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Stability Study of the 1978 Jetty Rehabilitation, Yaquina Bay, Oregon, in Response to 1979-1980 Storm Season Waves

by Robert D. Carver, Michael J. Briggs

Prepared for Headquarters, U.S. Army Corps of Engineers

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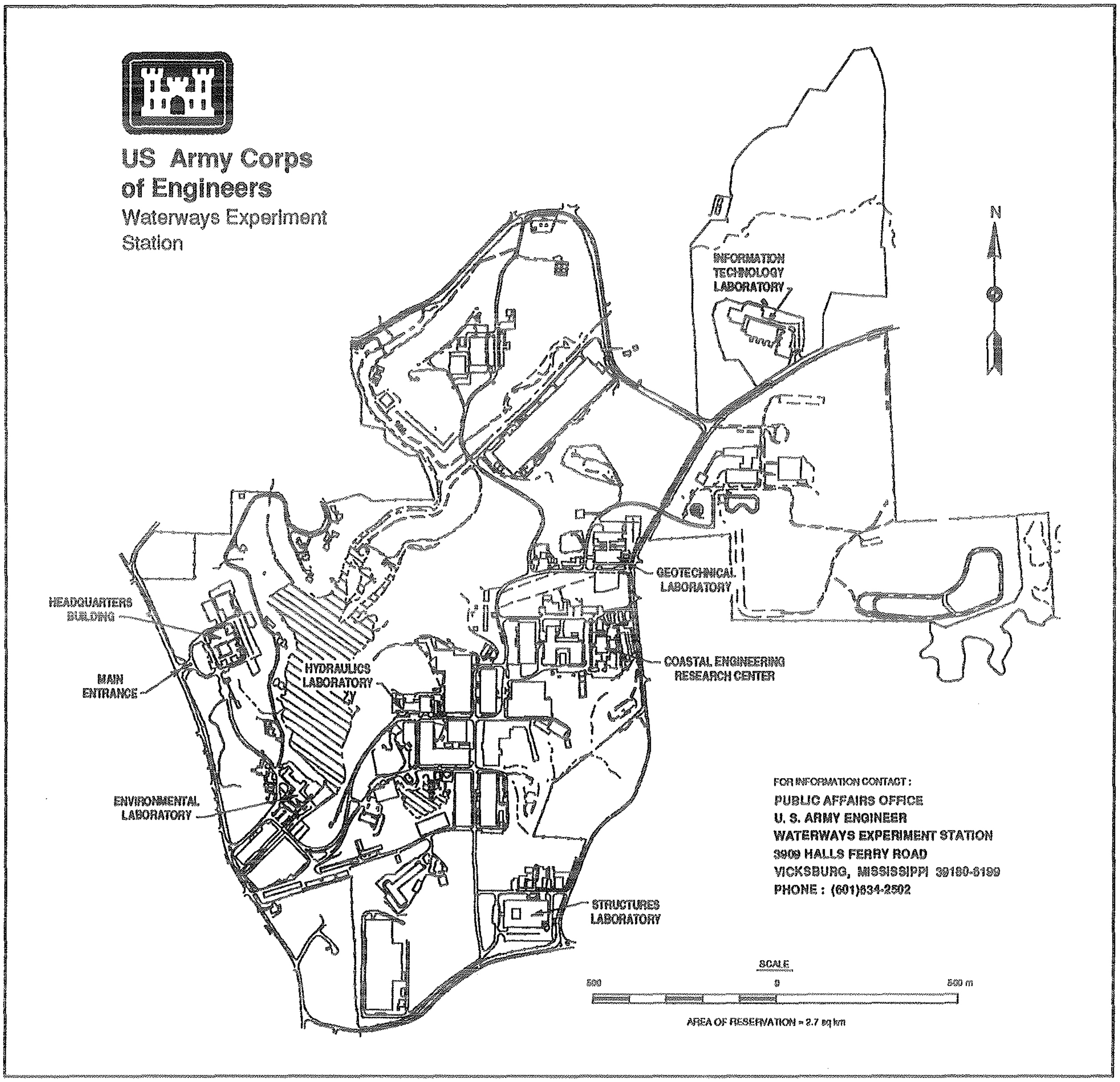

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Contents

Preface

This report is a product of the Monitoring of North Jetty at Yaquina Bay, Oregon (22117) work unit in the Monitoring Completed Coastal Projects Program (MCCP), Civil Works Research and Development, U.S. Army Corps of Engineers. Physical model testing was conducted during May 1990 at the Coastal Engineering Research Center (CERC) of the U.S. Army Engineer Waterways Experiment Station (WES). This testing was a recommendation of a workshop held at CERC in June 1989. Ms. Carolyn Holmes was MCCP Program Manager at CERC.

This report was prepared by Mr. Robert Carver and Mr. Michael J. Briggs, under the direct supervision of Mr. Dennis G. Markle, Chief, Wave Processes Branch (WPB), and Mr. D. Donald Davidson, Chief, Wave Research Branch (WRB), CERC. General supervision was provided by Dr. Steven Hughes, Wave Dynamics Division (WDD), Mr. C. E. Chatham, Chief, WDD, Mr. H. Lee Butler, Chief, Research Division (RD), Mr. Charles C. Calhoun, Jr., Assistant Director, CERC, and Dr. James R. Houston, Director, CERC.

Many individuals made significant contributions throughout this modeling effort. Mr. David A. Daily, WES Instrumentation Services Division, maintained the directional spectral wave generator (DSWG) and wave gauges, and assisted in data collection. Mr. Jeffrey Melby, WRB, identified storm conditions and tide levels. Mrs. Barbara Tracy, RD, performed the Wave Information Study (WIS) hindcast of the storm conditions. Mrs. D. R. Green, WPB, generated control signals for the DSWG from the WIS hindcast data and collected and analyzed data. Stability tests were conducted by Mr. C. R. Herrington. Dr. Fred Raichlen, Professor, California Institute of Technology, provided helpful suggestions regarding the physical modeling process. Mrs. Myra Willis, Branch Secretary, assisted in the preparation of the final report.

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
cubic feet	0.2831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
horsepower (550 foot-pounds per second)	745.6999	watts
miles, nautical (U.S.)	1.852	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
square miles	2.589998	square kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

The Prototype

Yaquina Bay is an estuary located on the Oregon Coast approximately 110 miles[1] (204 km) south of the mouth of the Columbia River (Figure 1). The bay is fed by the Yaquina River, which drains a predominantly forested watershed of approximately 250 square miles (647 km^2). Elements of the existing project at Yaquina Bay maintained by the U.S. Army Corps of Engineers include two rubble-mound jetties at the entrance and a 40-ft- (12-m-) deep by 400-ft- (122-m-) wide entrance channel. The jetties, entrance channel, and other project features were constructed to provide safer access for vessels serving the Yaquina River ports of Newport and Toledo, Oregon. Commercial products handled at these ports include lumber, pulp, paperboard, petroleum, and seafood. The Yaquina Bay area is also frequently used by individuals who enjoy recreational fishing and boating.

The Problem

A narrow basaltic offshore reef influences vessels navigating into Yaquina Bay. The reef lies approximately 3,500 ft (1,067 m) seaward of river mile 0.0 and extends from a point about 2,500 ft (762 m) south of the channel, northward for approximately 17 miles (31 km). Parallel jetties were constructed through a narrow opening in the reef on an approximate azimuth of S62°W to permit navigation through this opening.

The north jetty at Yaquina Bay was originally constructed in 1895 to a length of 2,300 ft (701 m). In 1930, efforts to restore the jetty and extend the length to 3,700 ft (1,128 m) were completed. Additional reconstruction projects were performed in 1933 and 1934. The present design length of 7,000 ft (2,134 m) was authorized in 1958 and completed in 1966, at which time the jetty extended the entire distance from shore to the edge of the basaltic reef. By 1970, winter storms had damaged the jetty to such an extent that the outer

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

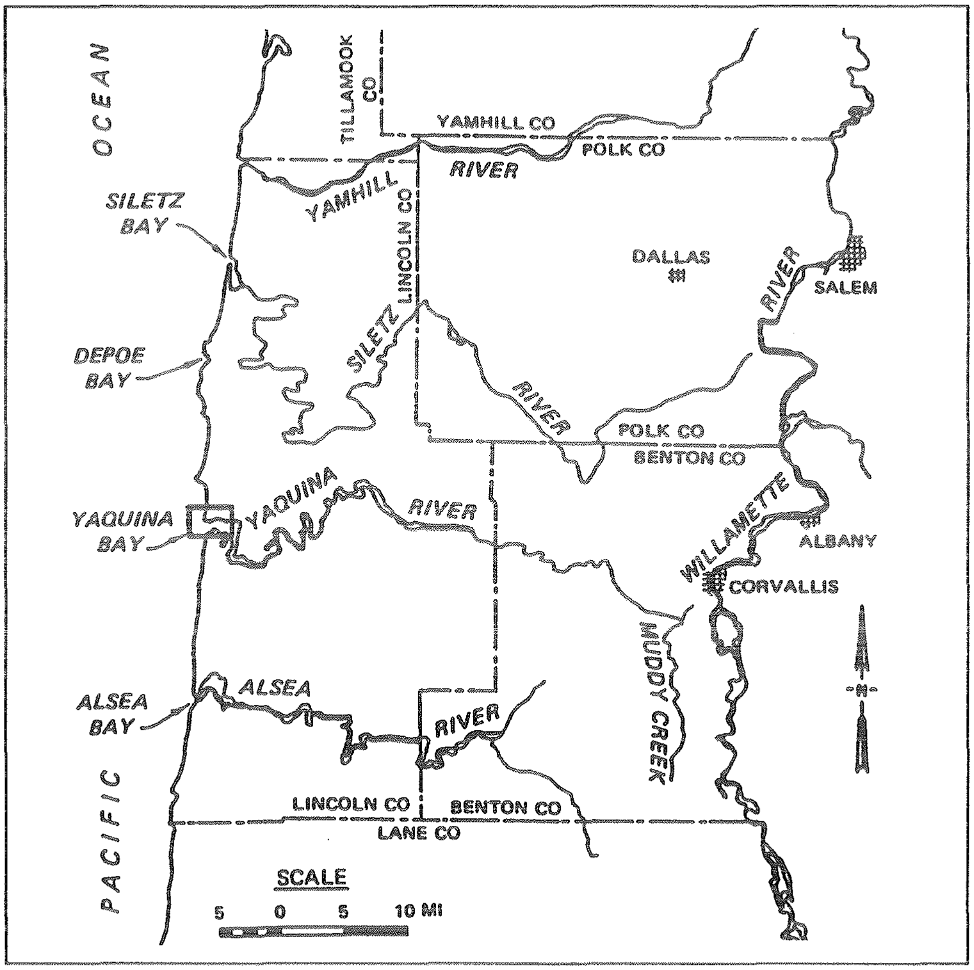


Figure 1. Yaquina Bay, Oregon

330-ft (101-m) section was submerged. A rehabilitation project was authorized in 1976, and this work was completed in 1978. One year after rehabilitation, 60 ft (18 m) of material had been lost from the jetty end, and after two years, the outer 250-ft (76-m) section was gone. Aerial photos taken in 1985 indicated that more than 400 ft (122 m) of the north jetty's seaward end had been damaged to below mean water level (mwl). In summary, the north jetty has been plagued with a history of unusually rapid deterioration when compared with similar North Pacific jetties that were built with the same design criteria and construction techniques. Possible causes of this deterioration are foundation scour caused by currents during storm events, wave-induced displacement of the armor stone, or some combination of the above. The proximity of the reef to the end of the north jetty appears to be an important factor in modifying waves and currents at this location, especially since little or no damage has occurred to the south jetty, which has similar construction characteristics and wave exposure.

Purpose of Model Study

The purpose of the present model investigation was to determine if waves alone were primarily responsible for deterioration of the north jetty at Yaquina Bay. The model jetty was constructed on a fixed foundation and subjected only to wave action from known storm conditions as hindcast using the Wave Information Study (WIS) numerical model. If the model jetty proved to be stable, it could be assumed that some other factor(s) (possibly current action, foundation stability, scour, etc.) caused or at least contributed to the prototype failure.

Report Organization

In Chapter 2, descriptions are given of the physical model, model design, test facilities and equipment, and model construction methods for the north jetty. Wave condition hindcasting, simulation, generation, and calibration are described in Chapter 3. Chapter 4 presents results from the stability tests. Finally, Chapter 5 contains a summary and conclusions of the physical modeling effort. The recommendations of the International Association of Hydraulic Research List of Sea State Parameters (1986) are followed wherever possible throughout this report and in the computer software implemented for wave generation and analysis.

2 The Model

Design of Model

The study was conducted in a 96-ft-long by 121-ft-wide (29-m-long by 37-m-wide) wave basin (Figure 2). Bathymetry was the same as that used in the earlier physical model study of the proposed 1988 rehabilitation (Grace and Dubose 1988). No additional surveys or verification of the nautical charts

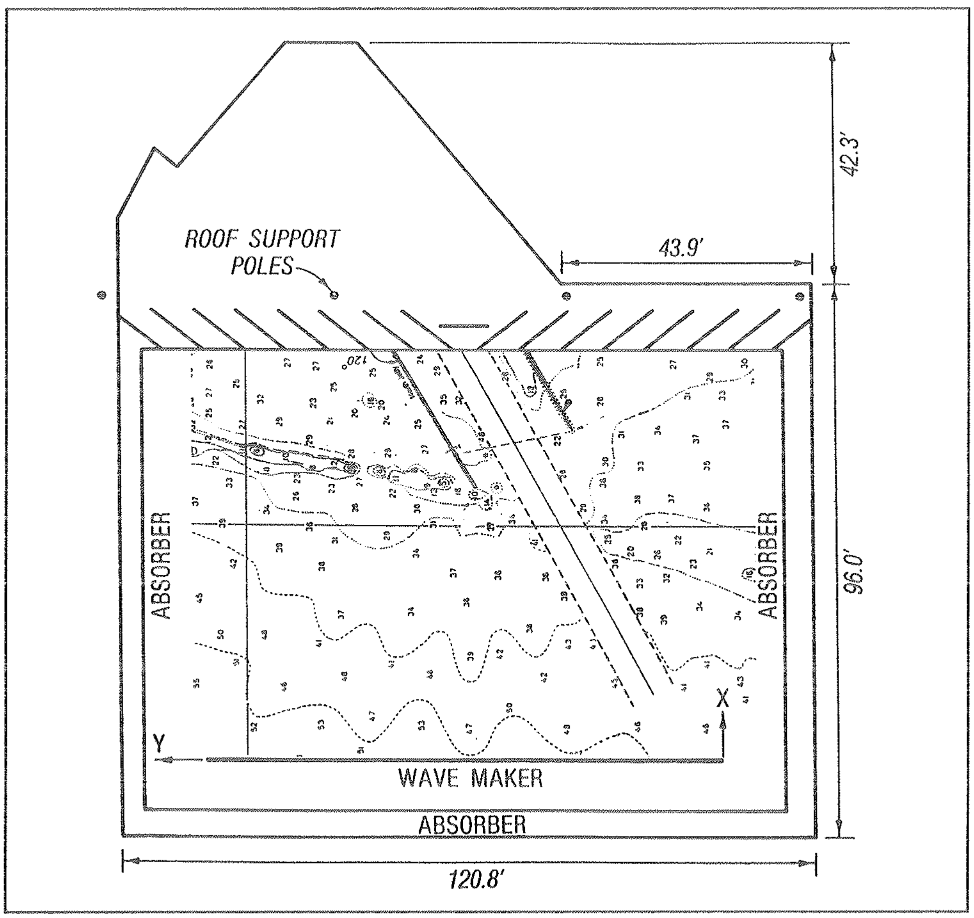


Figure 2. Plan view of physical model

were attempted. Therefore, any deviations from the charts could be a source of error in the response of the model to waves. All basin walls were lined with wave absorber frames and horsehair to minimize contamination of the desired wave field by reflected wave energy.

Tests were conducted at a geometrically undistorted scale of 1:45, model to prototype. Selection of the 1:45 scale was based on several factors including: (a) size of the available wave basin, (b) boundaries of the bathymetric area to be modeled, (c) capabilities of the directional spectral wave generator (DSWG), (d) availability of required model armor-stone sizes, and (e) preclusion of stability scale effects (Hudson 1975). Based on Froude's Model Law (Stevens et al. 1942) and the linear scale of 1:45, the following model-prototype relations were derived. Dimensions are in terms of length (L)[1] and time (T).

Characteristic	Dimension	Model-Prototype Scale Relation
Length	L	$L_r = 1:45$
Area	L^2	$A_r = L_r^2 = 1:2025$
Volume	L^3	$V_r = L_r^3 = 1:191125$
Time	T	$T_r = L_r^{1/2} = 1:6.7$

The specific weights of water used in the model and that of seawater were assumed to be 62.4 and 64.0 pounds per cubic foot (pcf) (1,000 and 1,025 kg/m^3), respectively. Likewise, specific weights of construction materials used in the model (165 pcf; 2,643 kg/m^3) were not identical to their prototype counterparts (170 pcf; 2,723 kg/m^3). These variables were related using the following transference equation:

$$\frac{(W_a)_m}{(W_a)_p} = \frac{(\gamma_a)_m}{(\gamma_a)_p} \left(\frac{L_m}{L_p}\right)^3 \left[\frac{(S_a)_p - 1}{(S_a)_m - 1}\right]^3 \qquad (1)$$

where

W_a = weight of an individual armor unit, lb

m, p = model and prototype quantities, respectively

γ_a = specific weight of an individual armor unit, pcf

$L_m/L_p = L_r$ = linear scale of the model

1 For convenience, symbols and abbreviations are listed in the notation (Appendix G).

S_a = specific gravity of an individual armor unit relative to the water in which it was placed, i.e., $S_a = \gamma_a/\gamma_w$

γ_w = specific weight of water, pcf

Due to the limited area of the test basin, it was impossible to model the entire length of both jetties at the selected scale (1:45). It was essential that the offshore bathymetric features be duplicated to the extent that wave transformation into shallow water was properly modeled. This placed the wave board in a water depth corresponding to the -58-ft (-18-m) mean lower low water (mllw) contour. This, in turn, allowed construction of about 1,440 ft (439 m) (32-ft (10-m) model) of the north jetty and 950 ft (290 m) (21-ft (6-m) model) of the south jetty. The head of the north jetty was positioned in the basin in such a way that it could be subjected to wave attack from any direction within a 50-deg window without substantial loss of wave energy from the ends of the unidirectional waves (Figure 3).

Test Facilities and Equipment

Wave heights were measured at 10 different locations using capacitance wave gauges (Figure 3). Gauges 1 to 8 were used in a calibration phase to ensure accurate reproduction of the target wave conditions. The last two gauges were located on either side of the north jetty head to measure wave transformation. Gauges 2 to 8 comprised a "2-3-1-7-5-1/2" linear array patterned after the larger linear array design of Oltman-Shay at the U.S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center Field Research Facility (Crowson et al. 1988). The unit lag spacing of 2 ft (0.6 m) was selected to optimize the frequency and directional resolution of the array for the 42-ft (13-m) contour.

Test waves were produced by the DSWG, an electronically controlled, electromechanical system consisting of four modules (Figure 4). Each module contains fifteen 1.5-ft-wide by 2.5-ft-high (76-cm-wide by 0.76-cm-high) paddles; therefore, the entire 90-ft-long (27.4-m-long) systemconsists of 60 paddles, each of which is independently driven by a 0.75-hp (559 watts) electric motor. Adjacent paddles are connected with a flexible-plate seal to provide continuity over the face of the wave board and minimize the introduction of spurious waves (Outlaw and Briggs 1986, Briggs and Hampton 1987).

Wave board control signals were simulated on a CRAY Y-MP supercomputer and downloaded to a VAX 11/750 computer for transmittal to the DSWG. This same computer was used to collect data for transfer to a VAX 3600 computer for later analysis.

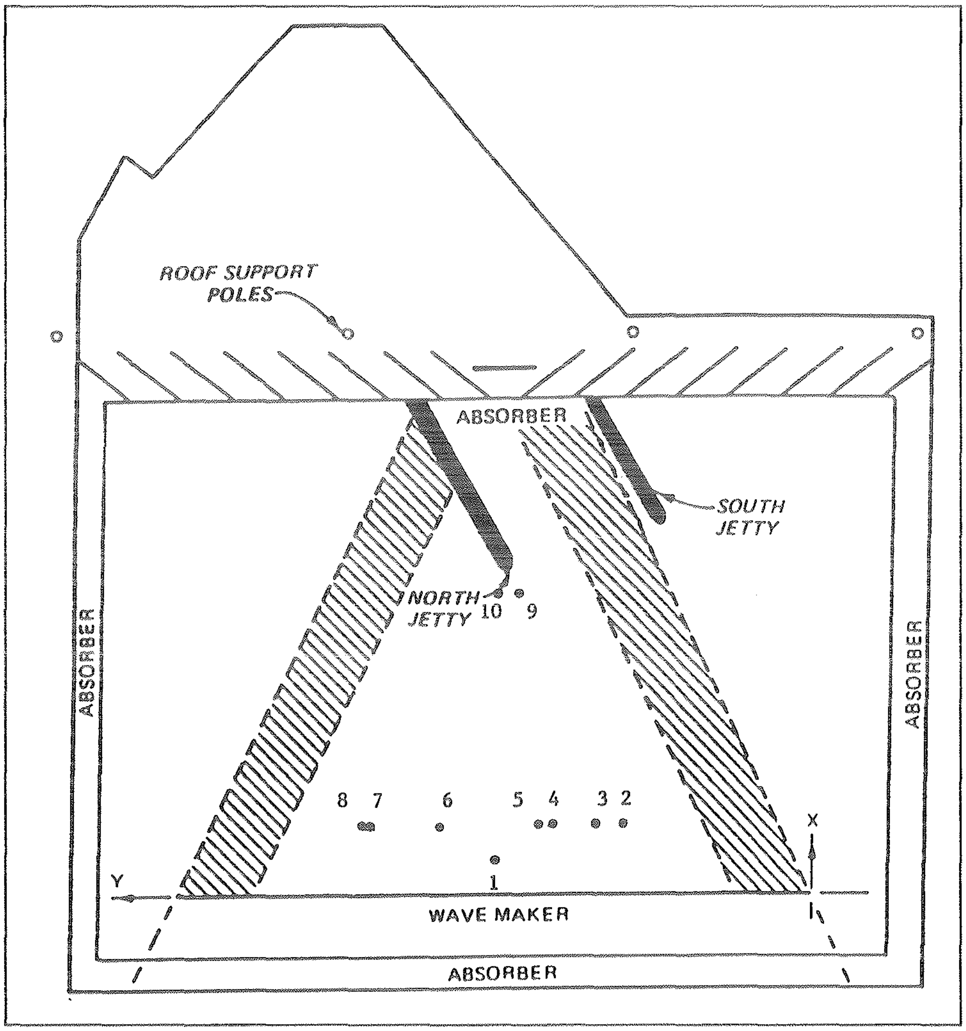


Figure 3. Wave gauge locations and wave direction limits

Method of Constructing Test Sections

Jetty sections in the model were constructed to reproduce, as closely as possible, results of prototype jetty construction. No information was available on the present condition of the bedding layer; therefore, bedding and core materials in the undamaged jetty sections were dumped by shovel and leveled to grade lines that corresponded to as-built conditions. Primary armor consisted of two layers of parallelepiped-shaped stones, long slab-like stones with a maximum length between two and three times their shortest dimension. The special shaped stones were handmade to Portland District (NPP) specifications and placed with their long axis perpendicular to the jetty slope above mllw. Stone placement below mllw was random.

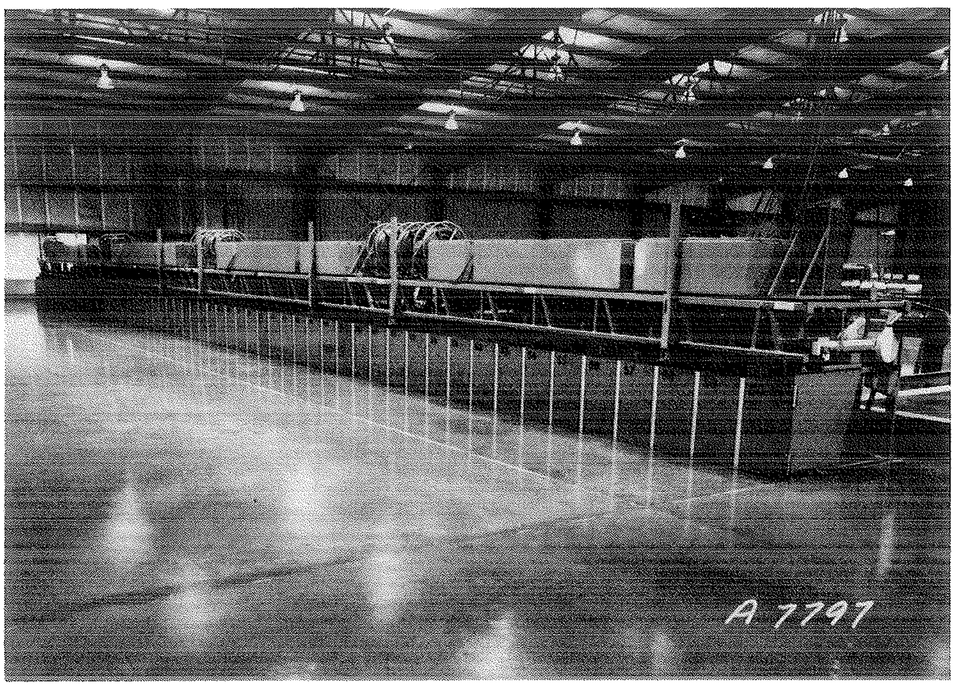


Figure 4. Directional spectral wave generator

3 Wave Conditions

Prototype Storms

Numerical simulation

Based on an analysis of meteorological and National Oceanic and Atmospheric Administration buoy data, three storms in 1979 were identified for numerical simulation: October 17-23, November 17-23, and December 19-27. These three storm events were hindcast over a 60-nautical mile (n.m.) (111-km) grid of the Pacific Ocean between latitude 20°N to 60°N and longitude 110°W to 200°W using the WIS deepwater numerical model DWAVE (Corson 1987). Output from this oceanic hindcast was input to the shallow-water model SHALWV (Hughes and Jensen 1986) on a 5-n.m. (9.3-km) grid between latitude 44°N to 45°N and longitude 124°W to 125°W (Figure 5). This model includes refraction and shoaling in the numerical determination of the directional spectra.

Directional spectral information was saved at a depth of 16.5 m offshore of the north jetty for each storm at 12-hr intervals, approximately the same depth as the wavemaker in the physical model. The number of 12-hr segments selected for October, November, and December was 14, 14, and 18, respectively. These spectra were represented by 20 frequency bands between 0.03 and 0.22 Hz (0.01-Hz increments) and 36 direction bands between 0 and 350 deg (10-deg increments). Direction bands use a polar coordinate system with wave angle measured counterclockwise from east (i.e., 90 deg represents a wave travelling towards the north).

Comparisons with the DWAVE wind and wave results (Tracy and Payne 1990) were made with NOAA buoy 46002, located just to the west of the smaller grid. Appendix A contains plots of wind speed, peak wave period, and significant wave height for the three months October through December. Comparisons of peak period and significant wave height at 12-hr intervals showed reasonable agreement. Unfortunately, some of the peaks in the buoy data occurred at 6-hr intervals, between the larger 12-hr intervals. Thus, the WIS results underpredicted the October storm peak periods and wave heights.

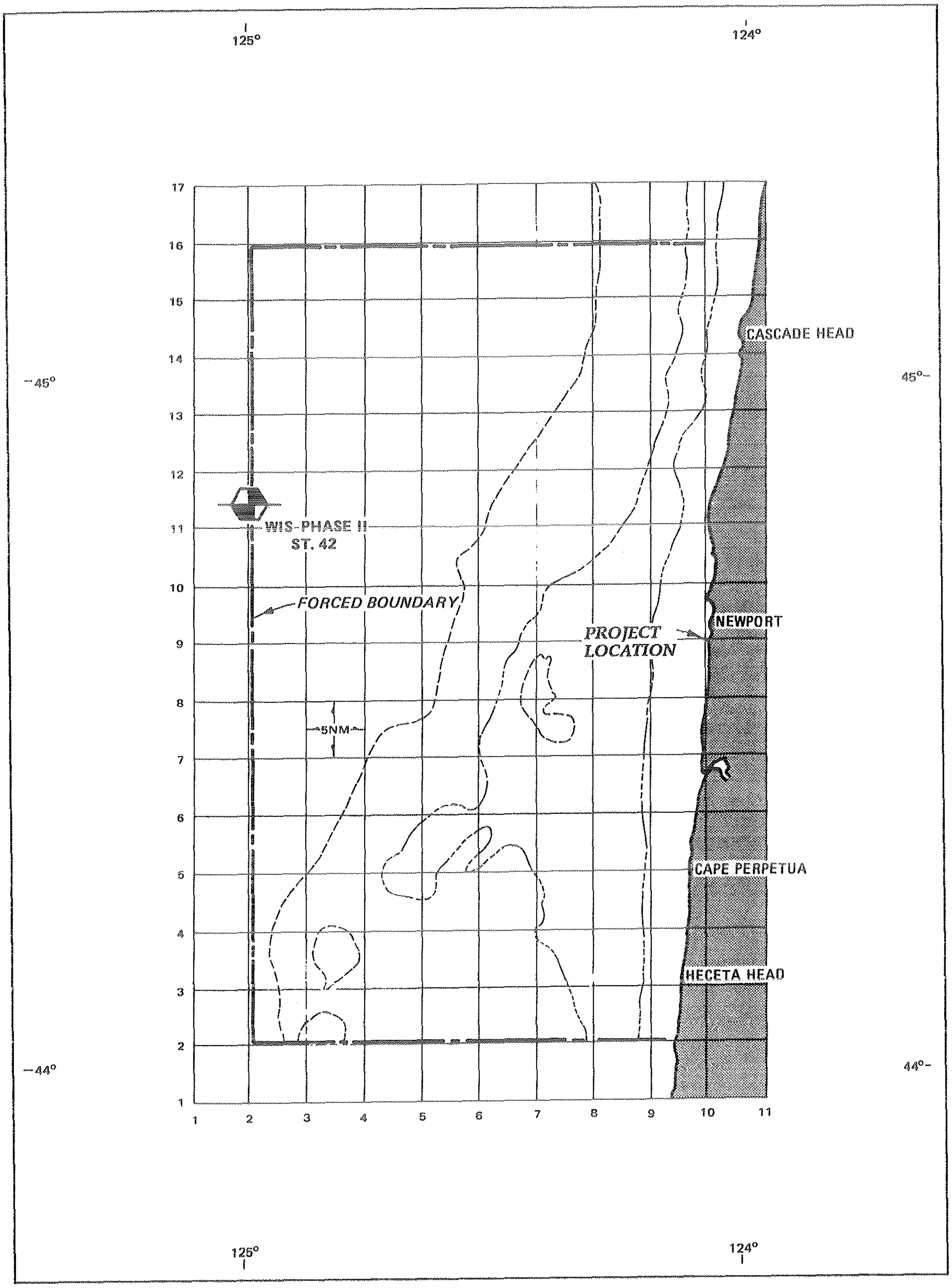


Figure 5. SHALWV model grid

Sources of uncertainty in the numerical model results are (a) the 12-hr time interval length (see above), (b) interpolation of wave directions between grids from the 22.5-deg to 10-deg increments, and (c) interpolation of National Meteorological Center wind fields on a 2.5-deg grid at 12-hr intervals. Also, much of the energy in these storms appeared to be traveling parallel to the coast in the northerly direction. Thus, some of the energy measured at the offshore buoy would miss the Yaquina jetties.

Model Storms

Numerical simulations included storm buildup and decay for each of the three storms. The original number of 12-hr segments was reduced from 46 to 13 after a review of wave heights and directions showed that some were characterized by low energy or storm tracks that stayed offshore. Table 1 lists the prototype and model peak period, significant wave height, and mean wave direction for the three October, seven November, and three December segments. Model wave directions are measured clockwise from east so that a wave traveling toward the north has an angle of -90 deg.

Because of time and funding constraints, each 12-hr segment was only simulated in the physical model for a 6-hr duration. These 6-hr events were divided into two 3-hr segments: one at high storm tide and one at low storm tide. Storm tide information was available from a tide gauge located in Yaquina Bay Harbor. Because the tide is diurnal, high and low water levels (including tide and storm surge) for each 12-hr cycle were selected from the high and low measured values for each tidal cycle. Table 2 lists measured storm tides and corresponding prototype and model water levels at the 17.7-m contour. The test ID's have a suffix of "H" for high water level and "L" for low water level. Exact scaling of the prototype water levels resulted in some model water levels that showed little variation. Therefore, model water levels were grouped into seven different levels to expedite calibration and testing. Instead of adjusting the water level prior to each test, all tests were run at a particular water level before going to the next level. Appendix B lists prototype water levels for each gauge for each test.

Model Wave Generation

Control signal simulation

Each of the 26 test cases (i.e., 13 high-water level and 13 low-water level) was numerically simulated using a double-summation, deterministic amplitude, random phase, frequency domain model (Borgman 1990) to generate stroke time series for each of the DSWG's 61 paddles. Because the digital-to-analog rate for the DSWG is 20 Hz, control signals of 40,000 points or 2,000 sec (33.3 min) were generated. Low- and high-frequency cutoffs corresponded to 0.01 and 2.00 Hz, respectively. Except for the water levels, directional spectral parameters were the same for both high and low water level versions of each test case.

Data collection and analysis

Wave gauges were calibrated prior to each test with a computer-controlled procedure incorporating a least square fit of measurements at 11 steps through the water column. After a wait of 30 sec to allow the slower traveling, high-frequency components to reach the jetty, wave elevations were sampled at 10 Hz for 1,600 sec (26.7 min). Data records were zero-meaned and tapered by a 10-percent cosine bell window using the time series analysis software package (Long, in preparation). For the frequency domain analysis, data were band averaged with a bandwidth of 0.067 Hz (degrees of freedom = 214) within lower and upper cutoff frequencies of 0.01 and 2.50 Hz, respectively. This bandwidth corresponds to the prototype bandwidth of 0.01 Hz. For the directional spectral analysis, a Maximum Likelihood Method (MLM) estimator and a Gaussian smoothing technique (Briggs, Borgman, and Outlaw 1987) were used within lower and upper frequency limits of 0.01 and 2.00 Hz, respectively. The equivalent number of smoothed frequency components was 256. A directional resolution of 10 deg, the same resolution as in the numerical hindcast simulations, was used.

Test Results

An initial calibration phase was conducted to measure and correct the control signals. The jetty model was covered with several layers of horsehair to prevent damage to and reflections from the model. A transfer function was used to correct control signals for observed variations in peak period, wave height, spectral shape, and directional spread (Briggs and Jensen 1988). Only gauges 3-6 in the linear array were used for this correction. After two iterations, a satisfactory agreement between target and measured directional spectra was achieved.

Directional wave spectra

Figure 6 illustrates target and measured model (scaled to prototype) directional spectra for high- and low-water levels for test case YD25M (i.e. December 25, midnight). Target and measured directional spectra for the other cases are contained in Appendix C. The entire linear array (gauges 2-8) was used in the directional spectral calculations. The 3-D directional spectra have units of m^2/Hz/deg. The rear vertical panels on each figure illustrate the integrated direction spectrum and frequency spectrum. The frequency spectrum is obtained by summing the directional spectrum over all directions for each

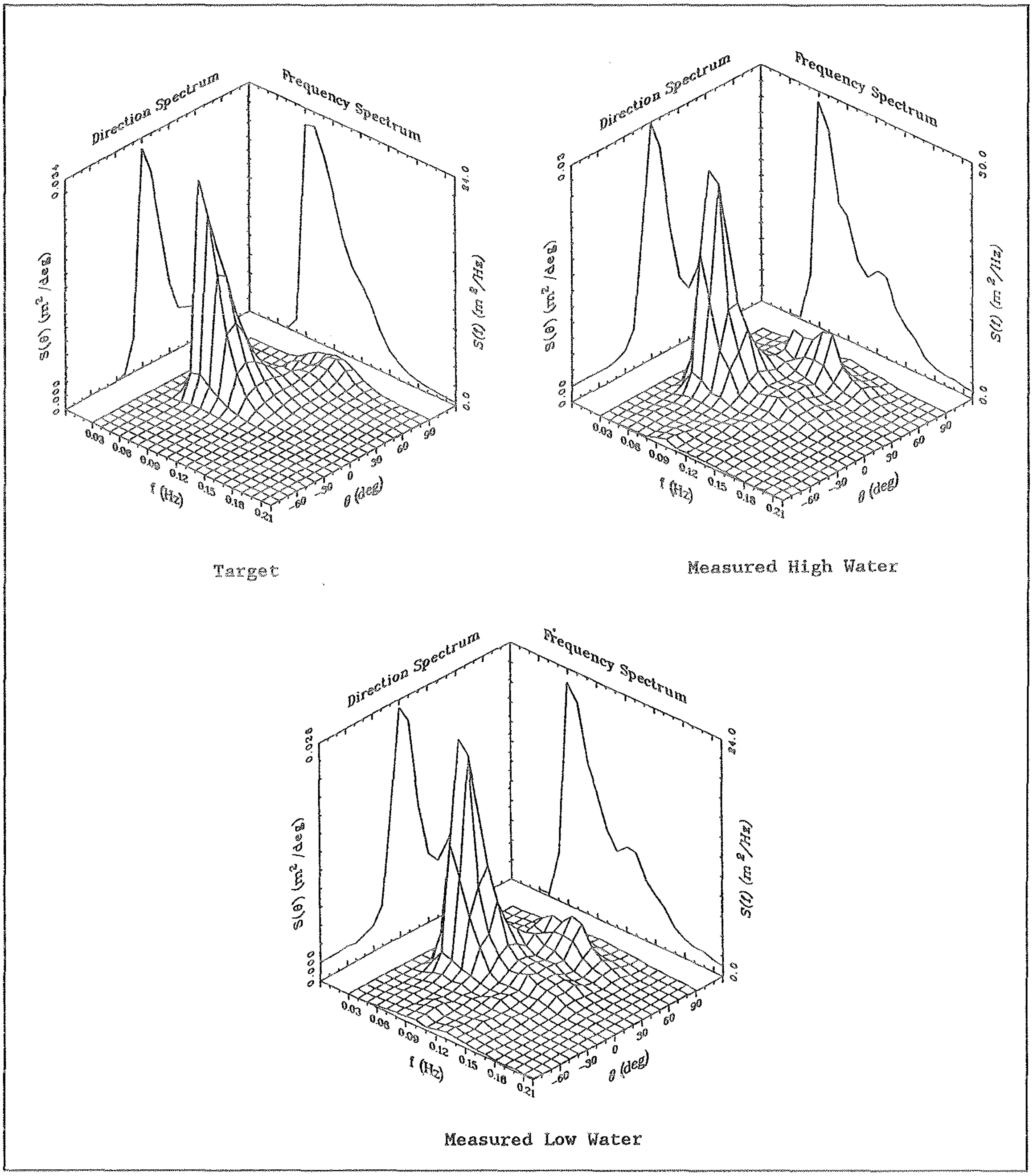


Figure 6. Target and measured model directional spectra for case YD25M

frequency and multiplying by the direction increment 10 deg. Similarly, the direction spectrum is the sum over all frequencies for constant direction, multiplied by the frequency increment 0.01 Hz. In general, the agreement is very good to excellent. In some cases, the target directional spectra had energy traveling in a northerly direction (i.e., 90 deg) which was not measurable with the linear array. Visual observation of the waves as they left the DSWG did verify, at least qualitatively, that this energy was being accurately simulated.

Figure 7 compares target and measured (i.e., OGA, offshore gauge array) normalized directional spectra for the YD25MH test case. Target and measured normalized directional spectra for the other cases are contained in Appendix D. Figure 7a illustrates the normalized frequency spectrum and Figure 7b shows the normalized directional spreading function at the peak frequency. The legend for Figure 7a lists the significant wave height and water depth in centimeters and the frequency increment in hertz. The legend for Figure 7b lists the peak frequency in hertz, and the mean wave direction and directional spread in degrees. The directional spread is half the width of the spreading function at the 50 percent level.

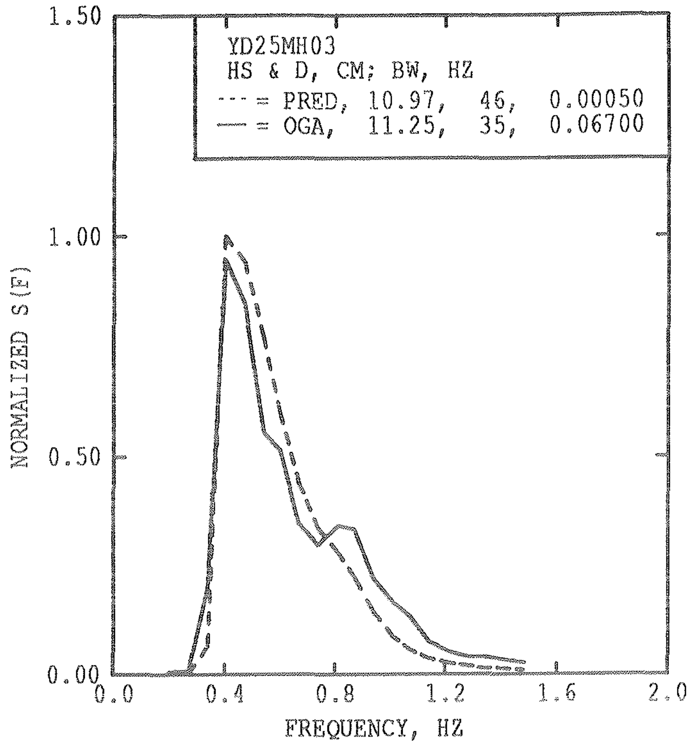
Frequency spectra

Measured model frequency spectra for all 10 gauges for case YD25MH are shown in Figure 8. Appendix E contains the frequency spectra for the other cases. Two gauges are plotted in each semi-log panel. The legend lists the gauge number and water depth in centimeters.

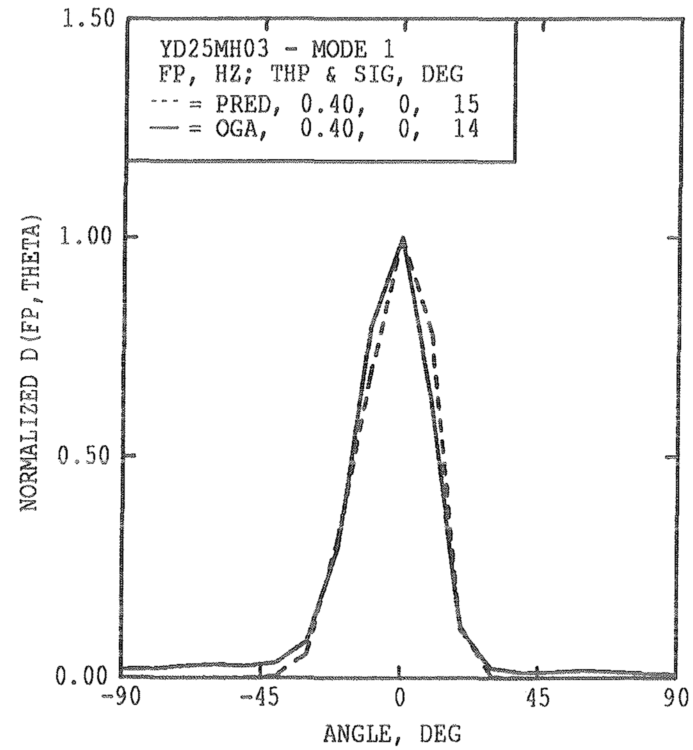
Peak period and wave height

Table 3 lists target and measured peak periods for each test case. Values are given for gauges 1-10 and the averages of gauges 1-8, 2-8, 3-6, and 9-10. Plots of measured peak period for each gauge and test case are contained in Appendix F. In general, the agreement is very good. Some of the gauges in the December cases exhibit substantial variability about the target periods. An explanation might be the large frequency bandwidth used in the band-averaging process.

Table 4 lists target and measured significant wave heights for each test case. The format is the same as for the wave periods. Plots of measured wave height are also contained in Appendix F. In general, the agreement is excellent. The variability exhibited by gauges 1-8 is within normal spatial tolerances for 3-D basins (Sand 1979). Gauges 3-6 exhibit less variability than gauges 2-8 of the linear array. Thus, they were used in the transfer functions during the calibration phase. Gauges 9 and 10 show an increase due to shoaling at the north jetty tip.



a. Pred. vs. OGA frequency spectra MLM, OGA=2-8, RAW



b. Pred. vs. OGA spreading @ peak freq MLM, OGA=2-8, RAW

Figure 7. Target and measured normalized directional spectra for case YD25MH

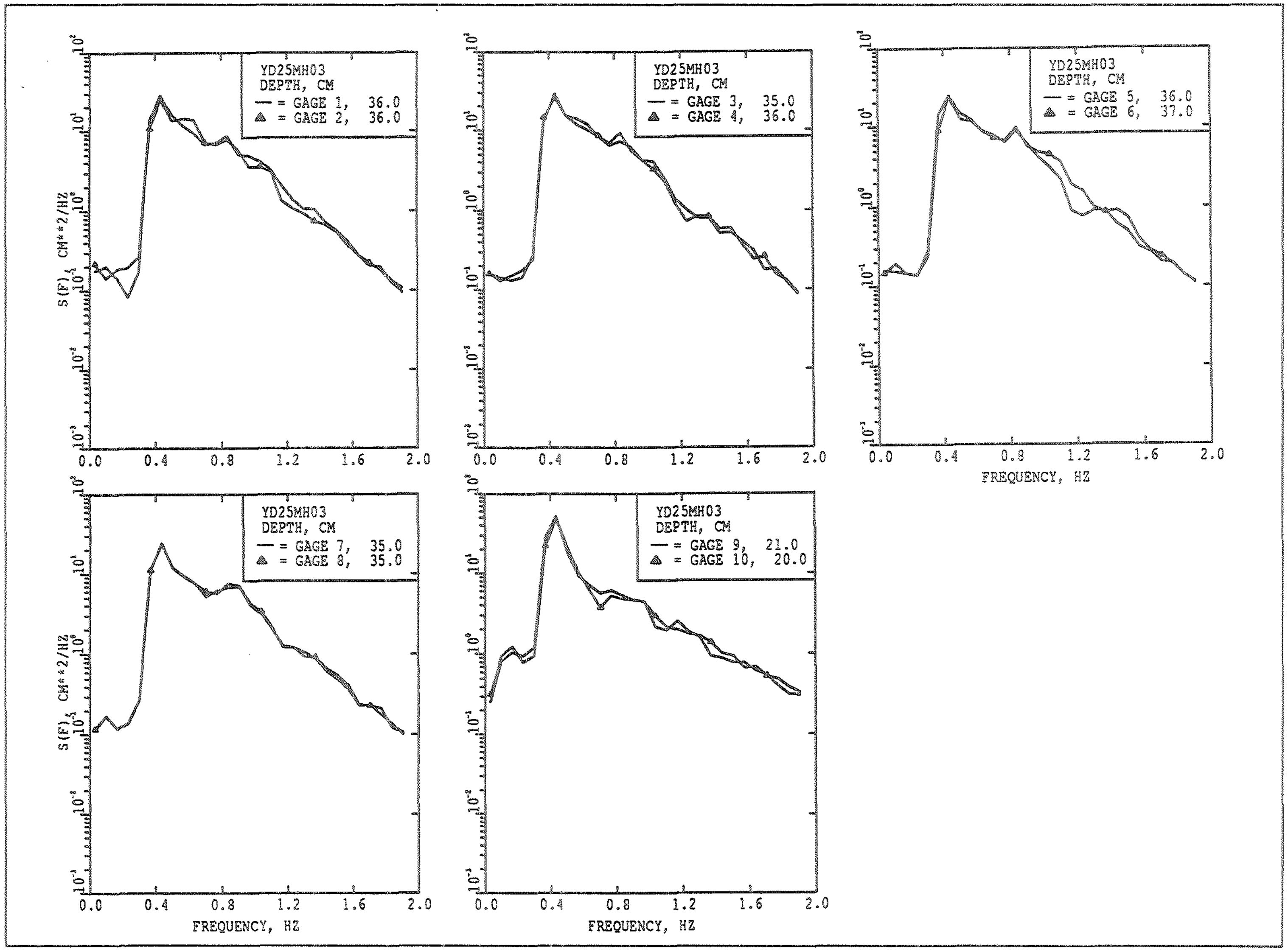


Figure 8. Measured model frequency spectra for all gauges

4 Jetty Stability Tests

Description of Rehabilitation Plan

The jetty profile and cross sections are presented in Figures 9, 10, and 11. The rehabilitation plan was characterized by a crest elevation of +20 ft (6 m) mllw and a crest width of 30 ft (9 m). Armor sections were typically composed of two layers of 6- to 25-ton (5,443- to 22,680-kg) stone (average weight = 10 tons (9,072 kg)). The model structure is shown in Photos 1 and 2.

One of the most important features of the rehabilitation plan was the use of the placed-stone construction technique. This procedure requires the use of parallelepiped-shaped stone with each special shaped stone placed with its long axis normal to the jetty slope. Past field experience (U.S. Army Engineer

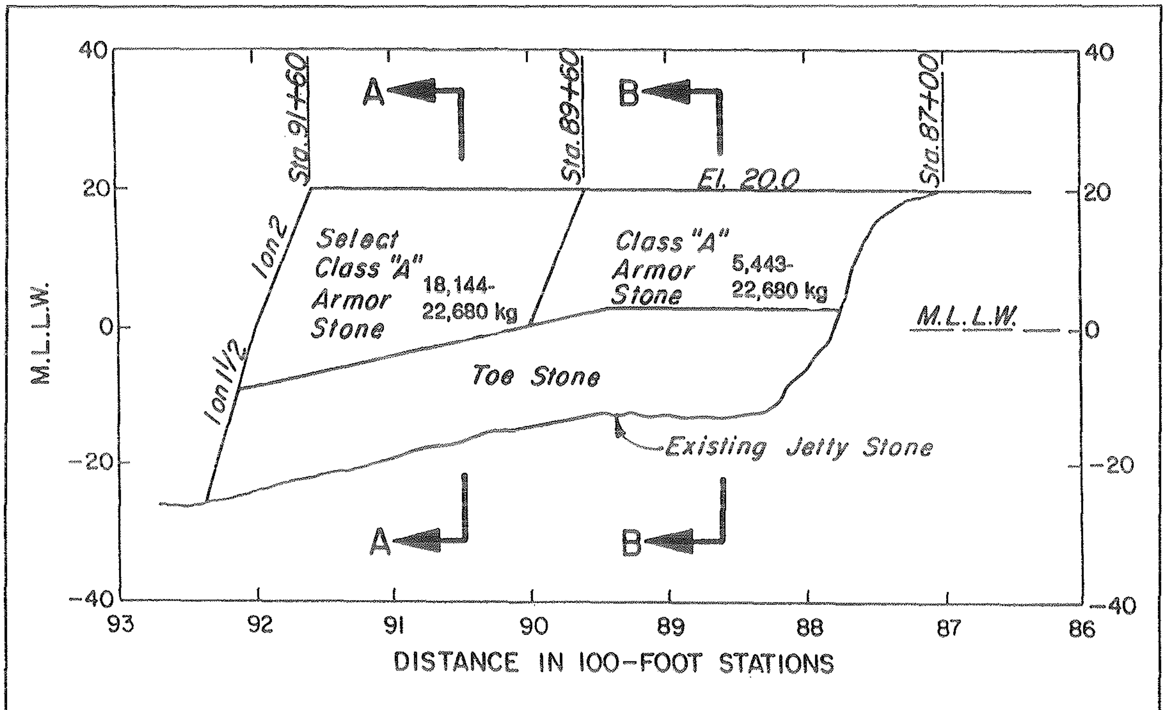


Figure 9. Jetty profile

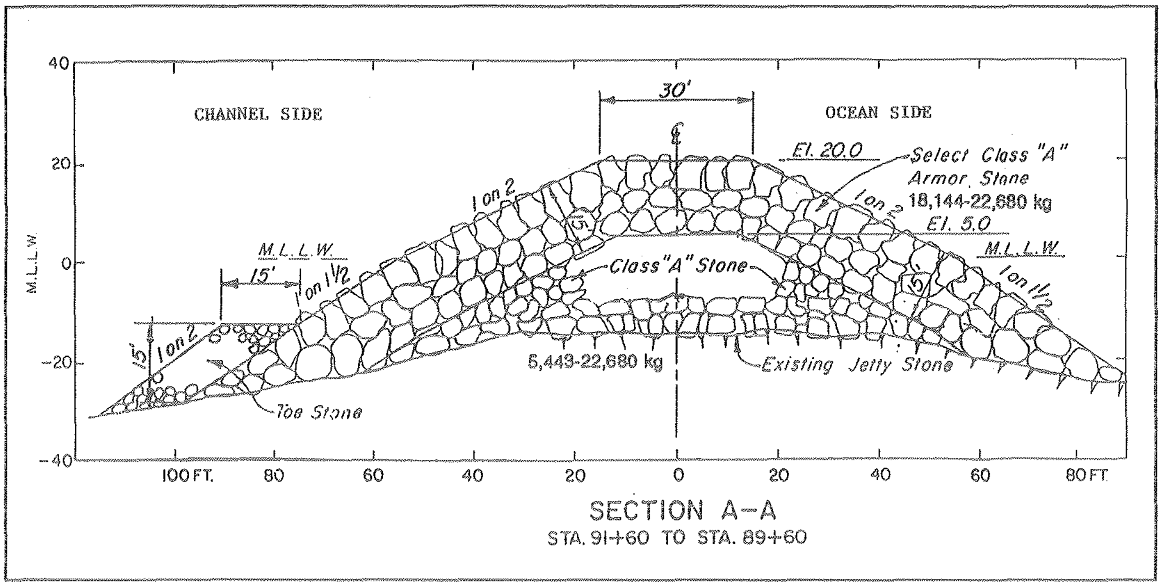


Figure 10. Jetty Section A-A

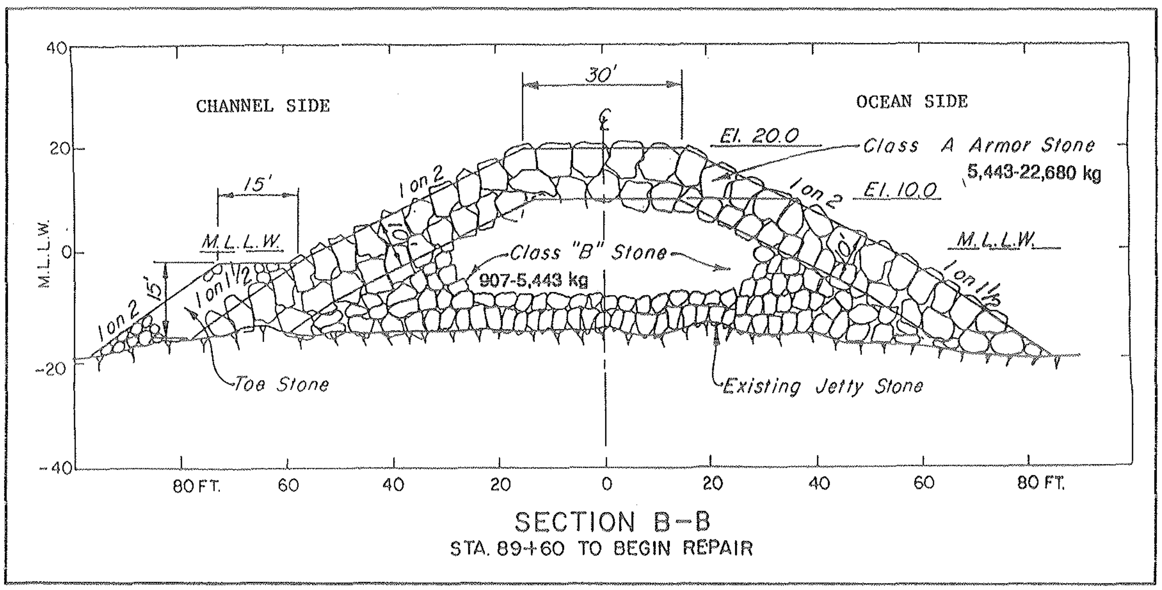


Figure 11. Jetty Section B-B

District, Buffalo 1946) and laboratory studies (U.S. Army Engineer Waterways Experiment Station 1963, Markle and Davidson 1979) have indicated that the use of placed-stone construction techniques results in increased stability of rubble-mound structures when compared with similar structures armored with randomly placed angular stone.

Storm Conditions Tested and Results

As described in Chapter 3, an extensive series of model calibration tests was conducted to develop model storm conditions (control signals) that would simulate the storm conditions that occurred during October, November, and December 1979. The first stability test consisted of a 26-step simulation representing the storms of interest over the 3-month period. Test conditions and results are summarized in Table 5. Presented therein are the still-water level (swl), characteristic period and height, and a brief summary of the structure's response for each step investigated.

The first three steps of the October storm produced only minor rocking of a few armor units followed by a general loosening of 8 to 10 armor stones during steps 4 and 5. No movement was detected during step 6 and the structure was still in good condition at the conclusion of the October storm.

November storm conditions, generally milder than October conditions, produced no movement during steps 7 through 17. Minor rocking of a few armor stones was observed during steps 18, 19, and 20; however, no significant impact on stability could be discerned.

Initiation of the December storm (step 21) caused displacement of one armor stone and rocking of a few others. General loosening of the armor above the swl was observed during steps 22, 23, and 24. Steps 25 and 26 produced minor rocking of 3 or 4 armor stones. The structure emerged from the 26-step test series in good condition. Loosening of the armor observed in steps 22, 23, and 24 abated during steps 25 and 26 and appeared to have no significant impact on overall stability (Photo 3).

After testing was completed, it was discovered that an error in the WIS hindcast processing of the October test segments caused them to be too low in period and height. Thus, these six segments did not subject the jetty model to the correct wave conditions during October, a relatively stormy period of the total test sequence. However, this error is not felt to be serious since none of the other storm segments produced any significant damage to the north jetty model.

Results of this 26-step stability test showed significantly less armor movement than was anticipated. Therefore, in an effort to determine the effects of more extreme wave heights on the model structure, December storm conditions were repeated with the gain increased (signal amplified) to the limits of the wave machine. This increased the wave heights by 20-40 percent (maximum height was 22 ft (7 m)). A few more armor stones were displaced; however, overall stability was still good.

The next step consisted of an additional series of tests to expose the north jetty to the maximum wave heights that could be generated over the full range of wave directions possible. Unidirectional and directional spectra, representative of the six most severe hindcast storms in the past 20 years, were generated. These storms were used in the earlier physical model tests (Briggs, Grace, and Jensen 1989) of the proposed 1988 rehabilitation of the north jetty using the "placed-stone" construction technique. They had a range of wave periods and heights of 12.5 to 16.7 sec and 15.4 to 23.0 ft (5 to 7 m), respectively. They were run at only one water level and for a very short duration. Even though a few more stones were randomly displaced, overall stability was still good.

Finally, the model structure was rebuilt to initiate "hot spots" by dislodging and loosening some stones, and retested. Since most of the observed movement during the first test series occurred during the December storm, it was decided to use only the six December storm conditions for this last test series. Test results from this repeat series are summarized in Table 6. Step 1 caused significant loosening of the armor with nine stones being displaced. At the conclusion of step 1 it was anticipated that the repeat test might show a significant increase in damage above that observed for the original test. However, steps 2, 3, and 4 produced only rocking of five or six armor units, with no additional displacement observed. Minor rocking of two or three armor units was observed during steps 5 and 6, with the structure emerging from the six-step simulation in good condition (Photos 4 and 5).

5 Summary and Conclusions

Yaquina Bay is located on the Oregon coast, approximately 110 miles (204 km) south of the Columbia River. Since authorization of the jetty system in 1880, the north jetty has undergone extension or rehabilitation a total of seven times, the most recent in 1988. The jetty tip now extends to just landward of an offshore basaltic reef.

During 1989 the MCCP program convened a workshop of 25 coastal experts, including personnel from academia, WES, the North Pacific Division, and NPP, to propose and evaluate damage hypotheses and to map future directions for the monitoring efforts. The five most likely damage hypotheses were (a) wave breaking on the jetty, (b) wave-current interaction due to the presence of the reef, (c) scour leading to armor unit slumping, (d) foundation failure, and (e) some combination of the above. One of the workshop recommendations was to conduct physical model tests of the 1978 jetty rehabilitation to attempt to recreate damage to the north jetty following the 1979-1980 storm season. Hopefully, these tests (this study) would test the wave-breaking damage hypothesis.

The model north jetty was meticulously constructed at a scale of 1 to 45 (model to prototype) to reproduce, as closely as possible, the prototype jetty. No information was available on the current condition of the bedding layer, so as-built conditions were assumed. The bathymetry was carefully molded from the most recent nautical charts. No attempt was made to ascertain their accuracy or changes that might have occurred since the surveys.

Meteorological and NOAA buoy records were scanned to identify the worst storms during the 1979-1980 storm season. A total of 46 storms were selected: 14 in October, 14 in November, and 18 in December. These storms were hindcast using the WIS numerical model DWAVE to the deepwater depth corresponding to the location of the NOAA buoy. Directional spectral information was saved at 12-hr intervals to correspond with tidal fluctuations. Comparisons of peak period and wave height between the WIS and NOAA buoy showed reasonable agreement. Sources of uncertainty were (a) differences in interval length (6-hr interval for the buoy), (b) wave energy travelling parallel to the coast in deep water not making landfall at Yaquina, (c) interpolations of wave directions between grids from 22.5 deg to 10 deg, and (d) interpolation of wind fields on a 2.5-deg grid at 12-hr intervals.

Results from DWAVE were input to the shallow-water numerical model SHALWV to refract and shoal the storms to a water depth of 54 ft (16 m), corresponding approximately to the depth of the wavemaker in the physical model. Because of duplication, low-energy storms, and storm tracks not intersecting the Yaquina coast, the original number of storm segments was reduced from 46 to 13.

Because of time and funding constraints, each 12-hr segment was only simulated for 6 hr in the physical model. Because the tide is diurnal, these 6-hr segments were divided into two 3-hr segments: one at high tide and one at low tide using measurements from a tide gauge in Yaquina Bay. Thus, 26 wave conditions were simulated from the 13 storm segments in October, November, and December 1979.

Control signals for the DSWG were simulated using the CRAY Y-MP supercomputer and downloaded to the VAX 11/750 for generation and data collection. Data analysis was performed on the VAX 3600 using MLM directional spectral analysis techniques. After calibration, the agreement between measured and target storms was very good to excellent. Some storms still had energy travelling in a northerly direction, away from the Yaquina jetty system, and not measurable with the linear array of wave gauges. Variability in measured parameters is within the acceptable range for 3-D basins.

Although isolated stones rocked and were dislodged, stability tests with the 26 storm events failed to produce any significant damage to the model north jetty. After testing was completed, it was discovered that an error in the WIS hindcast processing of the October test segments caused them to be too low in period and height. Thus, these six segments did not subject the jetty model to the correct wave conditions during October. In retrospect, it is not felt that this error was significant since none of the other wave conditions produced any appreciable damage.

Some of the tests were repeated with the wave heights increased by 40 percent over the hindcast wave heights. The purpose of these tests was to eliminate the possibility that the hindcasts had underpredicted wave heights. It also was thought that increased wave heights would overcome any model effects that might have occurred due to inaccurate bathymetry in the model. Unfortunately, these increased wave height tests also failed to induce any significant damage.

Next, some of the wave conditions from the earlier physical model study of the 1988 rehabilitation were simulated. These waves consisted of unidirectional and directional waves representing the six worst storms in a 20-year interval. They had been hindcast using the same WIS numerical models. Peak wave periods and wave heights ranged from 12.5 to 16.7 sec and 15.4 to 23.0 ft (5 to 7 m), respectively. They were run at only one water level and for a very short duration. Even though a few more stones were randomly displaced, overall stability was still good.

Thinking that the north jetty had been built too tightly, "hot spots" were created by selectively removing stones from the jetty tip. Again, only selected storms were run for short durations, but the result was still the same: no appreciable damage. Finally, the jetty was reconstructed in a very loose matrix. Again, selective testing of this loose structure did not result in appreciable damage. However, minor damage was observed when more severe wave conditions were run. The recorded damage in the model did not even begin to resemble the extensive damage that actually occurred at Yaquina.

Damage to the north jetty at Yaquina may occur in rapid fashion as the result of one storm or over the course of several storms or winter seasons. Wave grouping or episodic waves, either of which can produce more damage than isolated waves, may play a role at Yaquina Bay. All of the storms in these physical model tests were limited because of time and funding constraints. A review of the physical modeling methodology did not indicate any serious shortcomings. Based on this limited physical model test series, it is concluded that armor instability due to wave attack alone is probably not the responsible failure mechanism at the Yaquina Bay north jetty. If as-built construction data and measured prototype wave, current, and bathymetry become available, additional physical model tests could be more accurately performed prior to any new rehabilitation.

References

Borgman, L. E. (1990). "Irregular ocean waves: Kinematics and forces," *The Sea*, Vol 9, Part A, LeMehaute and Hanes, eds., John Wiley and Sons, New York, 121-68.

Briggs, M. J., and Hampton, M. L. (1987). "Directional spectral wave generator basin response to monochromatic waves," Technical Report CERC-87-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1-90.

Briggs, M. J., and Jensen, R. E. (1988). "Simulation of extreme storm events in coastal structural models." *Ocean Structural Dynamics Symposium*, Corvallis, OR.

Briggs, M. J., Borgman, L. E., and Outlaw, D. G. (1987). "Generation and analysis of directional spectral waves in a laboratory basin," OTC 5416, *Offshore Technology Conference*, Houston, TX.

Briggs, M. J., Grace, P. J., and Jensen, R. E. (1989). "Directional spectral wave transformation in the nearshore region; Report 1, Directional spectral performance characteristics," Technical Report CERC-89-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1-77.

Corson, W. D., et al. (1987). "Pacific coast hindcast Phase II wave information," WIS Report 16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Crowson, R. A., Birkemeier, W. A., Klein, H. M., and Miller, H. C. (1988). "SUPERDUCK nearshore processes experiment: Summary of studies, CERC Field Research Facility," Technical Report CERC-88-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Grace, P. J., and Dubose, W. G. (1988). "Jetty rehabilitation stability study, Yaquina Bay, Oregon," Technical Report CERC-88-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hudson, R. Y. (1975). "Reliability of rubble-mound breakwater stability models; hydraulic model investigation," Miscellaneous Paper H-75-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hughes, S. A., and Jensen, R. E. (1986). "A user's guide to SHALWV: Numerical model for simulation of shallow water wave growth, propagation, and decay," IR CERC-86-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

IAHR Working Group on Wave Generation and Analysis. (1986). "List of sea state parameters," Supplement to Bulletin No. 52, 1-24.

Long, C. E. "Laboratory wave generation and analysis: An instructional report for unidirectional wave generation and analysis," in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Markle, D. G., and Davidson, D. D. (1979). "Placed-stone stability tests Tillamook, Oregon," Technical Report HL-79-16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Outlaw, D. G., and Briggs, M. J. (1986). "Directional irregular wave generator design for shallow wave basins." *21st American Towing Tank Conference*, Washington, DC.

Sand, S. E. (1979). "Three-dimensional deterministic structure of ocean waves," Series Paper No. 24, Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, 1-177.

Stevens, J. C., et al. (1942). "Hydraulic models," *Manuals of Engineering Practice*, No. 25, American Society of Civil Engineers, New York.

Tracy, B., and Payne, J. (1990). "Summary information for WIS Yaquina Bay study," CERC Memorandum for Record, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Engineer District, Buffalo. (1946). "Project maps," Buffalo, NY.

U.S. Army Engineer Waterways Experiment Station. (1963). "Stability of South Jetty Siuslaw River, Oregon," Technical Report No. 2-631, Vicksburg, MS.

Table 1
Prototype and Model Wave Conditions[1]

Prototype					Model			
No.	Test ID[2]	T_p (sec)	H_{mo} (m)	θ^3 (deg)	T_p (sec)	f_p (Hz)	H_{mo} (cm)	θ^3 (deg)
1	YO22N	10.00	4.40	35.00	1.49	0.67	9.78	-35.00
2	YO23M	12.50	4.50	18.00	1.86	0.54	10.00	-18.00
3	YO23N	11.10	3.80	6.00	1.65	0.60	8.44	-6.00
4	YN20N	14.30	2.10	5.00	2.13	0.47	4.67	-5.00
5	YN21M	14.30	1.60	11.00	2.13	0.47	3.56	-11.00
6	YN21N	16.70	2.50	6.00	2.49	0.40	5.56	-6.00
7	YN22M	16.70	3.10	6.00	2.49	0.40	6.89	-6.00
8	YN22N	16.70	3.20	5.00	2.49	0.40	7.11	-5.00
9	YN23M	14.30	3.10	11.00	2.13	0.47	6.89	-11.00
10	YN23N	14.30	3.30	23.00	2.13	0.47	7.33	-23.00
11	YD24N	14.30	5.20	22.00	2.13	0.47	11.46	-22.00
12	YD25M	16.70	5.00	15.00	2.49	0.40	11.11	-15.00
13	YD25N	12.50	3.70	16.00	1.86	0.54	8.22	-16.00

Notes:

1. T_p = Spectral peak period, $1/f_p$, sec
   H_{mo} = zero-moment wave height, an estimate of significant wave height
2. Nomenclature for Test ID
   Column 1: Y = Yaquina Bay Study
   Column 2: O = October, 1979 Storm
   N = November, 1979 Storm
   D = December, 1979 Storm
   Column 3: # = Day of Month
   Column 4: # = Day of Month
   Column 5: M= Midnight
   N = Noon
3. Dir = Wave direction of prototype and model, differences due to sign conventions

Table 2
Prototype and Model Water Levels at Wave Generator Depth

No.	Test ID[1]	Storm Tide (m)	Depth @ DSWG		
			Prototype (m)	Model (cm)	7 Level[2] (cm)
1	YO22NH	2.55	20.22	44.9	44.8
2	YO22NL	0.93	18.60	41.3	41.5
3	YO23MH	2.87	20.55	45.7	45.7
4	YO23ML	0.21	17.89	39.8	39.9
5	YO23NH	2.44	20.11	44.7	44.8
6	YO23NL	0.92	18.60	41.3	41.5
7	YN20NH	2.11	19.79	44.0	43.9
8	YN20NL	0.73	18.41	40.9	41.5
9	YN21MH	2.69	20.37	45.3	44.8
10	YN21ML	-0.34	17.34	38.5	38.7
11	YN21NH	2.23	19.90	44.2	43.9
12	YN21NL	0.88	18.56	41.2	41.5
13	YN22MH	2.76	20.43	45.4	45.4
14	YN22ML	-0.24	17.43	38.7	38.7
15	YN22NH	2.38	20.06	44.6	44.8
16	YN22NL	1.33	19.00	42.2	42.4
17	YN23MH	3.02	20.70	46.0	45.7
18	YN23ML	-0.17	17.51	38.9	38.7
19	YN23NH	2.11	19.79	44.0	43.9
20	YN23NL	1.12	18.80	41.8	42.4
21	YD24NH	3.06	20.74	46.1	45.7
22	YD24NL	1.34	19.01	42.3	42.4

Notes:

1. Nomenclature for Test ID
   Column 1: Y = Yaquina Bay Study
   Column 2: O = October, 1979 Storm
   N = November, 1979 Storm
   D = December, 1979 Storm
   Column 3: # = Day of Month
   Column 4: # = Day of Month
   Column 5: M = Midnight
   N = Noon
   Column 6: H = High Water Level
   L = Low Water Level
2. 7 Level = Seven levels selected for model tests from originally scaled 26 levels.

(Continued)

Table 2 (Concluded)					
			Depth @ DSWG		
No.	Test ID[1]	Storm Tide (m)	Protoype (m)	Model (cm)	7 Level[2] (cm)
23	YD25MH	2.72	20.39	45.3	45.7
24	YD25ML	0.35	18.03	40.1	39.9
25	YD25NH	2.76	20.44	45.4	45.7
26	YD25NL	0.99	18.67	41.5	41.5

Table 3
Measured Model Peak Wave Periods T_p in sec

Test Case	Run No.	Trgt T_p	Gauge Numbers 1	2	3	4	5	6	7	8	9	10	Averages 1-8	2-8	3-6	9-10
YO22NH	3	1.49	1.14	1.22	1.50	1.68	1.68	1.23	1.34	1.71	1.99	1.92	1.44	1.48	1.52	1.95
YO22NL	3	1.49	1.14	1.89	1.50	1.68	1.23	1.24	1.23	1.23	1.68	1.92	1.39	1.43	1.41	1.80
YO22MH	3	1.86	1.92	1.97	1.97	2.03	2.03	1.90	1.90	2.15	2.08	1.95	1.98	1.99	1.98	2.02
YO23ML	3	1.86	1.90	1.88	1.87	1.86	1.90	1.90	2.15	2.15	2.09	1.91	1.95	1.96	1.88	2.00
YO23NH	3	1.65	2.15	1.80	1.62	1.73	2.03	2.14	1.71	1.68	2.17	2.17	1.86	1.82	1.88	2.17
YO23NL	3	1.65	2.14	1.78	1.62	1.67	1.67	1.80	1.88	1.88	2.14	2.15	1.81	1.76	1.69	2.14
YN20NH	3	2.13	2.28	2.26	2.26	2.28	2.28	2.53	2.30	2.30	2.28	2.25	2.31	2.31	2.34	2.26
YN20NL	3	2.13	2.38	2.35	2.26	2.28	2.28	2.30	2.24	2.24	2.38	2.28	2.29	2.28	2.28	2.33
YN21MH	3	2.13	2.22	2.23	2.23	2.22	2.22	2.20	2.18	2.18	2.22	2.22	2.21	2.21	2.22	2.22
YN21ML	3	2.13	2.22	2.12	2.23	2.22	2.22	2.19	2.14	2.14	2.42	2.42	2.19	2.18	2.22	2.42
YN21NH	3	2.49	2.56	2.60	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.54	2.57	2.57	2.57	2.55
YN21NL	3	2.49	2.65	2.69	2.67	2.57	2.57	2.57	2.58	2.61	2.65	2.54	2.61	2.61	2.59	2.60
YN22MH	3	2.49	2.52	2.54	2.54	2.54	2.53	2.46	2.43	2.43	2.46	2.46	2.50	2.49	2.51	2.46
YN22ML	3	2.49	2.46	2.54	2.53	2.53	2.53	2.44	2.42	2.42	2.46	2.46	2.48	2.49	2.51	2.46

(Continued)

Table 3 (Concluded)																
Test Case	Run No.	Trgt T_p	Gauge Numbers										Averages			
			1	2	3	4	5	6	7	8	9	10	1-8	2-8	3-6	9-10
YN22NH	3	2.49	2.52	2.54	2.53	2.52	2.50	2.53	2.50	2.50	2.50	2.50	2.52	2.52	2.52	2.50
YN22NL	3	2.49	2.30	2.53	2.53	2.50	2.50	2.53	2.64	2.64	2.50	2.50	2.52	2.55	2.51	2.50
YN23MH	3	2.13	2.28	2.50	2.38	2.39	2.16	2.16	2.16	2.16	2.28	2.28	2.27	2.27	2.27	2.28
YN23ML	3	2.13	2.17	2.38	2.36	2.28	2.28	2.16	2.60	2.60	2.28	2.28	2.35	2.38	2.27	2.28
YN23NH	3	2.13	1.89	2.05	2.19	1.84	1.84	2.12	2.13	2.13	2.19	2.19	2.02	2.04	2.00	2.19
YN23NL	3	2.13	1.89	2.05	2.19	1.91	1.84	1.92	2.13	2.13	2.19	2.04	2.01	2.02	1.96	2.12
YD24NH	3	2.13	2.15	2.51	2.50	2.24	2.23	2.43	2.28	2.28	2.41	2.43	2.33	2.35	2.35	2.42
YD24NL	3	2.13	2.43	2.34	2.33	2.23	2.23	2.17	2.28	2.30	2.41	2.22	2.29	2.27	2.24	2.32
YD25MH	3	2.49	2.49	2.41	2.41	2.41	2.41	2.22	2.21	2.21	2.48	2.17	2.34	2.32	2.36	2.32
YD25ML	3	2.49	2,48	2.41	2.31	2.48	2.48	2.22	2.54	2.54	2.59	2.37	2.44	2.44	2.40	2.48
YD25NH	3	1.86	1.15	2.24	2.24	2.21	2.21	1.24	1.89	1.15	2.19	2.19	1.79	1.88	1.98	2.19
YD25NL	3	1.86	1.16	2.24	2.24	2.21	2.21	1.22	2.16	1.15	2.25	2.25	1.82	1.92	1.97	2.25

Table 4
Measured Model Zero Moment Wave Heights H_{mo} in cm

Test Case	Run No. 0_	Trgt. H_{mo} (cm)	Gauge Numbers 1 (cm)	2 (cm)	3 (cm)	4 (cm)	5 (cm)	6 (cm)	7 (cm)	8 (cm)	9 (cm)	10 (cm)	Averages 1-8 (cm)	2-8 (cm)	3-6 (cm)	9-10 (cm)
YO22NH	3	9.8	10.5	10.4	10.5	10.0	9.9	9.9	9.7	9.8	9.0	9.6	10.1	10.0	10.1	9.3
YO22NL	3	9.8	10.1	10.1	10.2	9.7	9.7	9.7	9.3	9.2	8.4	9.1	9.8	9.7	9.8	8.7
YO23MH	3	10.1	10.1	11.0	11.2	10.8	10.6	9.5	9.6	9.8	11.2	11.9	10.3	10.4	10.5	11.6
YO23ML	3	10.1	9.9	12.5	11.3	10.7	10.6	9.6	9.4	9.7	11.6	10.5	10.5	10.5	10.5	11.0
YO23NH	3	8.5	8.0	9.4	9.5	8.9	8.6	8.0	8.1	8.3	10.0	9.8	8.6	8.7	8.8	9.9
YO23NL	3	8.5	8.0	10.3	9.6	8.8	8.6	8.0	8.1	8.3	10.6	9.5	8.7	8.8	8.7	10.0
YN20NH	3	4.6	4.2	5.0	5.0	4.6	4.5	4.2	4.3	4.4	5.4	5.3	4.5	4.6	4.6	5.4
YN20NL	3	4.6	4.2	5.4	5.1	4.6	4.5	4.2	4.3	4.4	5.9	5.4	4.6	4.6	4.6	5.6
YN21MH	3	3.7	3.3	3.6	3.7	3.5	3.4	3.2	3.3	3.4	4.3	4.4	3.4	3.4	3.5	4.4
YN21ML	3	3.7	3.2	4.1	3.9	3.5	3.4	3.1	3.3	3.3	5.3	4.4	3.5	3.5	3.5	4.9
YN21NH	3	5.5	5.6	5.8	6.1	5.8	5.7	5.2	5.4	5.5	7.0	6.8	5.6	5.6	5.7	6.9
YN21NL	3	5.5	5.5	6.1	6.2	5.8	5.7	5.1	5.3	5.5	7.7	6.9	5.7	5.7	5.7	7.3
YN22MH	3	7.0	7.7	7.6	8.0	7.6	7.5	7.4	7.6	7.8	9.5	9.0	7.6	7.6	7.6	9.2
YN22ML	3	7.0	7.3	7.4	7.9	7.3	7.2	7.1	7.2	7.3	8.6	9.0	7.3	7.3	7.4	8.8

(Continued)

Table 4 (Concluded)

Test Case	Run No. 0_	Trgt. H_{mo} (cm)	Gauge Numbers 1 (cm)	2 (cm)	3 (cm)	4 (cm)	5 (cm)	6 (cm)	7 (cm)	8 (cm)	9 (cm)	10 (cm)	Averages 1-8 (cm)	2-8 (cm)	3-6 (cm)	9-10 (cm)
YN22NH	3	7.0	7.4	7.9	8.4	7.6	7.5	7.0	6.9	7.1	9.6	8.3	7.5	7.5	7.6	9.0
YN22NL	3	7.0	7.1	7.9	8.3	7.5	7.3	6.8	6.8	7.0	9.3	9.2	7.3	7.4	7.5	9.2
YN23MH	3	7.0	7.3	7.7	7.9	7.4	7.3	7.2	7.0	7.1	9.5	9.3	7.4	7.4	7.5	9.4
YN23ML	3	7.0	7.2	8.9	8.0	7.4	7.2	6.9	6.8	6.9	11.1	9.0	7.4	7.4	7.4	10.0
YN23NH	3	7.3	7.5	8.4	8.1	7.7	7.5	7.2	6.6	6.6	9.1	9.1	7.4	7.4	7.6	9.1
YN23NL	3	7.3	7.5	8.7	8.2	7.6	7.4	7.1	6.5	6.6	9.3	9.0	7.4	7.4	7.6	9.1
YD24NH	3	11.6	12.1	12.2	12.7	11.9	11.7	11.6	10.8	10.9	13.2	13.6	11.7	11.7	12.0	13.4
YD24NL	3	11.6	11.8	13.1	12.7	11.7	11.6	11.4	10.8	10.9	13.8	13.2	11.8	11.7	11.8	13.5
YD25MH	3	11.0	11.7	11.4	11.8	11.5	11.4	11.2	10.7	10.8	13.2	12.8	11.3	11.3	11.5	13.0
YD25ML	3	11.0	10.9	10.8	11.0	10.7	10.7	10.4	9.8	9.8	10.5	10.9	10.5	10.5	10.7	10.7
YD25NH	3	8.2	9.0	7.9	8.6	8.5	8.2	8.5	7.8	7.9	7.4	8.6	8.3	8.2	8.4	8.0
YD25NL	3	8.2	8.8	8.5	8.7	8.3	8.1	8.4	7.6	7.7	7.9	8.6	8.3	8.2	8.4	8.3

Table 5
Summary of Results for Stability Test 1

Step	SWL ft, mllw	T_p, sec	H_{mo}, ft	Observations
October Conditions				
1	+8.2	16.7	10.4	Minor rocking-2 or 3 stones
2	+3.2	10.0	14.4	No movement
3	+9.5	12.5	14.9	Minor rocking-2 or 3 stones
4	+1.0	12.5	14.9	Reorientation and loosening of 8 to 10 armor stone
5	+8.2	11.1	12.6	Additional loosening of stone identified in step 4
6	+3.2	11.1	12.6	No movement
November Conditions				
7	+6.8	14.3	6.8	No movement
8	+3.2	14.3	6.8	No movement
9	+8.2	14.3	5.4	No movement
10	-0.8	14.3	5.4	No movement
11	+6.8	16.7	8.1	No movement
12	+3.2	16.7	8.1	No movement
13	+9.5	16.7	10.4	No movement
14	-0.8	16.7	10.4	No movement
15	+8.2	16.7	10.4	No movement
16	+4.6	16.7	10.4	No movement
17	+9.5	14.3	10.4	No movement
18	-0.8	14.3	10.4	Minor rocking-2 or 3 stones
19	+6.8	14.3	10.8	Minor rocking-2 or 3 stones
20	+4.6	14.3	10.8	Minor rocking-2 or 3 stones
December Conditions				
21	+9.5	14.3	17.1	Reorientation of 1 stone and rocking of 3 or 4 others
22	+4.6	14.3	17.1	General loosening of armor above swl
23	+9.5	16.7	16.2	Same as step 22
24	+1.0	16.7	16.2	Same as step 22
25	+9.5	12.5	12.2	Minor rocking-3 or 4 stones
26	+3.2	12.5	12.2	Same as step 25

Table 6
Summary of Results for Stability Test 2

Step	SWL ft, mllw	T_p, sec	H_{mo}, ft	Observations
December Conditions				
1	+9.5	14.3	17.1	Loosening of armor, displacement of 9 stones, and 5 others rocking
2	+4.6	14.3	17.1	Rocking-5 or 6 stones
3	+9.5	16.7	16.2	Same as step 2
4	+1.0	16.7	16.2	Same as step 2
5	+9.5	12.5	12.2	Minor rocking-2 or 3 stones
6	+3.2	12.5	12.2	Same as step 5

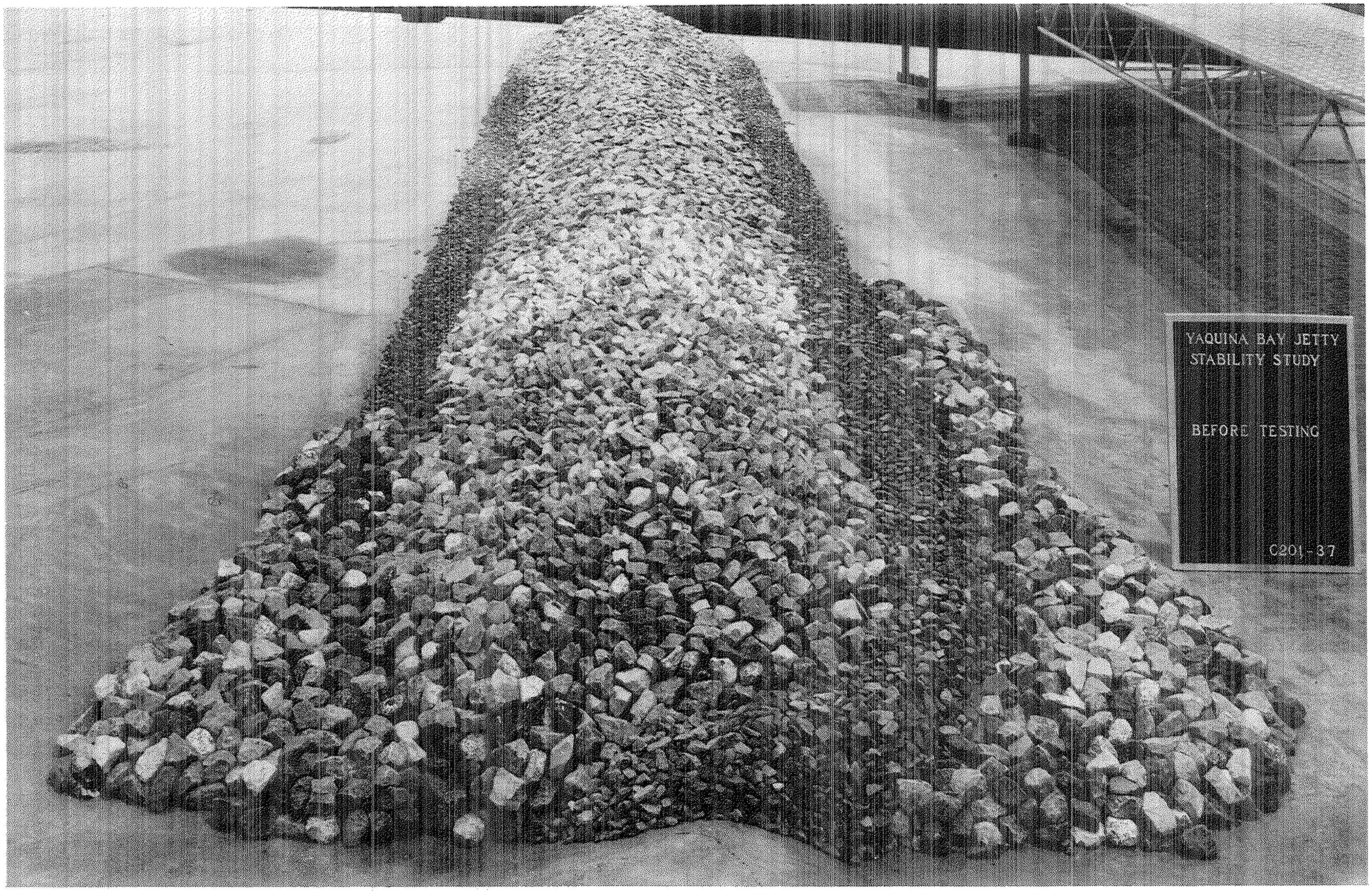


Photo 1. Long-axis view of structure before testing

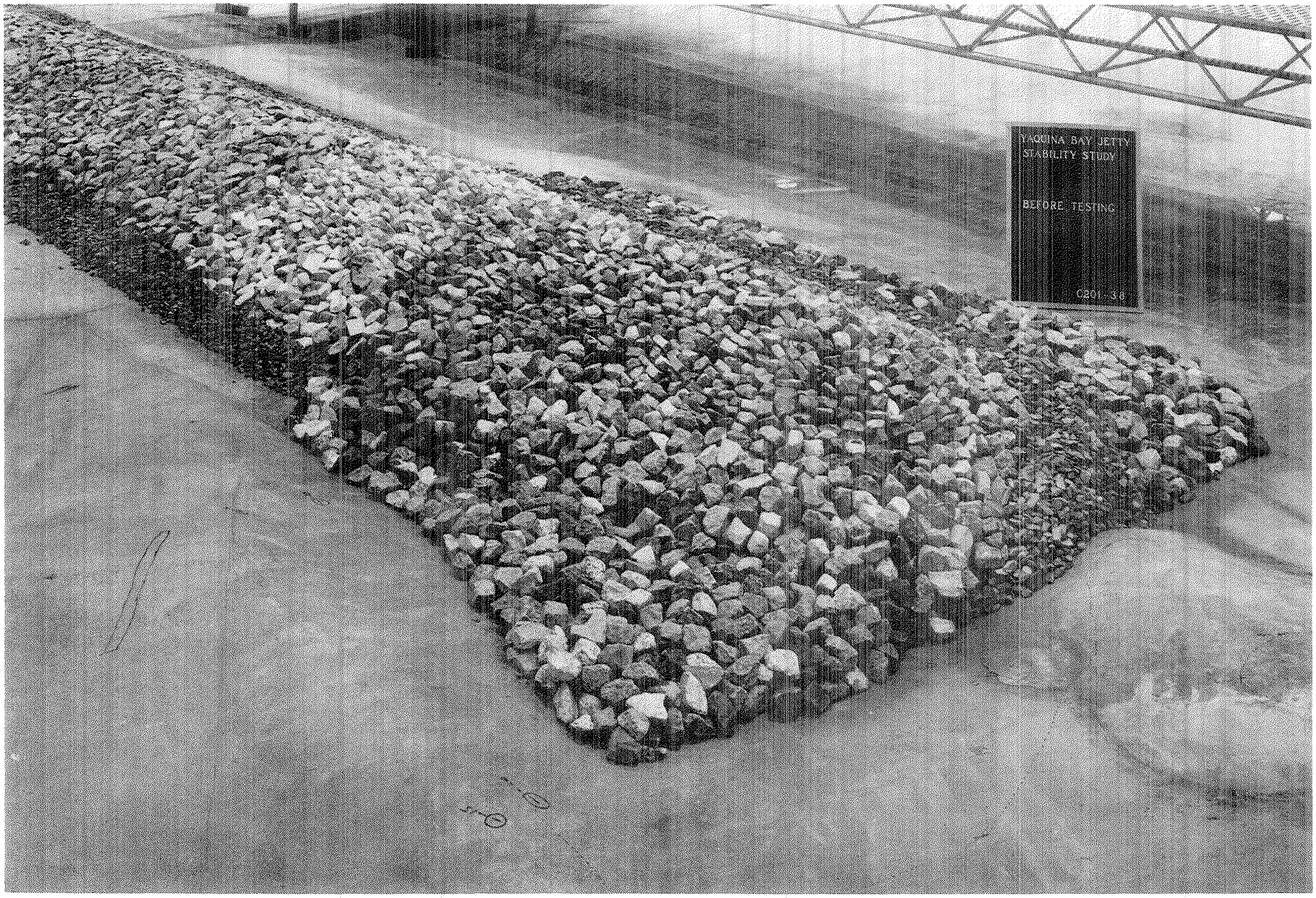


Photo 2. Sea-side view of structure before testing

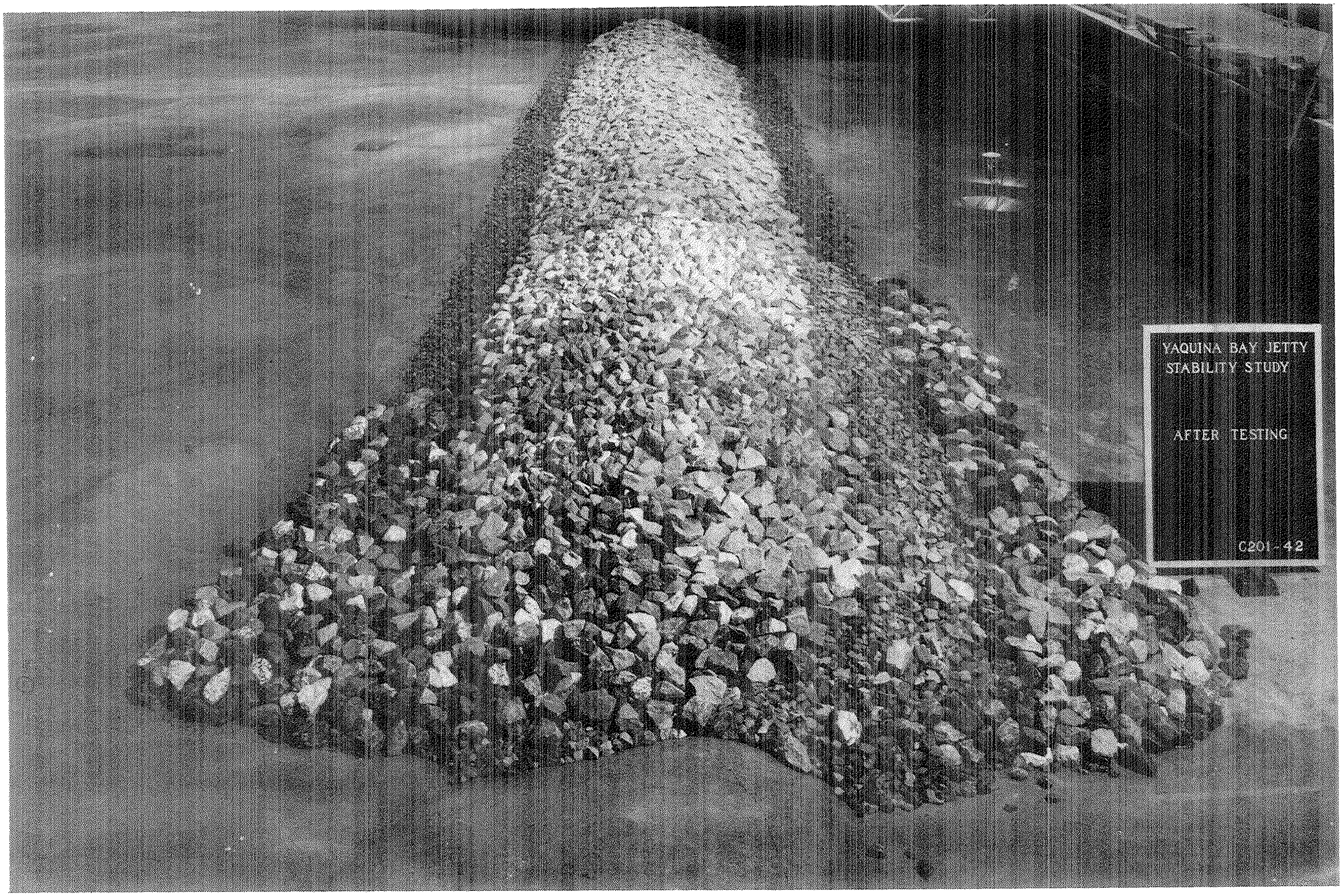


Photo 3. Long-axis view of structure following initial stability test

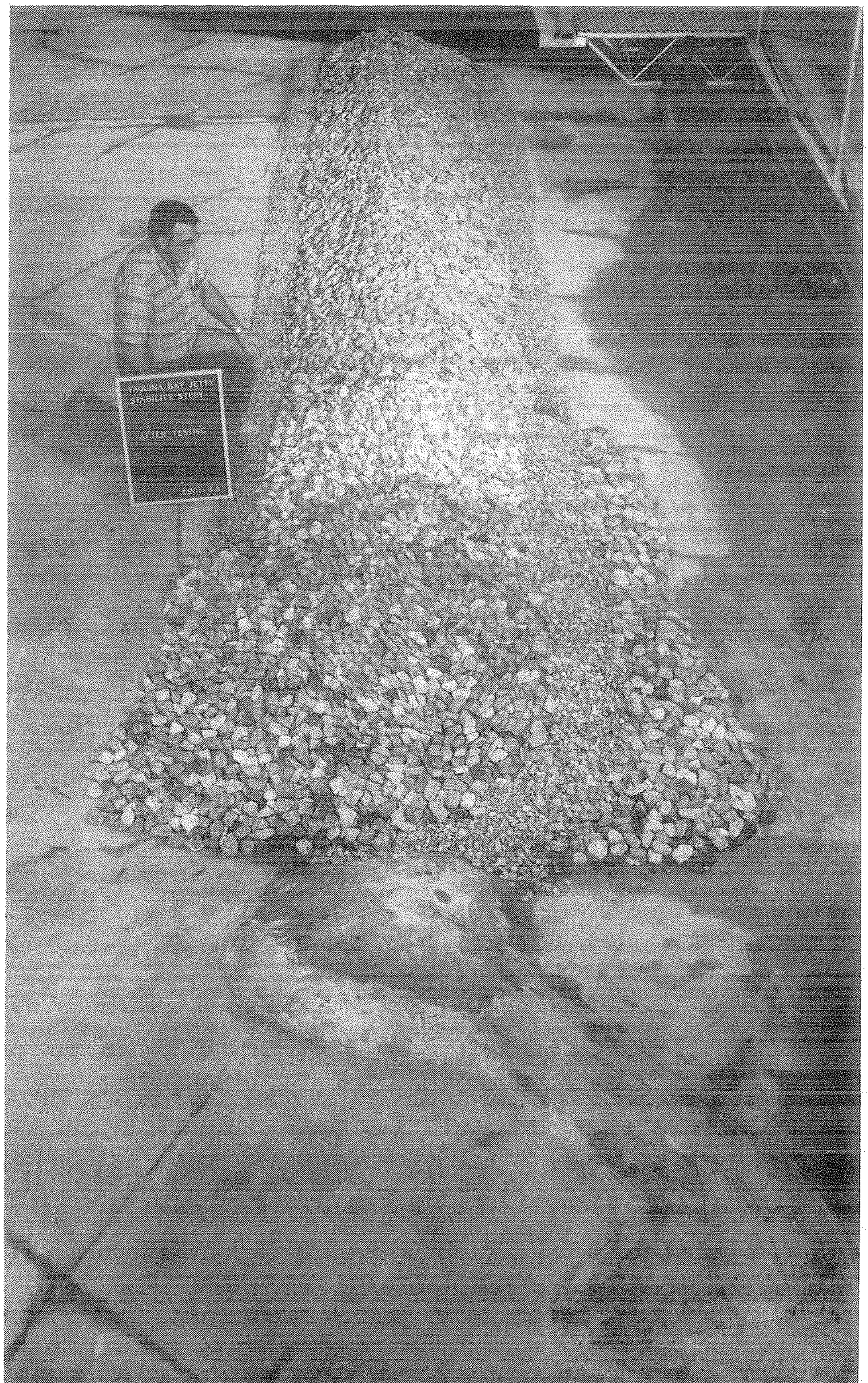


Photo 4. Overhead view of structure following repeat stability test

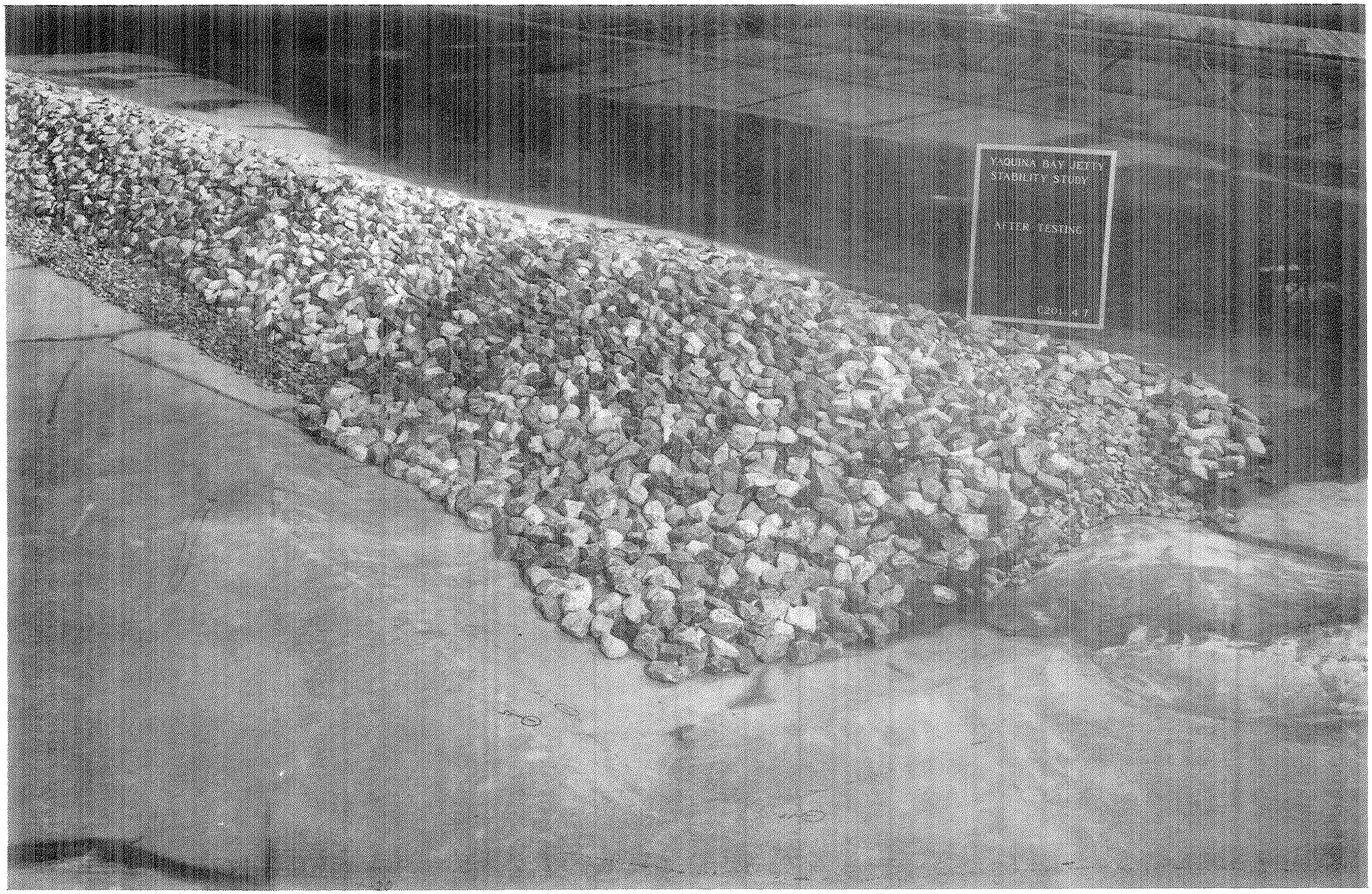
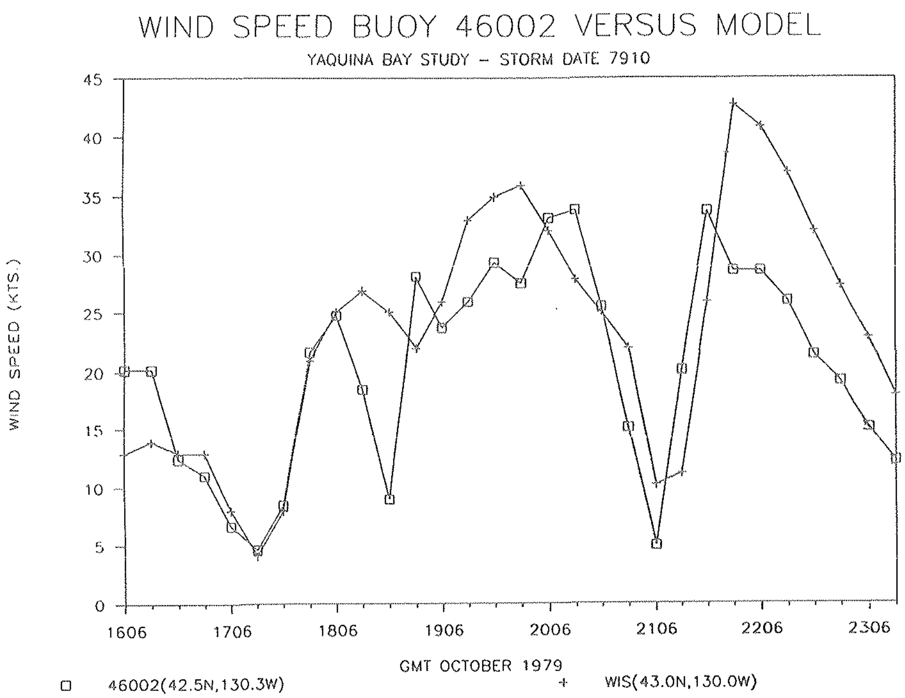
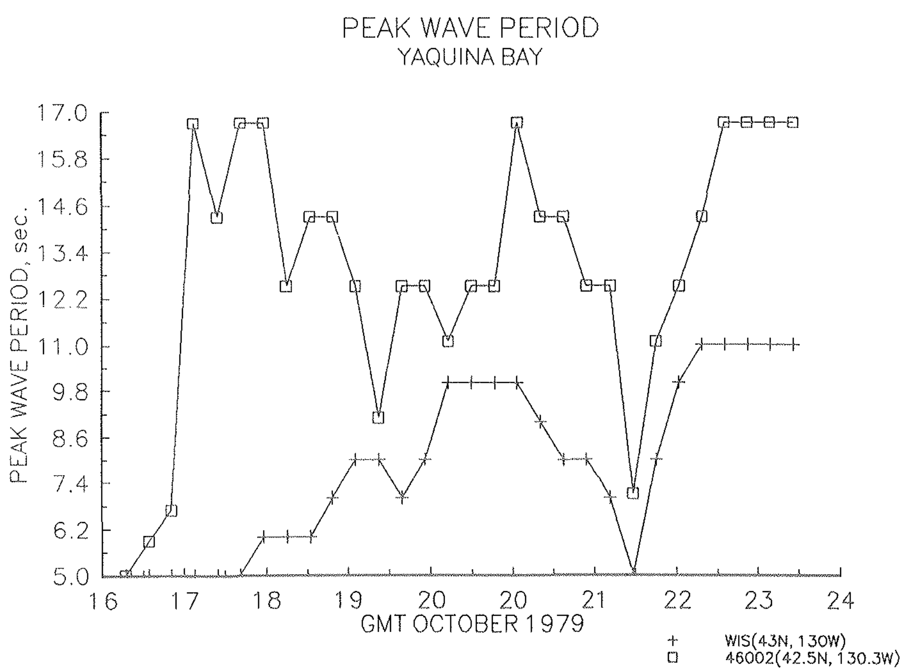
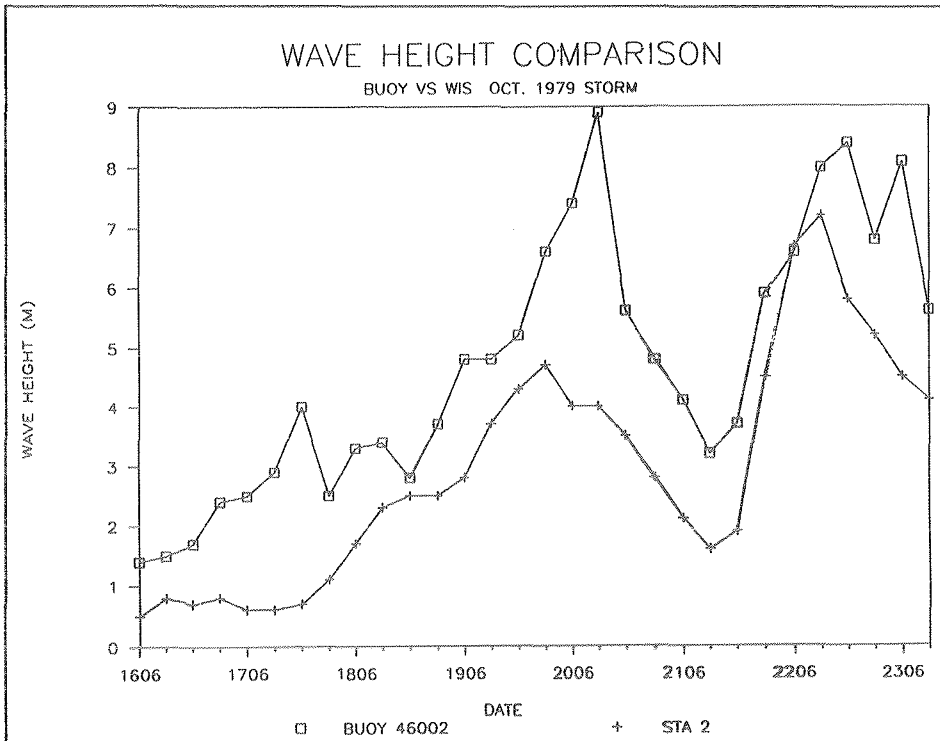


Photo 5. Sea-side view of structure following repeat stability test

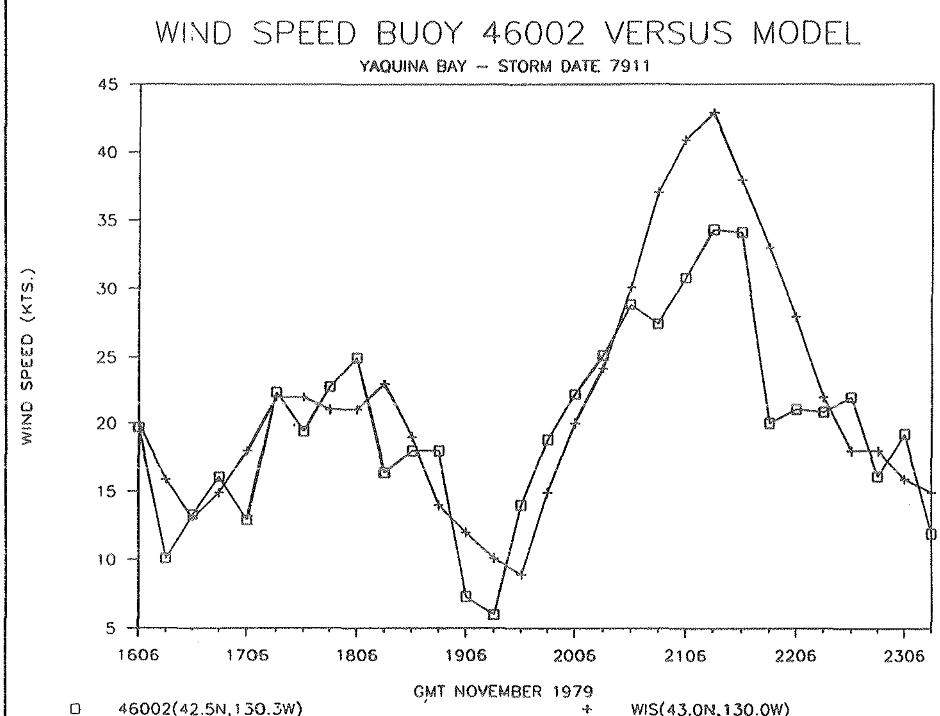
Appendix A
WIS Comparisons with Buoy 46002


WIND SPEED BUOY 46002 VERSUS MODEL
YAQUINA BAY STUDY - STORM DATE 7910
WIND SPEED (KTS.)
45
40
35
30
25
20
15
10
5
0
1606
1706
1806
1906
2006
2106
2206
2306
GMT OCTOBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)

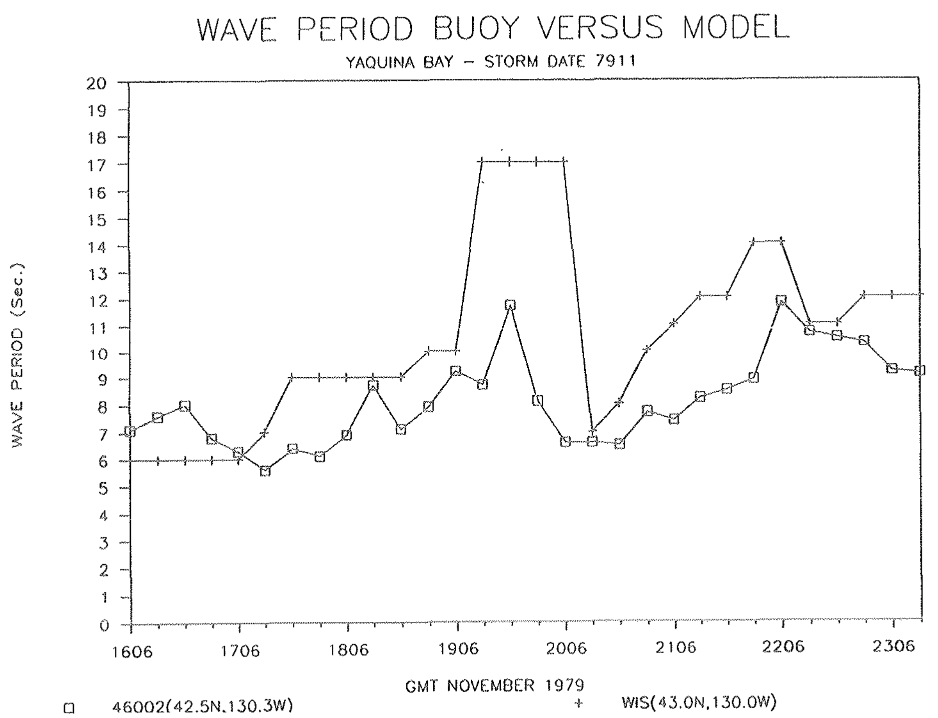

PEAK WAVE PERIOD
YAQUINA BAY
PEAK WAVE PERIOD, sec.
17.0
15.8
14.6
13.4
12.2
11.0
9.8
8.6
7.4
6.2
5.0
16
17
18
19
20
20
21
22
23
24
GMT OCTOBER 1979
WIS(43N, 130W)
46002(42.5N, 130.3W)

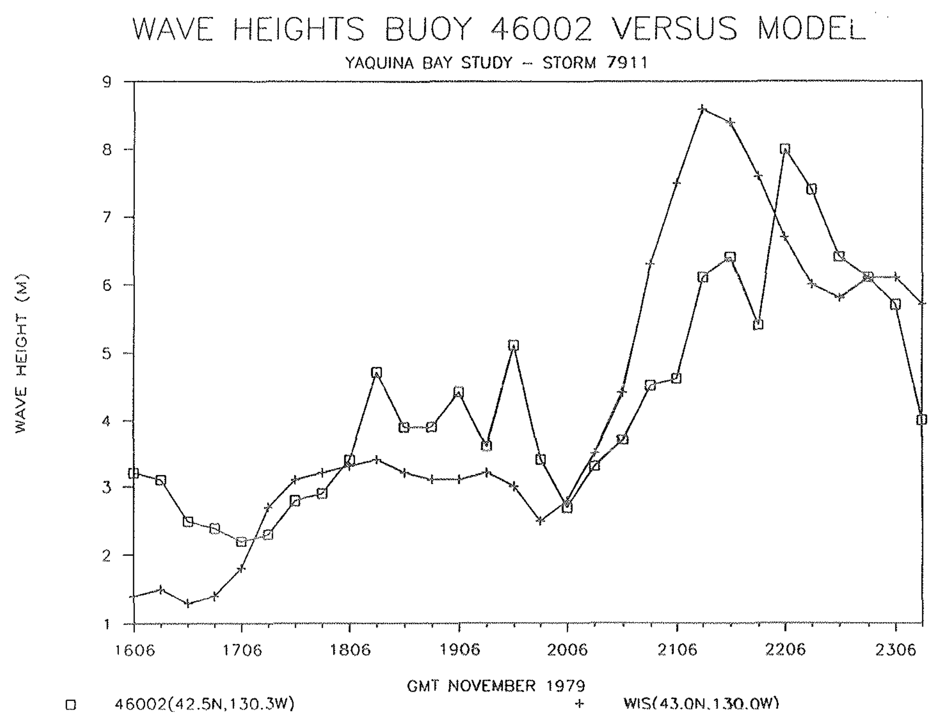


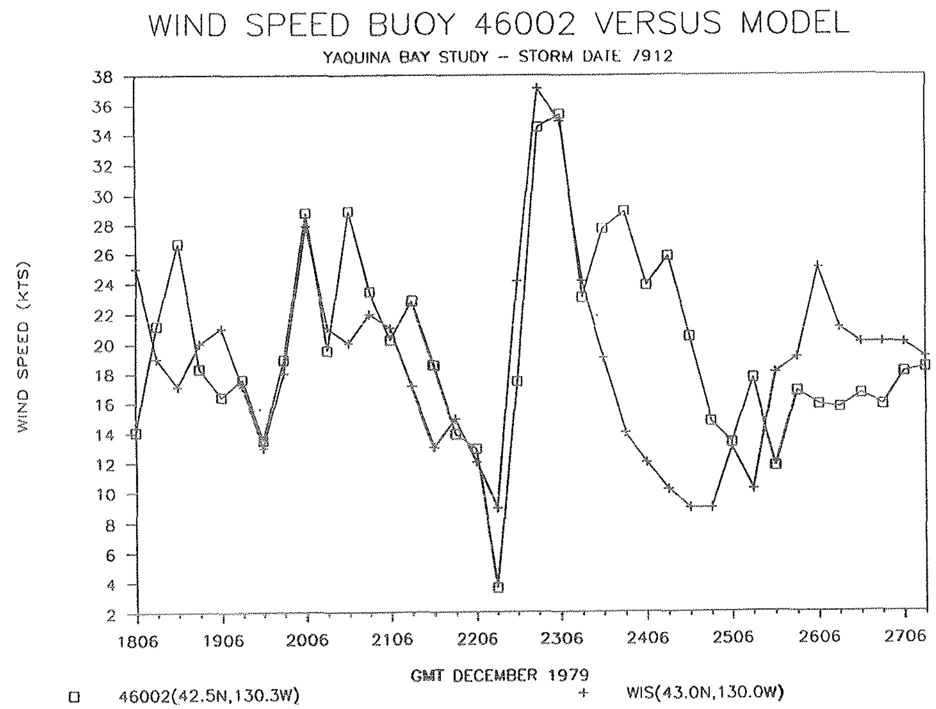
WAVE HEIGHT COMPARISON
BUOY VS WIS OCT. 1979 STORM
WAVE HEIGHT (M)
0
1
2
3
4
5
6
7
8
9
1606
1706
1806
1906
2006
2106
2206
2306
DATE
BUOY 46002
STA 2

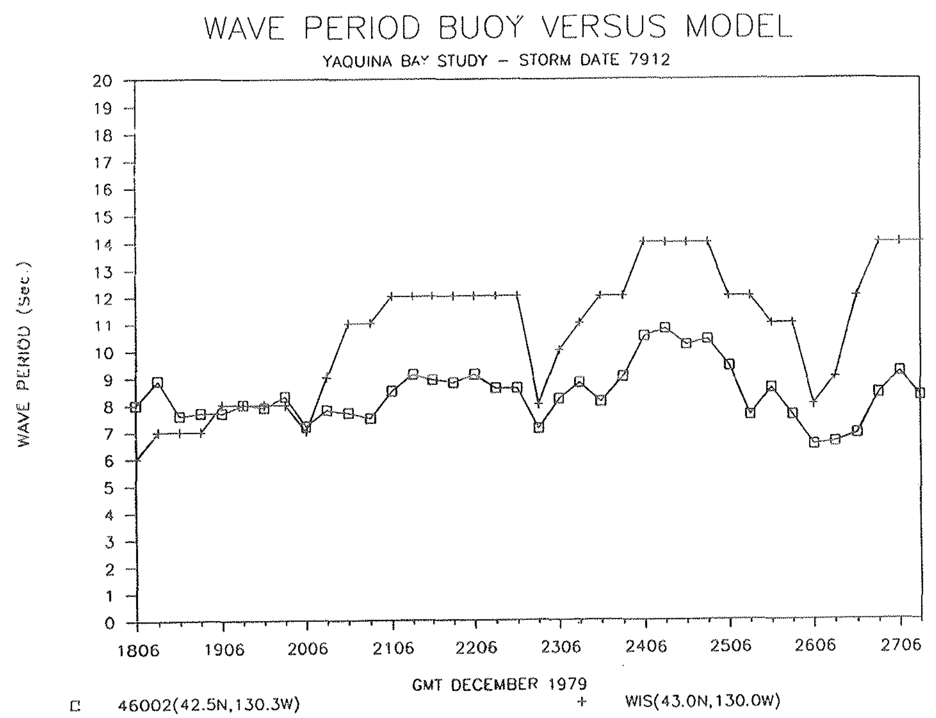


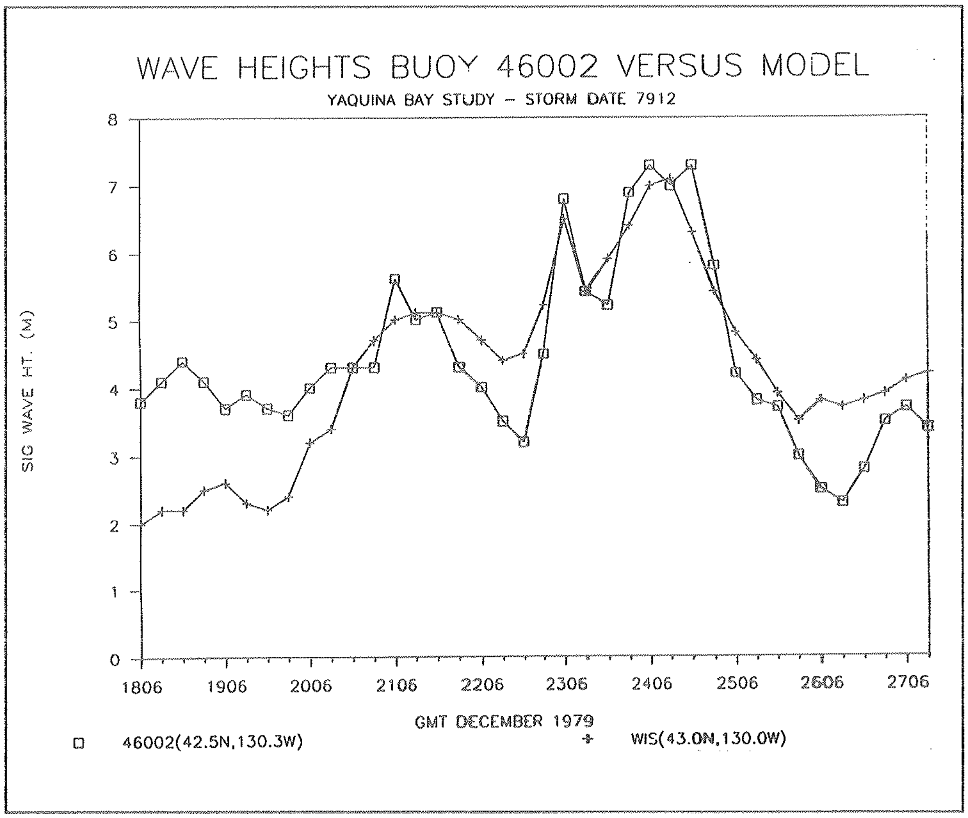
WIND SPEED BUOY 46002 VERSUS MODEL
YAQUINA BAY — STORM DATE 7911
WIND SPEED (KTS.)
5
10
15
20
25
30
35
40
45
1606
1706
1806
1906
2006
2106
2206
2306
GMT NOVEMBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)


WAVE PERIOD BUOY VERSUS MODEL
YAQUINA BAY – STORM DATE 7911
WAVE PERIOD (Sec.)
GMT NOVEMBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)


WAVE HEIGHTS BUOY 46002 VERSUS MODEL
YAQUINA BAY STUDY – STORM 7911
WAVE HEIGHT (M)
GMT NOVEMBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)


WIND SPEED BUOY 46002 VERSUS MODEL
YAQUINA BAY STUDY – STORM DATE 7912
WIND SPEED (KTS)
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
1806
1906
2006
2106
2206
2306
2406
2506
2606
2706
GMT DECEMBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)


WAVE PERIOD BUOY VERSUS MODEL
YAQUINA BAY STUDY – STORM DATE 7912
WAVE PERIOD (Sec.)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1806
1906
2006
2106
2206
2306
2406
2506
2606
2706
GMT DECEMBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)



WAVE HEIGHTS BUOY 46002 VERSUS MODEL
YAQUINA BAY STUDY – STORM DATE 7912
SIG WAVE HT. (M)
0
1
2
3
4
5
6
7
8
1806
1906
2006
2106
2206
2306
2406
2506
2606
2706
GMT DECEMBER 1979
46002(42.5N,130.3W)
WIS(43.0N,130.0W)

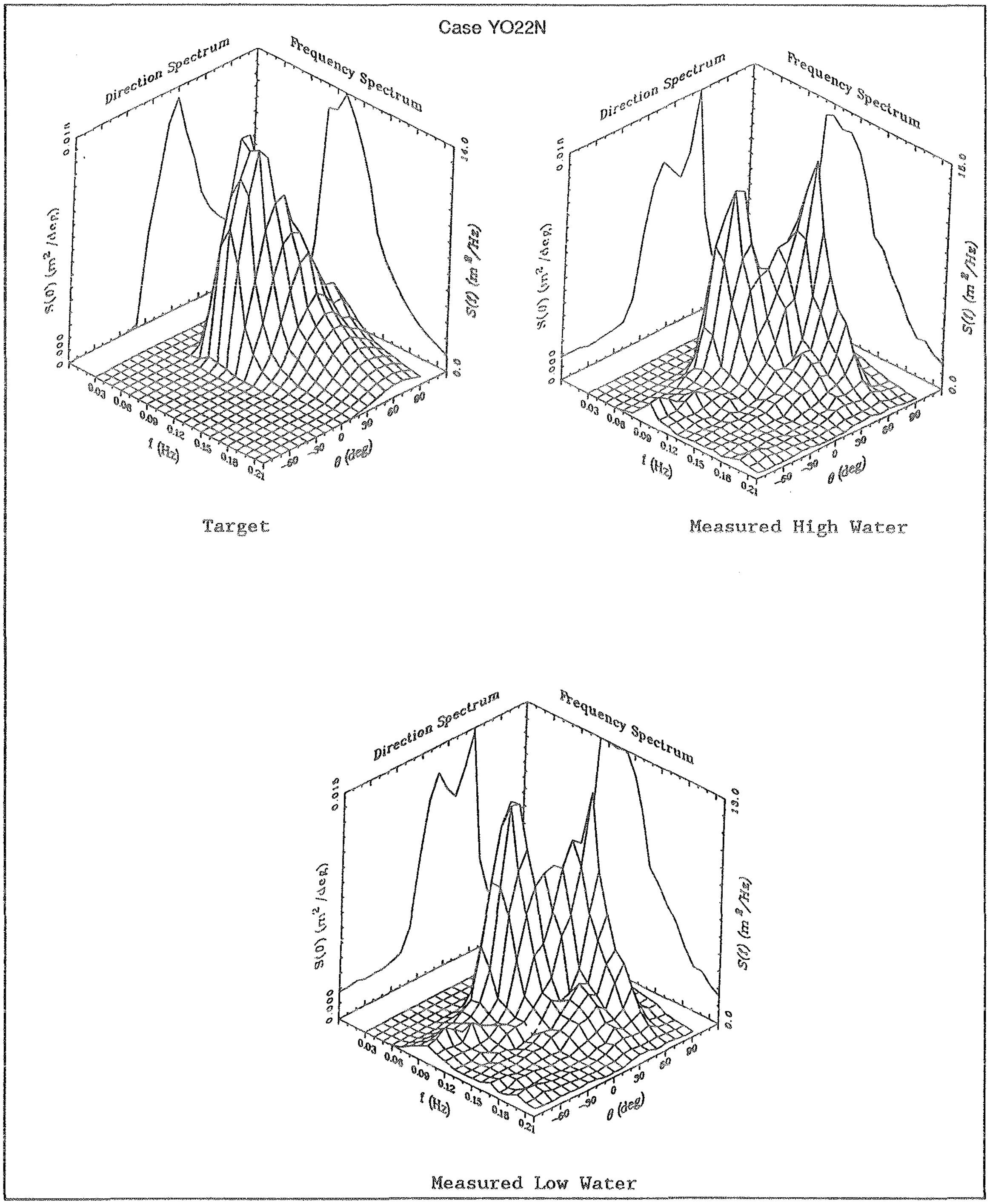
Appendix B
Prototype Gauge Depths

Appendix B
Rev.: 23 Jul 91

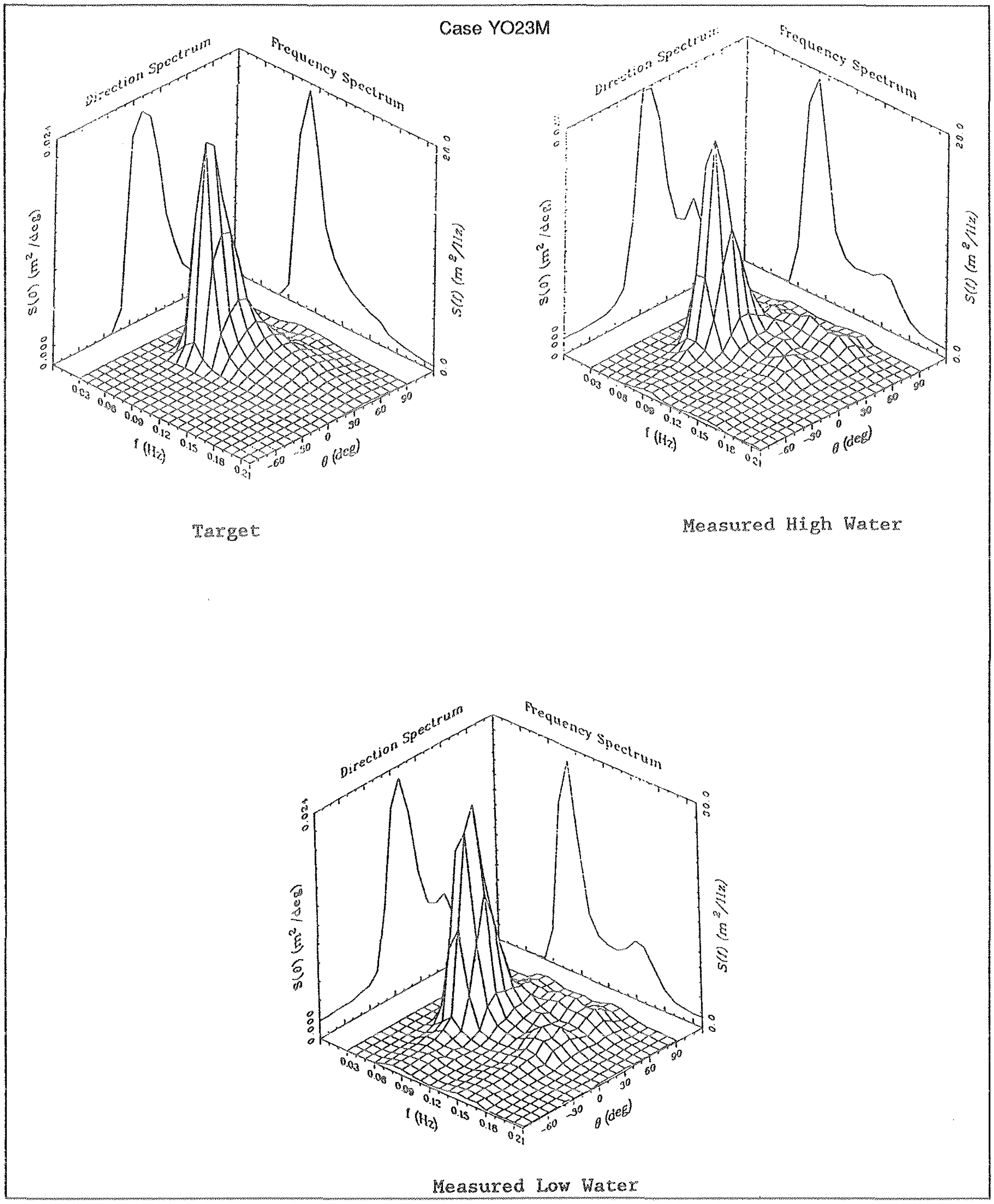
Equivalent Prototype Gage Depths
Yaquina Bay, Oregon

No.	Test ID	Gage 1 (m)	Gage 2 (m)	Gage 3 (m)	Gage 4 (m)	Gage 5 (m)	Gage 6 (m)	Gage 7 (m)	Gage 8 (m)	Gage 9 (m)	Gage 10 (m)
1	YO22NH	15.8	15.9	15.5	15.9	15.9	16.3	15.5	15.5	9.1	8.8
2	YO22NL	14.3	14.4	14.0	14.4	14.4	14.8	14.0	14.0	7.5	7.3
3	YO23MH	16.2	16.3	15.9	16.3	16.3	16.7	15.9	15.9	9.5	9.2
4	YO23ML	13.6	13.7	13.3	13.7	13.7	14.1	13.3	13.3	6.9	6.6
5	YO23NH	15.8	15.9	15.5	15.9	15.9	16.3	15.5	15.5	9.1	8.8
6	YO23NL	14.3	14.4	14.0	14.4	14.4	14.8	14.0	14.0	7.5	7.3
7	YN20NH	15.4	15.5	15.1	15.5	15.5	15.9	15.1	15.1	8.6	8.4
8	YN20NL	14.3	14.4	14.0	14.4	14.4	14.8	14.0	14.0	7.5	7.3
9	YN21MH	15.8	15.9	15.5	15.9	15.9	16.3	15.5	15.5	9.1	8.8
10	YN21ML	13.0	13.2	12.8	13.2	13.2	13.6	12.8	12.8	6.3	6.0
11	YN21NH	15.4	15.5	15.1	15.5	15.5	15.9	15.1	15.1	8.6	8.4
12	YN21NL	14.3	14.4	14.0	14.4	14.4	14.8	14.0	14.0	7.5	7.3
13	YN22MH	16.0	16.2	15.8	16.2	16.2	16.6	15.8	15.8	9.3	9.1
14	YN22ML	13.0	13.2	12.8	13.2	13.2	13.6	12.8	12.8	6.3	6.0
15	YN22NH	15.8	15.9	15.5	15.9	15.9	16.3	15.5	15.5	9.1	8.8
16	YN22NL	14.7	14.8	14.4	14.8	14.8	15.2	14.4	14.4	8.0	7.7
17	YN23MH	16.2	16.3	15.9	16.3	16.3	16.7	15.9	15.9	9.5	9.2
18	YN23ML	13.0	13.2	12.8	13.2	13.2	13.6	12.8	12.8	6.3	6.0
19	YN23NH	15.4	15.5	15.1	15.5	15.5	15.9	15.1	15.1	8.6	8.4
20	YN23NL	14.7	14.8	14.4	14.8	14.8	15.2	14.4	14.4	8.0	7.7
21	YD24NH	16.2	16.3	15.9	16.3	16.3	16.7	15.9	15.9	9.5	9.2
22	YD24NL	14.7	14.8	14.4	14.8	14.8	15.2	14.4	14.4	8.0	7.7
23	YD25MH	16.2	16.3	15.9	16.3	16.3	16.7	15.9	15.9	9.5	9.2
24	YD25ML	13.6	13.7	13.3	13.7	13.7	14.1	13.3	13.3	6.9	6.6
25	YD25NH	16.2	16.3	15.9	16.3	16.3	16.7	15.9	15.9	9.5	9.2
26	YD25NL	14.3	14.4	14.0	14.4	14.4	14.8	14.0	14.0	7.5	7.3

Appendix C
Target and Measured Prototype Directional Spectra


Case YO22N
Direction Spectrum
Frequency Spectrum
S(θ) (m² /deg)
S(f) (m²/Hz)
f (Hz)
θ (deg)
Target
Measured High Water
Measured Low Water

Case YO23M

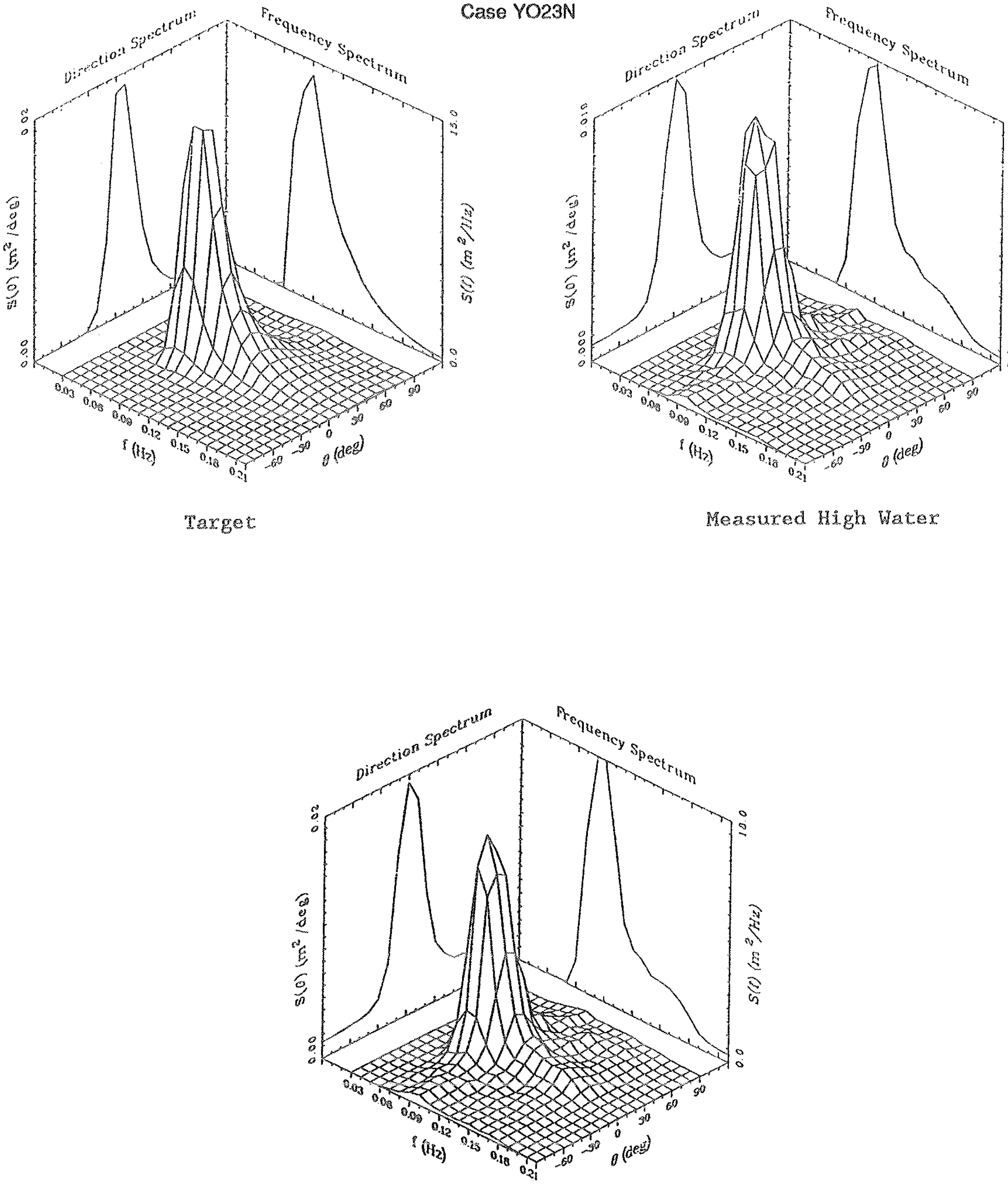


Target

Measured High Water

Measured Low Water

Case YO23N

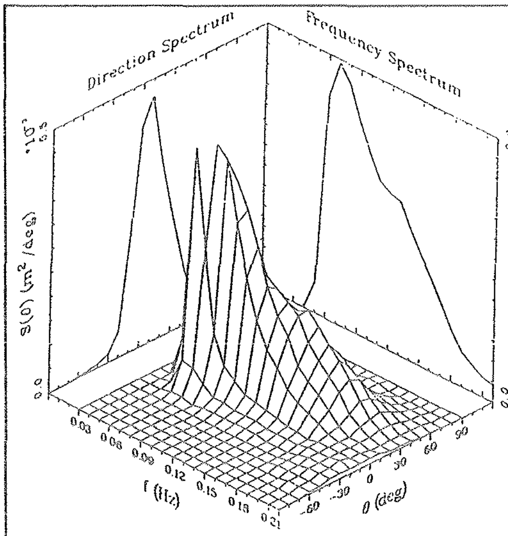


Target

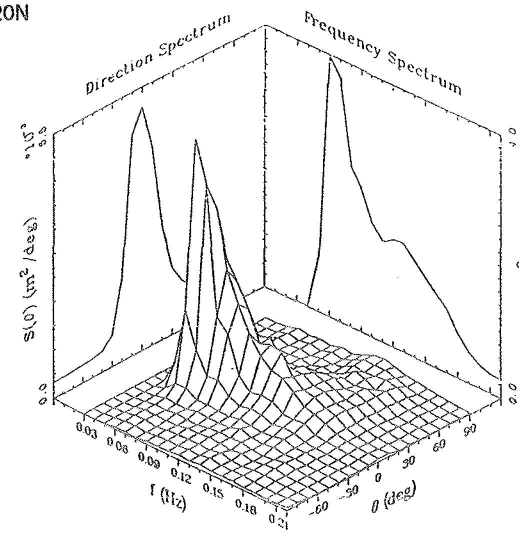
Measured High Water

Measured Low Water

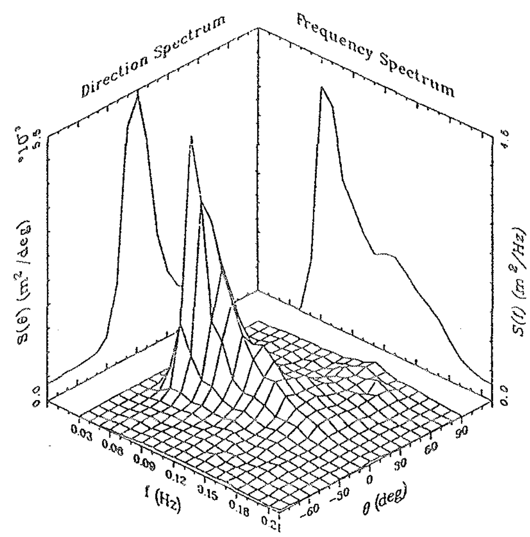
Case YN20N



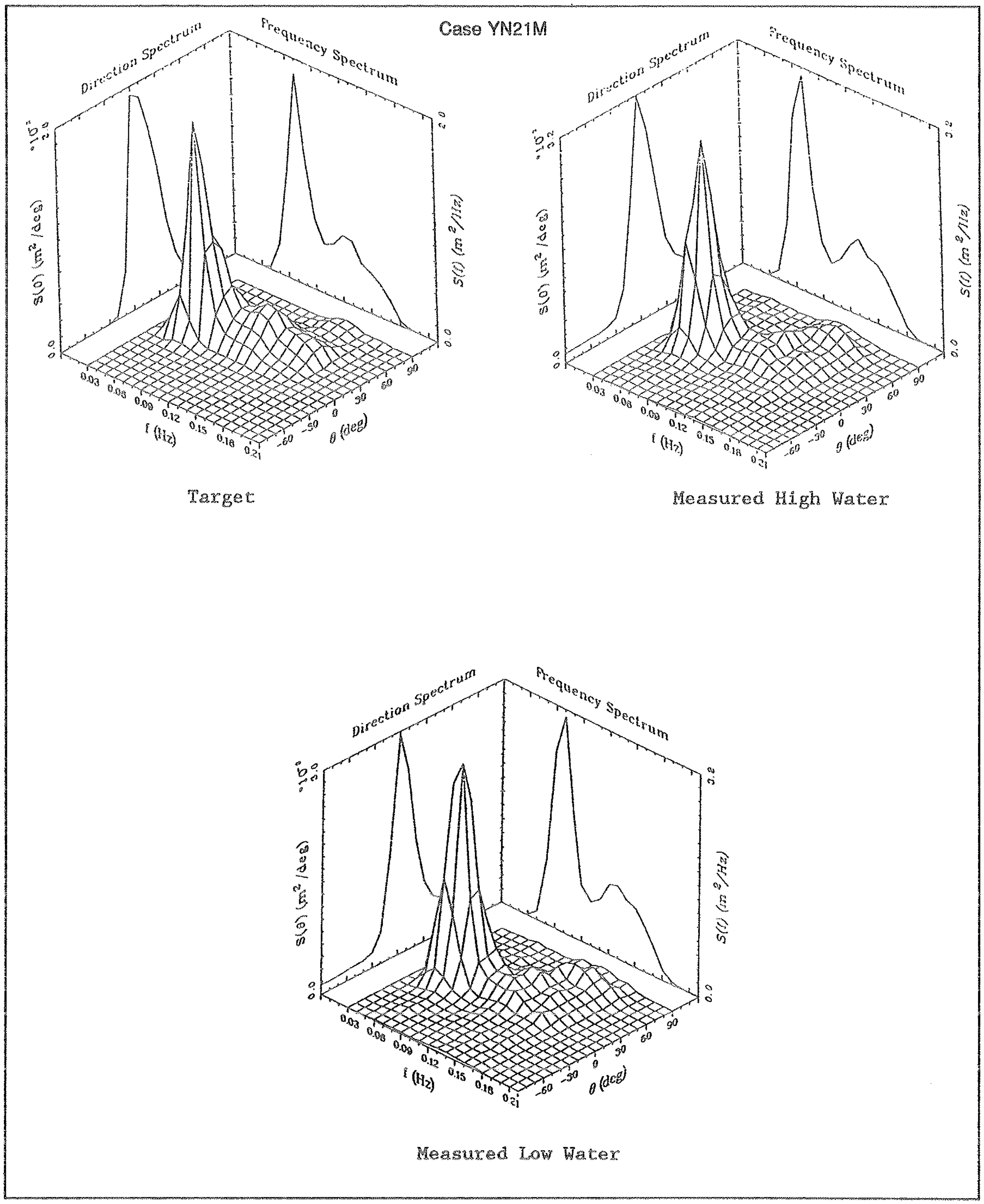
Target



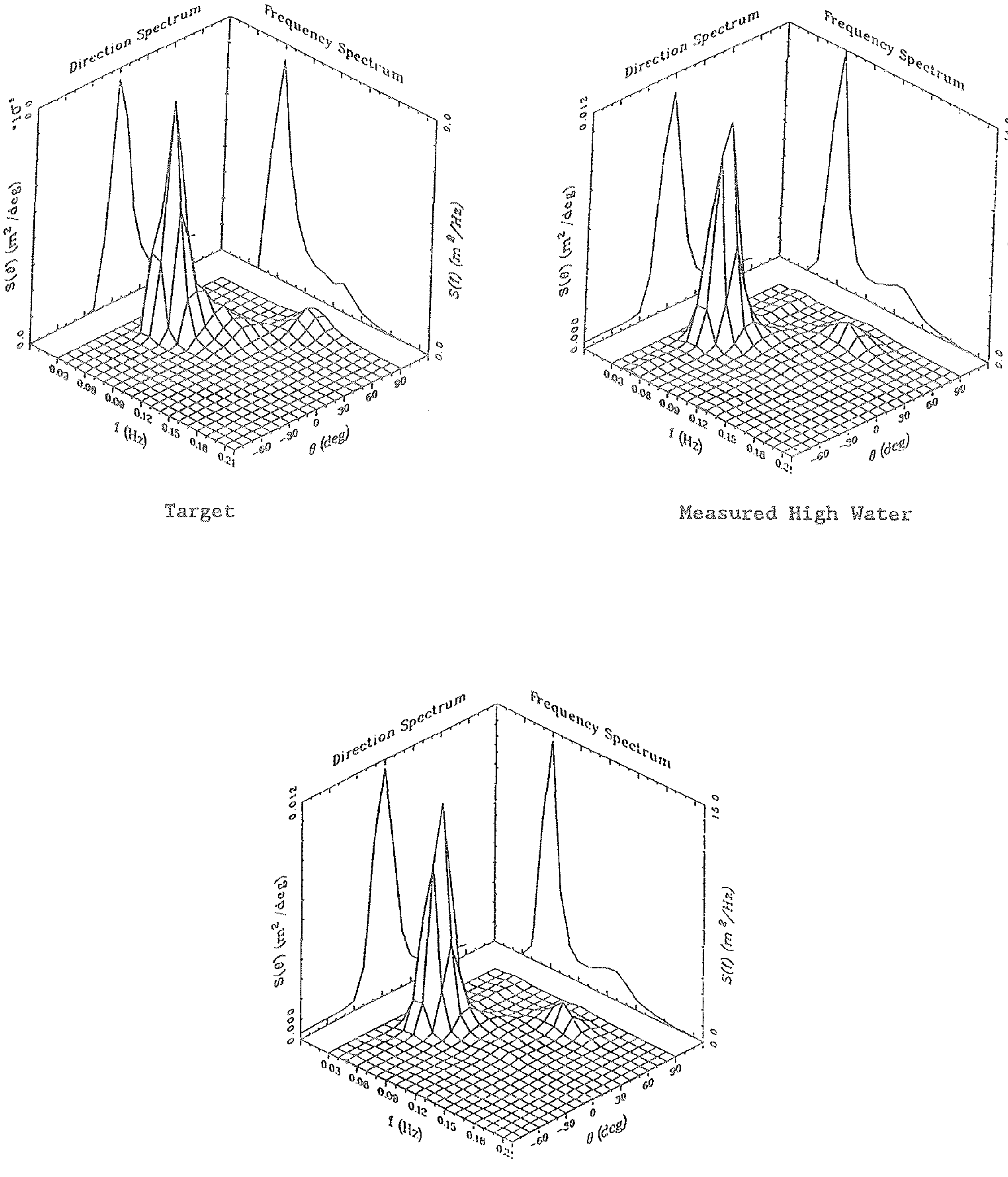
Measured High Water



Measured Low Water


Case YN21M
Direction Spectrum
Frequency Spectrum
S(θ) (m² /deg)
S(f) (m²/Hz)
f (Hz)
θ (deg)
0.03 0.06 0.09 0.12 0.15 0.18 0.21
-60 -30 0 30 60 90
Target
Measured High Water
Measured Low Water

Case YN21N

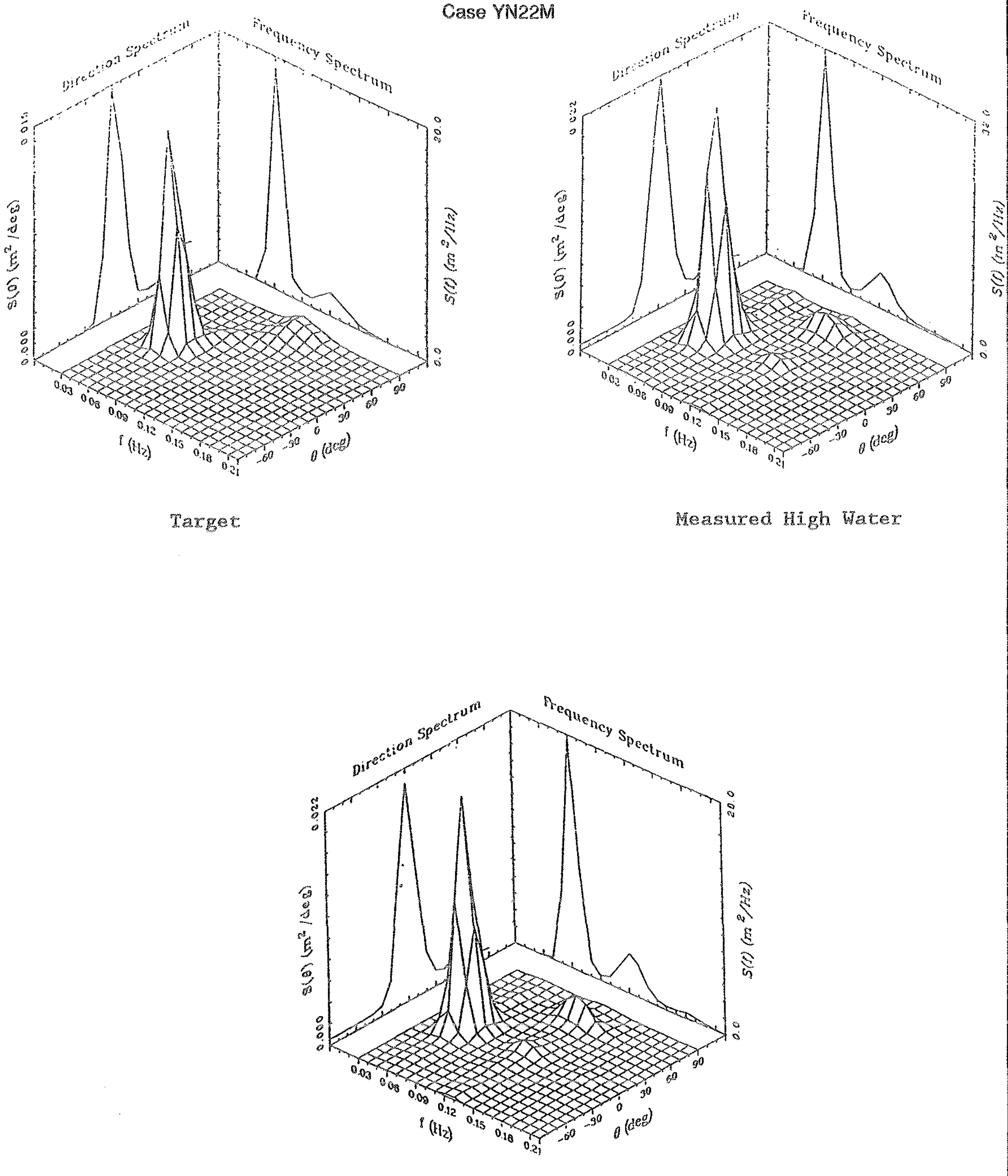


Target

Measured High Water

Measured Low Water

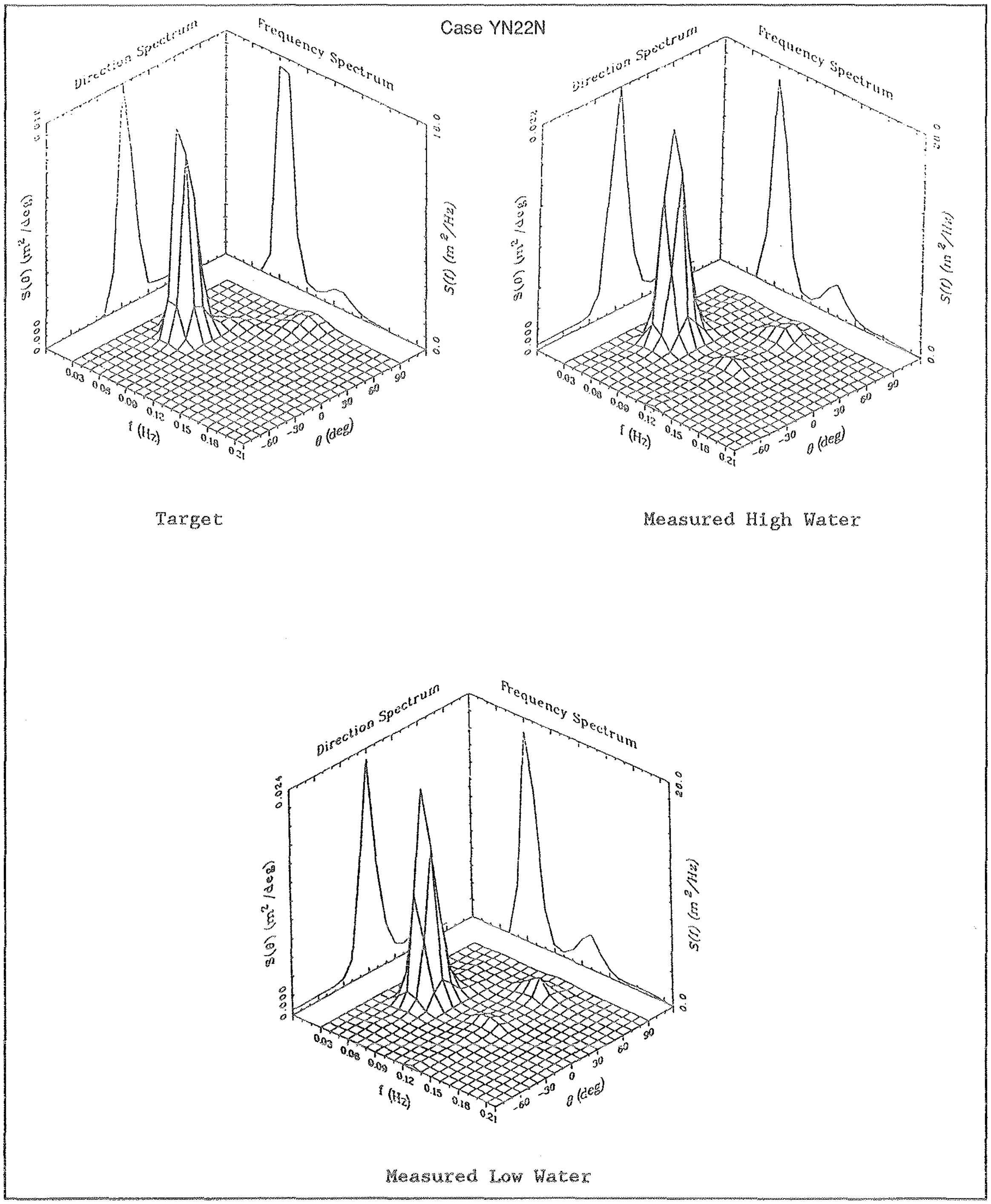
Case YN22M

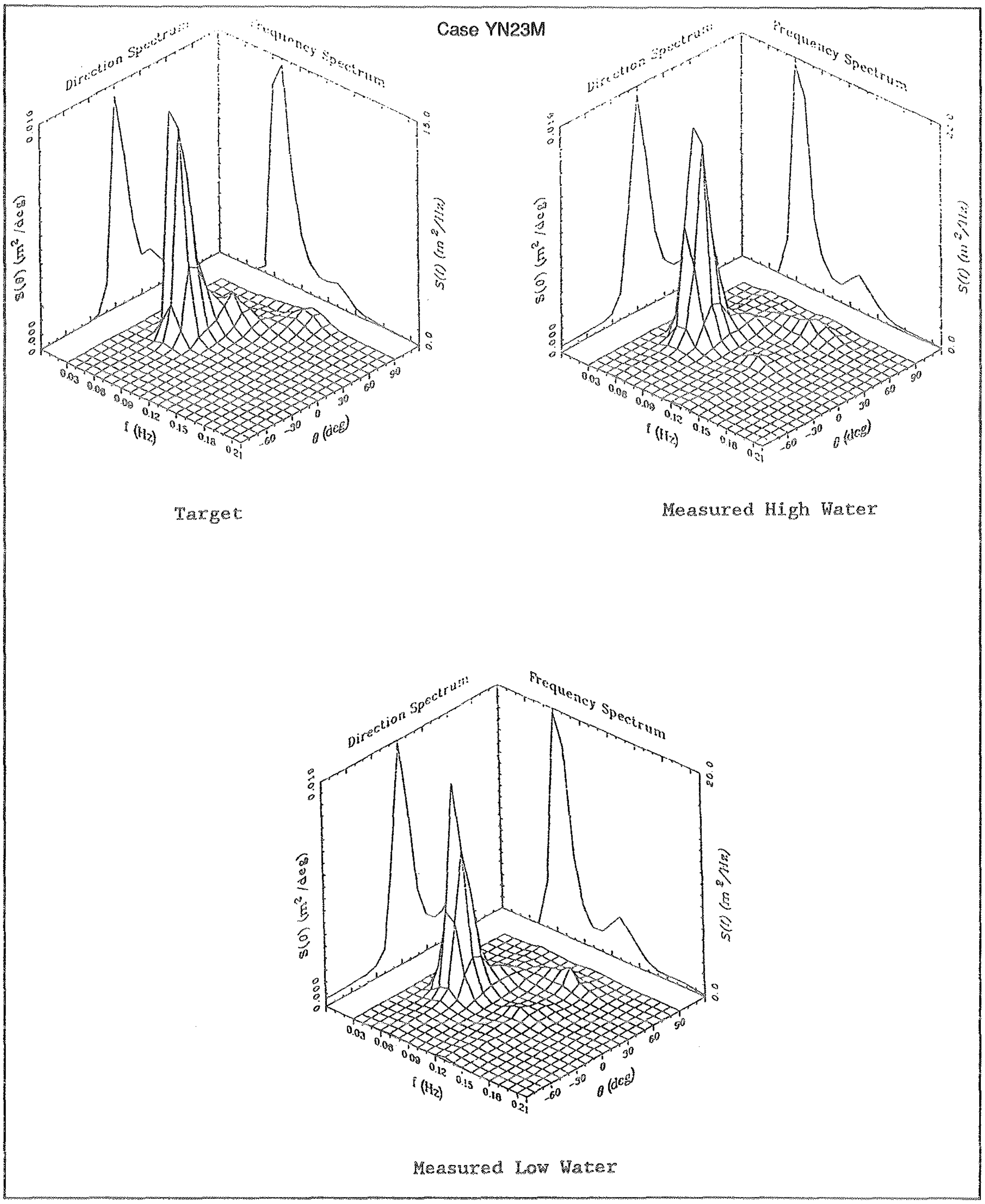


Target

Measured High Water

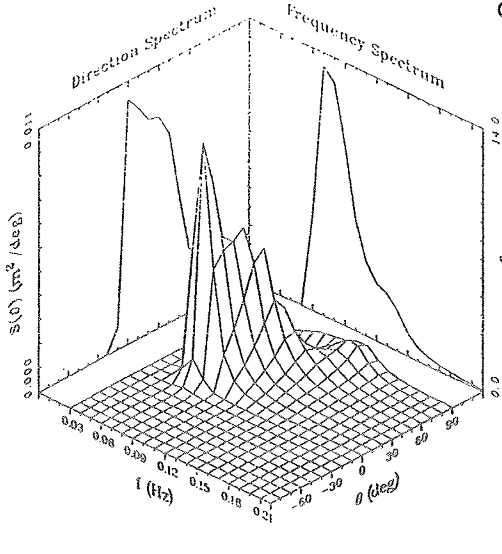
Measured Low Water


Case YN22N
Direction Spectrum
Frequency Spectrum
S(θ) (m²/deg)
S(f) (m²/Hz)
f (Hz)
θ (deg)
0.03 0.06 0.09 0.12 0.15 0.18 0.21
-60 -30 0 30 60 90
0.000
0.0
20.0
0.024
Target
Measured High Water
Measured Low Water

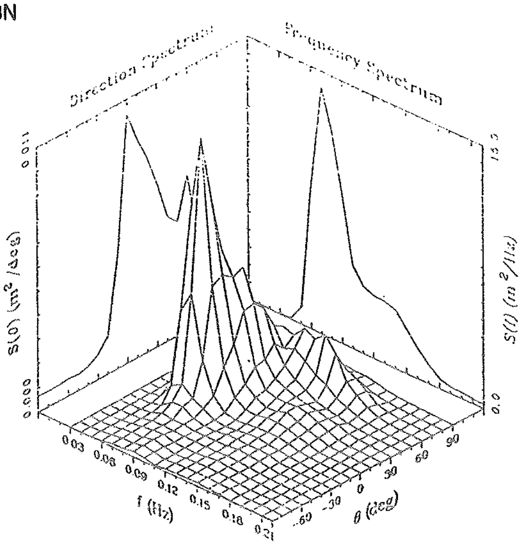


Case YN23M
Direction Spectrum
Frequency Spectrum
S(θ) (m²/deg)
S(f) (m²/Hz)
f (Hz)
θ (deg)
Target
Measured High Water
Measured Low Water

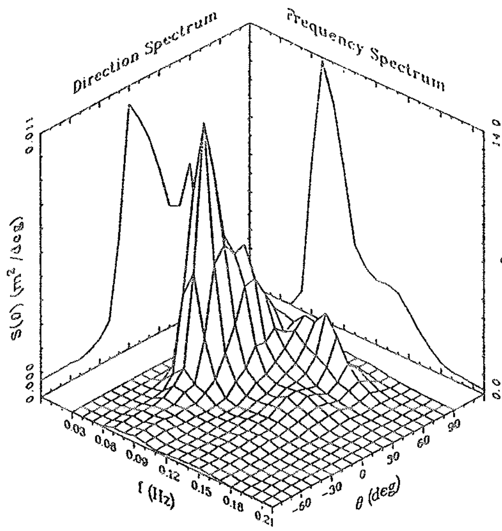
Case YN23N



Target

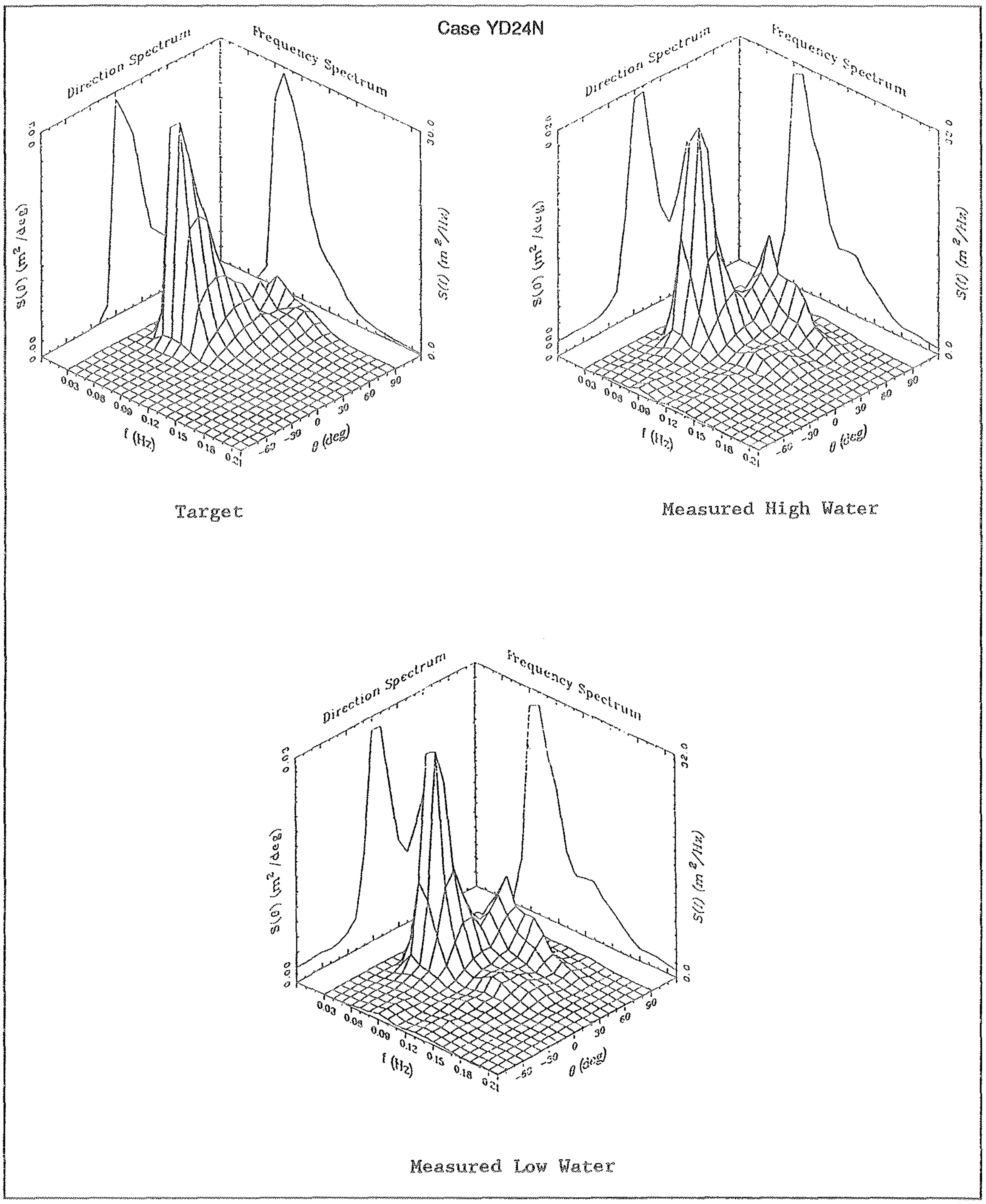


Measured High Water



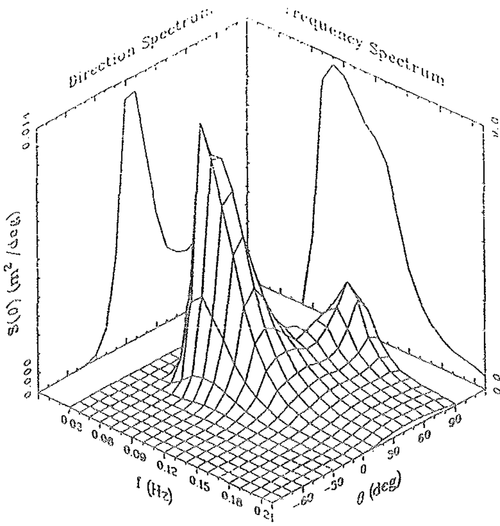
Measured Low Water

Case YD24N

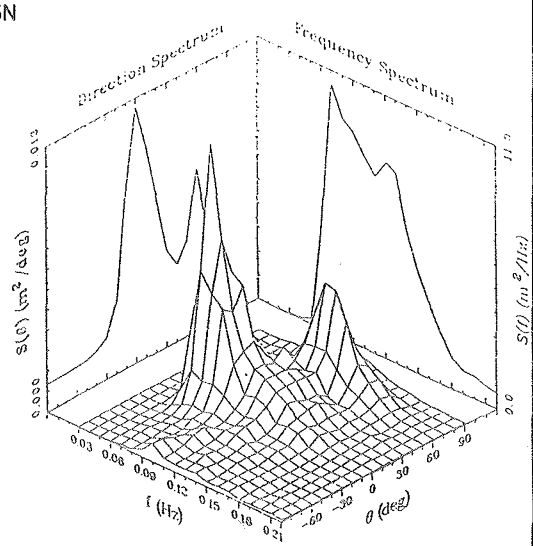


Direction Spectrum
Frequency Spectrum
Target
Measured High Water
Measured Low Water
f (Hz)
θ (deg)

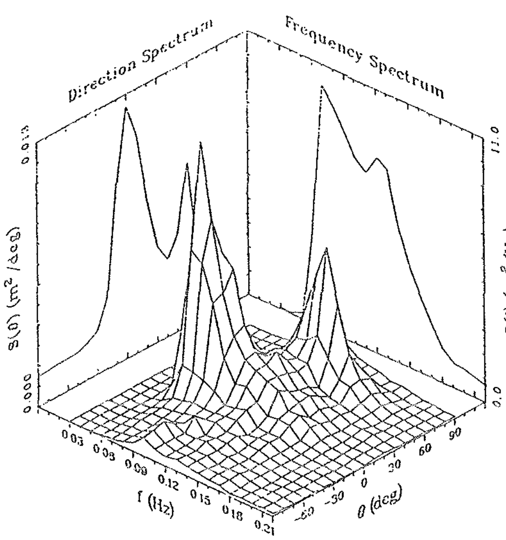
Case YD25N



Target

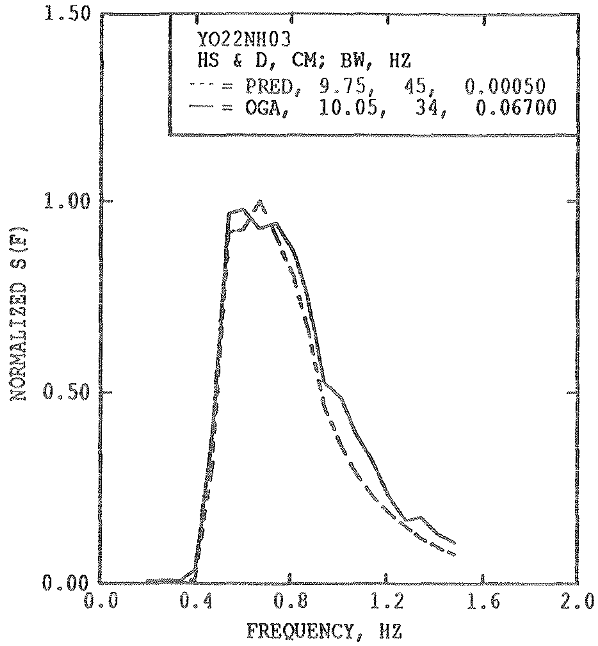


Measured High Water

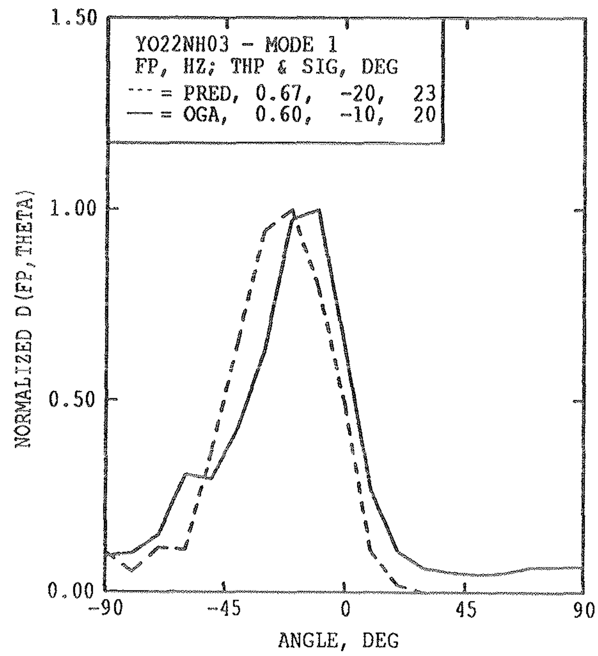


Measured Low Water

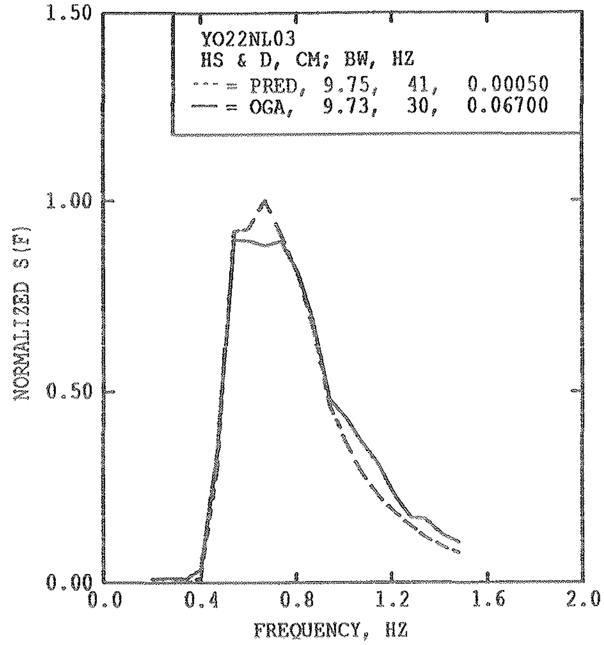
Appendix D
Measured Frequency Spectra and Directional Spreading Functions



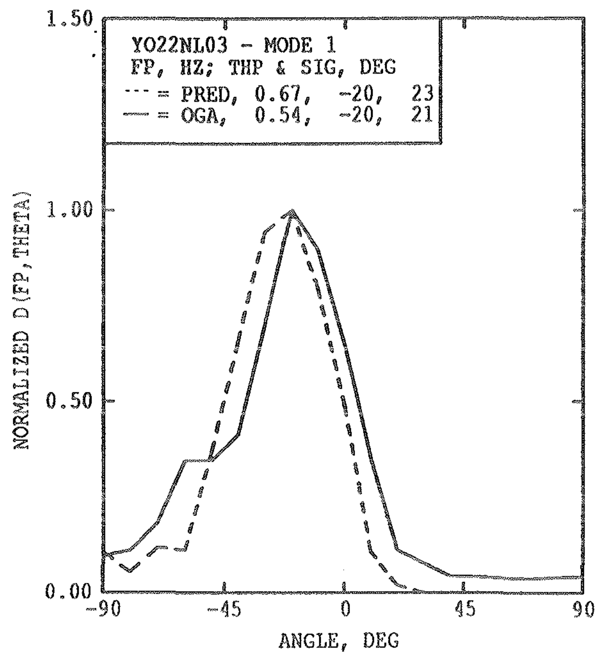
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



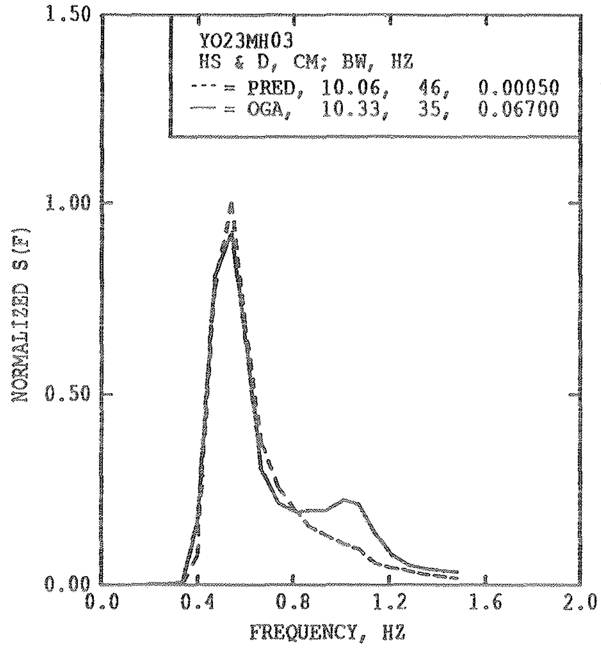
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



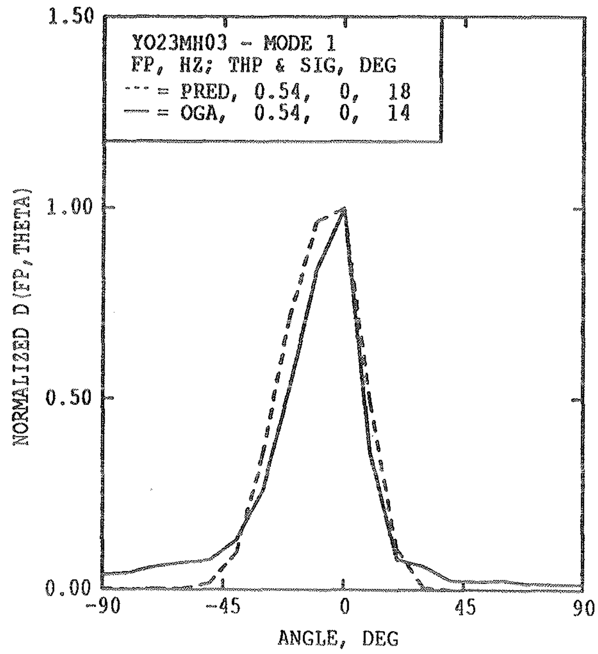
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



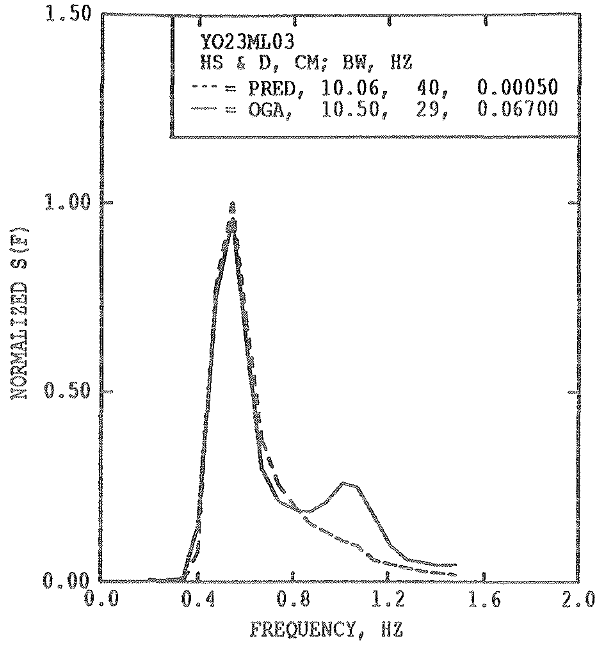
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



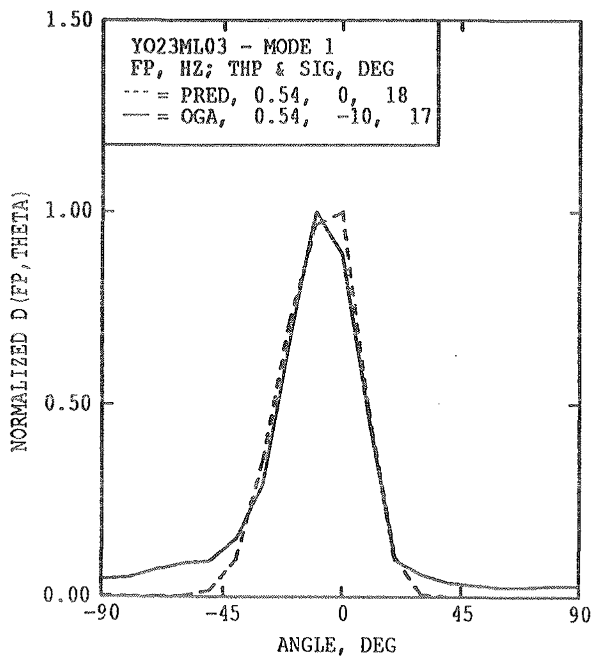
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



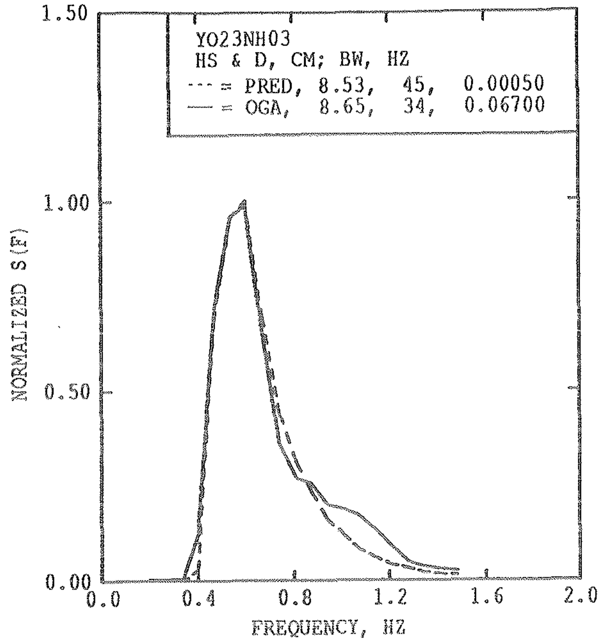
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



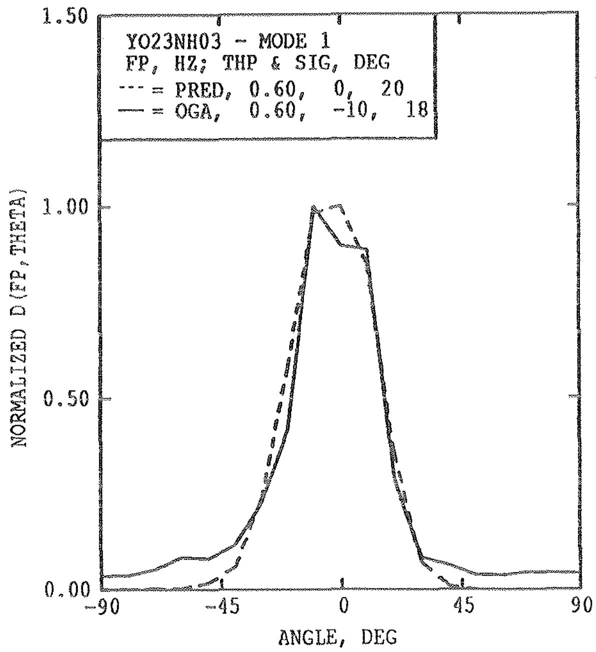
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



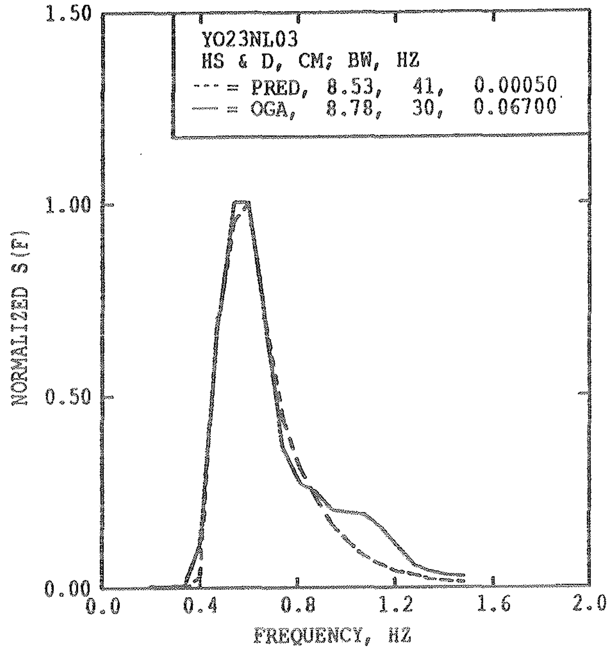
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



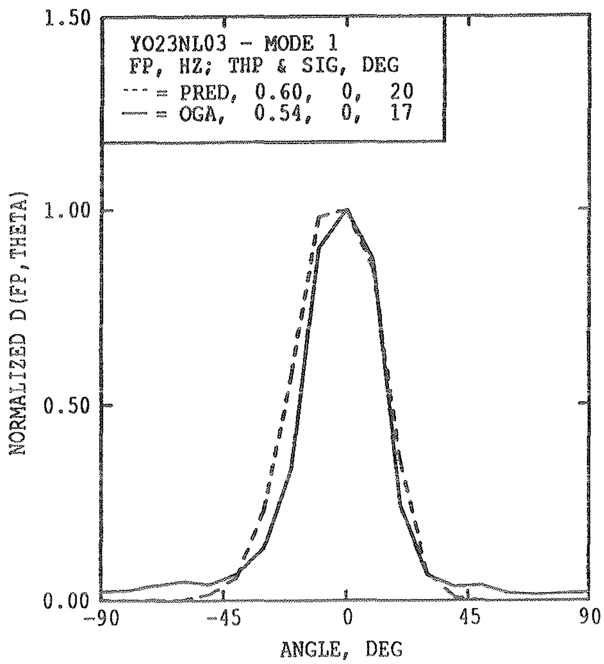
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



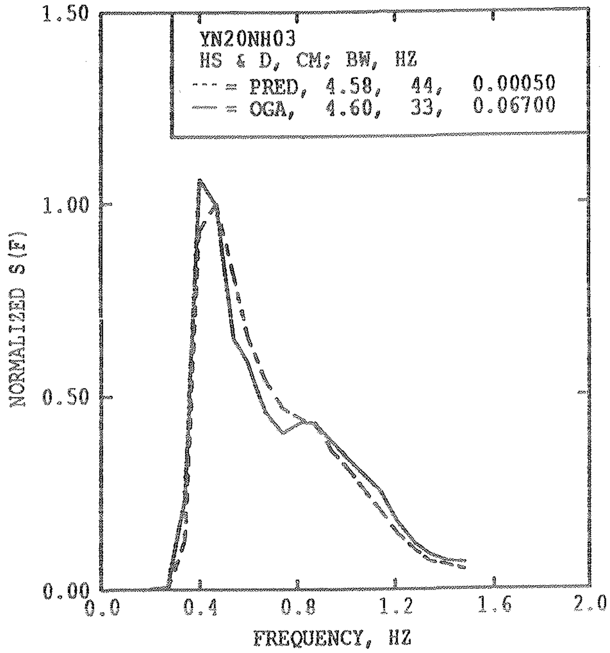
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



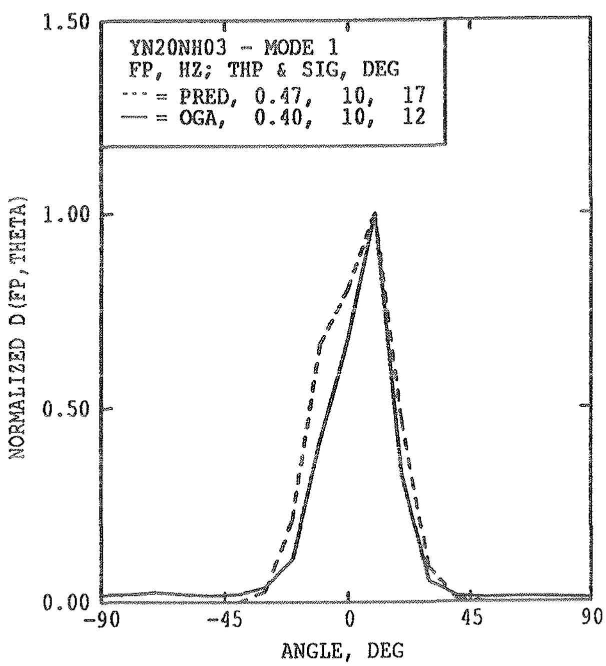
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



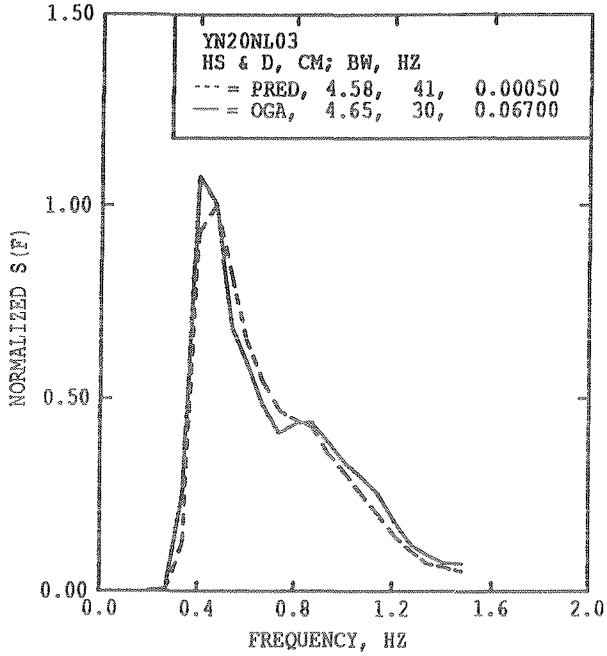
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



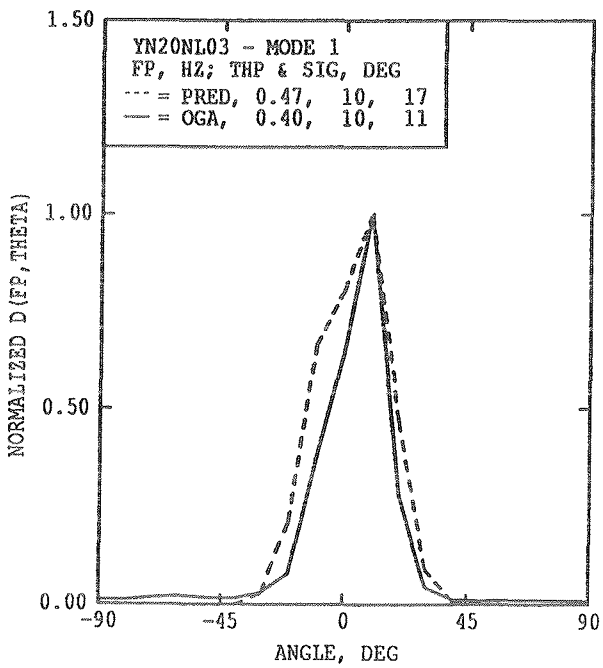
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



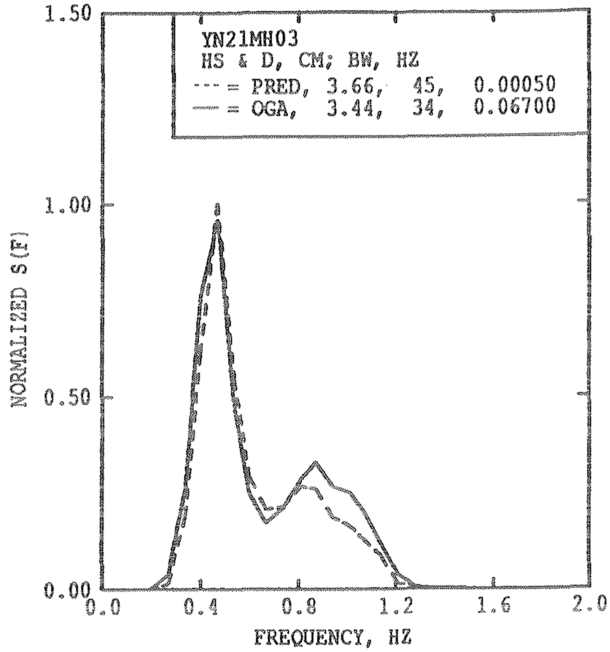
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



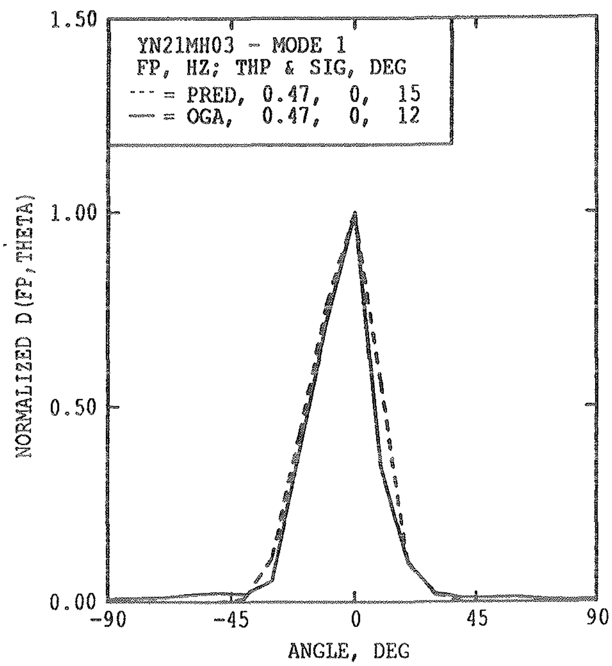
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



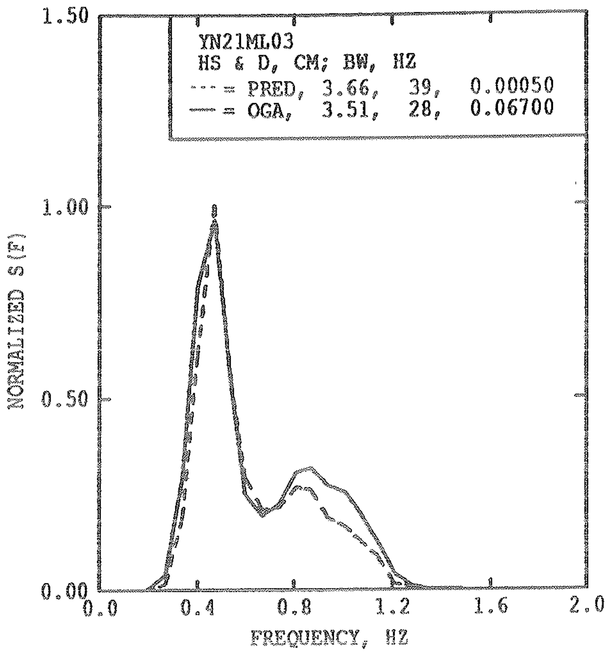
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



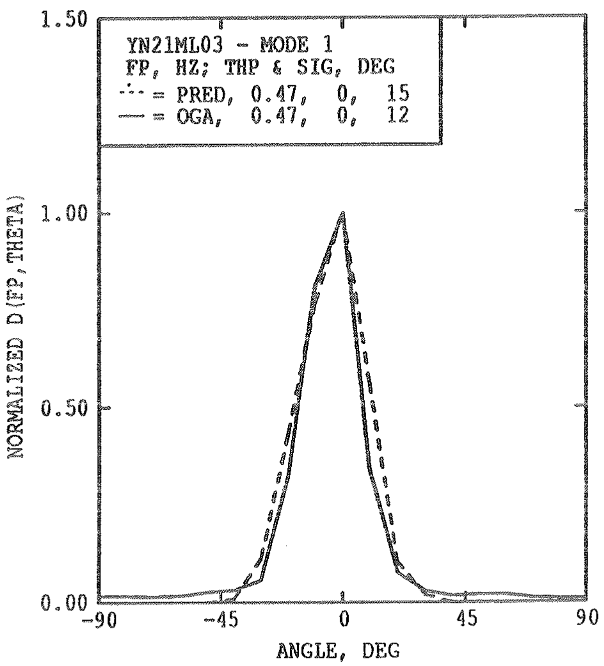
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



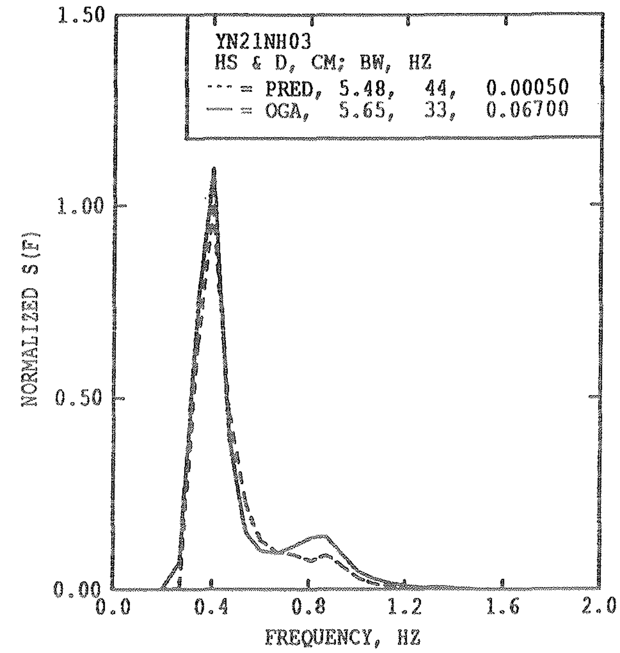
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



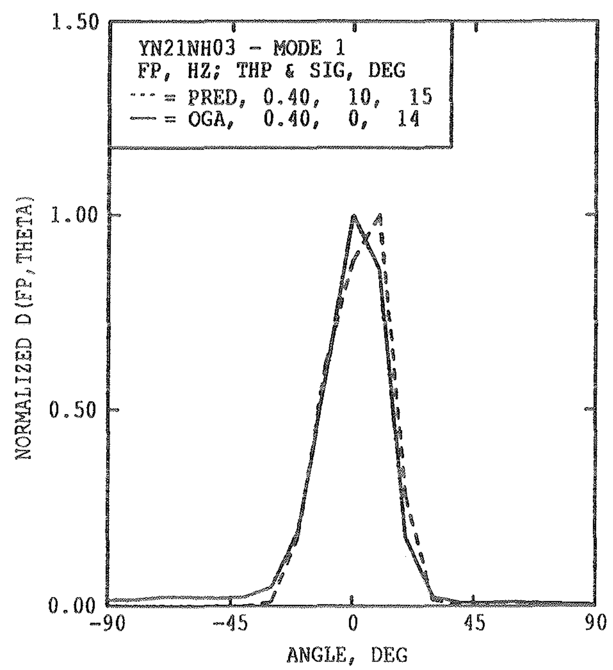
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



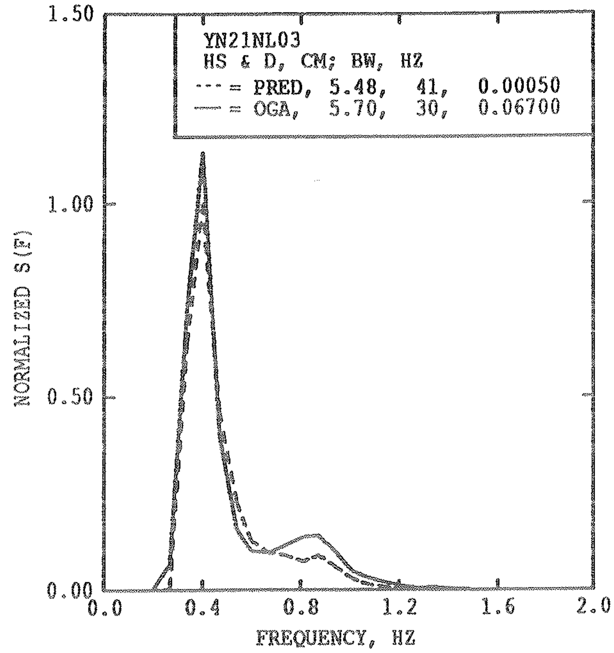
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



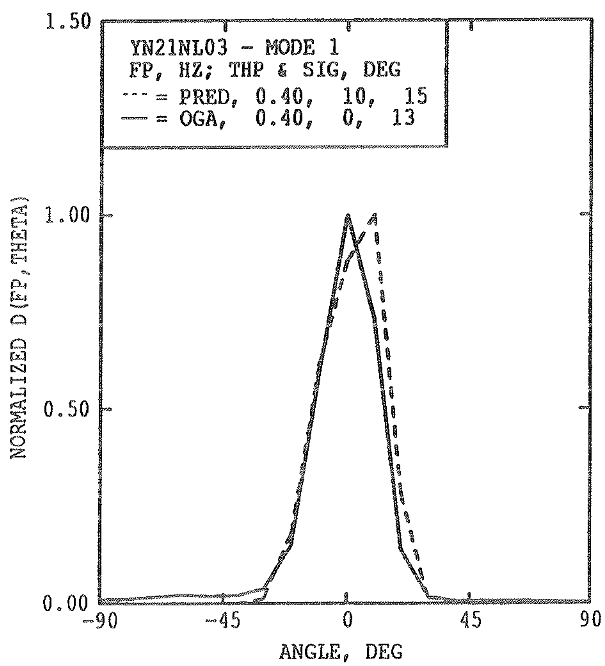
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



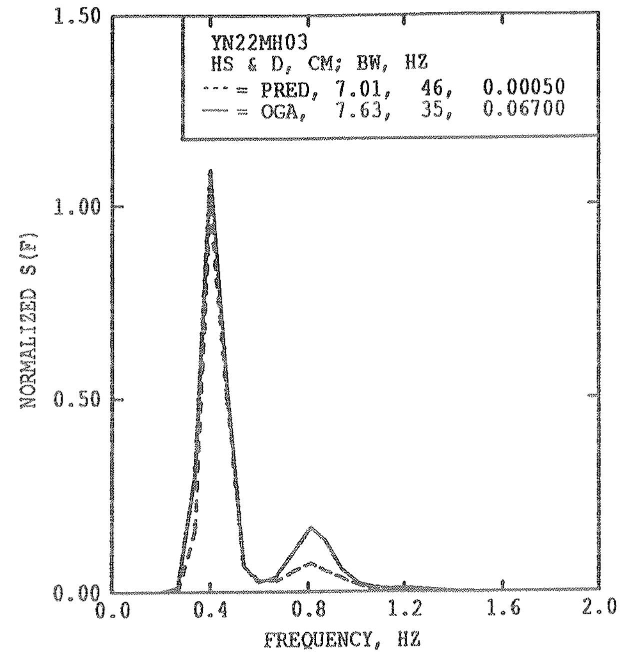
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



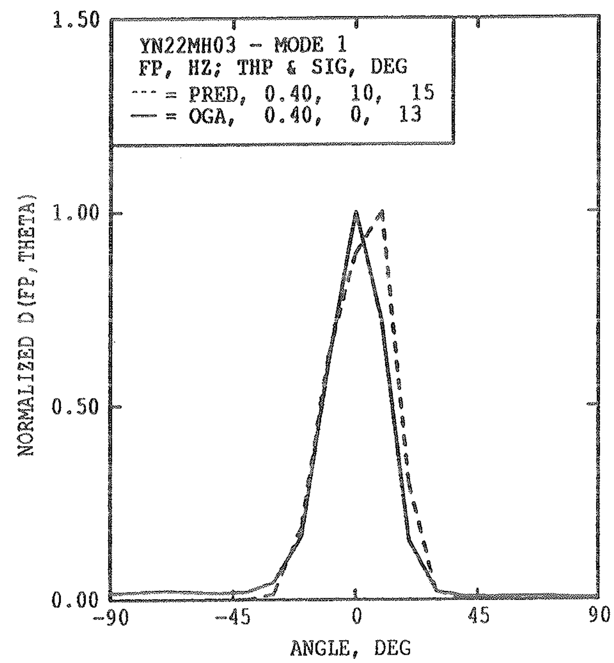
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



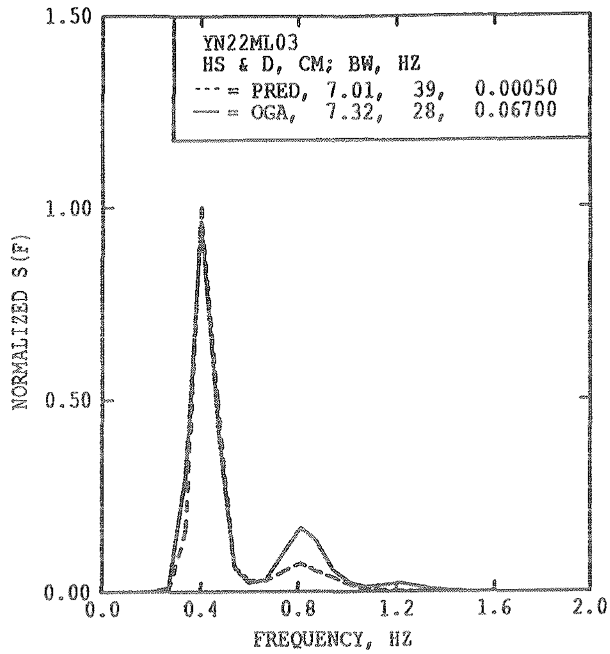
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



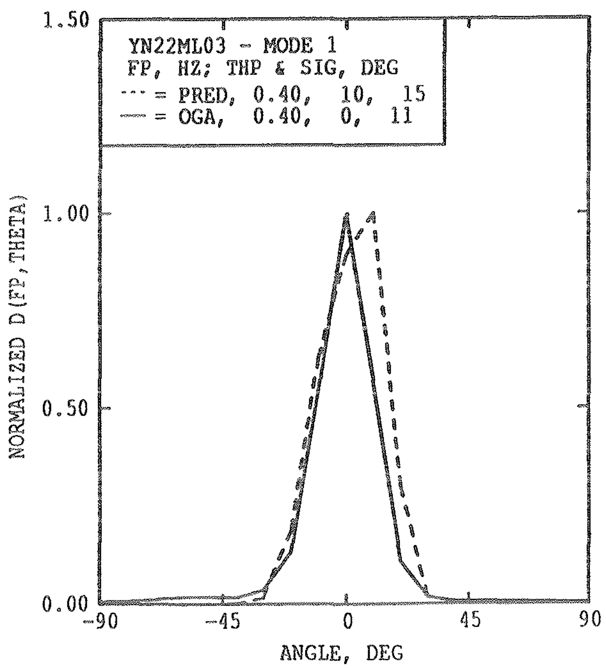
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



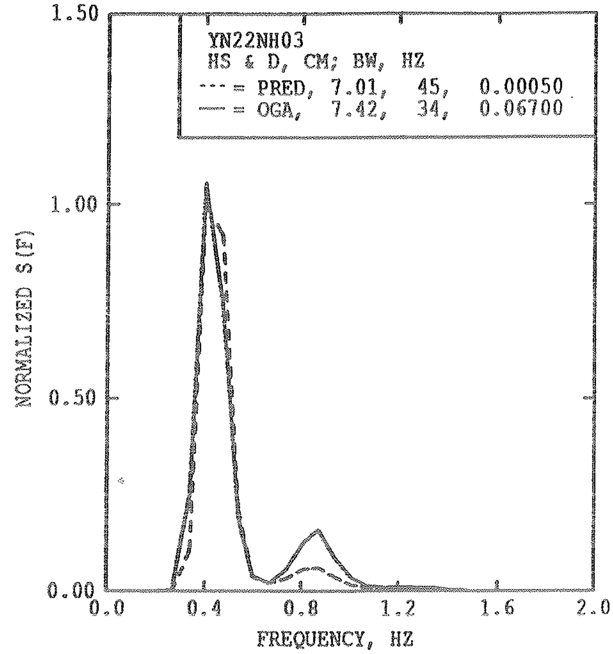
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



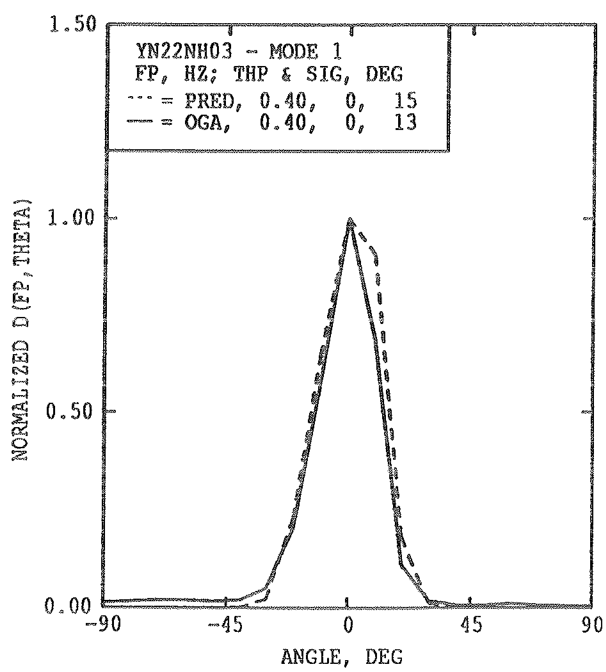
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



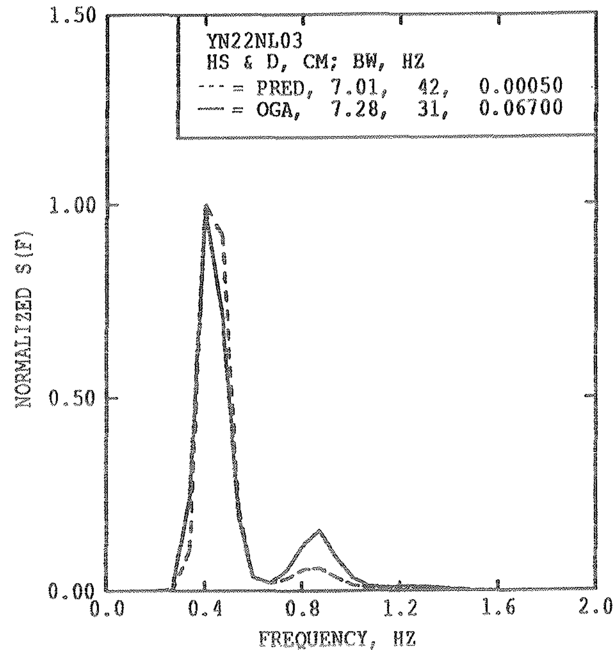
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



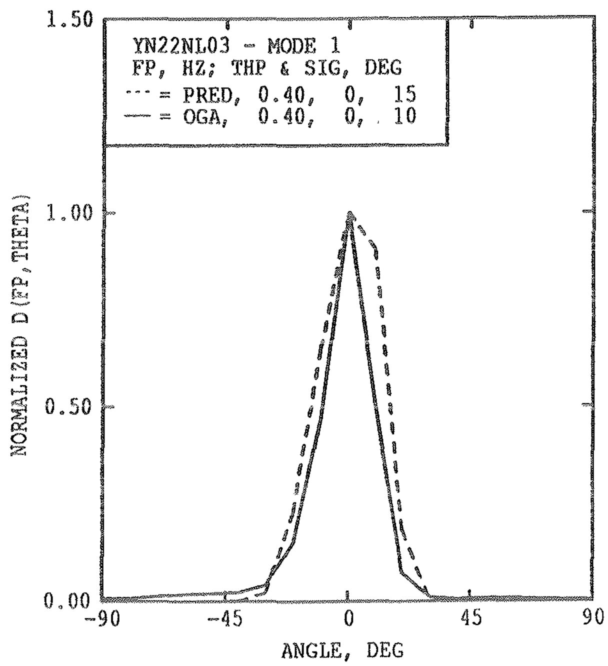
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



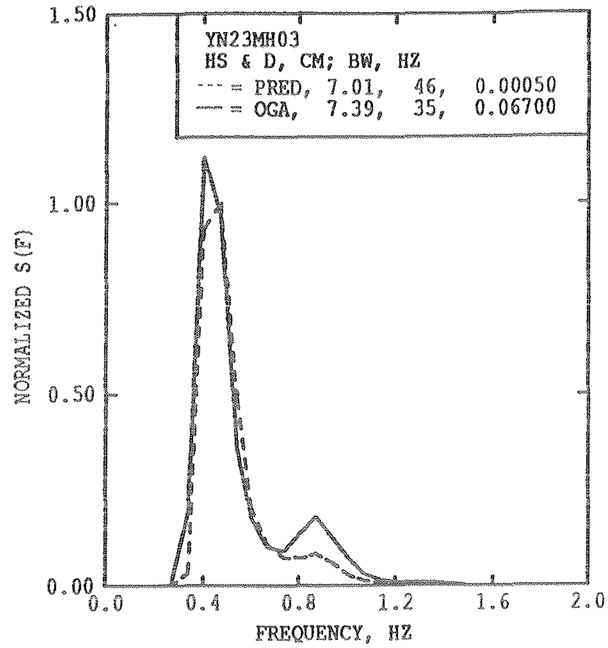
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



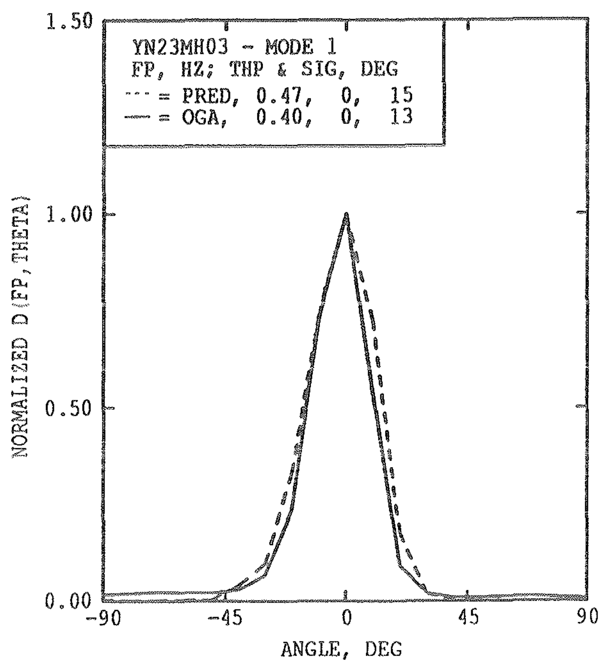
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



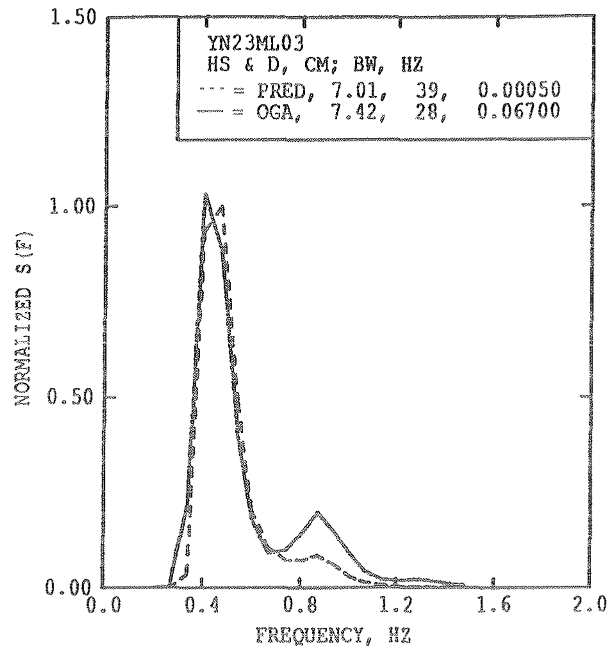
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



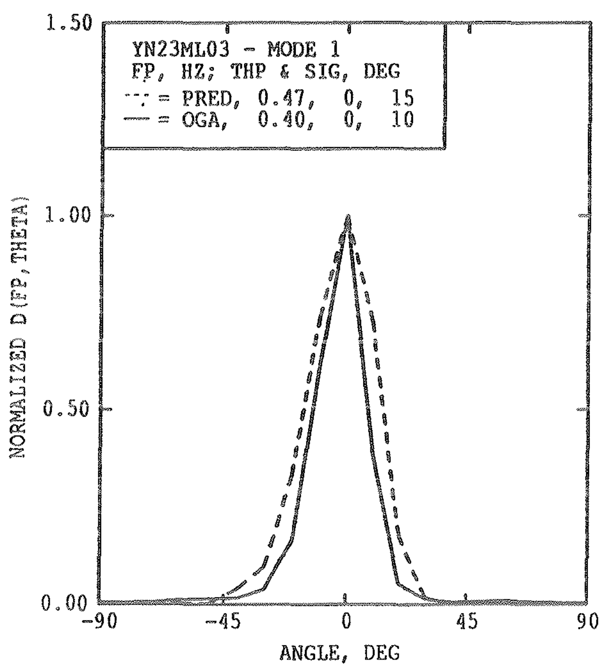
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



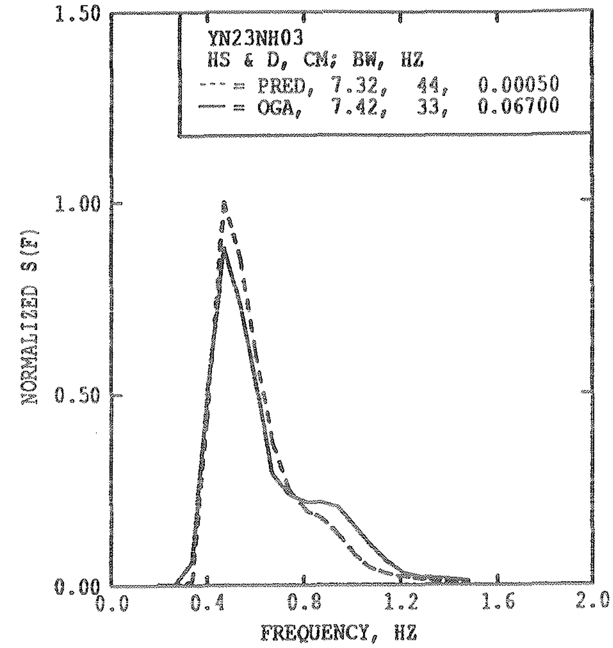
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



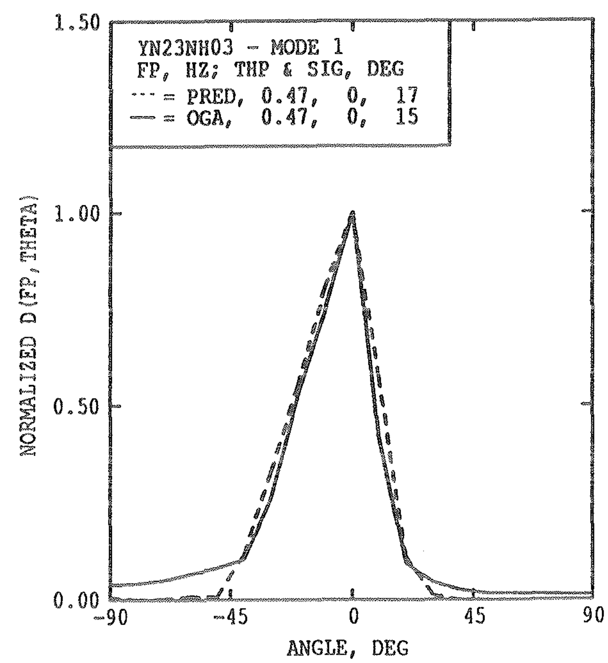
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



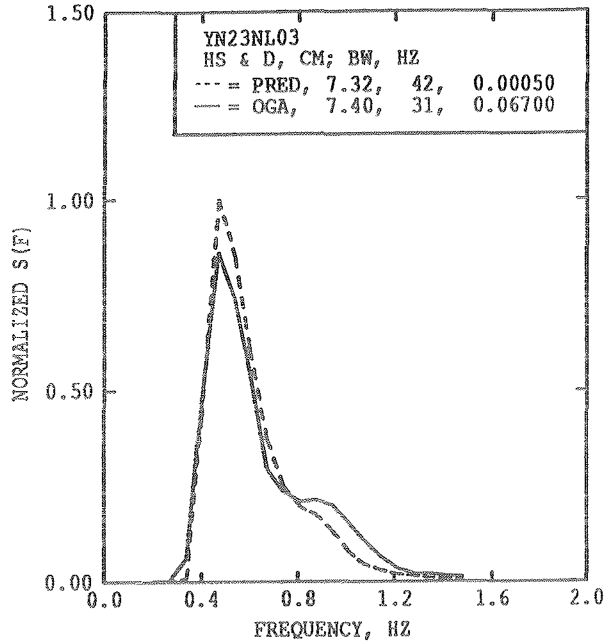
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



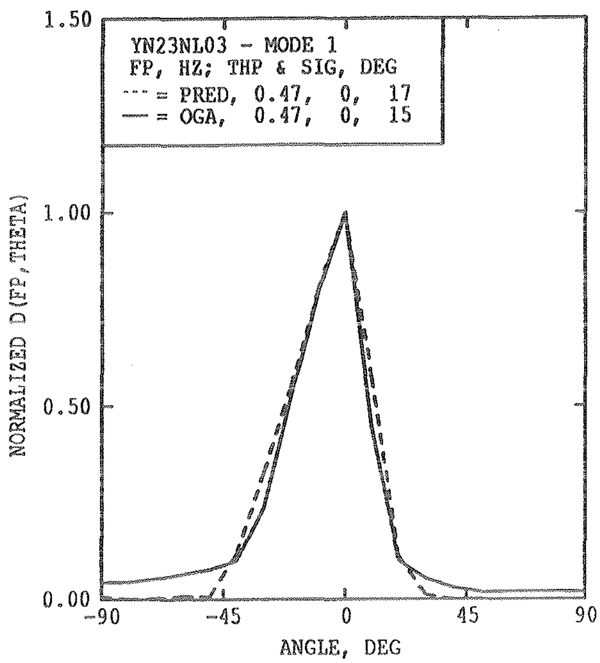
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



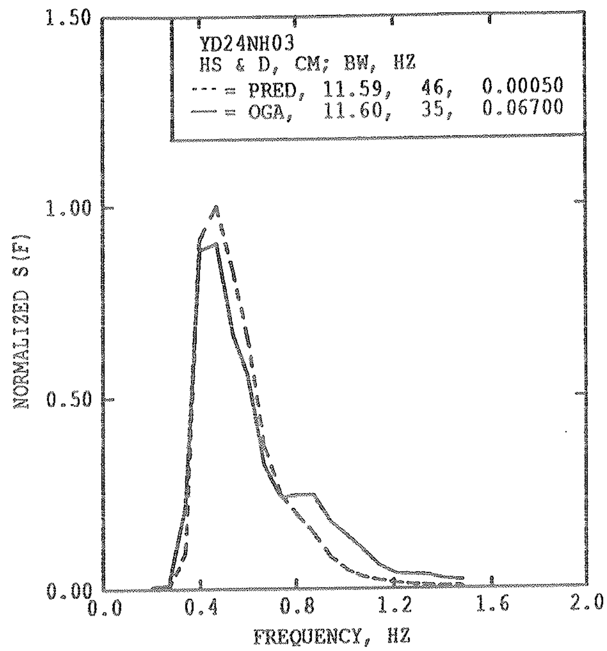
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



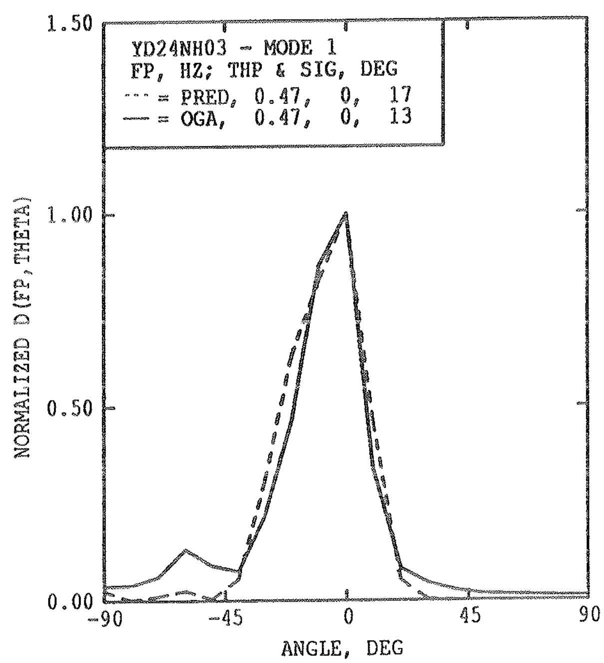
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



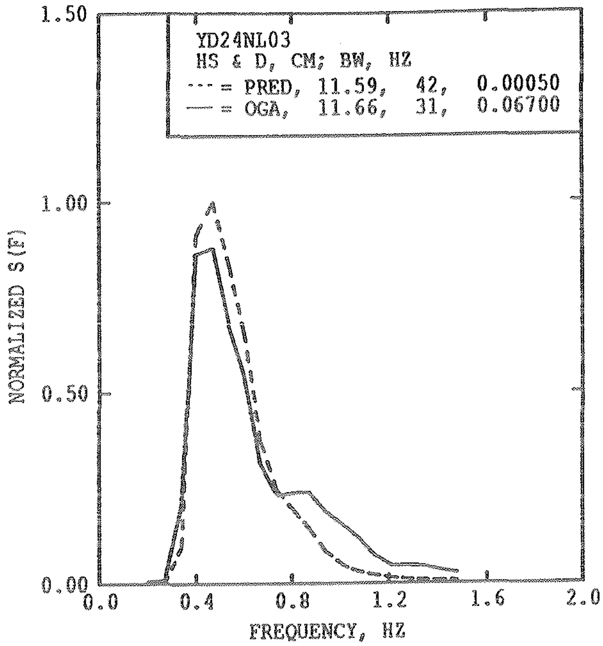
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



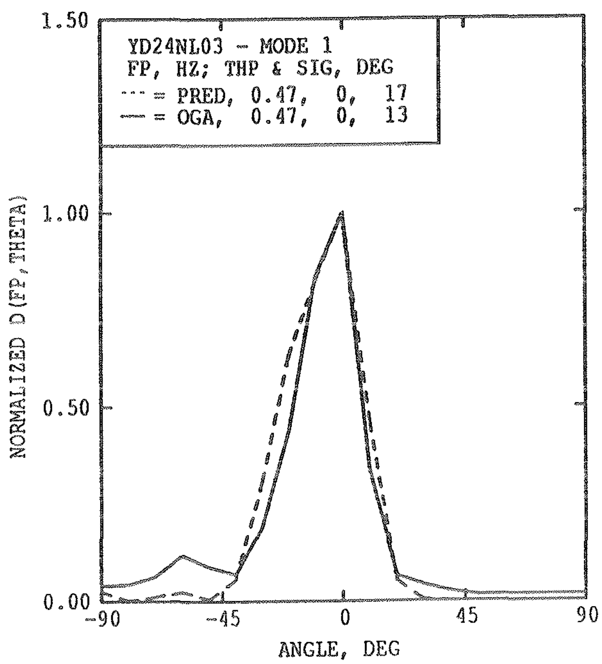
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



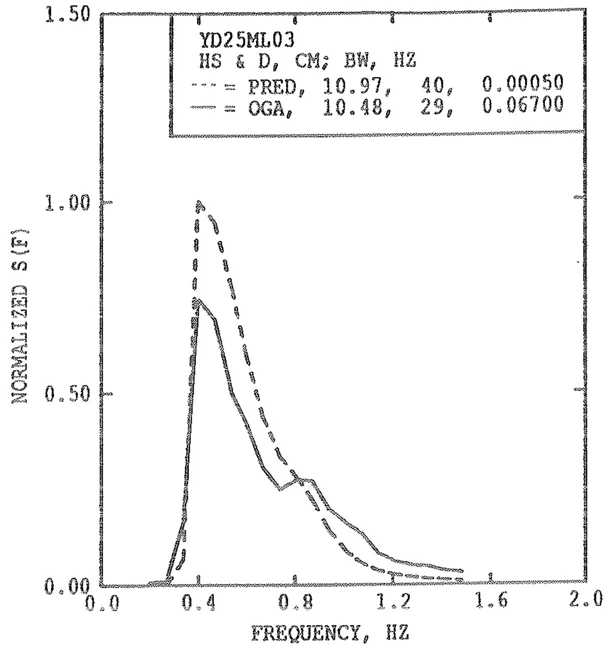
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



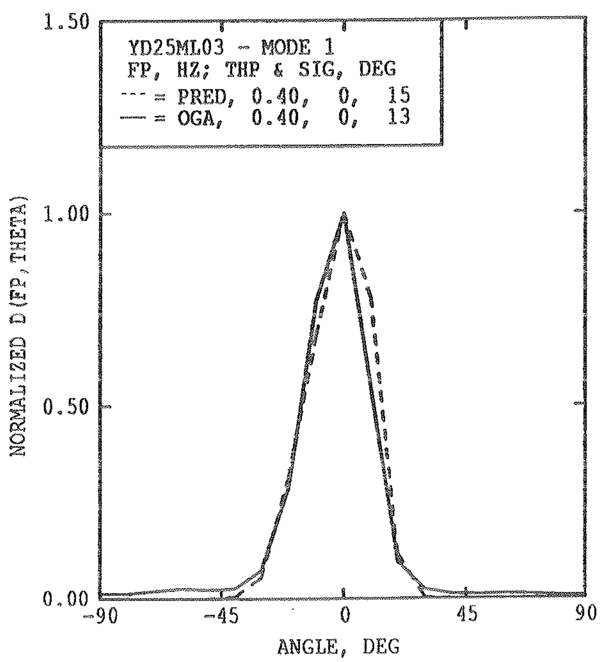
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



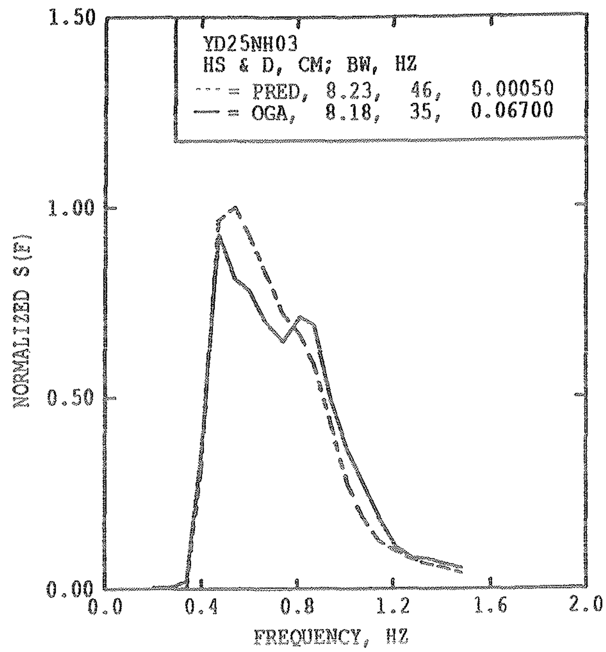
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



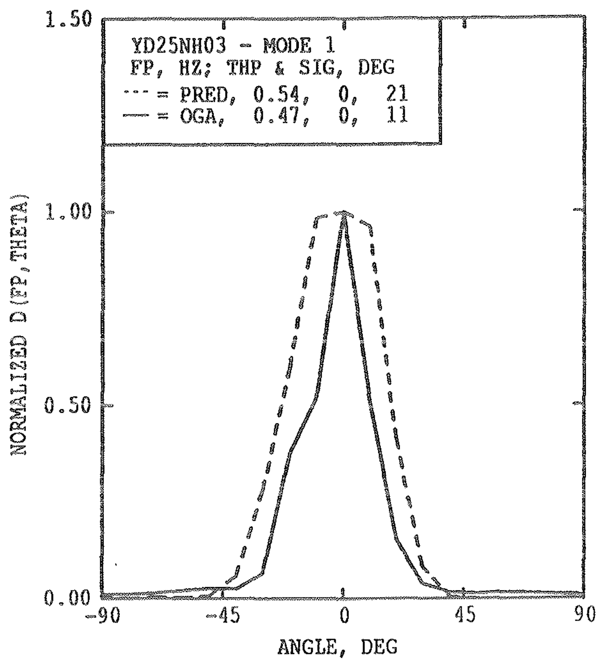
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



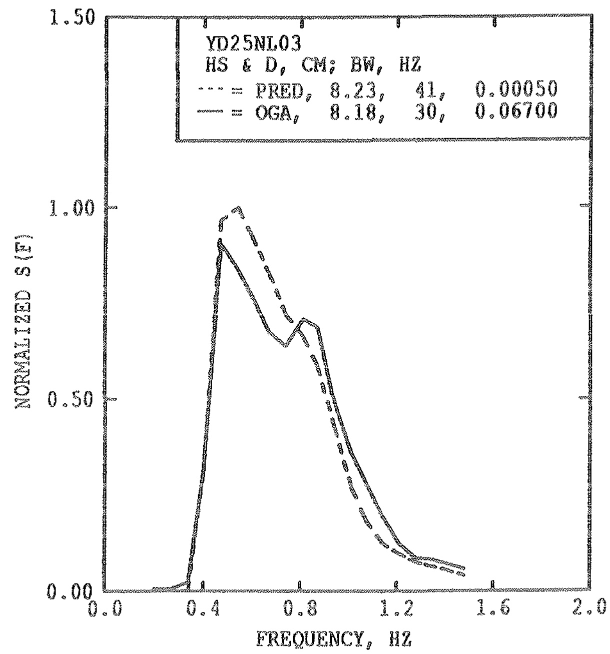
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW



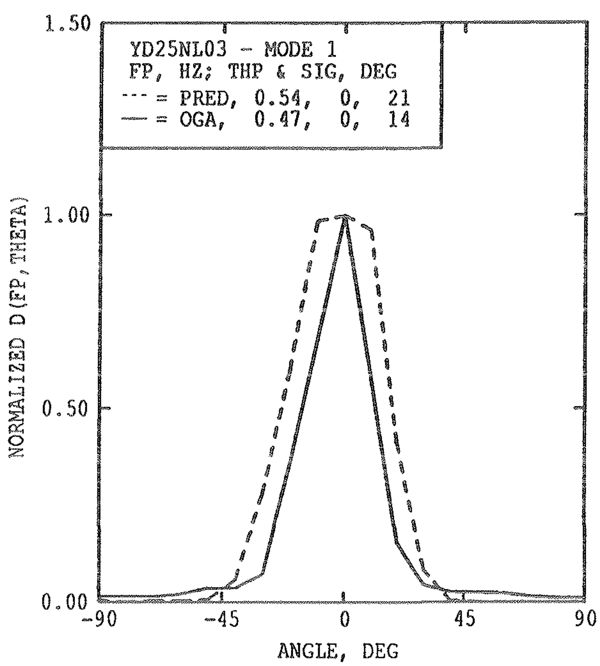
A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW



B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW

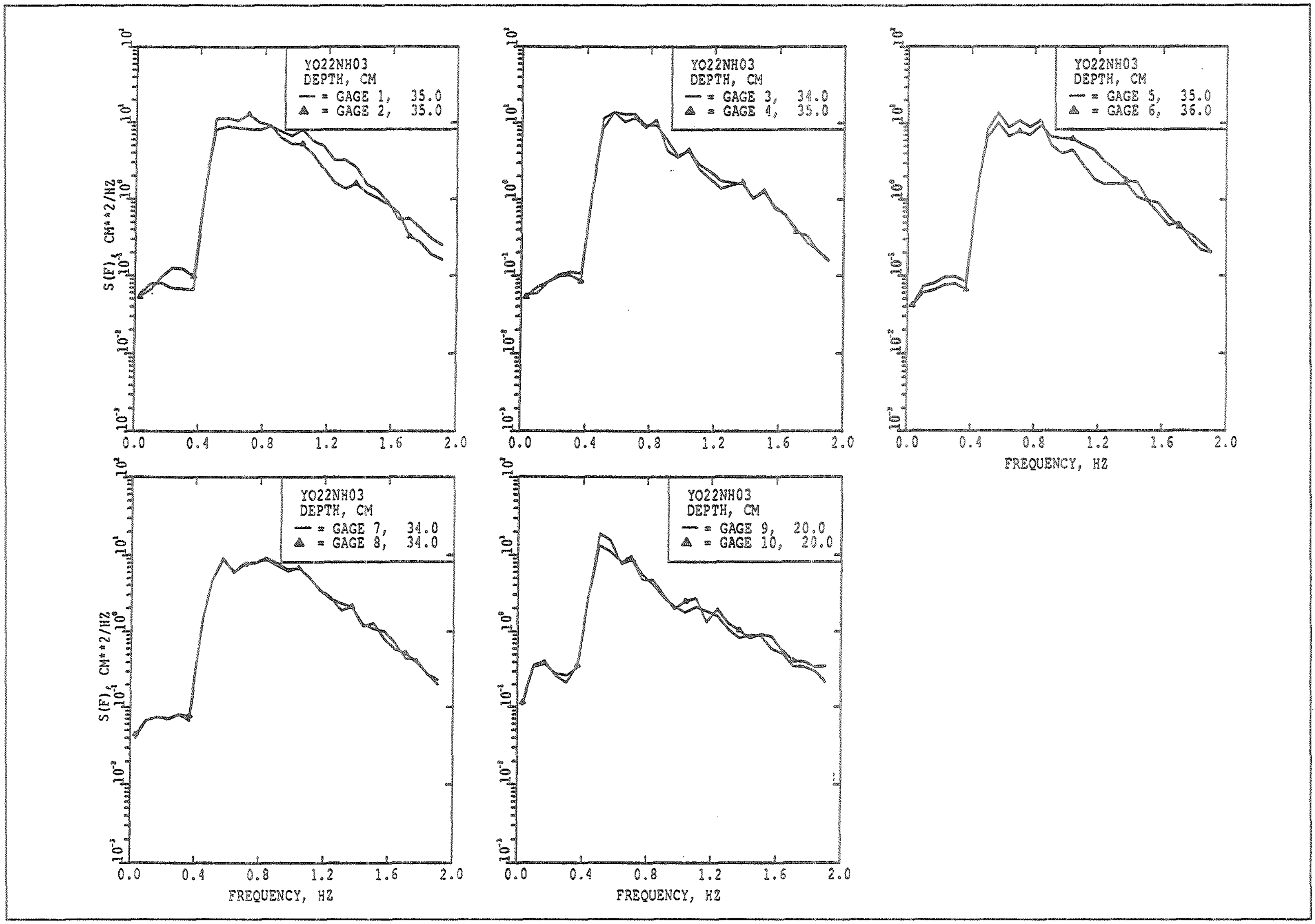


A) PRED. VS. OGA FREQUENCY SPECTRA
MLM, OGA=2-8, RAW

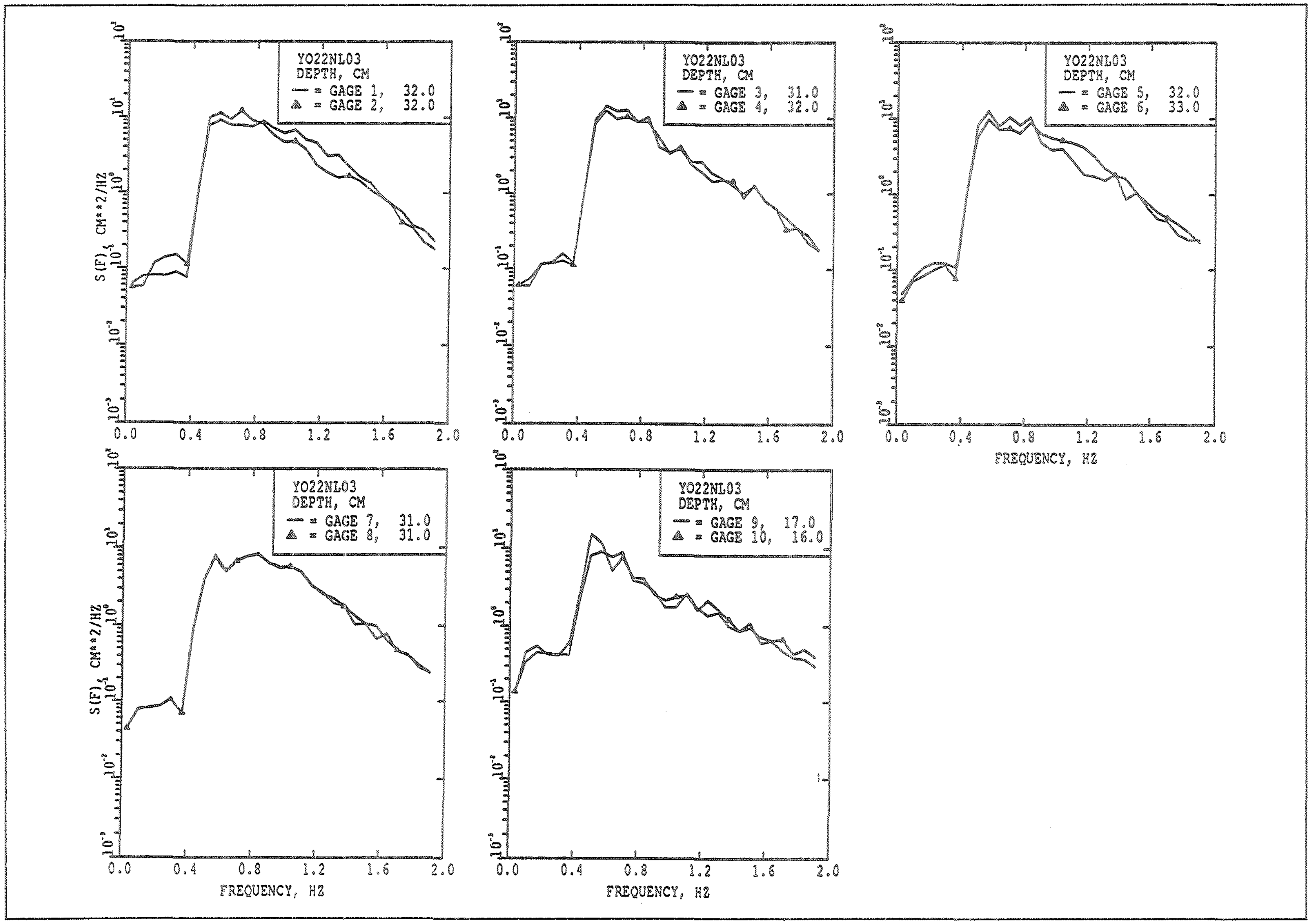


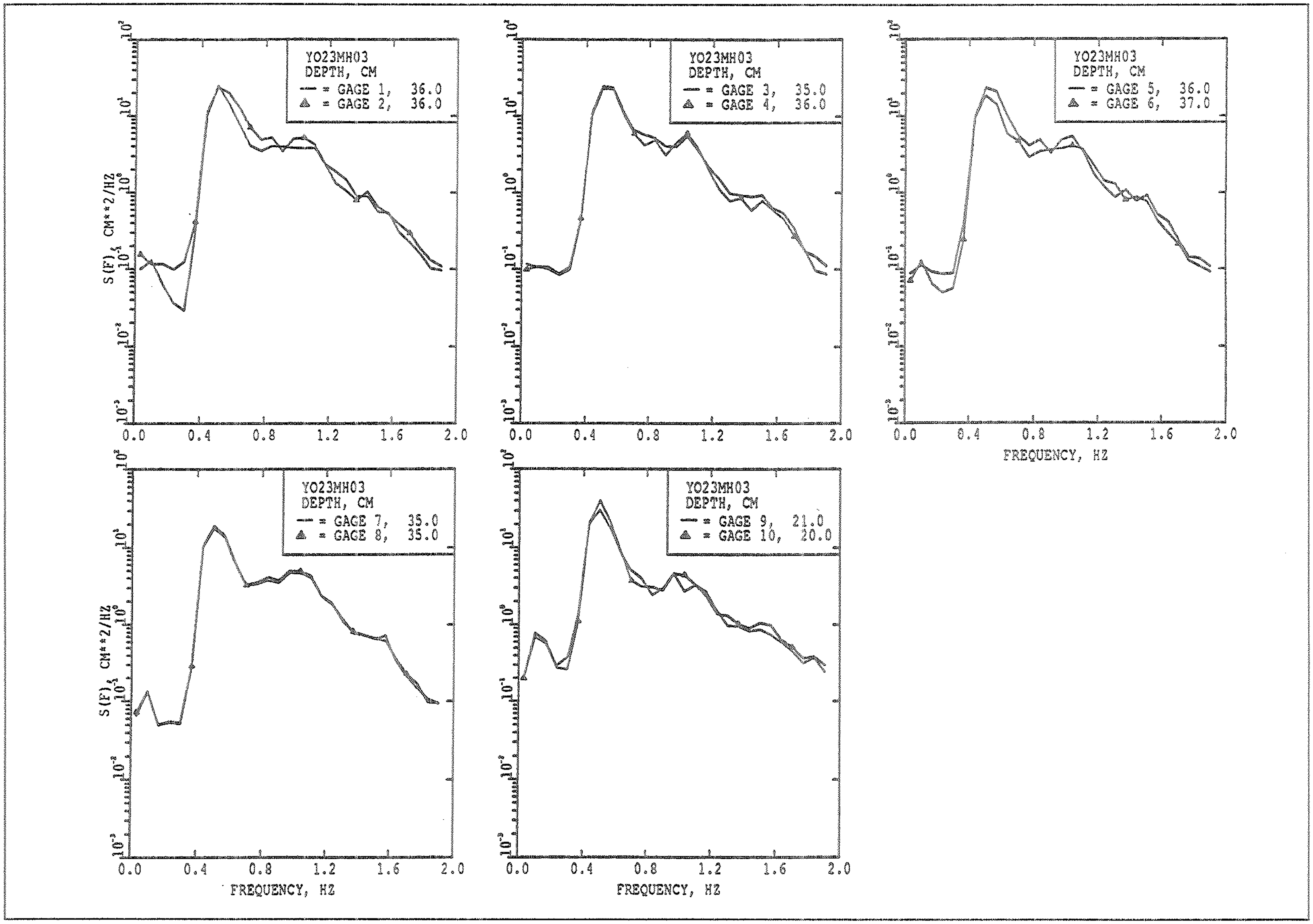
B) PRED. VS. OGA SPREADING @ PEAK FREQ
MLM, OGA=2-8, RAW

Appendix E
Measured Model Frequency Spectra for Gauges 1 to 10

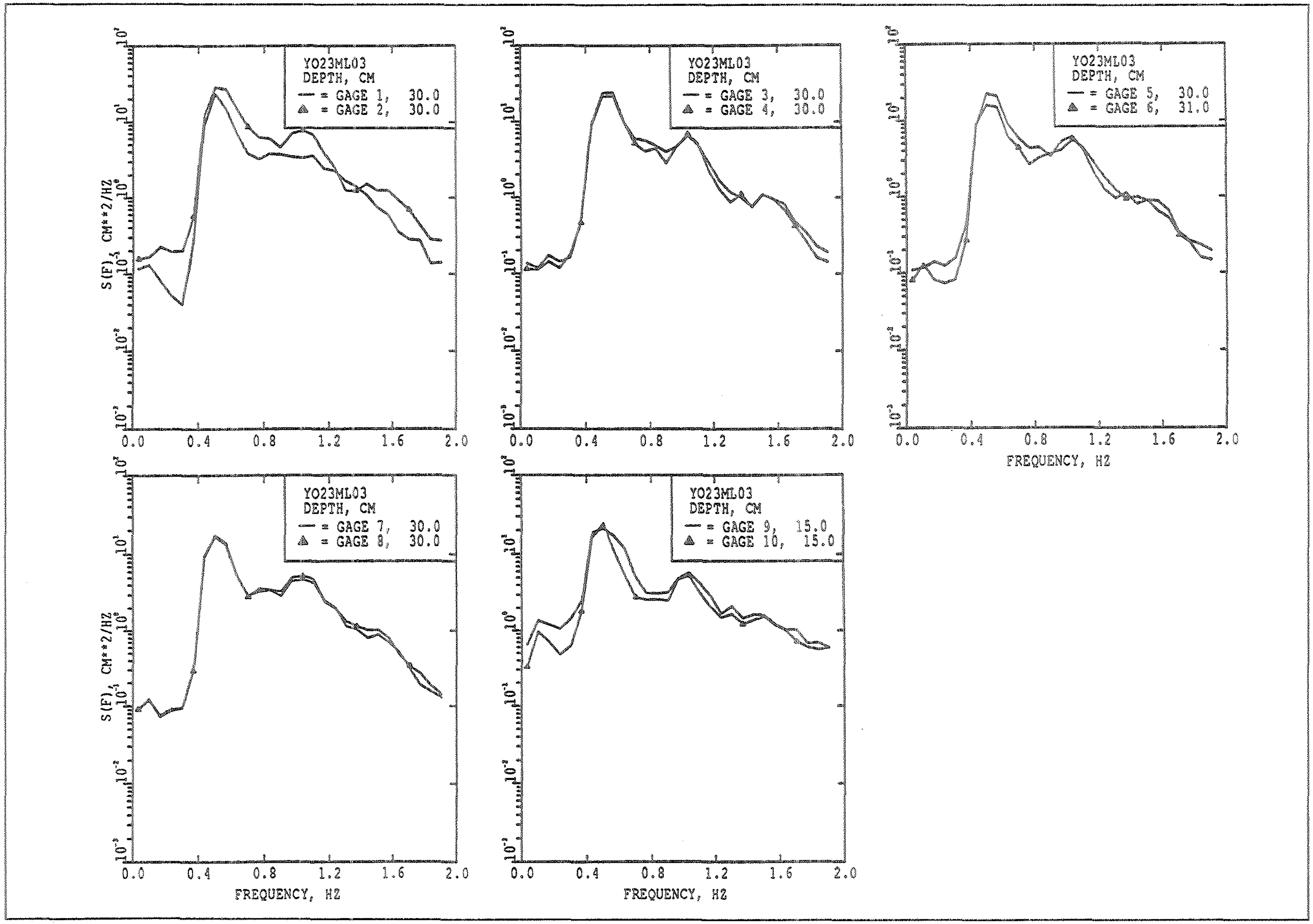


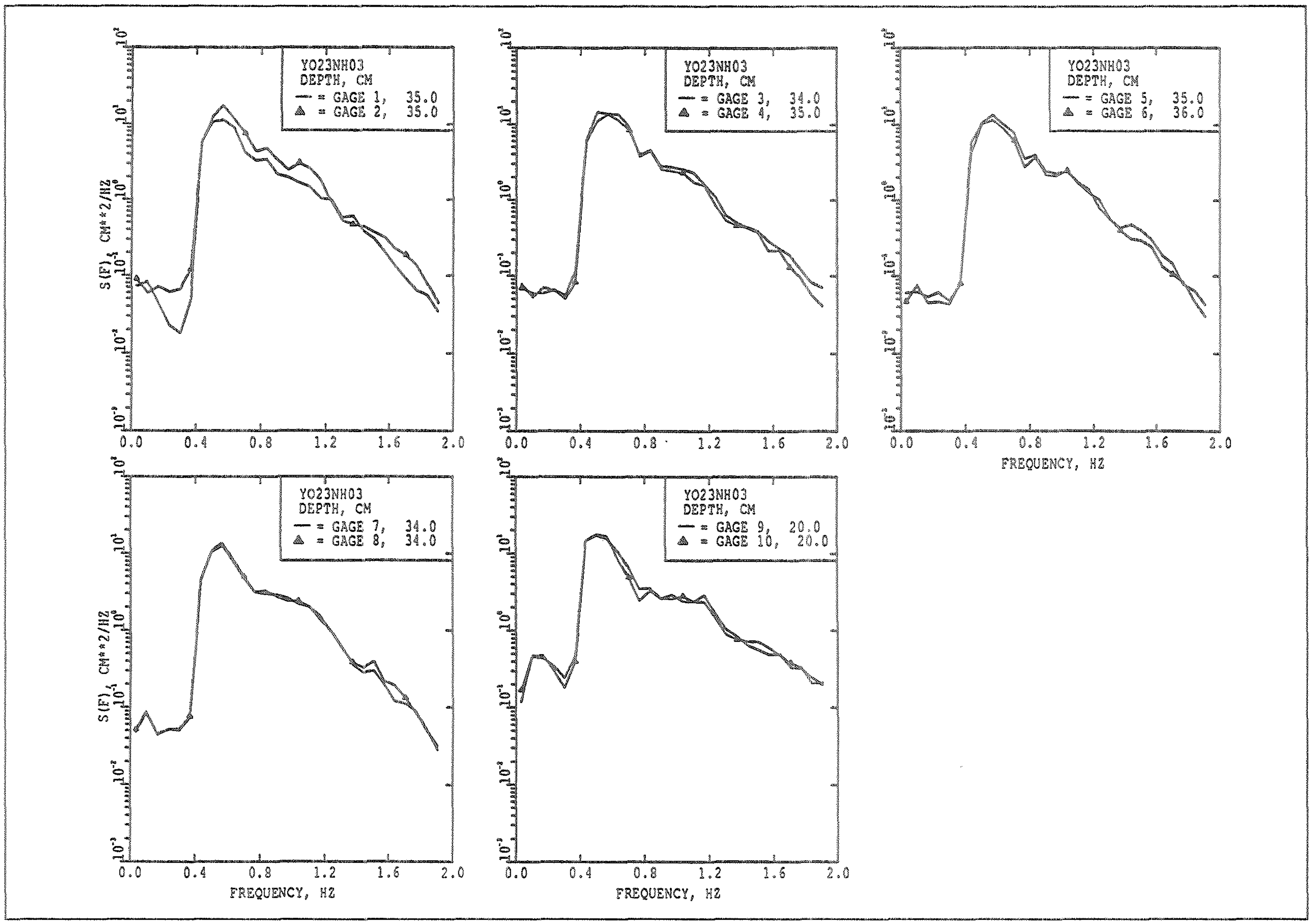
Appendix E Measured Model Frequency Spectra for Gauges 1 to 10


YO22NL03
DEPTH, CM
= GAGE 1, 32.0
= GAGE 2, 32.0
YO22NL03
DEPTH, CM
= GAGE 3, 31.0
= GAGE 4, 32.0
YO22NL03
DEPTH, CM
= GAGE 5, 32.0
= GAGE 6, 33.0
YO22NL03
DEPTH, CM
= GAGE 7, 31.0
= GAGE 8, 31.0
YO22NL03
DEPTH, CM
= GAGE 9, 17.0
= GAGE 10, 16.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

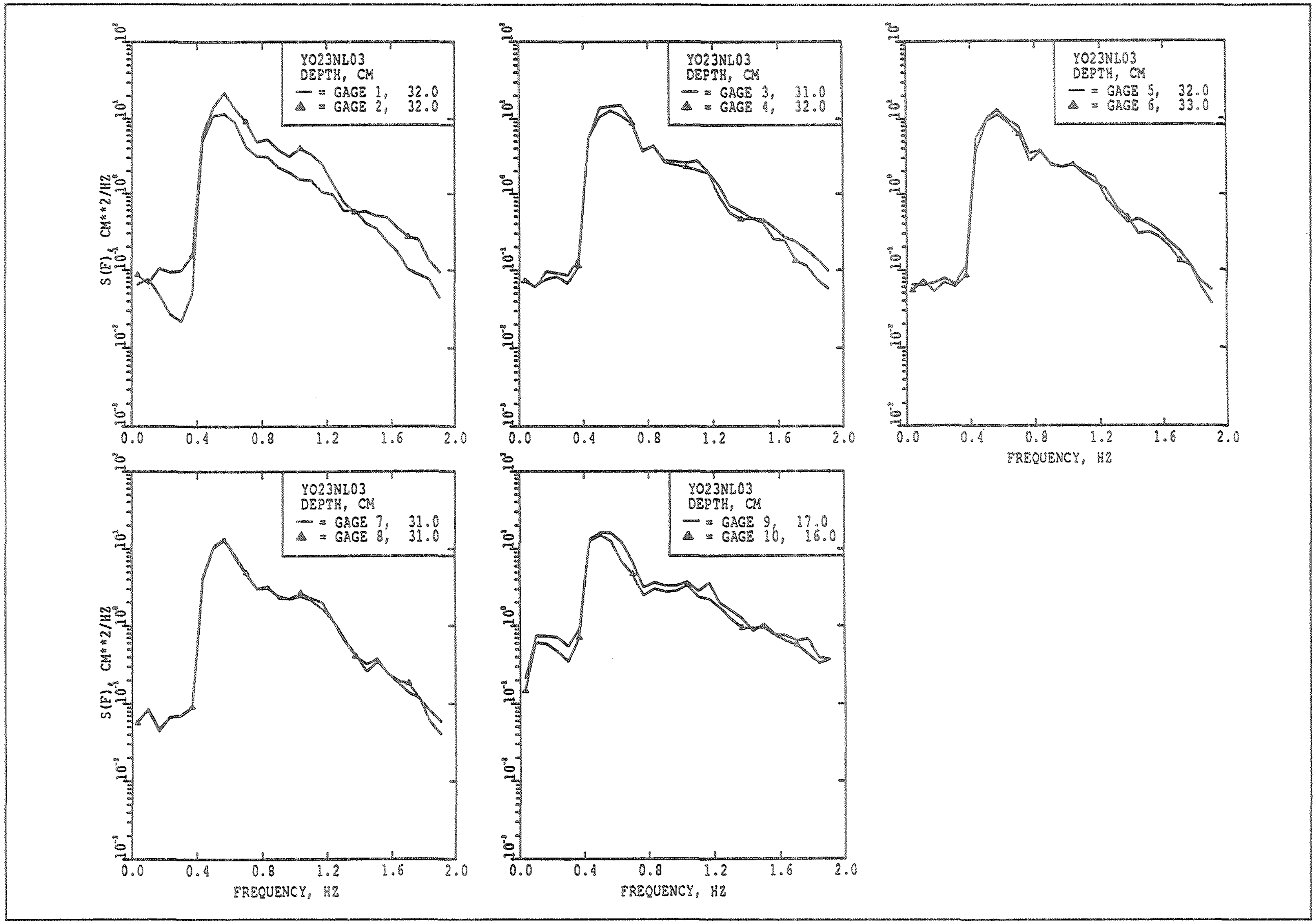


Appendix E Measured Model Frequency Spectra for Gauges 1 to 10

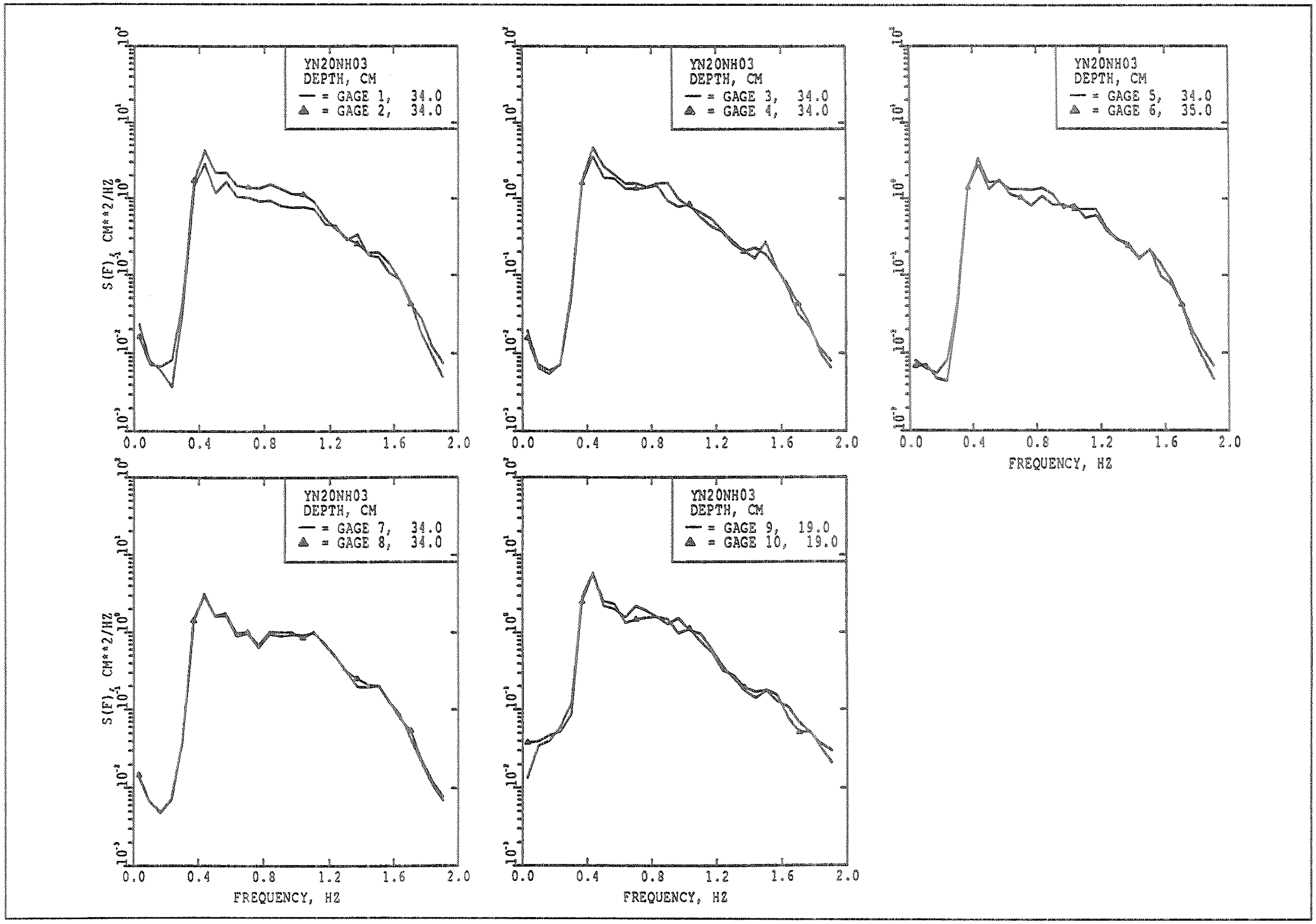

YO23ML03
DEPTH, CM
— = GAGE 1, 30.0
▲ = GAGE 2, 30.0
YO23ML03
DEPTH, CM
— = GAGE 3, 30.0
▲ = GAGE 4, 30.0
YO23ML03
DEPTH, CM
— = GAGE 5, 30.0
▲ = GAGE 6, 31.0
YO23ML03
DEPTH, CM
— = GAGE 7, 30.0
▲ = GAGE 8, 30.0
YO23ML03
DEPTH, CM
— = GAGE 9, 15.0
▲ = GAGE 10, 15.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

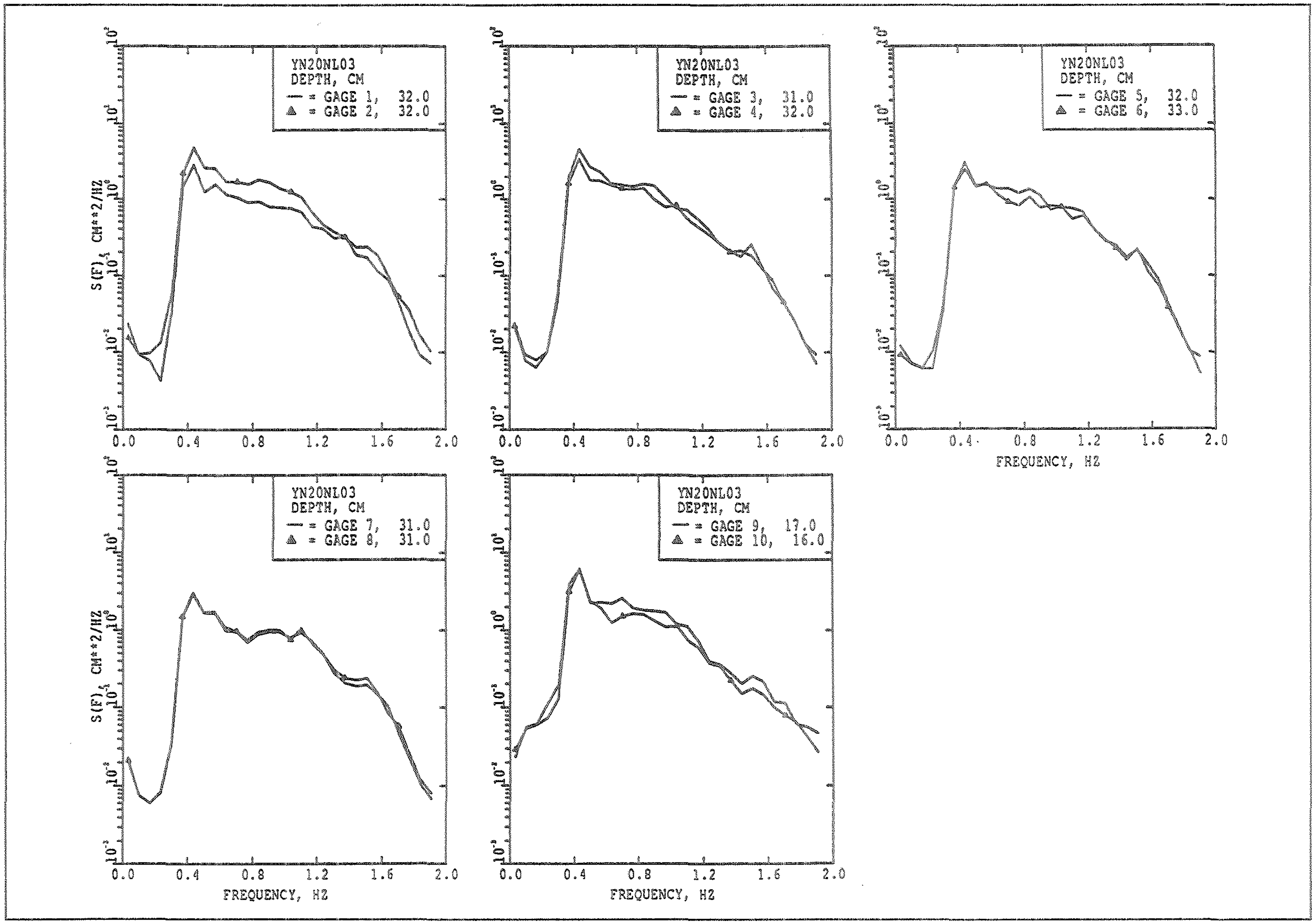


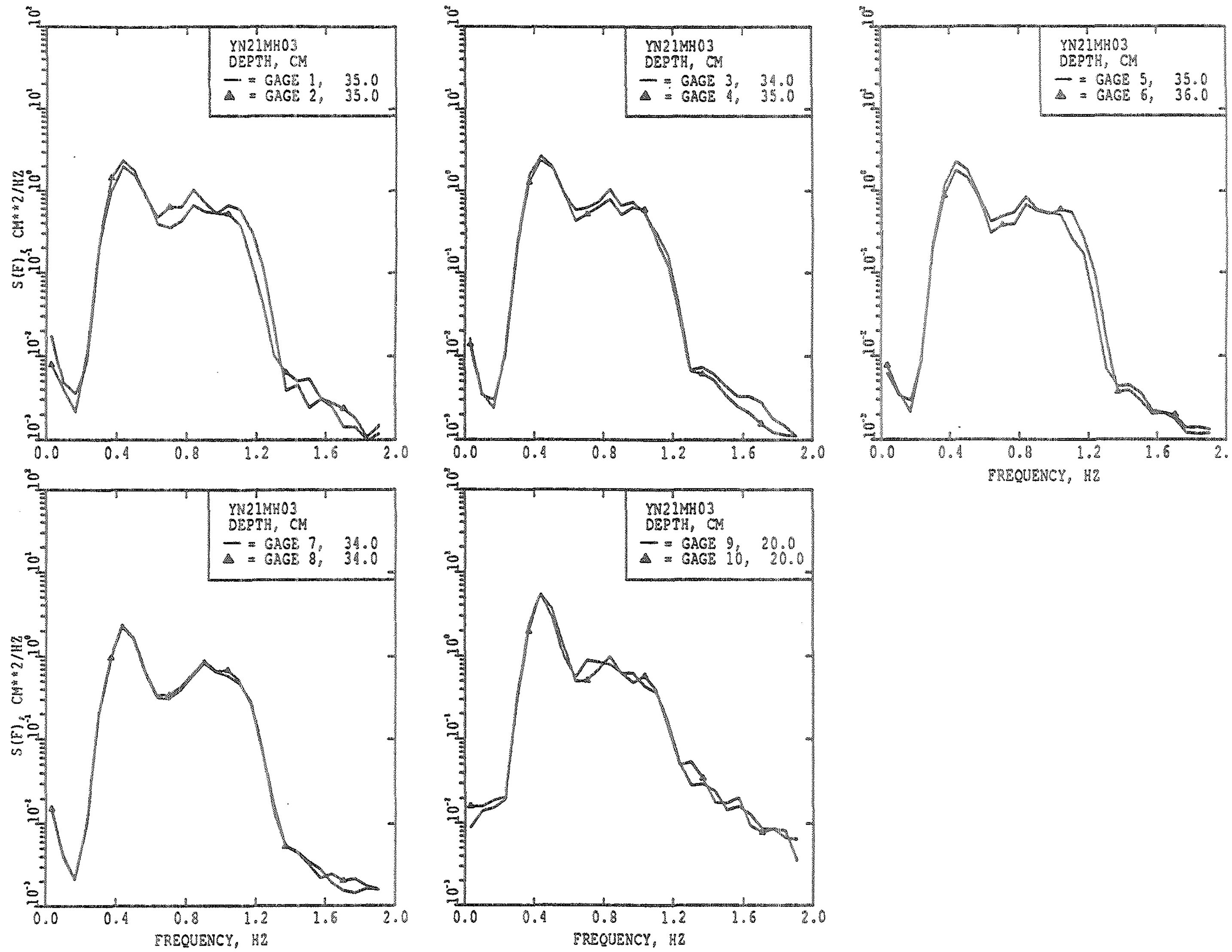
Appendix E Measured Model Frequency Spectra for Gauges 1 to 10

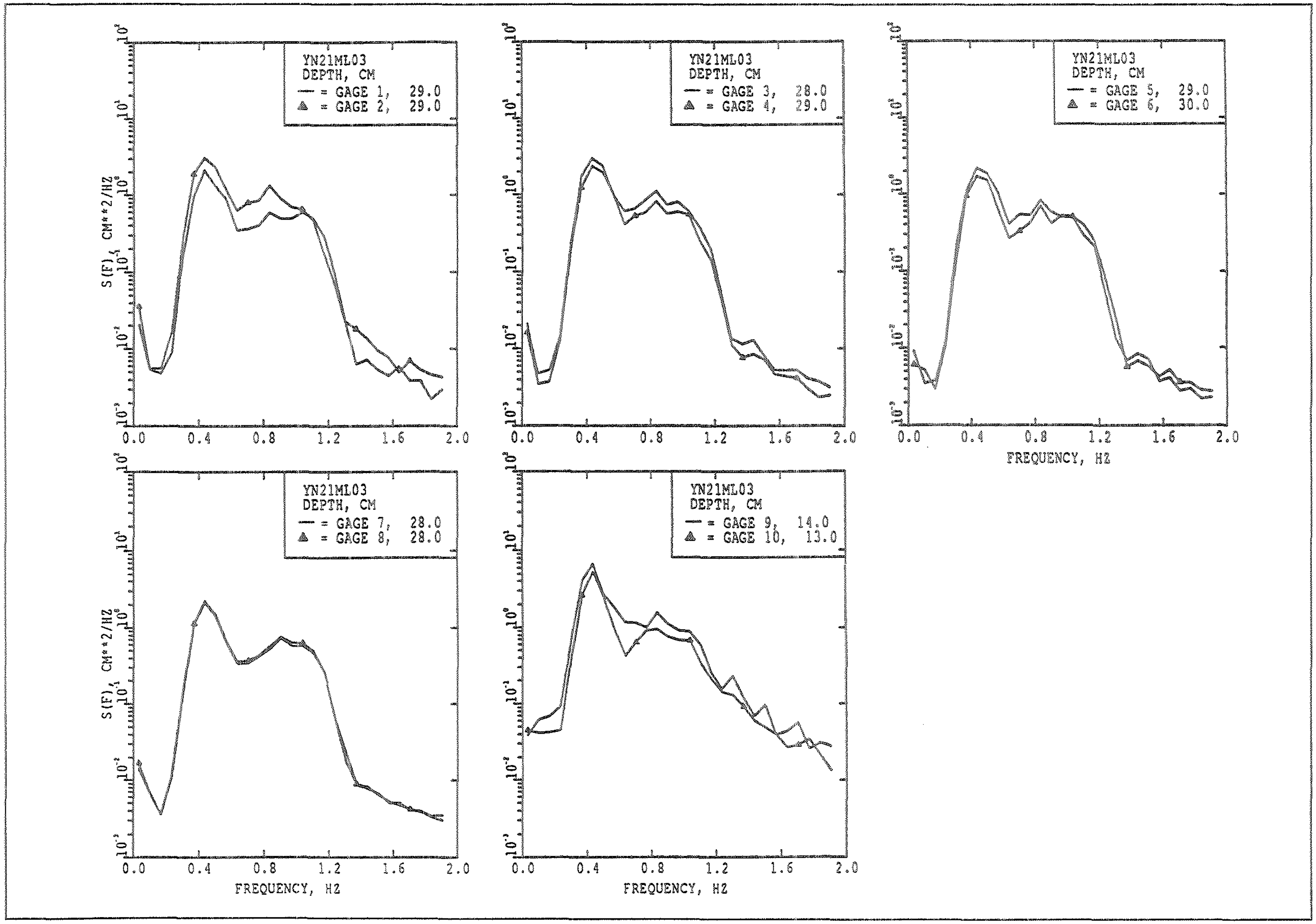


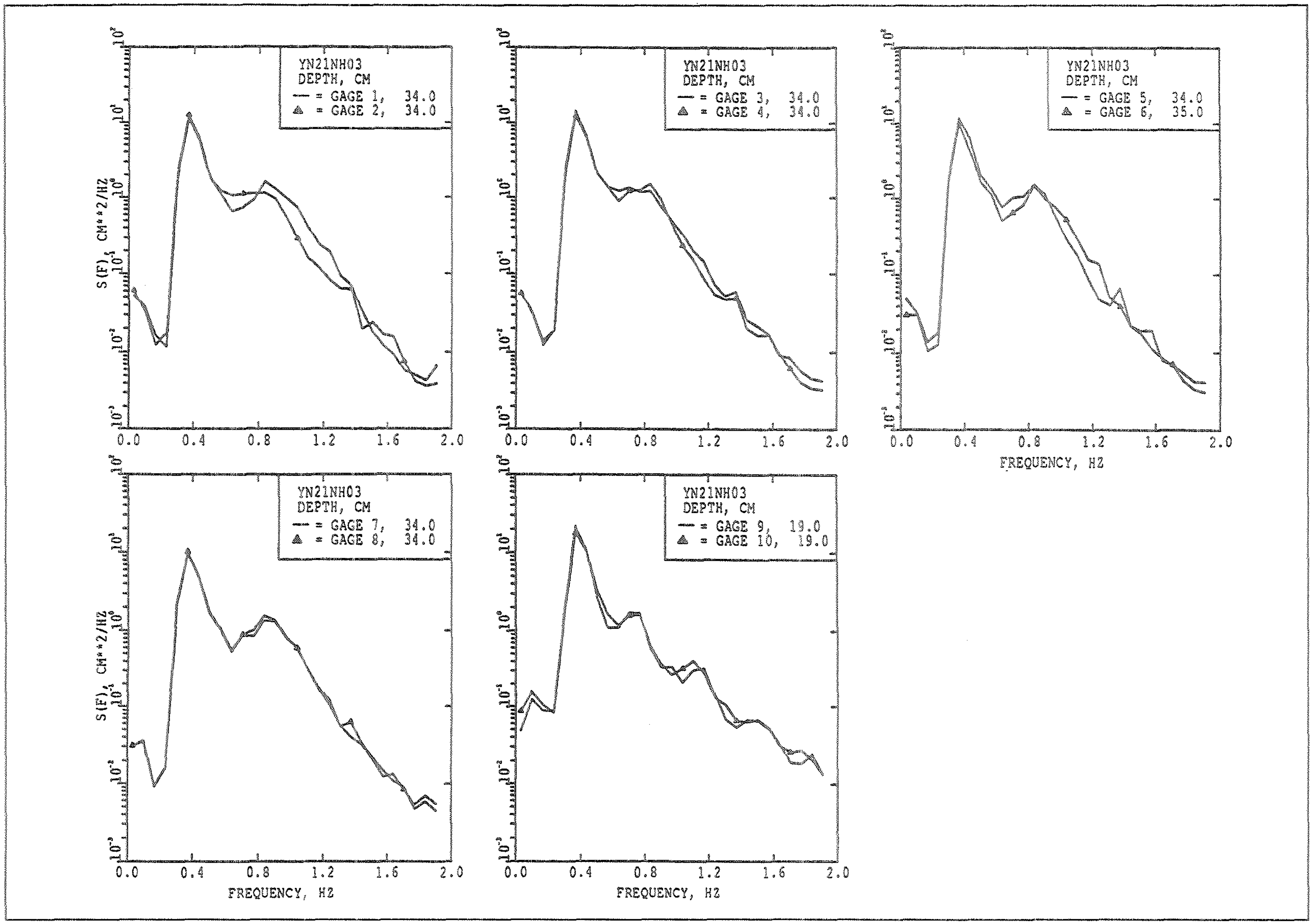
YO23NL03
DEPTH, CM
— = GAGE 1, 32.0
▲ = GAGE 2, 32.0
YO23NL03
DEPTH, CM
— = GAGE 3, 31.0
▲ = GAGE 4, 32.0
YO23NL03
DEPTH, CM
— = GAGE 5, 32.0
▲ = GAGE 6, 33.0
YO23NL03
DEPTH, CM
— = GAGE 7, 31.0
▲ = GAGE 8, 31.0
YO23NL03
DEPTH, CM
— = GAGE 9, 17.0
▲ = GAGE 10, 16.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0 0.4 0.8 1.2 1.6 2.0

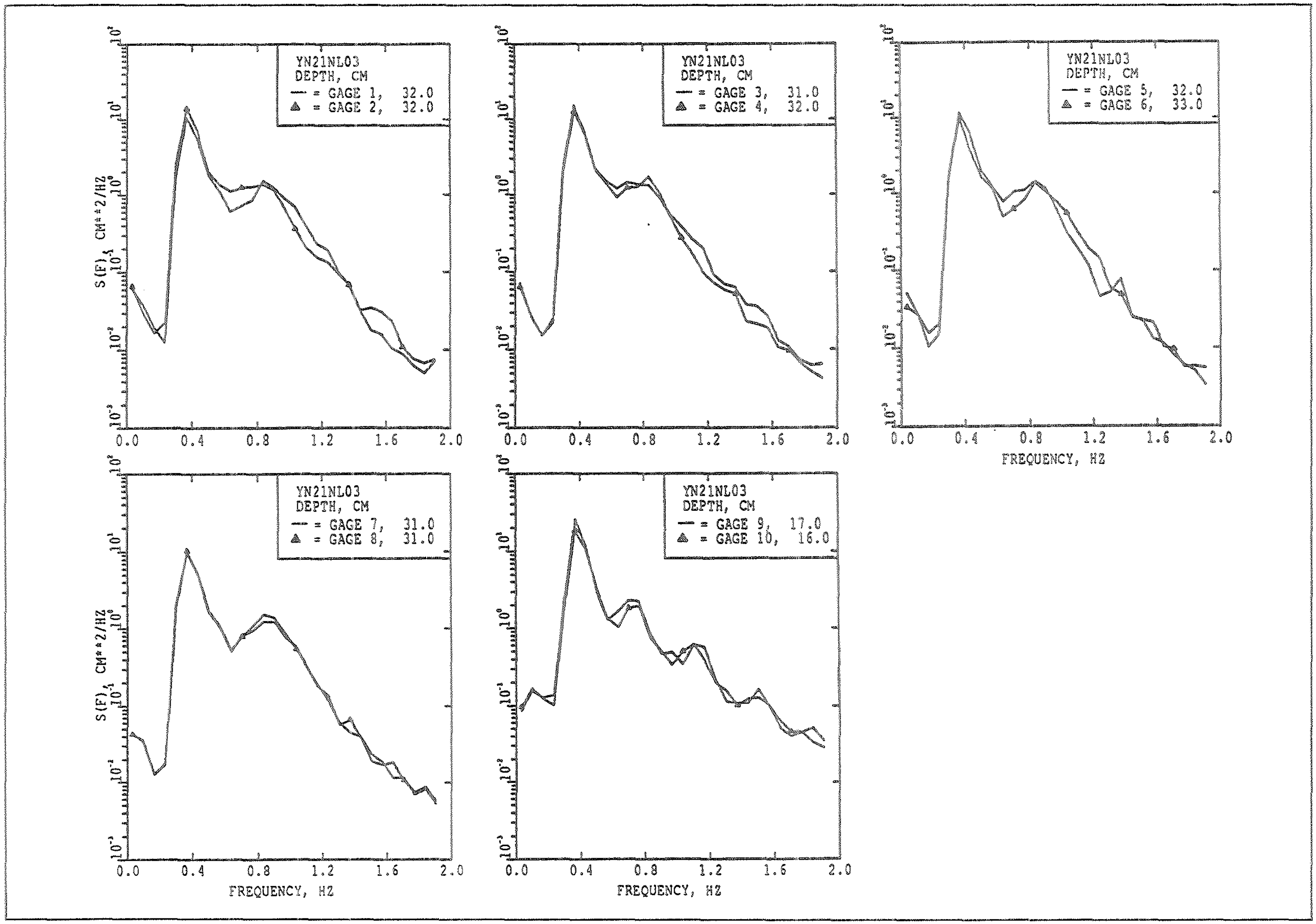

YN20NH03
DEPTH, CM
— = GAGE 1, 34.0
▲ = GAGE 2, 34.0
YN20NH03
DEPTH, CM
— = GAGE 3, 34.0
▲ = GAGE 4, 34.0
YN20NH03
DEPTH, CM
— = GAGE 5, 34.0
▲ = GAGE 6, 35.0
YN20NH03
DEPTH, CM
— = GAGE 7, 34.0
▲ = GAGE 8, 34.0
YN20NH03
DEPTH, CM
— = GAGE 9, 19.0
▲ = GAGE 10, 19.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

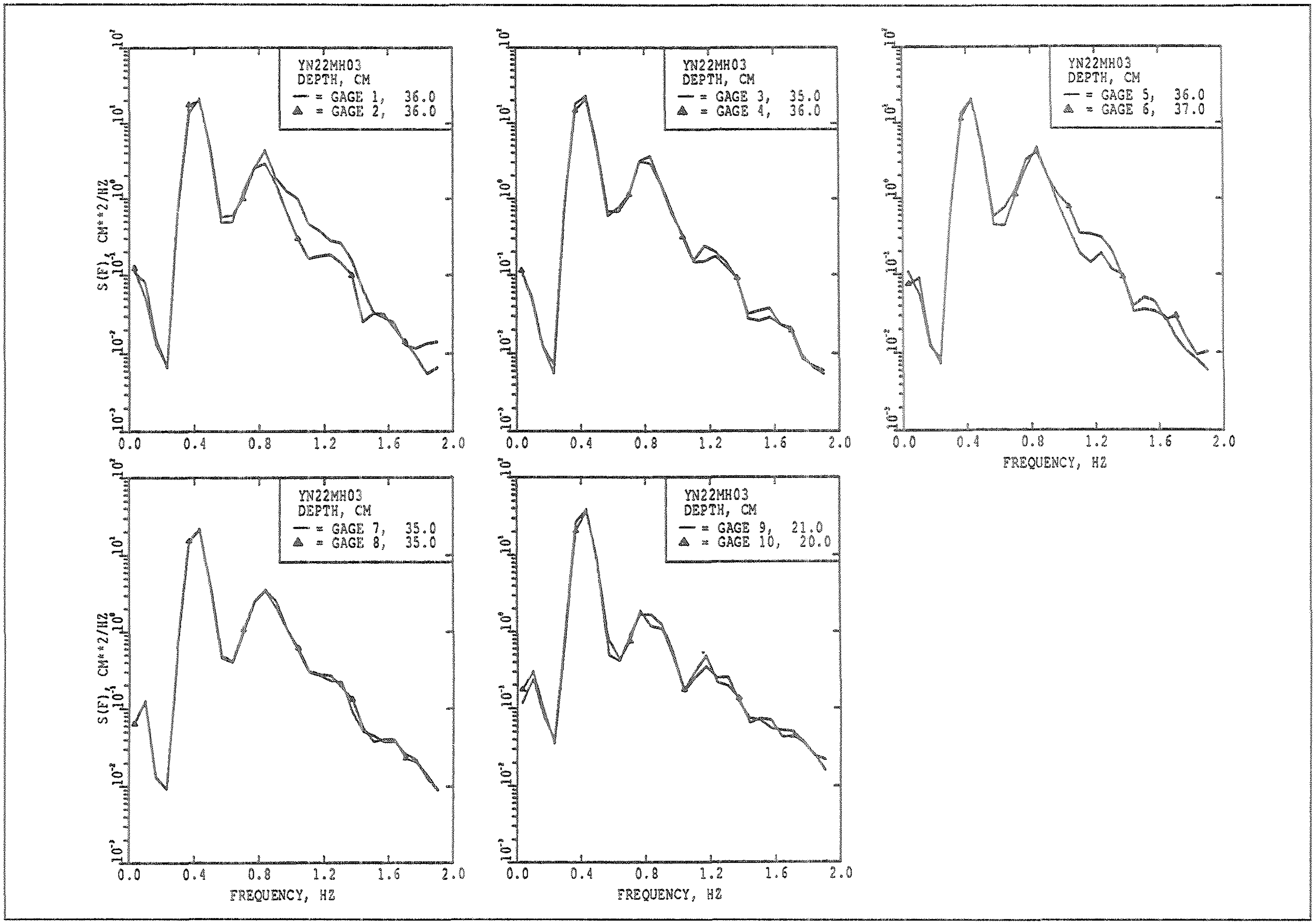

YN20NL03
DEPTH, CM
— = GAGE 1, 32.0
▲ = GAGE 2, 32.0
YN20NL03
DEPTH, CM
— = GAGE 3, 31.0
▲ = GAGE 4, 32.0
YN20NL03
DEPTH, CM
— = GAGE 5, 32.0
▲ = GAGE 6, 33.0
YN20NL03
DEPTH, CM
— = GAGE 7, 31.0
▲ = GAGE 8, 31.0
YN20NL03
DEPTH, CM
— = GAGE 9, 17.0
▲ = GAGE 10, 16.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0


YN21MH03
DEPTH, CM
— = GAGE 1, 35.0
▲ = GAGE 2, 35.0
YN21MH03
DEPTH, CM
— = GAGE 3, 34.0
▲ = GAGE 4, 35.0
YN21MH03
DEPTH, CM
— = GAGE 5, 35.0
▲ = GAGE 6, 36.0
YN21MH03
DEPTH, CM
— = GAGE 7, 34.0
▲ = GAGE 8, 34.0
YN21MH03
DEPTH, CM
— = GAGE 9, 20.0
▲ = GAGE 10, 20.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0 0.4 0.8 1.2 1.6 2.0

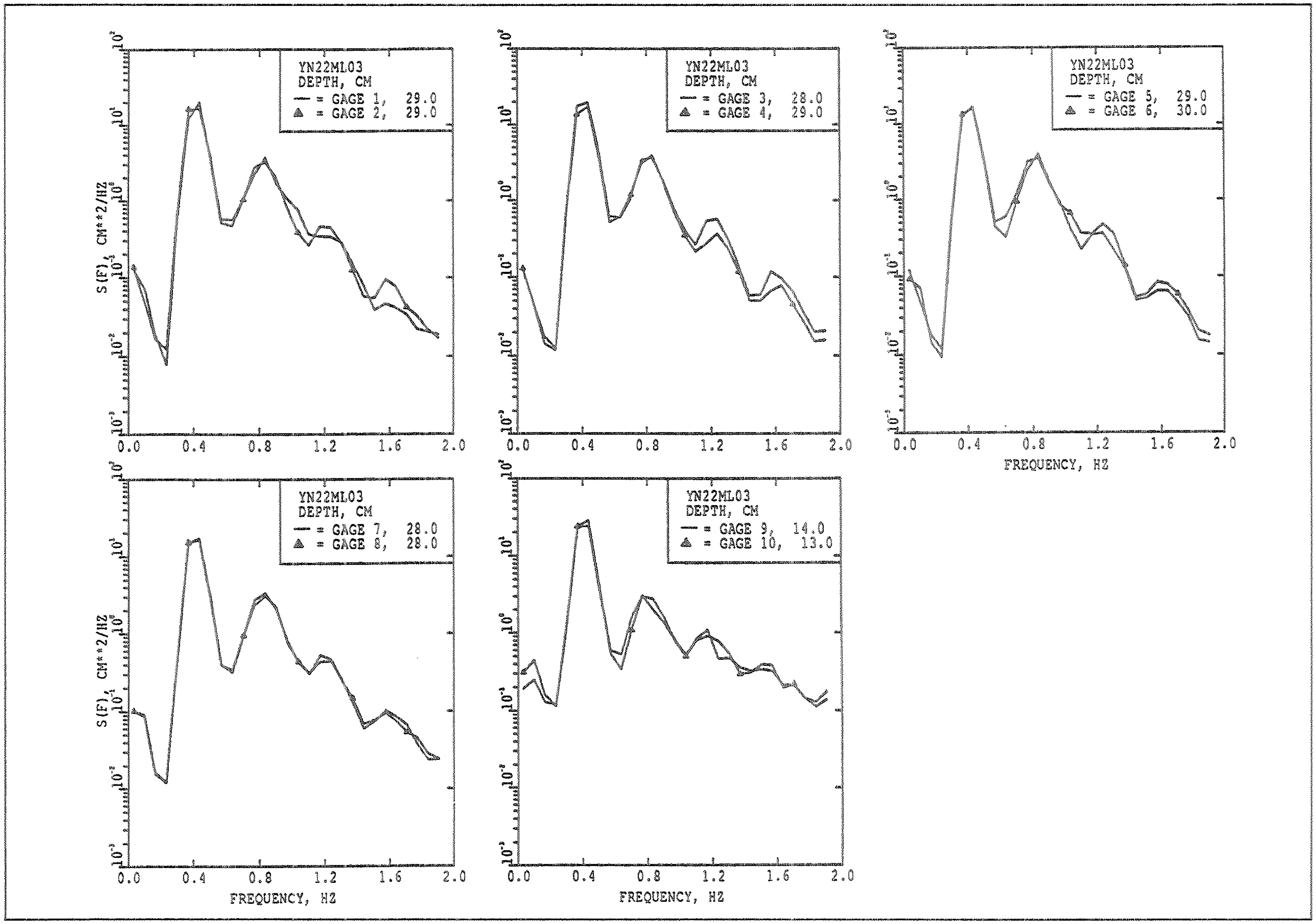

YN21ML03
DEPTH, CM
— = GAGE 1, 29.0
▲ = GAGE 2, 29.0
YN21ML03
DEPTH, CM
— = GAGE 3, 28.0
▲ = GAGE 4, 29.0
YN21ML03
DEPTH, CM
— = GAGE 5, 29.0
▲ = GAGE 6, 30.0
YN21ML03
DEPTH, CM
— = GAGE 7, 28.0
▲ = GAGE 8, 28.0
YN21ML03
DEPTH, CM
— = GAGE 9, 14.0
▲ = GAGE 10, 13.0
S(F), CM**2/HZ
FREQUENCY, HZ

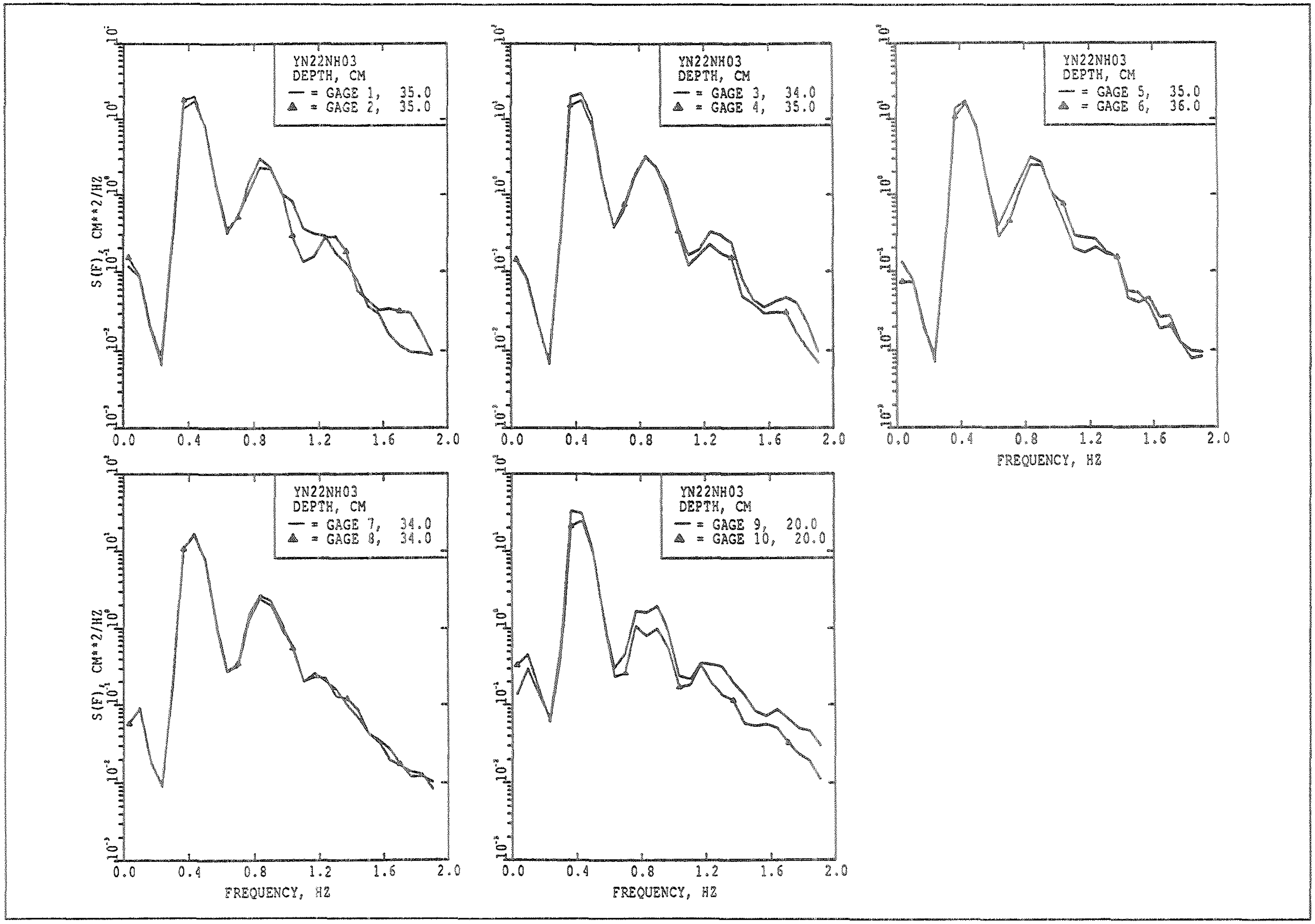

YN21NH03
DEPTH, CM
— = GAGE 1, 34.0
▲ = GAGE 2, 34.0
YN21NH03
DEPTH, CM
— = GAGE 3, 34.0
▲ = GAGE 4, 34.0
YN21NH03
DEPTH, CM
— = GAGE 5, 34.0
▲ = GAGE 6, 35.0
YN21NH03
DEPTH, CM
— = GAGE 7, 34.0
▲ = GAGE 8, 34.0
YN21NH03
DEPTH, CM
— = GAGE 9, 19.0
▲ = GAGE 10, 19.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0


YN21NL03
DEPTH, CM
— = GAGE 1, 32.0
▲ = GAGE 2, 32.0
YN21NL03
DEPTH, CM
— = GAGE 3, 31.0
▲ = GAGE 4, 32.0
YN21NL03
DEPTH, CM
— = GAGE 5, 32.0
▲ = GAGE 6, 33.0
YN21NL03
DEPTH, CM
— = GAGE 7, 31.0
▲ = GAGE 8, 31.0
YN21NL03
DEPTH, CM
— = GAGE 9, 17.0
▲ = GAGE 10, 16.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

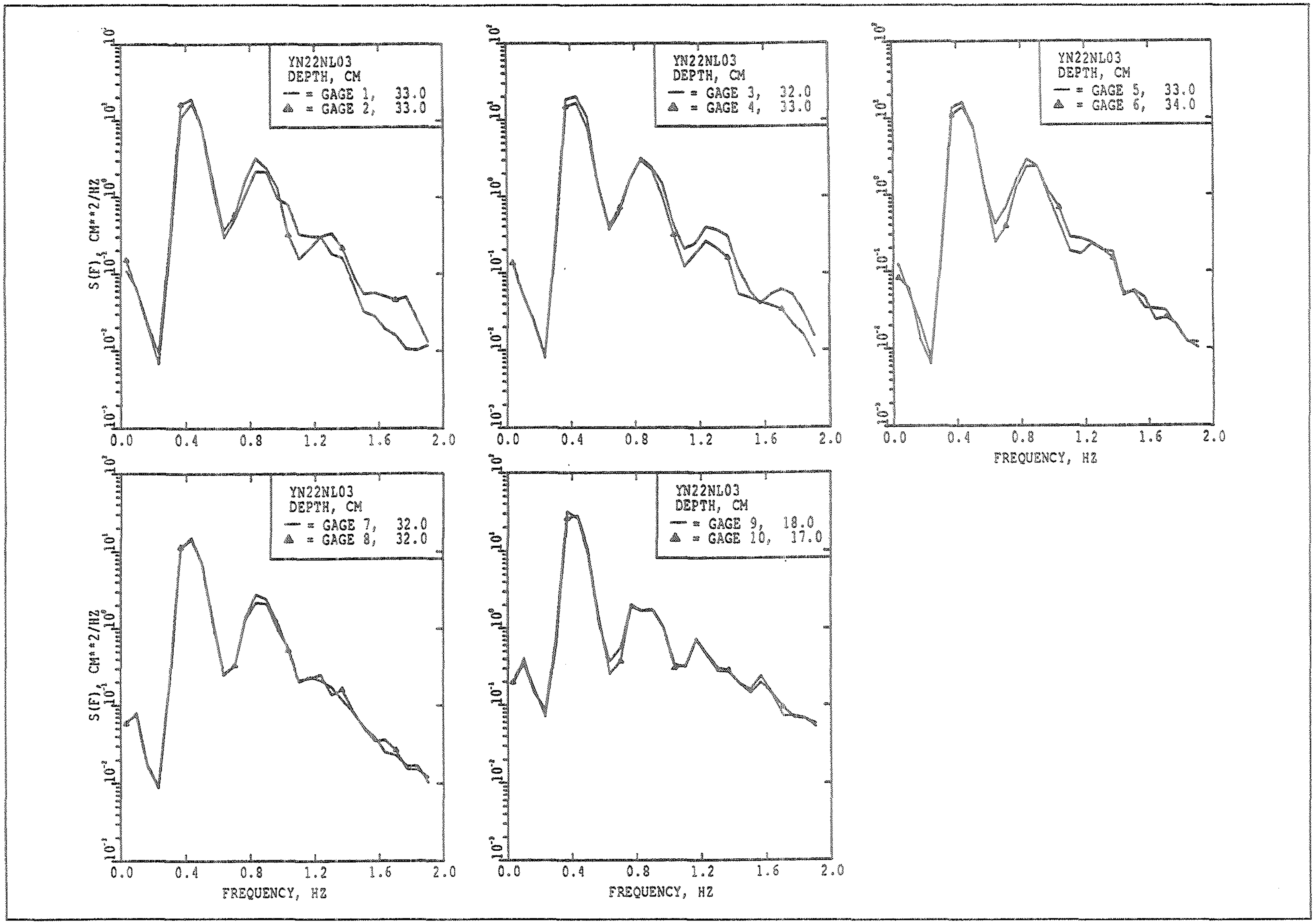


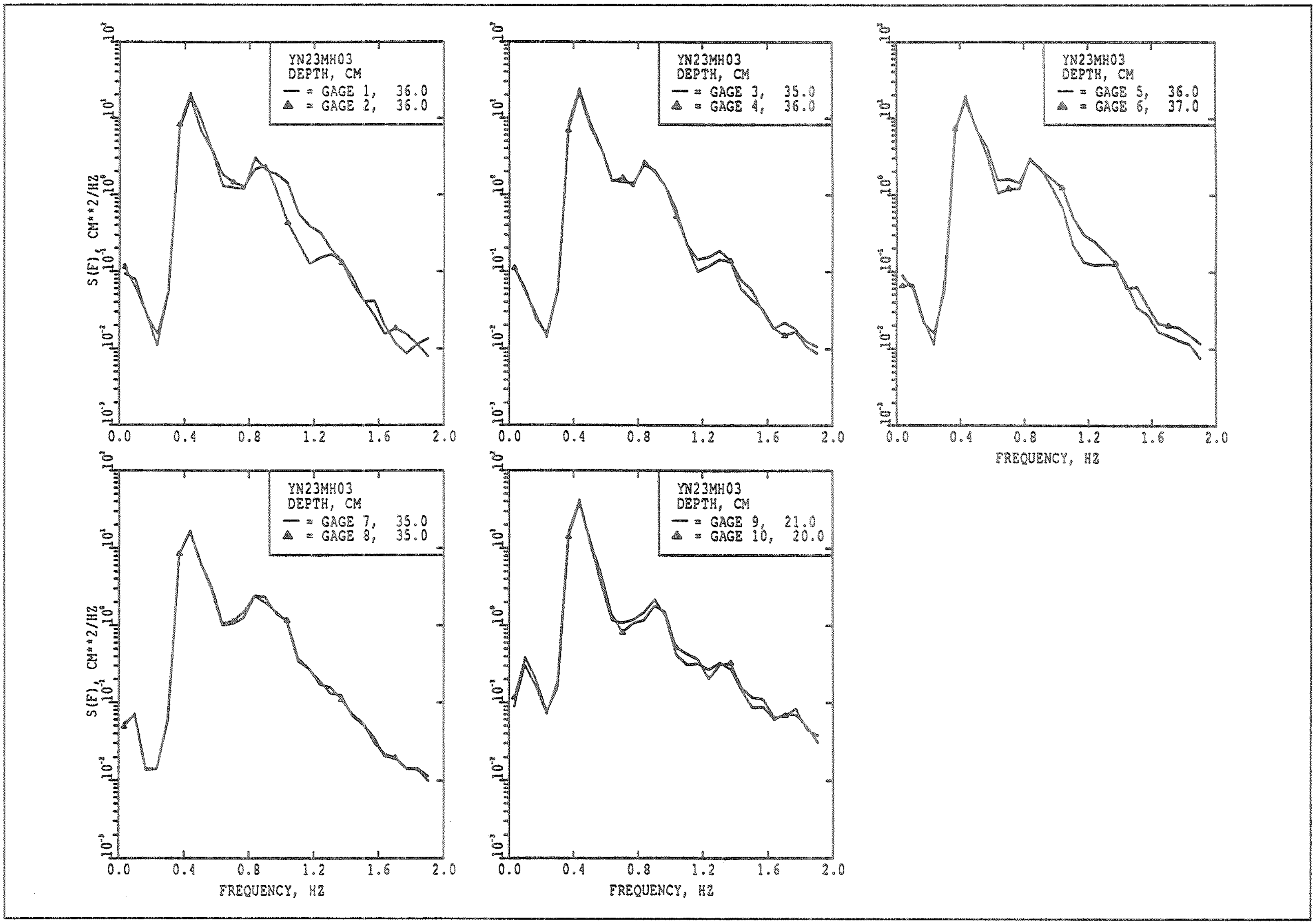
Appendix E Measured Model Frequency Spectra for Gauges 1 to 10

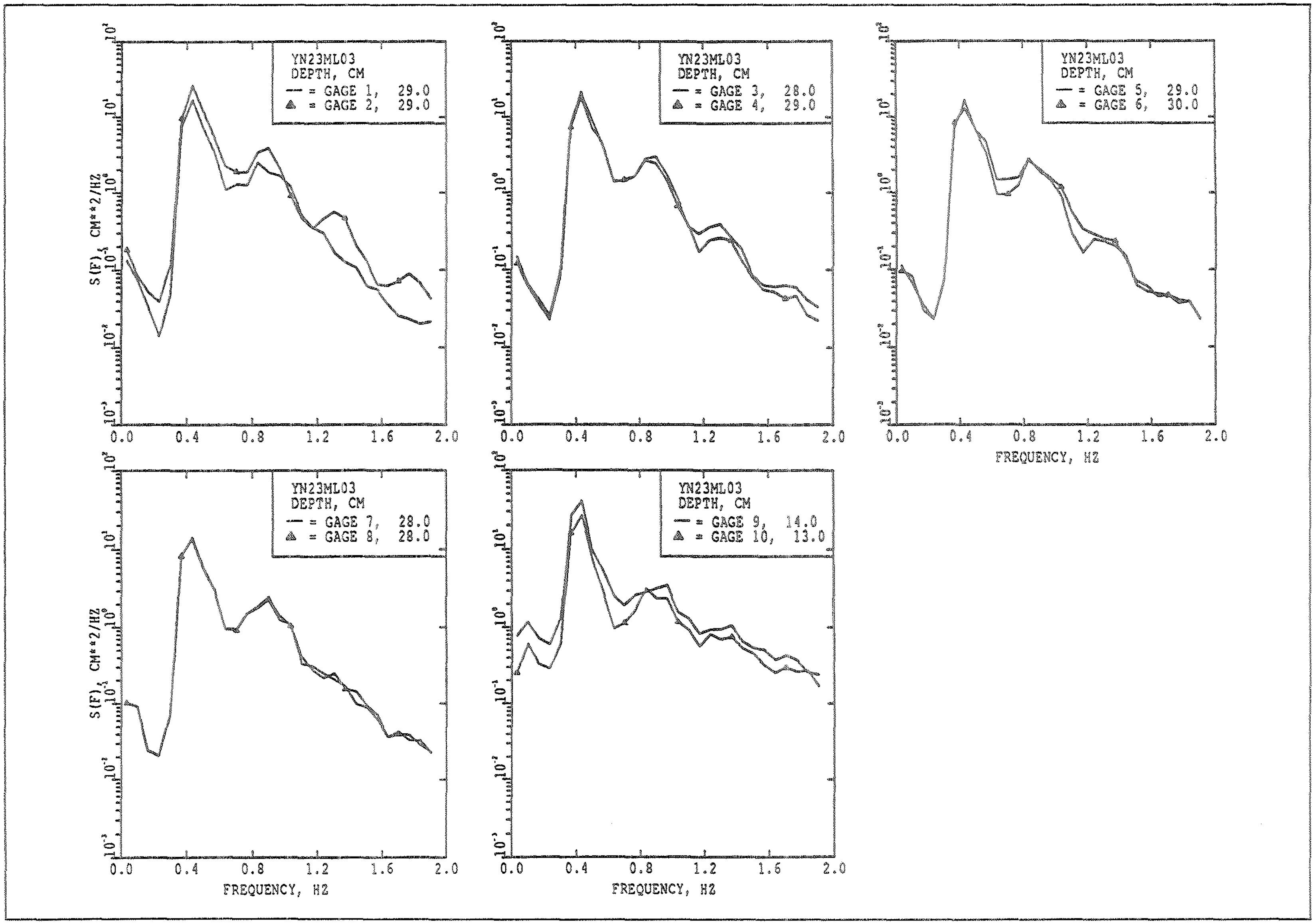

YN22ML03
DEPTH, CM
— = GAGE 1, 29.0
▲ = GAGE 2, 29.0
YN22ML03
DEPTH, CM
— = GAGE 3, 28.0
▲ = GAGE 4, 29.0
YN22ML03
DEPTH, CM
— = GAGE 5, 29.0
▲ = GAGE 6, 30.0
YN22ML03
DEPTH, CM
— = GAGE 7, 28.0
▲ = GAGE 8, 28.0
YN22ML03
DEPTH, CM
— = GAGE 9, 14.0
▲ = GAGE 10, 13.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0



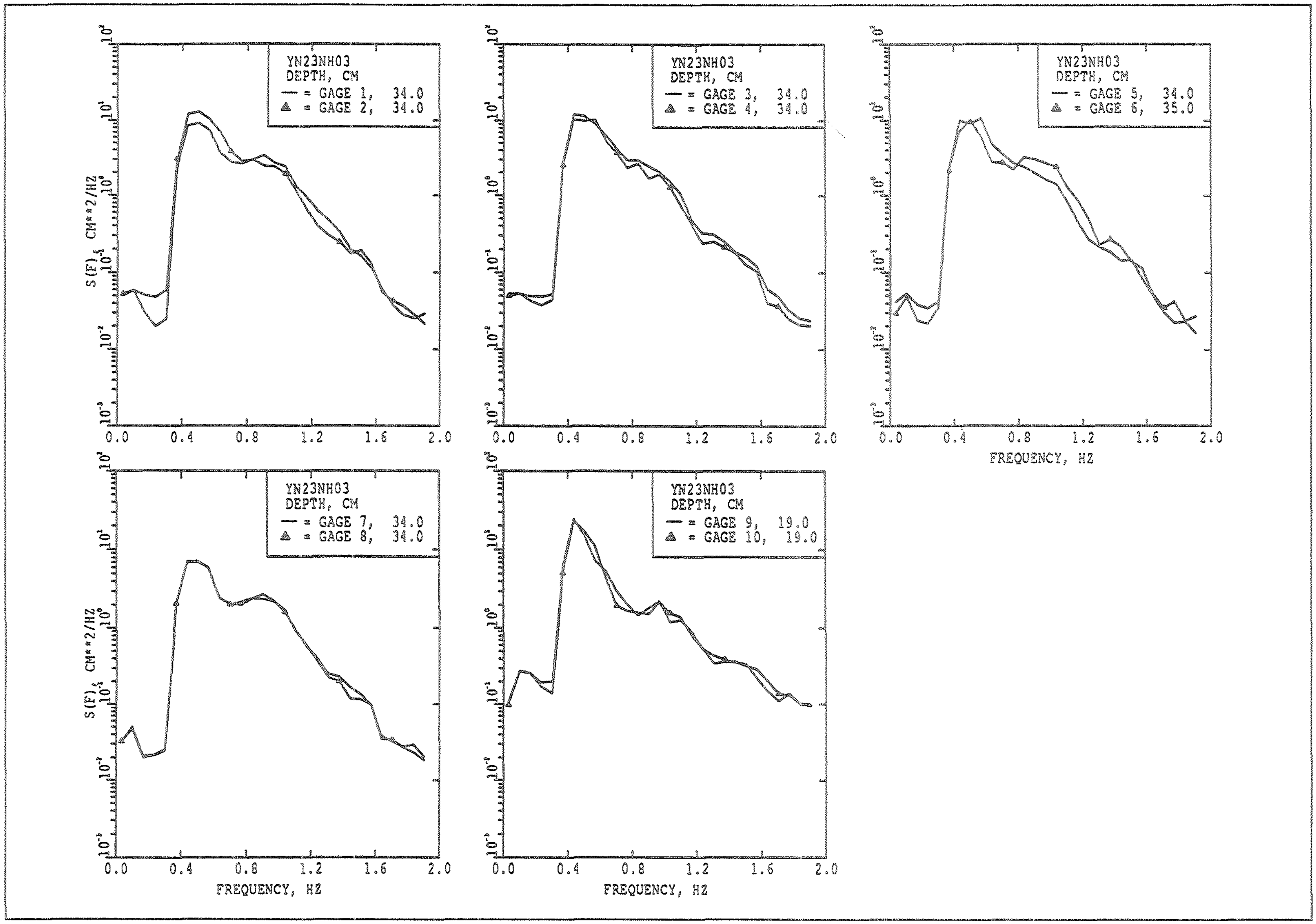
Appendix E Measured Model Frequency Spectra for Gauges 1 to 10


YN22NL03
DEPTH, CM
— = GAGE 1, 33.0
▲ = GAGE 2, 33.0
YN22NL03
DEPTH, CM
— = GAGE 3, 32.0
▲ = GAGE 4, 33.0
YN22NL03
DEPTH, CM
— = GAGE 5, 33.0
▲ = GAGE 6, 34.0
YN22NL03
DEPTH, CM
— = GAGE 7, 32.0
▲ = GAGE 8, 32.0
YN22NL03
DEPTH, CM
— = GAGE 9, 18.0
▲ = GAGE 10, 17.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

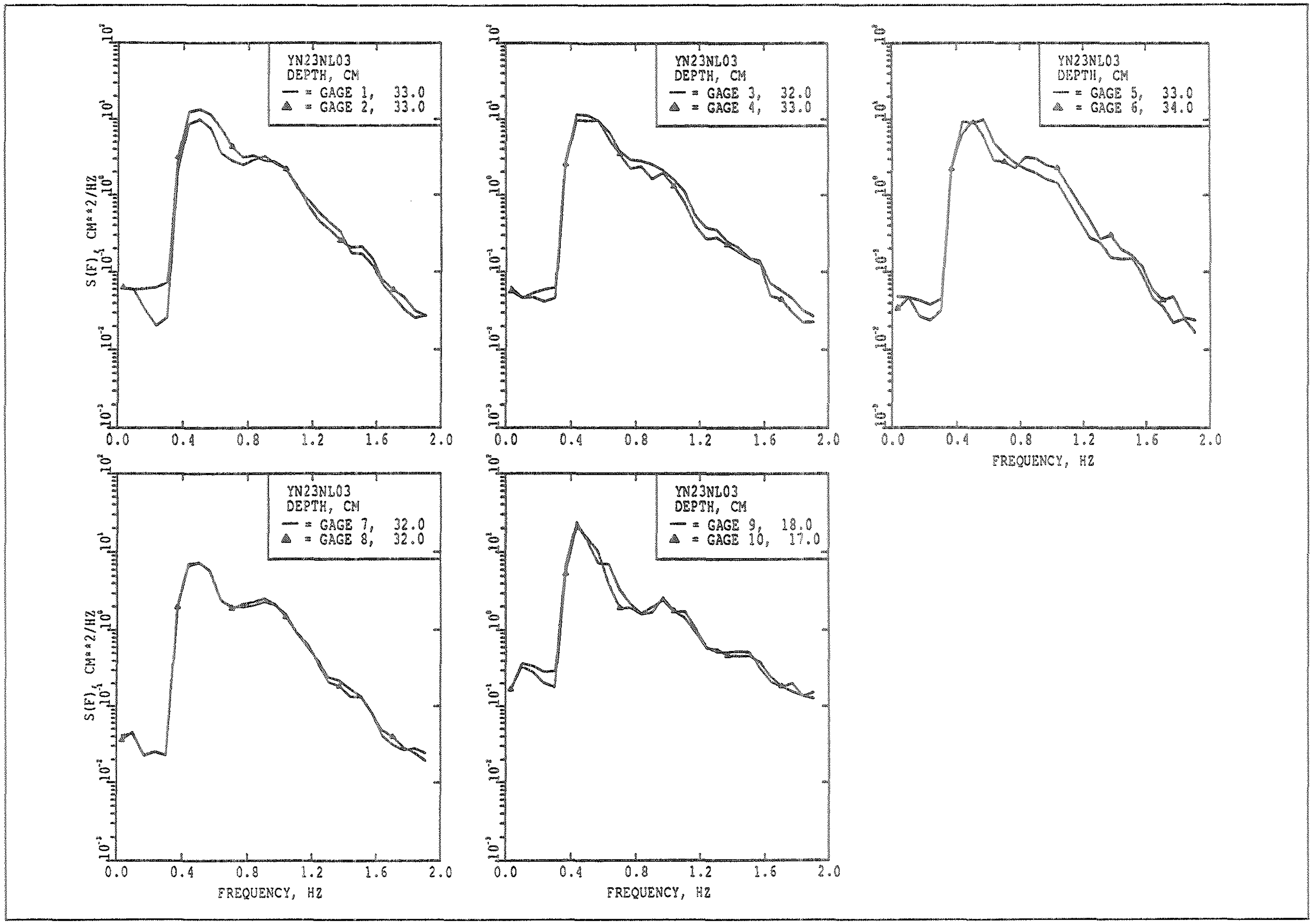

YN23MH03
DEPTH, CM
— = GAGE 1, 36.0
▲ = GAGE 2, 36.0
YN23MH03
DEPTH, CM
— = GAGE 3, 35.0
▲ = GAGE 4, 36.0
YN23MH03
DEPTH, CM
— = GAGE 5, 36.0
▲ = GAGE 6, 37.0
YN23MH03
DEPTH, CM
— = GAGE 7, 35.0
▲ = GAGE 8, 35.0
YN23MH03
DEPTH, CM
— = GAGE 9, 21.0
▲ = GAGE 10, 20.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

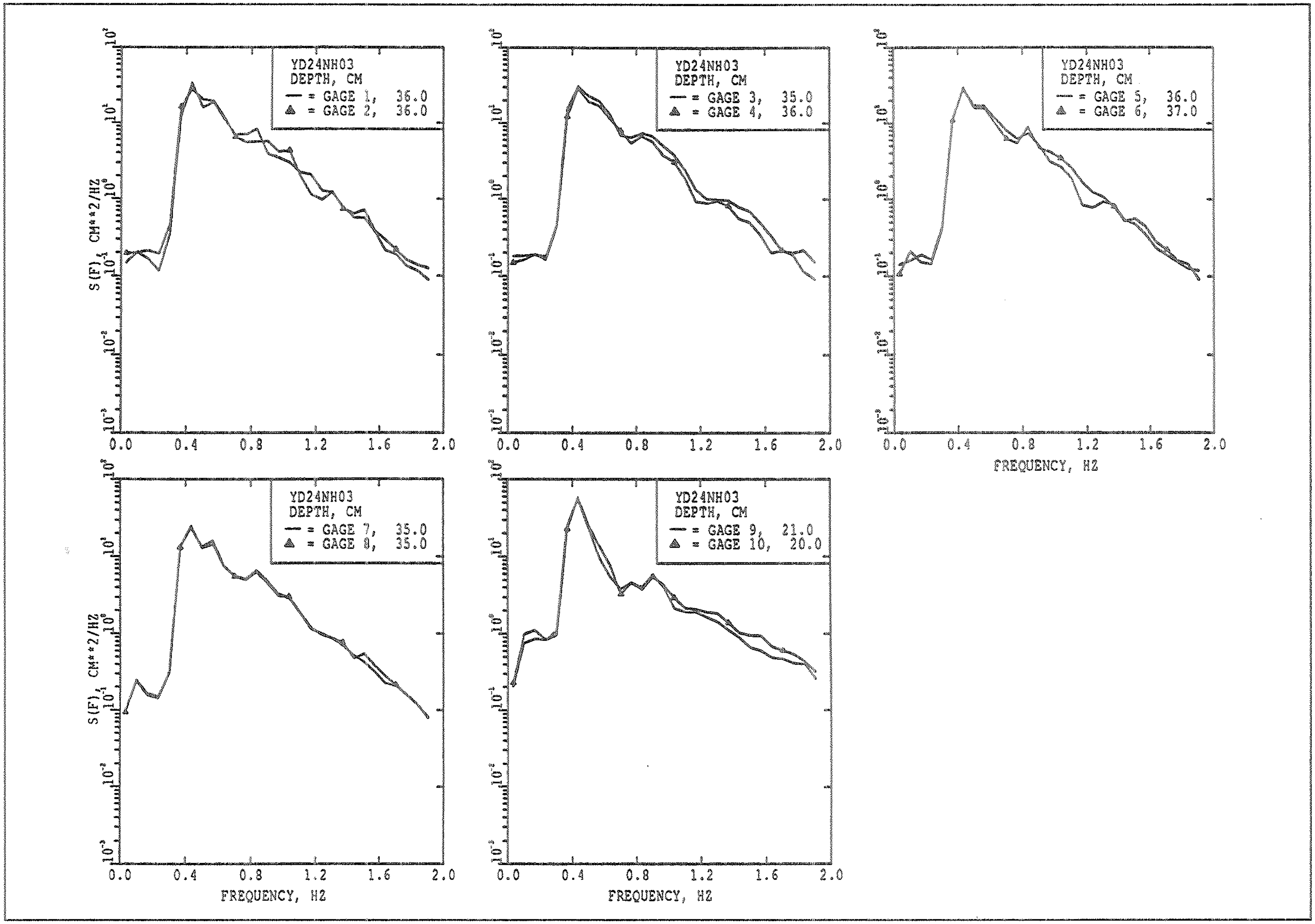


YN23ML03
DEPTH, CM
— = GAGE 1, 29.0
▲ = GAGE 2, 29.0
YN23ML03
DEPTH, CM
— = GAGE 3, 28.0
▲ = GAGE 4, 29.0
YN23ML03
DEPTH, CM
— = GAGE 5, 29.0
▲ = GAGE 6, 30.0
YN23ML03
DEPTH, CM
— = GAGE 7, 28.0
▲ = GAGE 8, 28.0
YN23ML03
DEPTH, CM
— = GAGE 9, 14.0
▲ = GAGE 10, 13.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

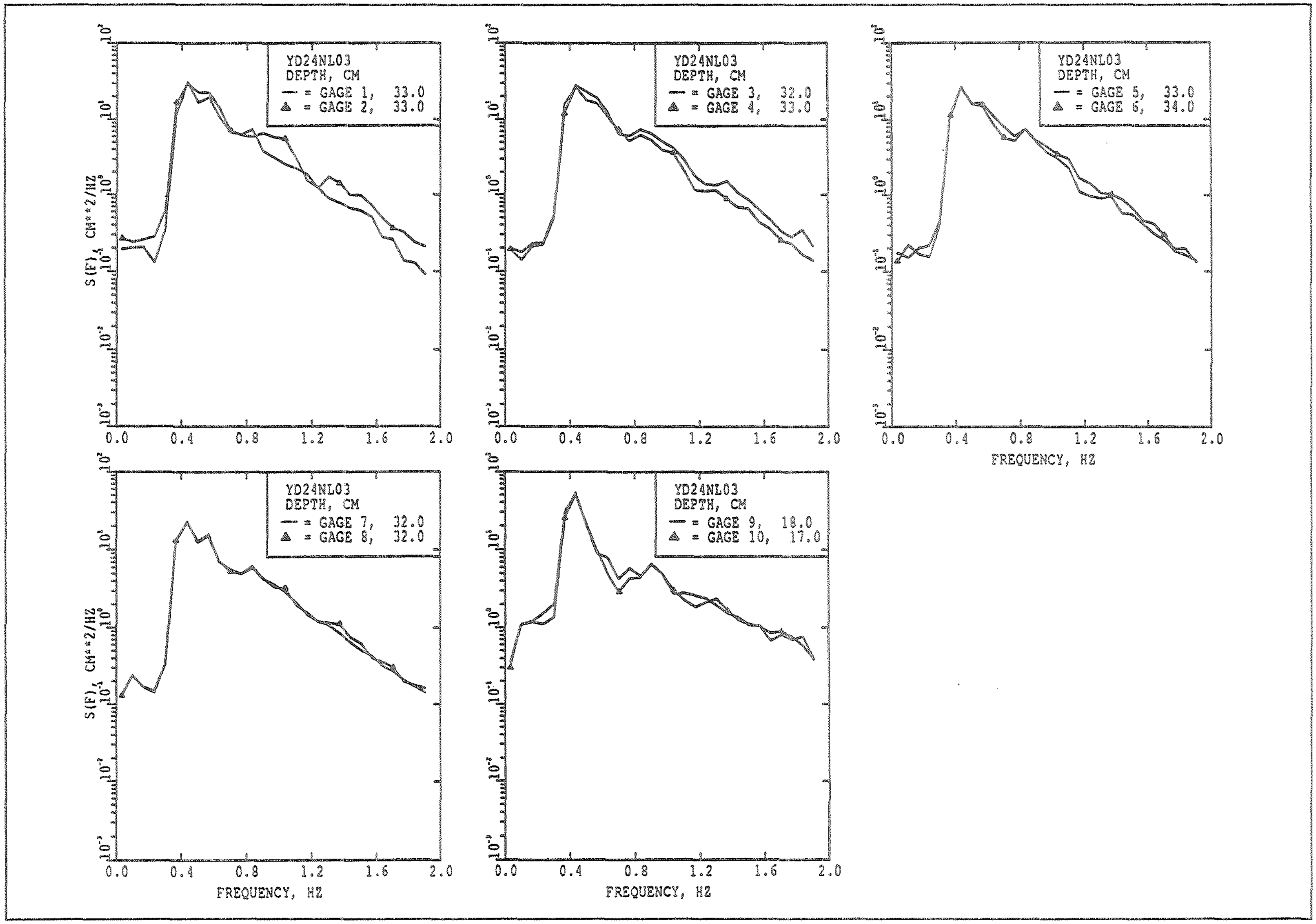


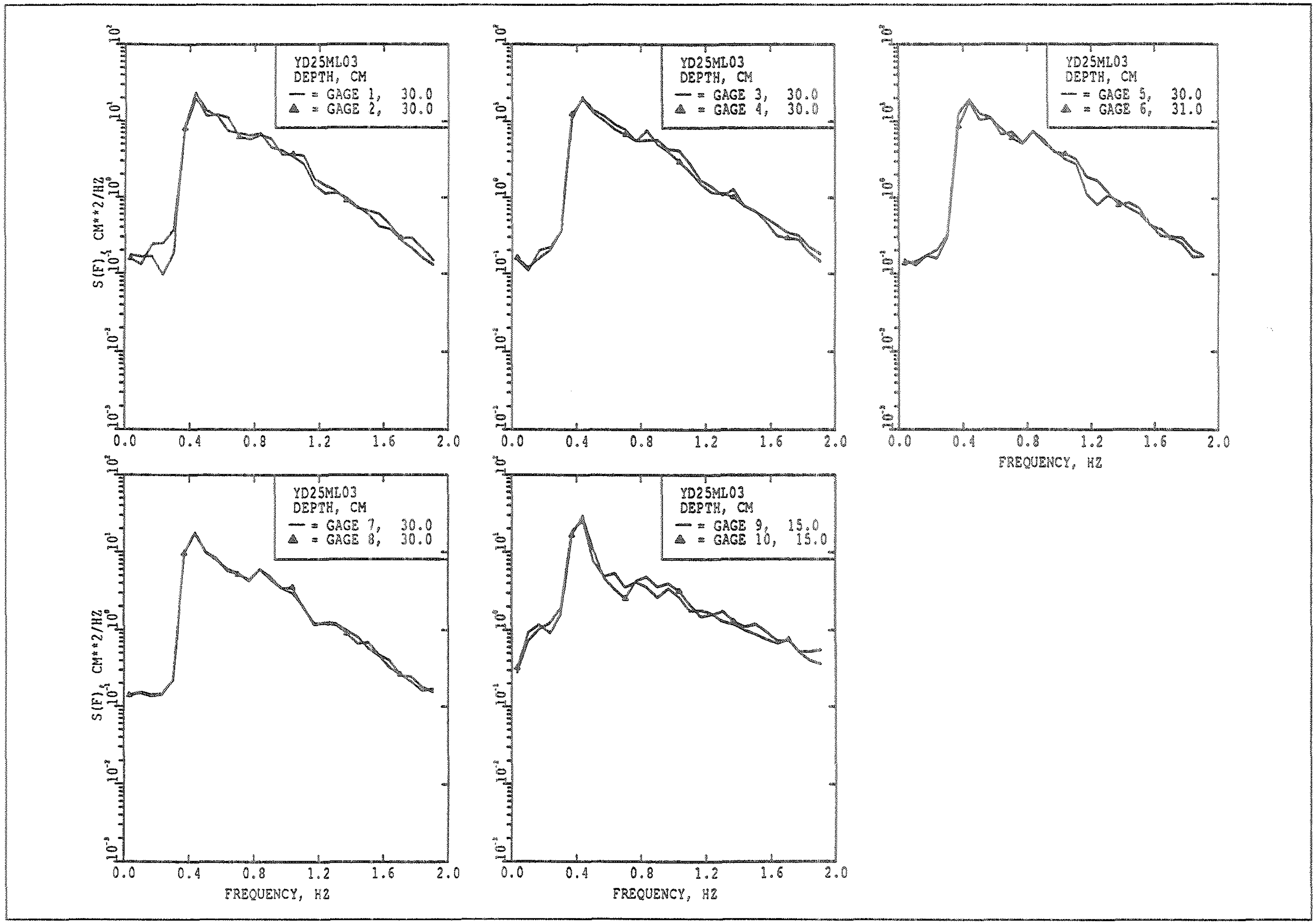
YN23NH03
DEPTH, CM
— = GAGE 1, 34.0
▲ = GAGE 2, 34.0
YN23NH03
DEPTH, CM
— = GAGE 3, 34.0
▲ = GAGE 4, 34.0
YN23NH03
DEPTH, CM
— = GAGE 5, 34.0
▲ = GAGE 6, 35.0
YN23NH03
DEPTH, CM
— = GAGE 7, 34.0
▲ = GAGE 8, 34.0
YN23NH03
DEPTH, CM
— = GAGE 9, 19.0
▲ = GAGE 10, 19.0
S(F), CM**2/HZ
0.0
0.4
0.8
1.2
1.6
2.0
FREQUENCY, HZ


YN23NL03
DEPTH, CM
= GAGE 1, 33.0
= GAGE 2, 33.0
YN23NL03
DEPTH, CM
= GAGE 3, 32.0
= GAGE 4, 33.0
YN23NL03
DEPTH, CM
= GAGE 5, 33.0
= GAGE 6, 34.0
YN23NL03
DEPTH, CM
= GAGE 7, 32.0
= GAGE 8, 32.0
YN23NL03
DEPTH, CM
= GAGE 9, 18.0
= GAGE 10, 17.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

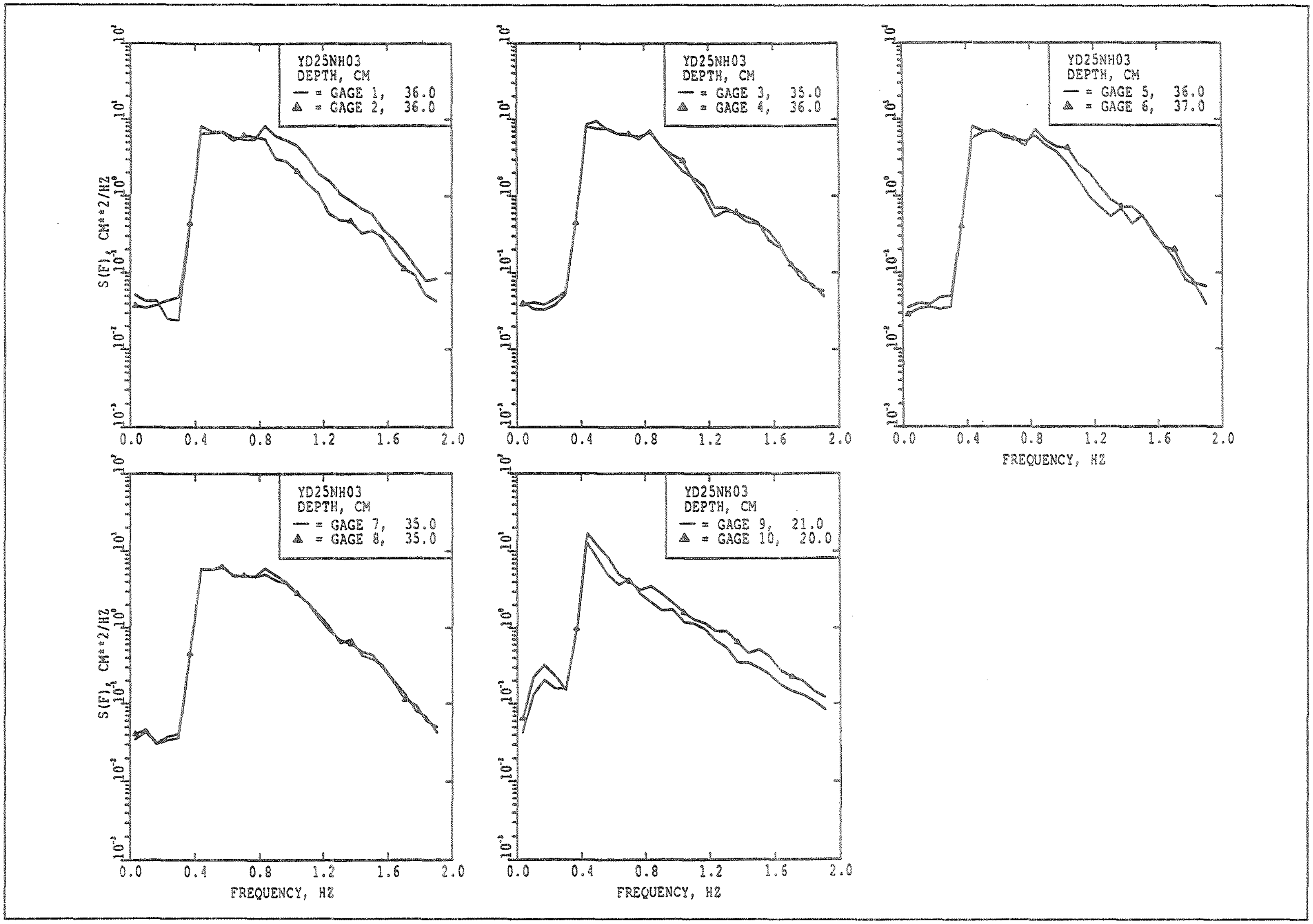


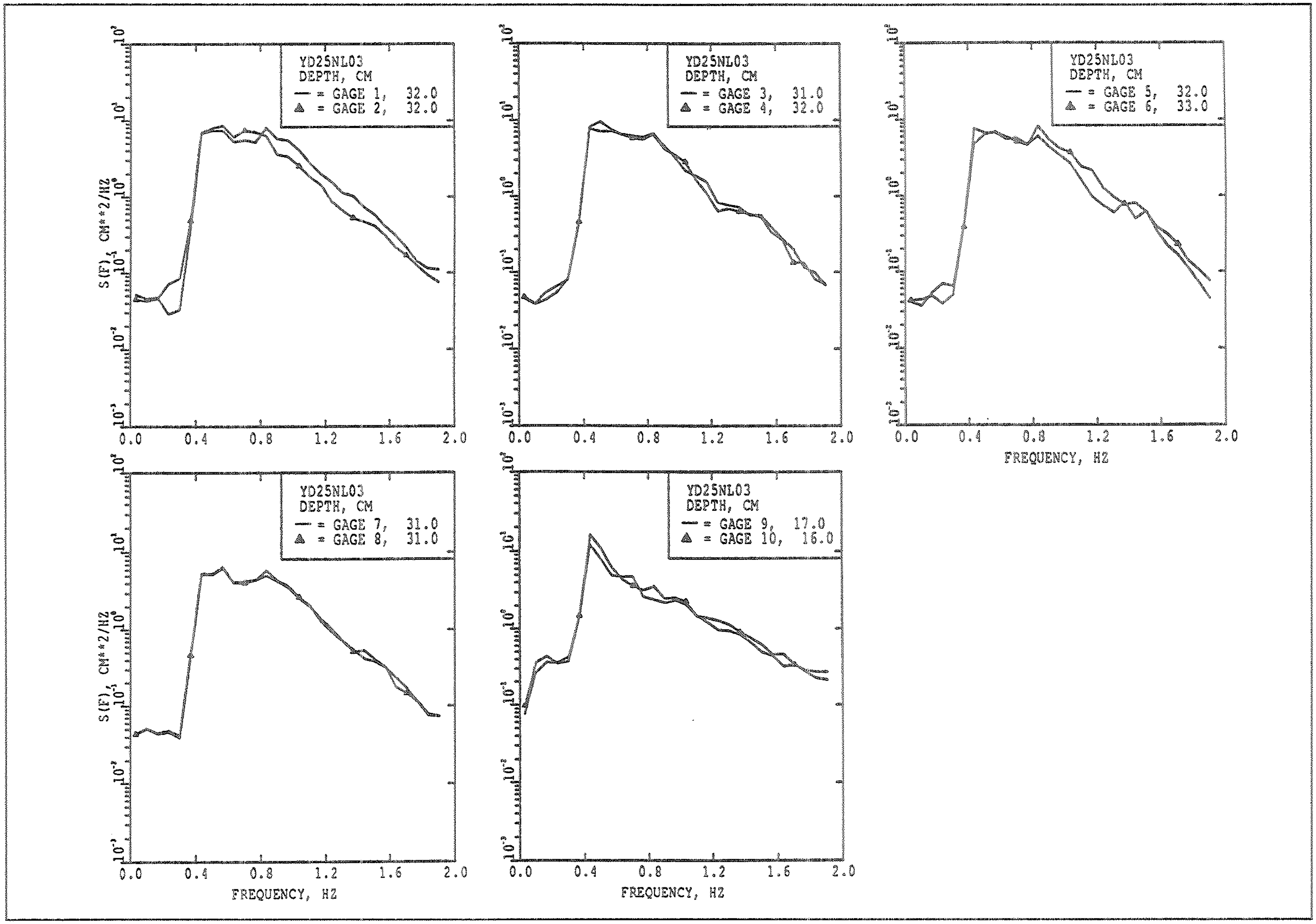
Appendix E Measured Model Frequency Spectra for Gauges 1 to 10


YD24NL03
DEPTH, CM
— = GAGE 1, 33.0
▲ = GAGE 2, 33.0
YD24NL03
DEPTH, CM
— = GAGE 3, 32.0
▲ = GAGE 4, 33.0
YD24NL03
DEPTH, CM
— = GAGE 5, 33.0
▲ = GAGE 6, 34.0
YD24NL03
DEPTH, CM
— = GAGE 7, 32.0
▲ = GAGE 8, 32.0
YD24NL03
DEPTH, CM
— = GAGE 9, 18.0
▲ = GAGE 10, 17.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

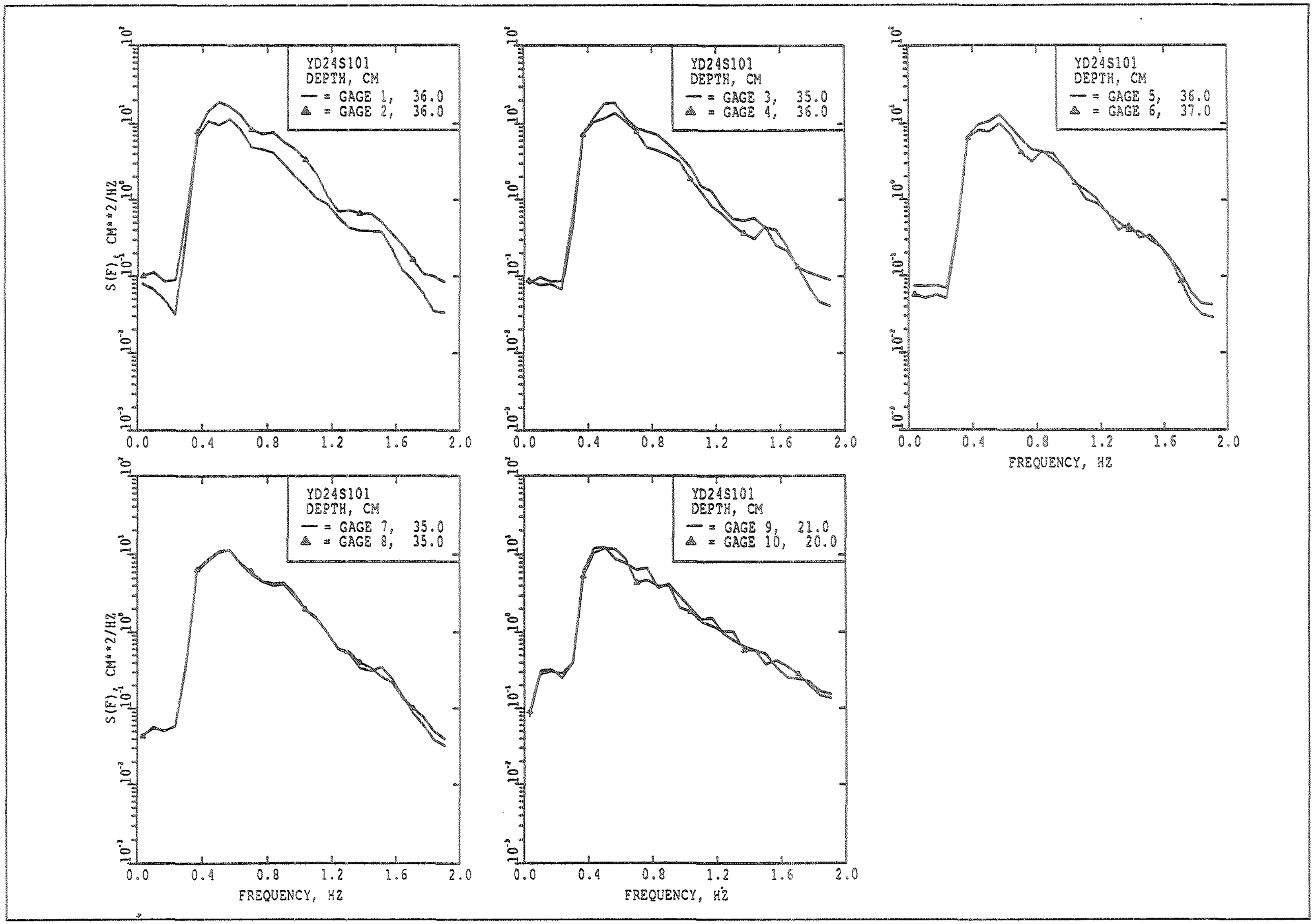


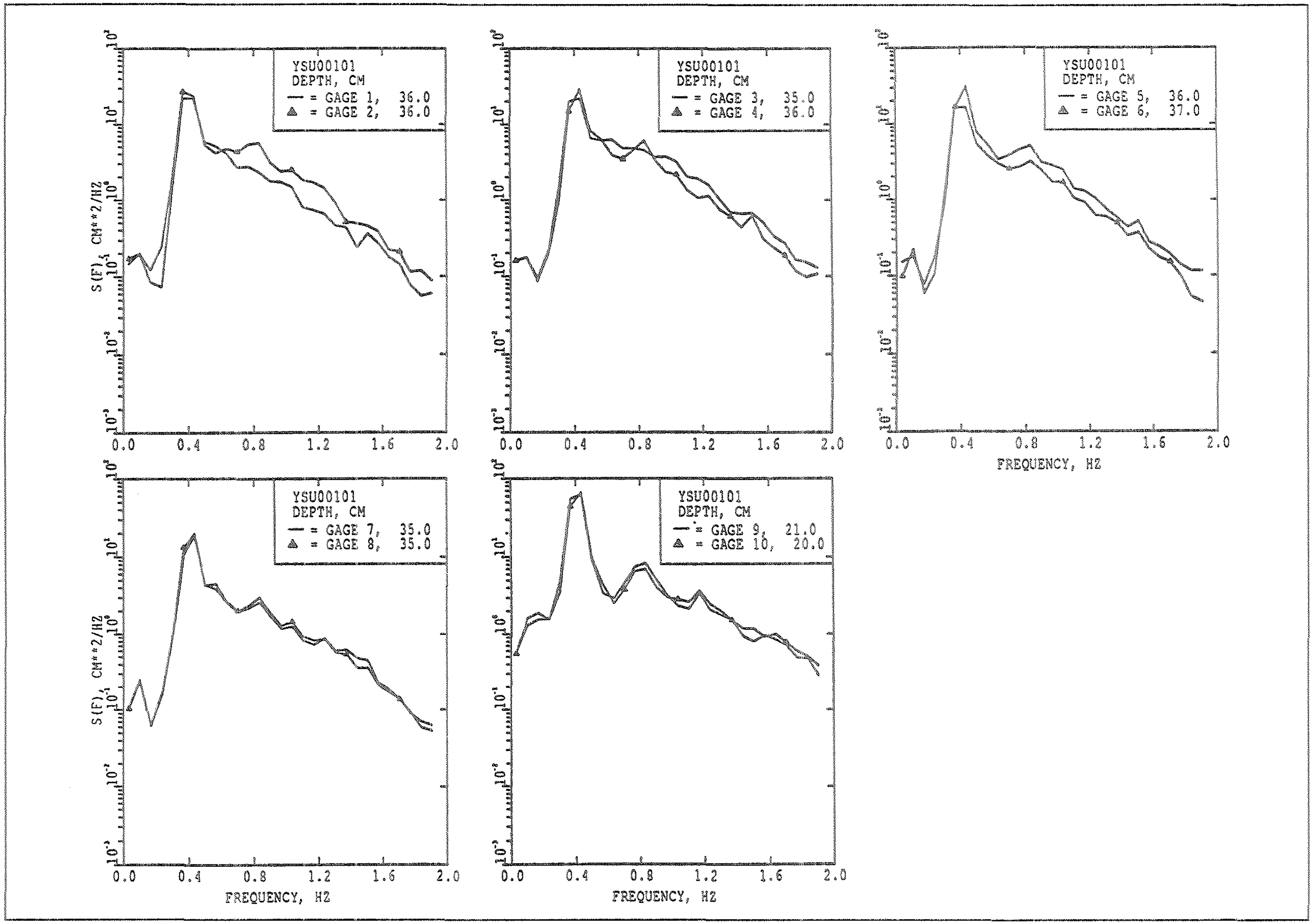
Appendix E Measured Model Frequency Spectra for Gauges 1 to 10


YD25NH03
DEPTH, CM
— = GAGE 1, 36.0
▲ = GAGE 2, 36.0
YD25NH03
DEPTH, CM
— = GAGE 3, 35.0
▲ = GAGE 4, 36.0
YD25NH03
DEPTH, CM
— = GAGE 5, 36.0
▲ = GAGE 6, 37.0
YD25NH03
DEPTH, CM
— = GAGE 7, 35.0
▲ = GAGE 8, 35.0
YD25NH03
DEPTH, CM
— = GAGE 9, 21.0
▲ = GAGE 10, 20.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0



Appendix E Measured Model Frequency Spectra for Gauges 1 to 10


YD24S101
DEPTH, CM
— = GAGE 1, 36.0
▲ = GAGE 2, 36.0
YD24S101
DEPTH, CM
— = GAGE 3, 35.0
▲ = GAGE 4, 36.0
YD24S101
DEPTH, CM
— = GAGE 5, 36.0
▲ = GAGE 6, 37.0
YD24S101
DEPTH, CM
— = GAGE 7, 35.0
▲ = GAGE 8, 35.0
YD24S101
DEPTH, CM
— = GAGE 9, 21.0
▲ = GAGE 10, 20.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0



YSU00101
DEPTH, CM
— = GAGE 1, 36.0
▲ = GAGE 2, 36.0
YSU00101
DEPTH, CM
— = GAGE 3, 35.0
▲ = GAGE 4, 36.0
YSU00101
DEPTH, CM
— = GAGE 5, 36.0
▲ = GAGE 6, 37.0
YSU00101
DEPTH, CM
— = GAGE 7, 35.0
▲ = GAGE 8, 35.0
YSU00101
DEPTH, CM
— = GAGE 9, 21.0
▲ = GAGE 10, 20.0
S(F), CM**2/HZ
FREQUENCY, HZ
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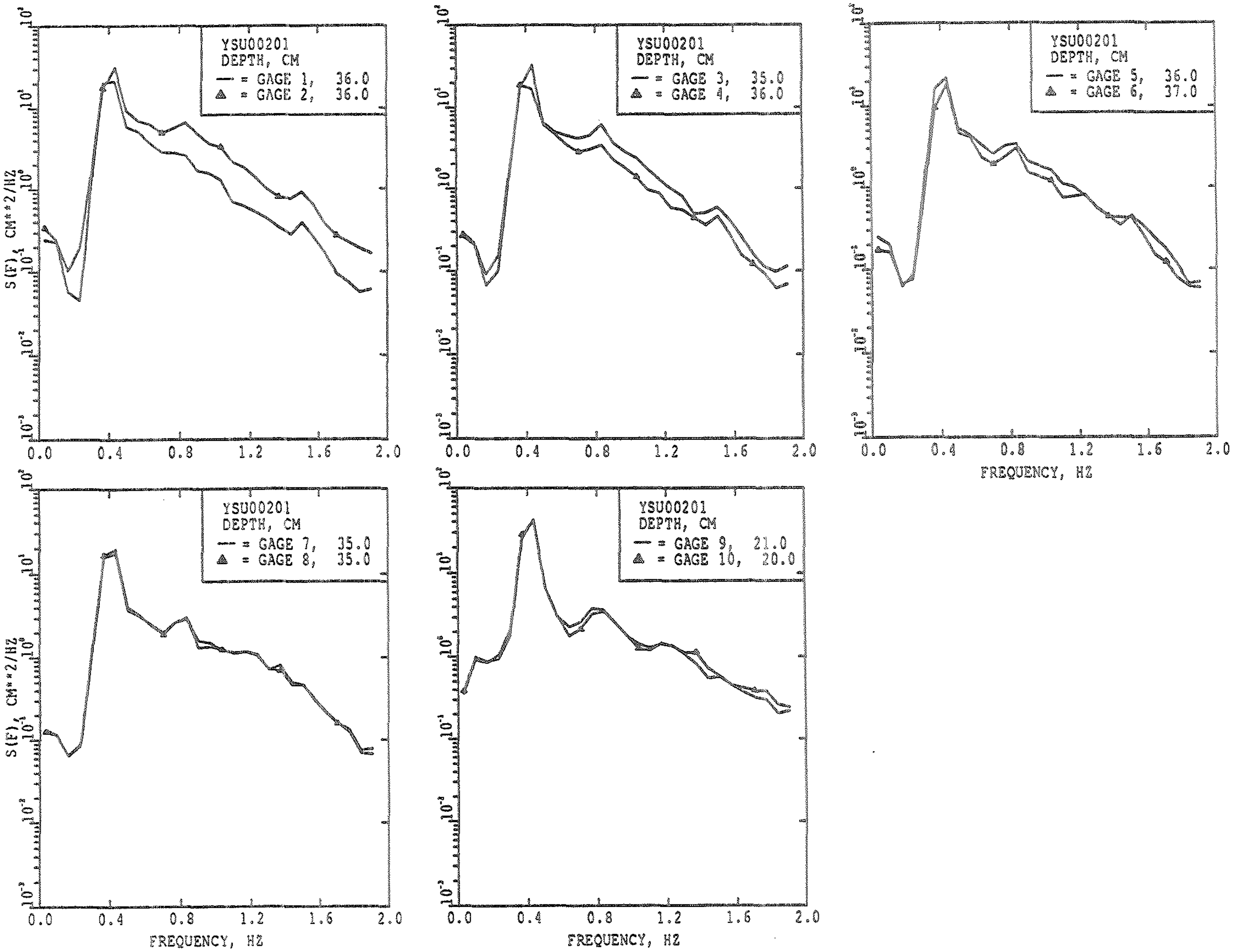
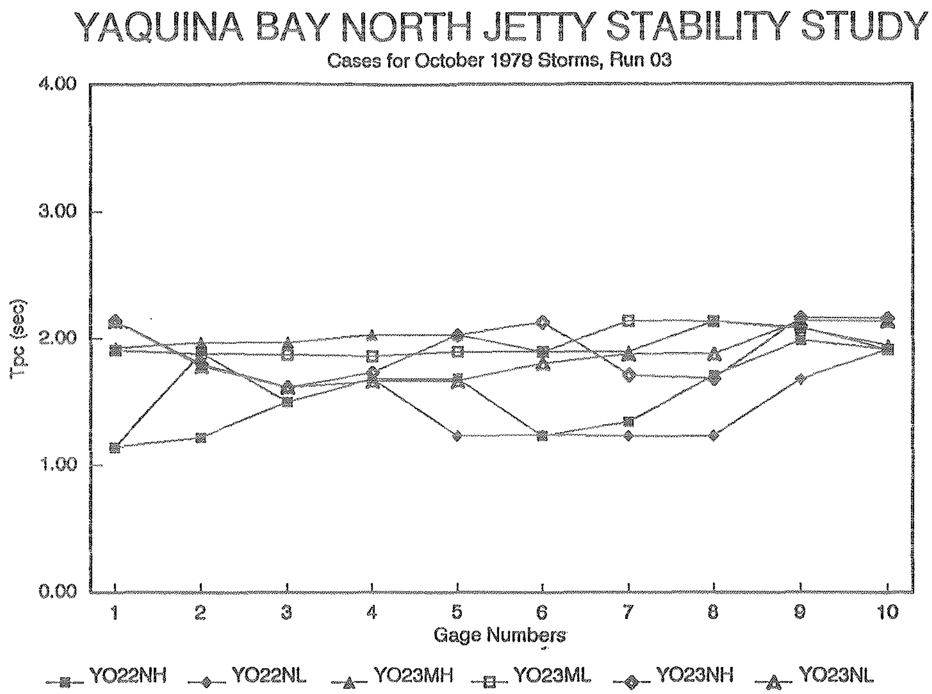
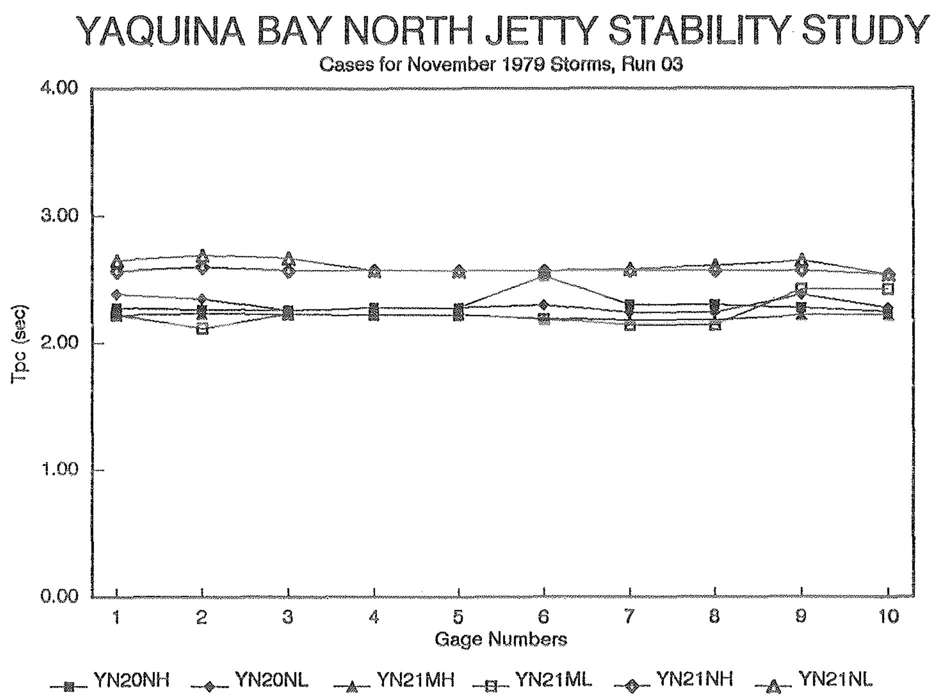
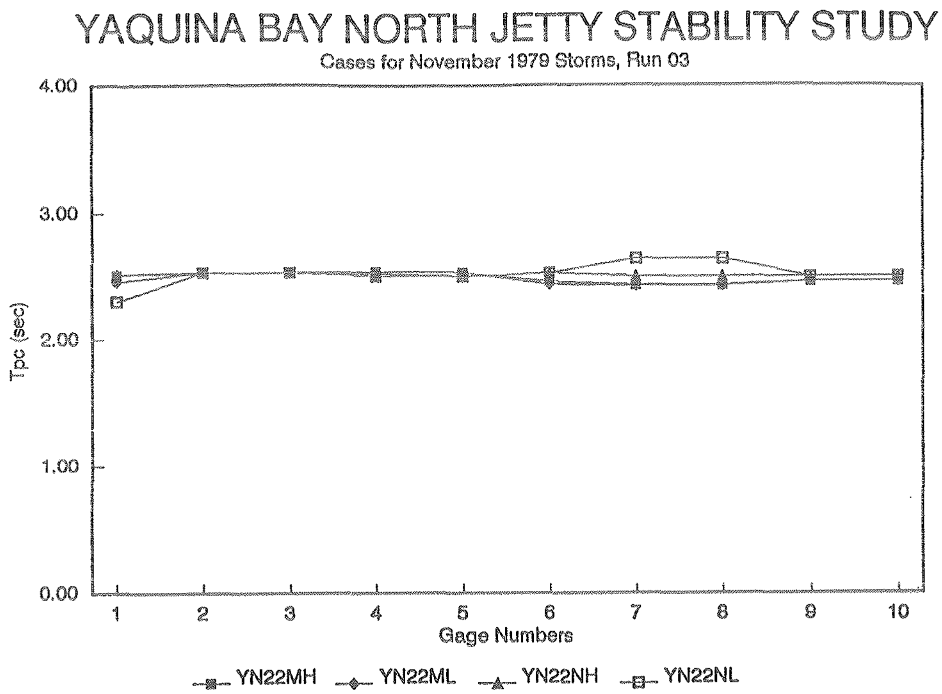
0.4
0.8
1.2
1.6
2.0

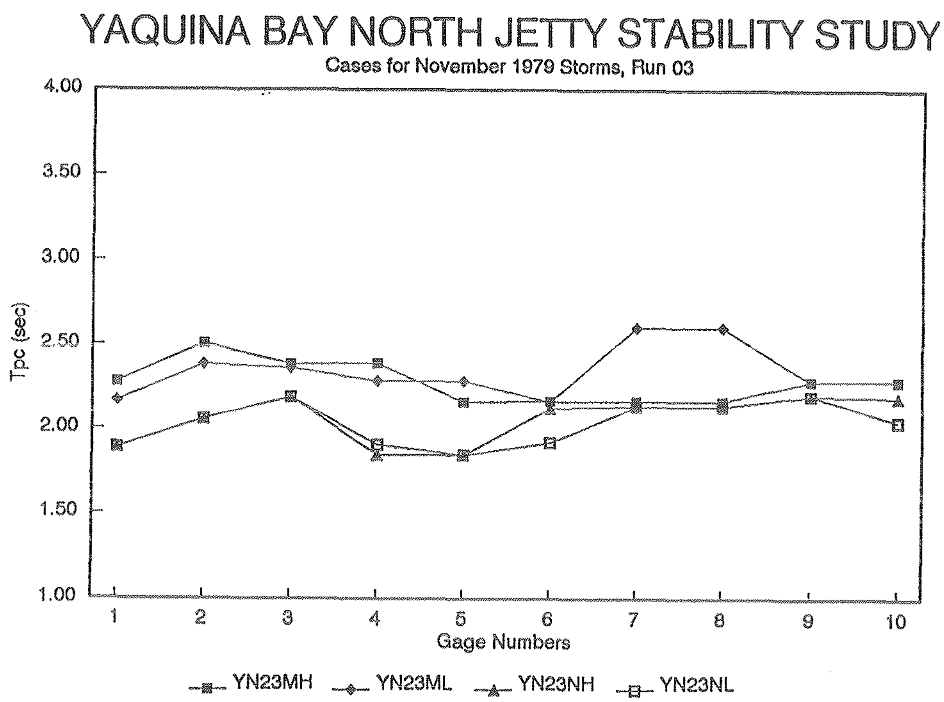

YSU00201
DEPTH, CM
— = GAGE 1, 36.0
▲ = GAGE 2, 36.0
YSU00201
DEPTH, CM
— = GAGE 3, 35.0
▲ = GAGE 4, 36.0
YSU00201
DEPTH, CM
— = GAGE 5, 36.0
▲ = GAGE 6, 37.0
YSU00201
DEPTH, CM
— = GAGE 7, 35.0
▲ = GAGE 8, 35.0
YSU00201
DEPTH, CM
— = GAGE 9, 21.0
▲ = GAGE 10, 20.0
S(F), CM**2/HZ
FREQUENCY, HZ
0.0
0.4
0.8
1.2
1.6
2.0

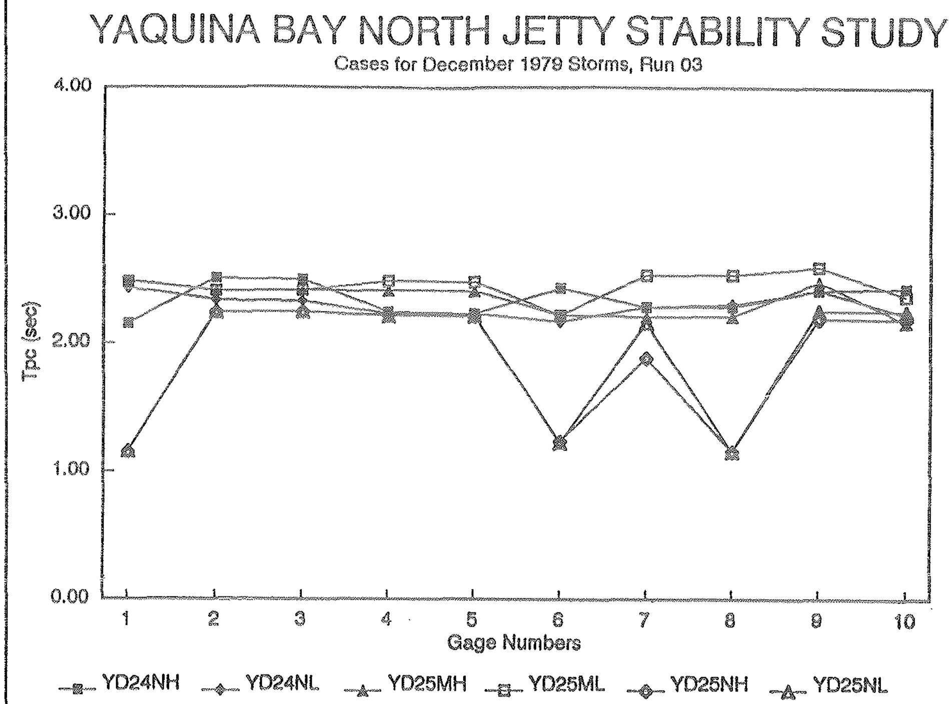
Appendix F
Measured Peak Periods and Wave Heights

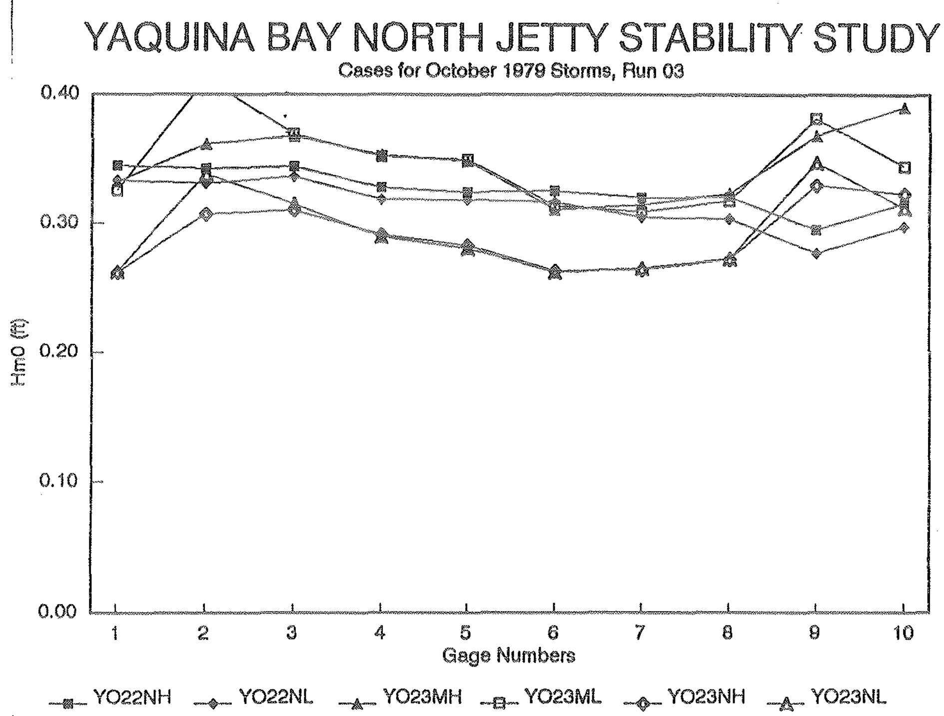

YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for October 1979 Storms, Run 03
Tpc (sec)
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YO22NH
YO22NL
YO23MH
YO23ML
YO23NH
YO23NL

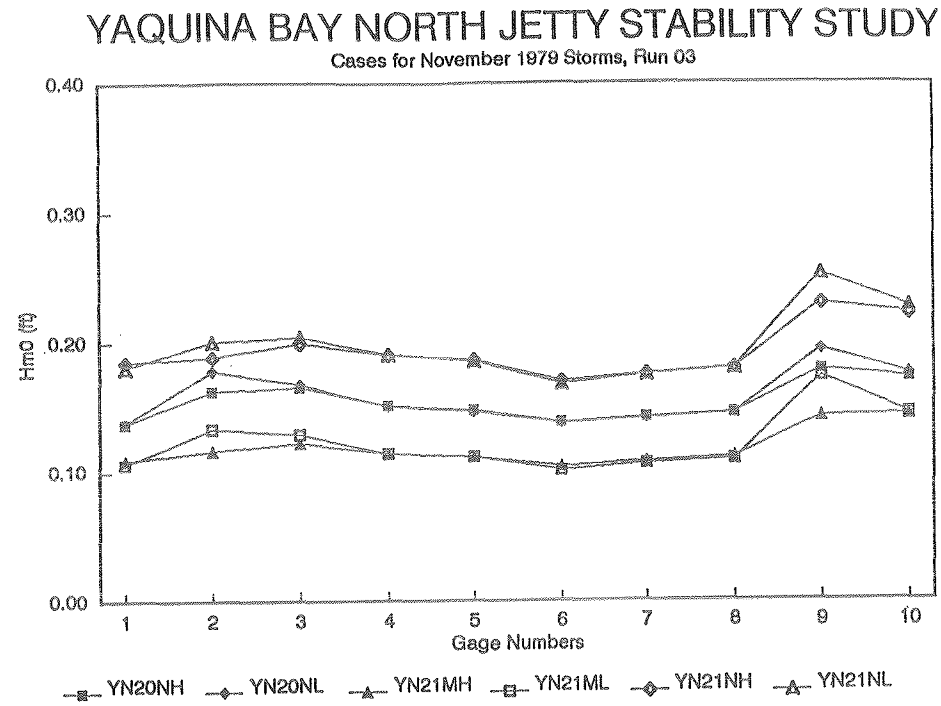

YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for November 1979 Storms, Run 03
Tpc (sec)
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YN20NH
YN20NL
YN21MH
YN21ML
YN21NH
YN21NL

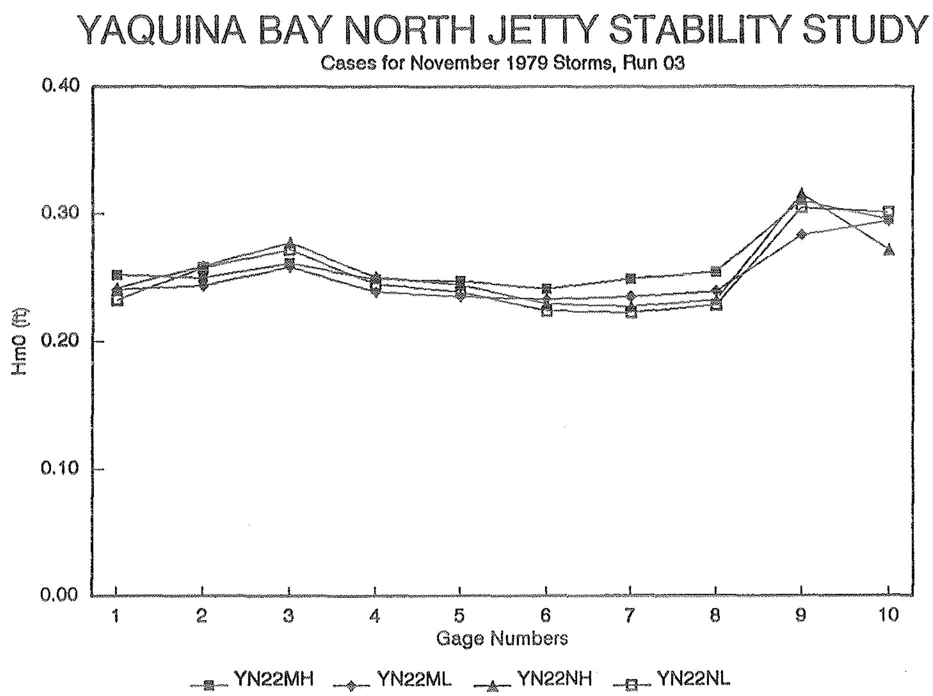

YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for November 1979 Storms, Run 03
Tpc (sec)
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YN22MH
YN22ML
YN22NH
YN22NL

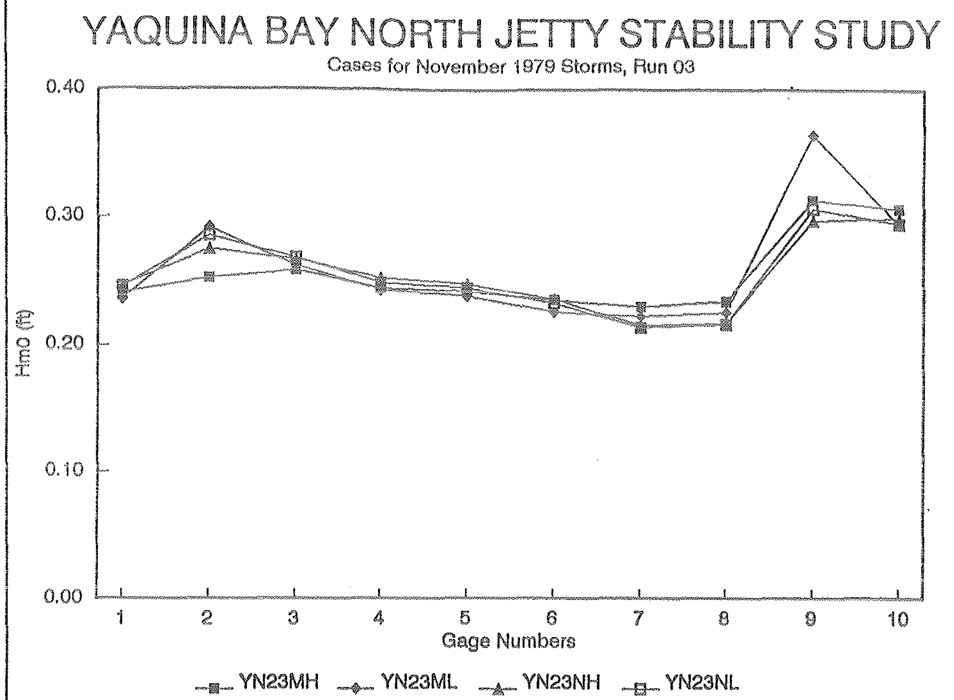

YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for November 1979 Storms, Run 03
Tpc (sec)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YN23MH
YN23ML
YN23NH
YN23NL


YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for December 1979 Storms, Run 03
4.00
3.00
2.00
1.00
0.00
Tpc (sec)
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YD24NH
YD24NL
YD25MH
YD25ML
YD25NH
YD25NL

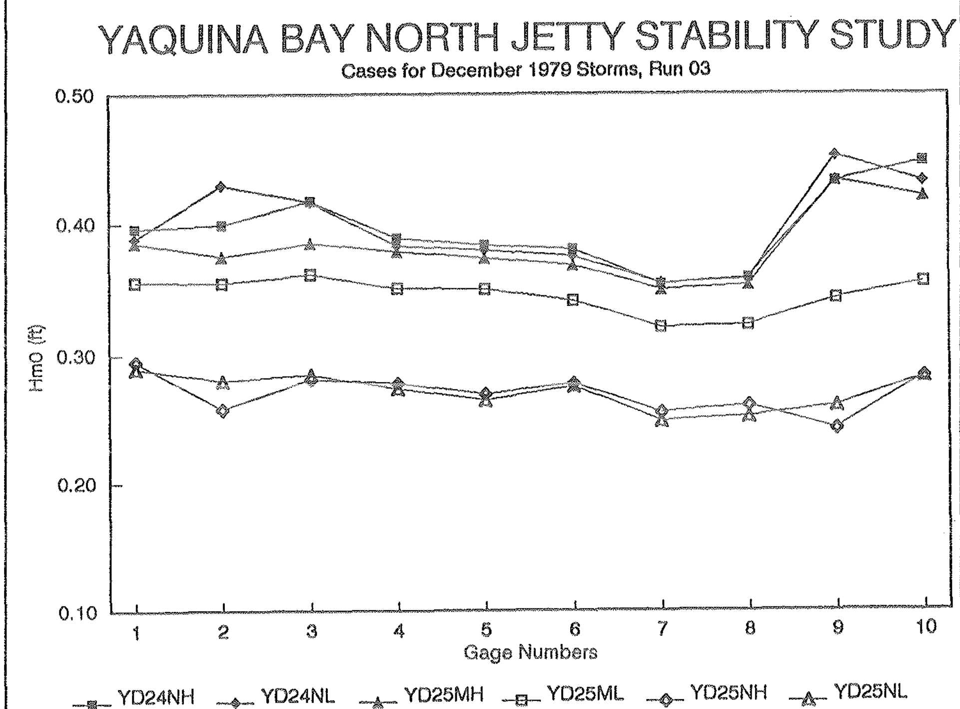

YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for October 1979 Storms, Run 03
0.40
0.30
0.20
0.10
0.00
Hm0 (ft)
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YO22NH
YO22NL
YO23MH
YO23ML
YO23NH
YO23NL


YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for November 1979 Storms, Run 03
Hm0 (ft)
0.40
0.30
0.20
0.10
0.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YN20NH
YN20NL
YN21MH
YN21ML
YN21NH
YN21NL


YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for November 1979 Storms, Run 03
Hm0 (ft)
0.40
0.30
0.20
0.10
0.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YN22MH
YN22ML
YN22NH
YN22NL



YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for November 1979 Storms, Run 03
Hm0 (ft)
0.40
0.30
0.20
0.10
0.00
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YN23MH
YN23ML
YN23NH
YN23NL



YAQUINA BAY NORTH JETTY STABILITY STUDY
Cases for December 1979 Storms, Run 03
Hm0 (ft)
0.50
0.40
0.30
0.20
0.10
1
2
3
4
5
6
7
8
9
10
Gage Numbers
YD24NH
YD24NL
YD25MH
YD25ML
YD25NH
YD25NL

Appendix G Notation

f	Frequency
h	Water depth
H_{mo}	Zero-moment wave height - Table 1
L	Wavelength
L_m/L_p	Linear scale of the model
m, p	Model and prototype quantities, respectively
S_a	Specific gravity of an individual armor unit relative to the water in which it was placed, i.e., $S_a = \gamma_a/\gamma_w$
t	Time
T_p	Spectral peak period - Table 1
W_a	Weight of an individual armor unit, lb
x	X-axis coordinate
γ_a	Specific weight of an individual armor unit, pcf
γ_w	Specific weight of water, pcf
θ	Wave direction, angle of wave propagation

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13. ABSTRACT *(Maximum 200 words)*

The north jetty at Yaquina Bay, Oregon, has been plagued with a history of unusually rapid deterioration when compared with similar North Pacific jetties built with the same design criteria and construction techniques. Since authorization of the jetty system in 1880, the north jetty has undergone extension or rehabilitation a total of seven times, the most recent in 1988.

A workshop held in 1989 selected five damage hypotheses, including (a) wave breaking on the jetty, (b) wave-current interaction due to the presence of the offshore reef, (c) scour leading to armor unit slumping, (d) foundation failure, and (e) some combination of the above. One of the recommendations of the workshop was to evaluate the first hypothesis using a physical model of the jetty system on a fixed foundation in an attempt to recreate damage to the north jetty that occurred following the 1979-1980 storm season.

The physical model was constructed according to available "as-built" drawings and bathymetry. A total of 13 storms in the time period October to December were hindcast, simulated, and tested for 6-hr durations at high and low water levels appropriate for the diurnal tide using the directional spectral wave generator. Except for isolated rocking and displacement of random stones, the north jetty remained stable and intact. Thus, based on this limited series of tests, it must be concluded that wave action alone was probably not responsible for the damage caused to the north jetty.

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