor	Numerical modeling
Hawaii	Wave response

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