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PERFORMANCE ANALYSIS OF A TETHERED FLOAT BREAKWATER

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SUMMARY

The report describes laboratory experiments at one-half scale using simulated random seas and field tests at full scale of an installation of a dynamic floating breakwater system in a limited fetch situation. An analytical model is described which successfully predicts the performance of any tethered float breakwater configuration, given the incident wave spectrum.

The metnodology for selecting the arbitrary resistance coefficients in the predictive model is discussed. Predicted and measured performance data for a total of 60 laboratory and field experiments are displayed, covering a very broad range of wave climates.

1. INTRODUCTION

Seymour and Isaacs (1974) describe a floating breakwater in which the energy is removed from the waves through the drag created by the vigorous oscillations of tethered floats. This system, first proposed by Professor John Isaacs in 1970, has been under development at the Scripps Institution of Oceanography (SIO) since that time under the joint sponsorship of the California Department of Navigation and Ocean Development (DNOD) and the California Sea Grant College Program. As shown in Seymour and Isaacs (1974), an effective predictive model for the breakwater was developed as part of this effort.

In 1974, DNOD and the U. S. Navy Facilities Engineering Command (NAVFAC) undertook a joint program, parallel to the SIO project, leading to the development of an operational ocean-scale tethered float breakwater. As part of this Navy/DNOD effort a "marina-scale" breakwater was built and installed in San Diego Bay. This unit was of a scale suitable for providing protection from waves in the 2- to 4-second period range, typical of the wave protection problems for marinas and anchorages in semi-protected waters.

Prior to the design of this marina-scale breakwater, an intensive laboratory modeling program was undertaken at SIO under the DNOD/Sea Grant project. The instrumenting and performance analysis of the San Diego Bay experiment was also performed under this same project. This report describes the laboratory and field experience and the comparison of predicted and measured breakwater performance.

2. THEORY OF PERFORMANCE PREDICTION

Laboratory measurements of breakwater performance, described in later sections, suggest that scattering and reflection are minor contributors to the reduction of wave energy. Therefore, the model for predicting performance considers only drag dissipation.

Fluid drag, proportional to the velocity squared, is nonlinear even in steady flows. In the case of the floats oscillating in response to the wideband random flow produced by a wave field, the drag is proportional to the square of the relative velocity -- itself a wideband random variable. It is therefore very difficult to predict the drag in a deterministic sense from some measured parameter such as the surface elevation history. As in most random processes, it proves more convenient to work in the frequency domain and to deal with the statistics of float motion and drag.

Considering a single float, its average drag power may be defined as

$$\langle P_d \rangle = C^* \langle V^3 \rangle \quad \text{.....(1)}$$

where, P_d = drag power

$\langle\ \rangle$ indicates time averaging

C^* is the standard drag force coefficient, $\frac{\rho}{2} A C_d$

V is the relative velocity

Since V can be considered a Gaussian variable, the average value of f(V) can be calculated by

$$\langle f(\bar{V}) \rangle = 2 \int_0^\infty f(\bar{V})\ e^{-\bar{V}^2}\ d\bar{V} \quad \text{.....(2)}$$

where $V = \bar{V}\sigma_v$

σ_v is the standard deviation or r.m.s. value of the relative velocity

Evaluating equation (2) yields

$$\langle V^3 \rangle = \sigma_v^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Since the variance, σ^2, is given by summing a properly scaled spectrum of the variable, equation (1) can be written

$$\langle P_d \rangle = C^* \sigma_v \; 1/2 \; \Sigma S_v(f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where $S_v(f)$ is the spectrum of relative velocity

From equation (4), assuming a linear process, the frequency dependence of P_d can be determined.

$$S_{P_i} = \langle P_{d_i}(f) \rangle = C^* \sigma_v \; 1/2 \; S_{v_i}(f) \quad \ldots\ldots\ldots\ldots (5)$$

where S_p is the spectrum of float drag power

It was shown by Seymour(1974) that the spectrum of relative velocity for a single float can be estimated by

$$S_v(f) = S_u \, \gamma(f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\text{where } \gamma(f) = 1 + |H|^2 - 2|H| \cos\theta \quad \ldots\ldots\ldots\ldots (7)$$

$|H|$ and θ are defined from the complex transfer function of float position relative to water particle horizontal motion, $H(f)$

$$H(f) = |H| e^{-i\theta(f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

and S_u is the energy spectrum of horizontal water particle velocity, which

can be readily obtained from the spectrum of surface elevation by linear theory

$$S_u(f) = S_\eta(f) \beta(f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where S_η is the surface elevation spectrum

$$\beta(f) = \frac{\cosh^2 k(h-d_s)\omega^2}{\sinh^2 kh}$$

k is the wave number

ω is the radian frequency, $2\pi f$

h is the water depth

d_s is the depth of the float

Therefore, combining equations (5), (6), and (9) provides an expression for the spectrum of average drag power of a single float in terms of the wave spectrum

$$S_p = S_\eta \gamma \beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The power consumed in the drag of the float is at the expense of the spectrum of incident wave power, which can be expressed per unit of float spacing along the wave crest

$$S_w(f) = S_\eta(f)\alpha(f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

where S_w is the spectrum of wave power

$\alpha(f) = 1/2\rho g Cn(f)s$

Cn is the group velocity

s is the float spacing

Thus the energy transmission ratio, ETR, which is the traditional parameter for describing breakwater performance, can be specified in terms of the three coefficients

$$ETR(f) = \frac{S_w - S_p}{S_w} = 1 - \frac{\gamma\beta(f)}{\alpha} \quad \ldots\ldots\ldots\ldots (12)$$

In equation (12), only γ has dependence on the float dynamics. Both α and β depend upon the wave field alone. Seymour(1974) shows a method for linearizing drag so that the equation of motion for the float can be solved to yield H(f). As a result of the linearizing technique, however, H(f) is a function of σ_v.

$$|H|(f) = \left[\frac{D^2\omega^4 + (C^*U_0\omega)^2}{(B - M\omega^2)^2 + (C^*U_0\omega)^2} \right]^{1/2} \quad \ldots\ldots\ldots(13)$$

$$\theta(f) = \arctan \frac{\omega C^* U_0}{B - M\omega^2} - \arctan \frac{D\omega}{C^* U_0} \quad \ldots\ldots\ldots(14)$$

where $U_0 = \frac{8}{3\sqrt{\pi}} \sigma_v$, is a characteristic velocity for linearizing drag

$D = M_w (1 + C_m)$

$B = \frac{g}{L} (M_w - M_s)$

$M = C_m M_w + M_s$

M_w = mass of water displaced by the float

M_s = mass of float

L = effective tether length

C_m = added mass coefficient

Seymour and Isaacs(1974) describe a method for solving iteratively for σ_v. In this approach, a value is assumed for σ_v, and equations (13), (14) and (7) are solved to yield values of α for each frequency band. Equation (6) can be summed over frequency to give an estimate of σ_v^2. The assumed value of σ_v is then adjusted until there is reasonable agreement between the assumed value and the value calculated from summing the spectrum. The final values of $\gamma(f)$ obtained in this iteration are then used in equation (12) to calculate ETR(f). By applying the ETR values as a spectral density function to the incident spectrum, a transmitted spectrum is obtained for the first row of floats in the breakwater. The process is repeated through each row to obtain the final exiting spectrum behind the array.

Thus it has been shown that, in principle, the performance of a tethered float breakwater can be estimated knowing only the incident wave field characteristics, the breakwater geometry, and appropriate average values for two coefficients, C_d and C_m.

3. PHYSICAL ARRANGEMENT OF EXPERIMENTS

a) Laboratory Model at Half Scale

A half scale section of the San Diego Bay Field Experiment Breakwater was installed in the 40 m long Wind Wave Channel at the Hydraulic Laboratory, Scripps Institution of Oceanography. The general characteristics of this model are shown in the following table. The nomenclature is defined in Figure 1.

Table I

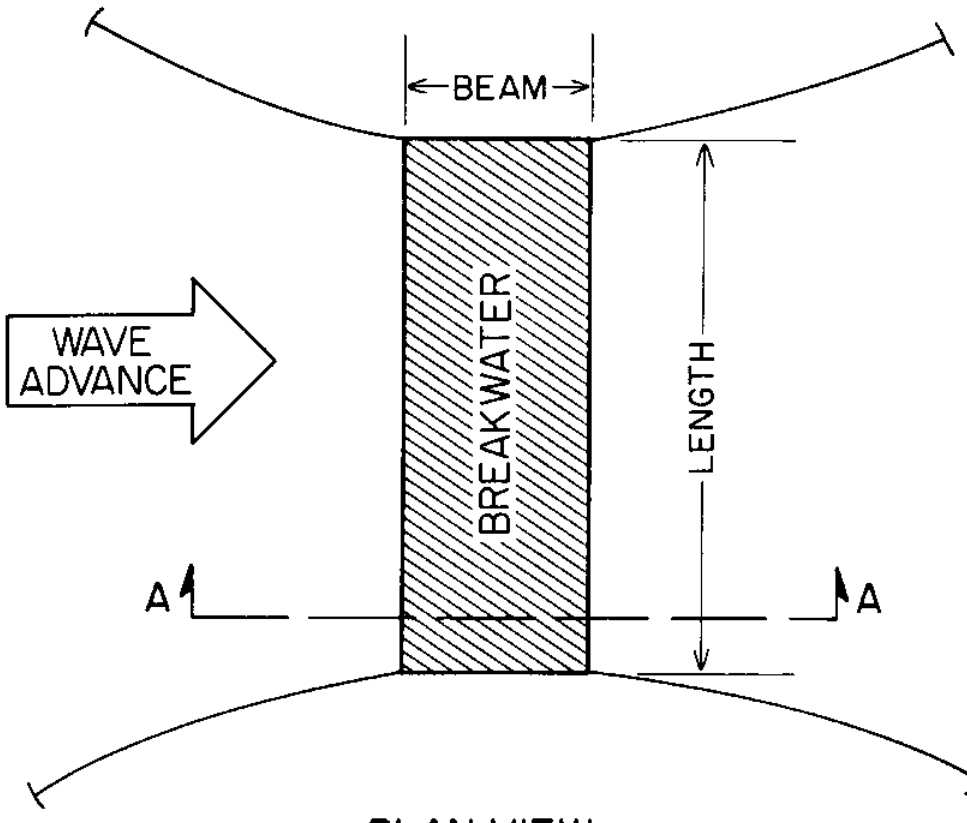
Laboratory Model Breakwater at Half Scale

Float diameter	15.8 cm
Effective tether length	83.8 cm
Float spacing (beam)	31.6 cm
Float spacing (length)	31.6 cm
Number of rows	11
Float density	0.04 gm/cc
Water depth	178 cm
Breakwater length	239 cm
Channel width	244 cm
Freeboard	each row separately variable

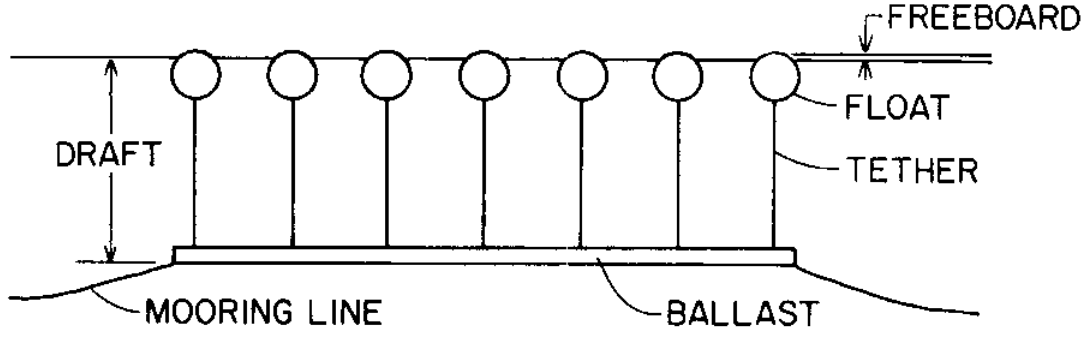
Figure 2 illustrates a model of similar scale in the wave channel.

The model was slack-moored by a single mooring line extending toward the wave generator. The slow currents set up by the generation of waves result in a net motion of the breakwater toward the beach. Thus, the mooring line might occasionally become taut for short periods of time.

Wave heights were measured with surface-piercing digital wave staffs having 5 mm resolution. The outputs of the wave staffs were sampled at 16 Hz and stored in core by an IBM 1130 computer. After storing 2048 samples of each of two wave staffs, the records were transferred to magnetic tape.



PLAN VIEW



SECTION A-A

DEFINITION SKETCH – TETHERED FLOAT BREAKWATER

FIGURE 1

MODEL TETHERED FLOAT BREAKWATER IN WAVE CHANNEL

FIGURE 2

b) San Diego Bay Field Experiment

A 46 m length of breakwater, twice the scale of the laboratory section, was installed in San Diego Bay near the Naval Undersea Center on Point Loma. The breakwater was subjected to ship and boat wakes generated in the main entrance channel to San Diego Bay and to limited fetch wind waves when winds from the south occurred. The breakwater was protected from ocean-generated waves because it was located on the lee side of Point Loma.

A detailed description of the configuration, construction, and installation of this breakwater is contained in Berkley and Johnson (1976). The wind wave attenuation performance is illustrated in Figure 3, and the physical arrangement is shown in Figure 4.

Table II defines the basic characteristics of this installation.

Table II

San Diego Bay Field Experiment

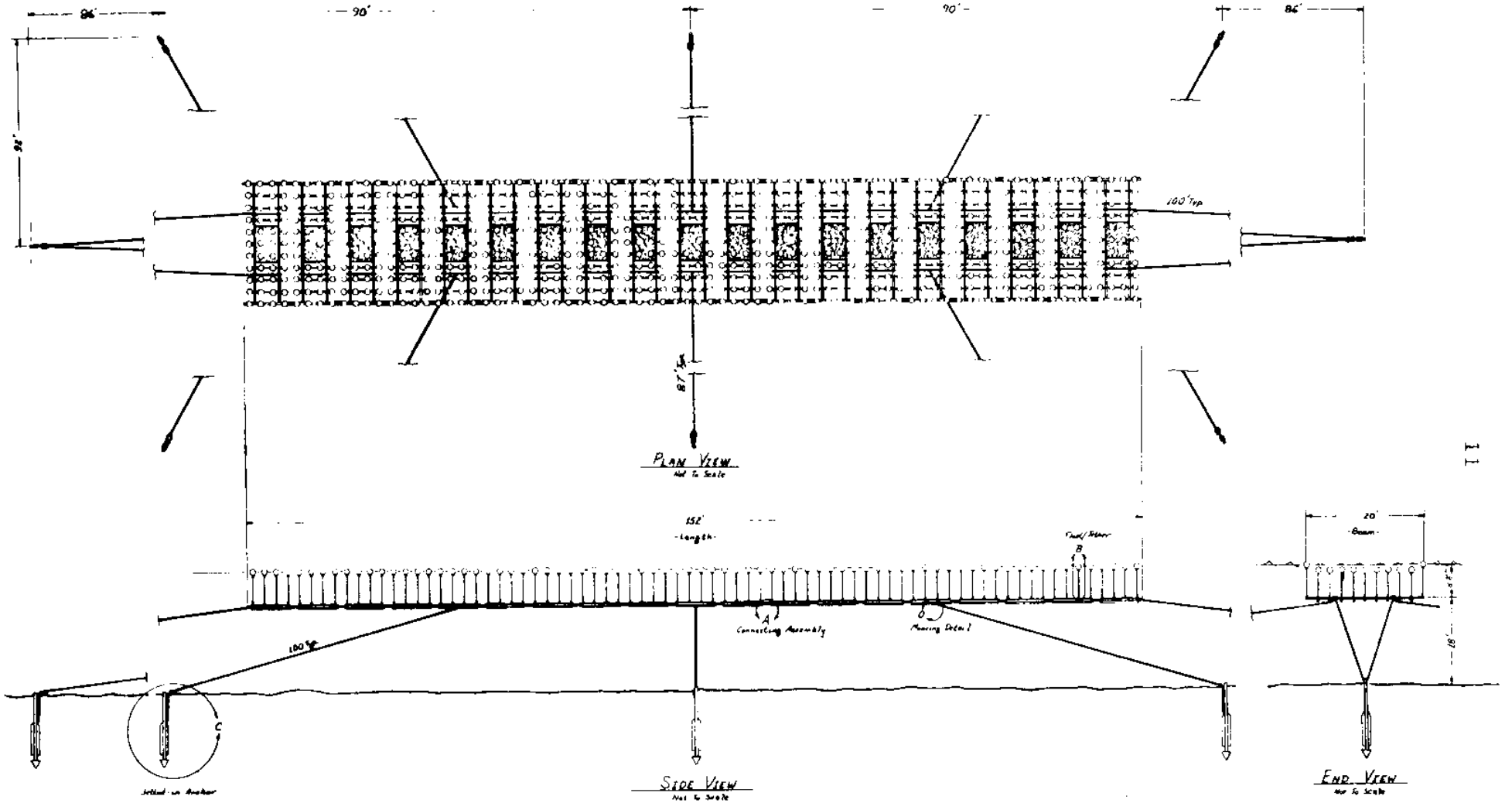
Float diameter	29.2 cm
Effective tether length	168 cm
Float spacing (beam)	61 cm
Float spacing (length)	61 cm
Number of rows	11
Float density	0.085 gm/cc
Water depth	approx. 8m
Breakwater beam	6 m
Breakwater length	46 m
Freeboard	positive 15 cm (front and rear rows), negative 7.5 cm (interior nine rows)
Positive buoyancy	approx. 10% of float volume

The breakwater was slack-moored with three lines forward and three lines aft at approximately 12 m intervals. Lateral restraint was supplied by slack moors at each end of the system. The tide range is approximately 2 m, and tidal currents reach a maximum value of about 1 m/sec.

Incident and transmitted wave heights were measured by dual wire resistance gages mounted on tilting spares pivoting on gravity anchors at the bottom. These gages were connected by submerged cables to a van onshore. There, the signals were digitized, multiplexed, and transmitted over a leased telephone line on command from a dedicated minicomputer at Scripps Institution of Oceanography. The gages were located

WIND WAVE ATTENUATION IN
SAN DIEGO BAY FIELD EXPERIMENT

FIGURE 3



ARRANGEMENT OF SAN DIEGO BAY BREAKWATER

FIGURE 4

approximately equidistant from the ends of the breakwater and about 15 m away from the nominal breakwater position, one in front and one behind.

c) Extended Tether Laboratory Model

A second laboratory breakwater model was evaluated in which all of the physical parameters were identical to the half-scale model described in Section 3 a) above, except that the tether length was increased to 134.6 cm.

4. WAVE CLIMATE

a) Laboratory Experiments

The laboratory breakwater experiments were conducted using simulated random seas generated in response to magnetic tape control. The methodology for producing these broad-band random wave spectra is described in Seymour (1975). A series of eight tapes was employed for these experiments. The statistics of each are shown in Table III. These are derived from bare-channel measurements made with the breakwater removed. H_s, the significant wave height, is calculated from

$$H_s = 4\ \sigma_\eta,$$

and H_m, the maximum wave height, is taken as the difference between the maximum and minimum excursions from the mean during the experiment.

Table III

Laboratory Wave Climate Parameters

Tape Designation	Peak Freq. (Hz)	H_s (cm)	H_m (cm)	Ratio H_m/H_s
T1	.883	6.89	11.51	1.67
T2	.675	10.33	17.84	1.73
T3	.510	11.80	18.58	1.58
T4	.375	9.69	14.44	1.49
T5	.375	17.16	28.05	1.63
T6	.290	17.60	25.10	1.43
T7	.250	16.16	24.62	1.52
T8	.190	15.28	21.17	1.39

For the shorter period wave trains, tapes A, B, and C, it was possible to maintain the H_m/H_s ratio close to the nearly constant oceanic value of 1.65 reported by Goda (1974). For longer period wave trains, the wave generator efficiency at lower frequencies limited the attainable H_m/H_s ratios.

The measured spectra of these wave trains are shown in Figure 5.

The wave generator control voltages were provided by one track of a two-track tape deck. By means of a computer start signal on the second track, wave data were recorded at identical intervals in the time series. This ensured that incident waves characterized in a bare-channel experiment would be exactly reproduced with the breakwater in place.

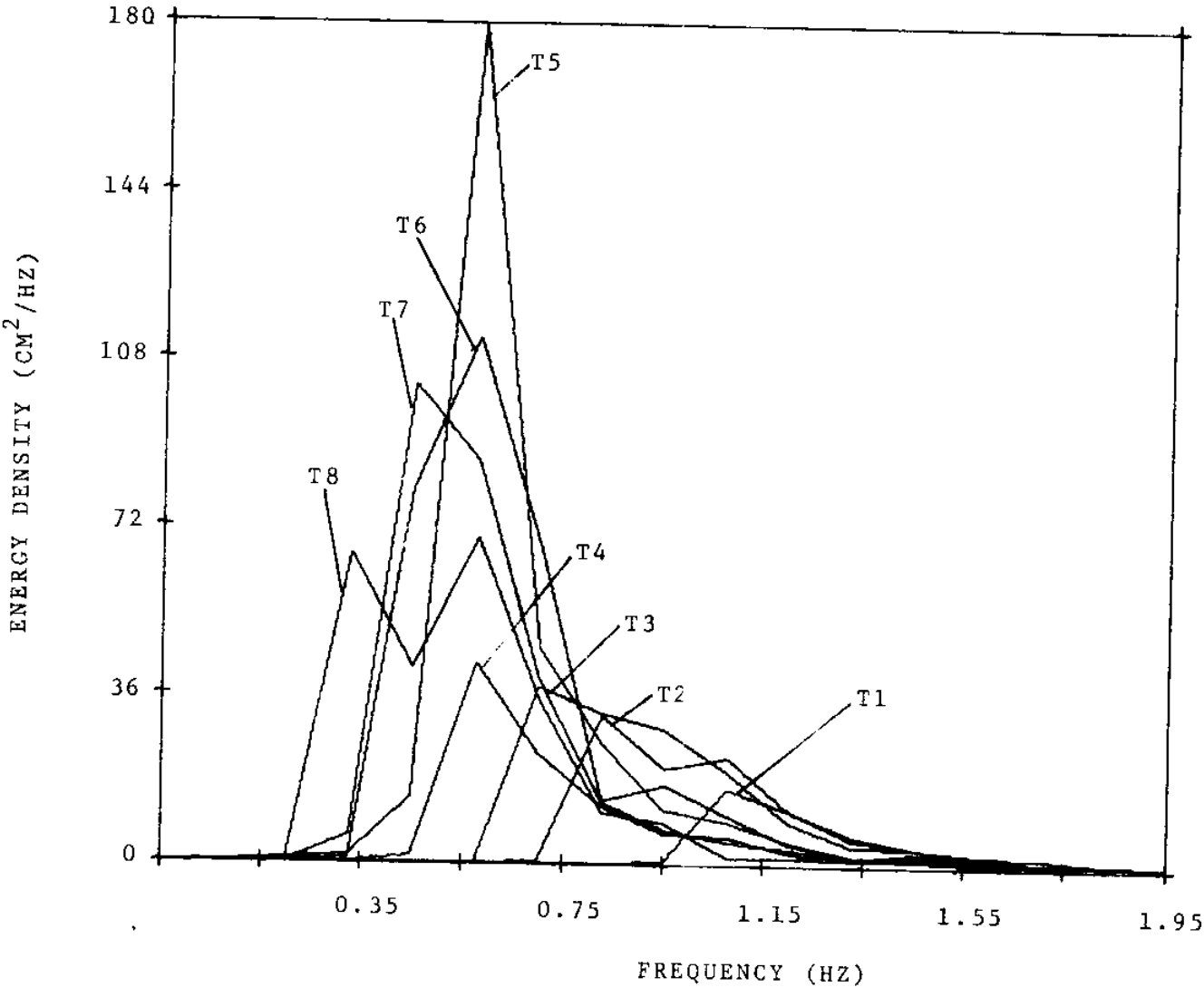
b) San Diego Bay Experiments

Significant south wind activity was observed at the Point Loma site only twice in the eight-month span of this experiment. Because of the scarcity of opportunity, the wave measurement system was programmed to monitor the wave climate for a five-minute period every 15 minutes. If the standard deviation of the surface elevation (σ_η) exceeded the threshold of 5 cm for two consecutive trials, the computer would take data continuously for six hours and then retest. This would assure data retrieval even if a southerly storm occurred outside of normal working hours.

The two storm periods that were recorded occurred on 22 January and 9 February 1976. On the 22 January occurrence, the wind rose from calm at 0945 A.M. PST to a maximum of 22 knots at 1015 A.M., varying between 12 and 16 knots from 1100 A.M. to 1245 P.M. The direction was constant from 180°. On 9 February, the wind direction varied from 180° to 200°. The peak speed was 20 knots between 0930 A.M. and 1015 A.M. and continued to exceed 12 knots through 1700 P.M.

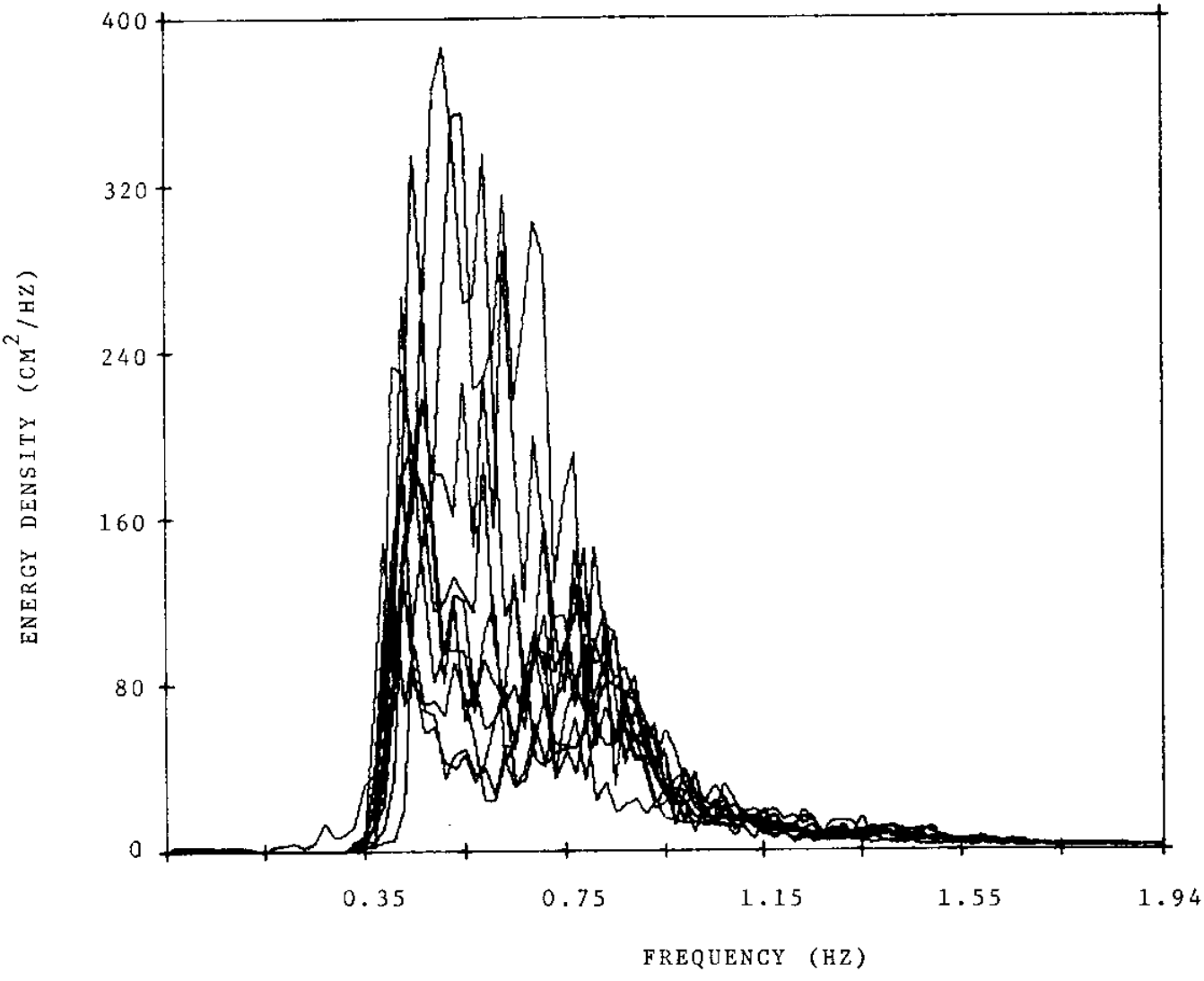
Ten experiments were obtained on 22 January, each with 4096 samples taken at approximately 5.11 Hz, in the interval between 1024 A.M. and 1300 P.M. PST. These experiments are designated S1 through S10. The incident wave spectra for these runs are shown in Figure 6.

A total of 16 experiments were recorded on 9 February. Three were in the morning between 1000 A.M. and 1130 A.M. and 13 in the afternoon between 1340 P.M. and 1700 P.M. These runs were designated S11 through S26. The incident wave spectra are shown in Figure 7.



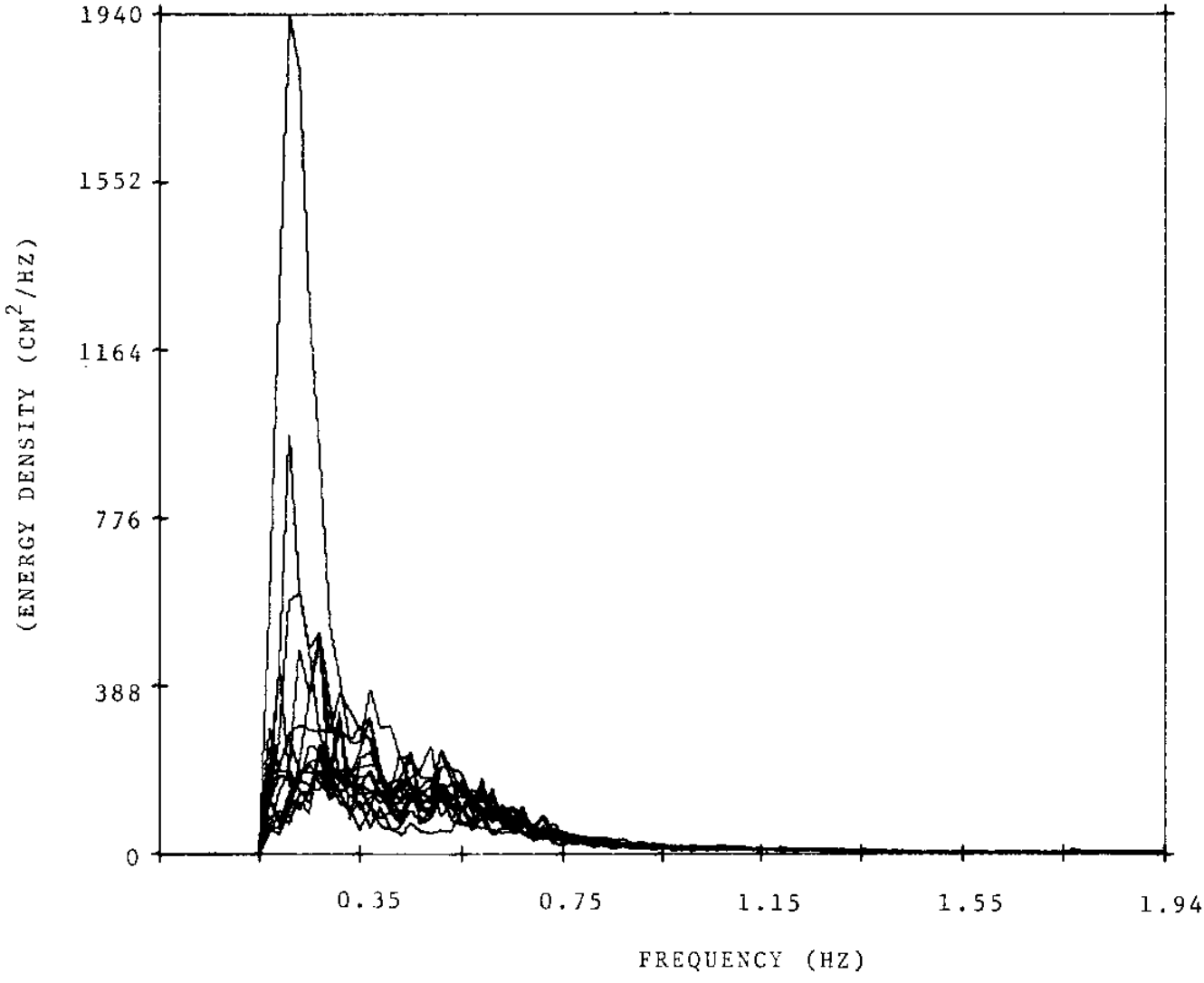
SPECTRA FOR LABORATORY EXPERIMENTS

FIGURE 5



INCIDENT SPECTRA - STORM OF JANUARY 22, 1976

FIGURE 6



INCIDENT SPECTRA - STORM OF FEBRUARY 9, 1976

FIGURE 7

These spectra are quite broad, bearing little resemblance to the sharply peaked spectra characteristic of waves generated on the open ocean. This broadening is caused by the extreme degree of fetch width restriction as discussed in Seymour (1976). These broad spectra, however, are reasonably close to the longer period laboratory spectra.

Certain types of rigid floating breakwaters which depend upon reflection and disruption of the wave orbits have been observed to yield a spatial variation in wave intensity behind the breakwater such that the measured energy close to the breakwater is less than that observed some distance away. This condition, when observed in a wave flume in which there is no opportunity for diffraction around the ends of the breakwater, is most likely caused by a temporary imbalance between the potential and kinetic energies which is eliminated within a few wavelengths behind the structure. This condition obviously requires correct placement of the wave probe measuring transmitted energy in order to determine the true breakwater performance.

This phenomenon was explored with the present system to determine if measurable differences in transmitted energy could be detected at various distances behind the breakwater. The laboratory breakwater model, illustrated in Figure 2, was similar to the half-scale model described in Section 3 a. The experiments were conducted using wave tape number T2. The results are shown in Table IV.

Table IV

Investigation of Variation in Transmitted Energy with Wave Probe Position

Measurement Point Distance Behind Breakwater (m)	Observed Significant Wave Height (cm)
1	4.90
2	4.95
4	4.75
6	4.74
8	4.51

The maximum distance observed, 8 m is approximately 2.3 times the wavelength of the energy peak in this spectrum. It can be readily observed that the variation approaches a small

systematic decline with distance which is of the correct order to account for losses to the high-frequency end of the spectrum as predicted by Lamb (1932).

The rear wave probe position used in the present work was approximately 8 meters behind the breakwater. To account for the high-frequency losses, the incident wave spectrum employed was measured in the bare channel at this same location. Since the actual incident spectrum is somewhat larger, this results in conservative estimates of breakwater performance.

5. SPECIFICATION OF RESISTANCE COEFFICIENTS

It was shown in Section 2 that values of the resistance coefficients, C_d and C_m, must be specified in the performance predictive model.

It is theoretically possible to define deterministic time-varying values for these coefficients in oscillating flows. For example, the instantaneous value for C_d may be found, in concept, by comparing the instantaneous value of that component of resistance which is in phase with the velocity with the value of the square of the instantaneous velocity. Since the flow conditions are changing radically through the oscillations in velocity, it is clear that the instantaneous values of the resistance coefficients must also change. Therefore, such a time-varying parameter is of no value for the statistical predictive model presently employed.

In Seymour (1974), the method was described for determining average constant values for the resistance coefficients for broad-band oscillatory flows. That resulted in minimum errors in predicting certain statistical properties of the resistance. This concept of utilizing constant coefficients to approximate the resistance of a single float is embodied in the predictive model for breakwater performance described above.

The concept is further extended in the model, however, to include the use of single-constant values for all floats within the breakwater, even though the average flow conditions in a functional breakwater vary significantly between the front and the rear rows as the wave is attenuated. Thus, these coefficients are even further removed from the true, or instantaneous, values that they attempt to approximate.

At the beginning of Section 2 it was stated that free surface effects such as scattering or reflection have been assumed to be small and are therefore not considered explicitly in the predictive model. However, these free surface effects do exist, particularly with floats whose diameter is an appreciable fraction of a wavelength and which are arranged near the surface. The net sum disturbance of the free surface can be considered as an increase in the resistance force. The increase in resistance that is in phase with the velocity would therefore result in an apparent increase in the drag coefficient. In the same manner, that portion of the resistance increase which is in phase with the acceleration would result in an apparent increase in the inertial coefficient.

The energy associated with the true drag of the float is lost to the wave field. The energy associated with the disturbance of the free surface may not necessarily be lost, but only phase shifted or changed in direction. In recognition of this, two drag coefficients have been defined. One, C_r, is used to define the apparent drag resistance (total of true drag and free surface disturbance). C_r is used in the equation (6) to calculate the spectrum of relative velocity. The second, C_d, is used in equation (5) to estimate the drag power spectrum. In practice, these two values vary only slightly. (C_r must be larger than or equal to C_d), but they allow a slight additional flexibility in selecting coefficients to employ in the predictive model.

This procedure is in marked contrast to the traditional approach used by naval architects in which the frictional and wave-making components of resistance are separated and independently scaled. The present approximation, in which wave-making resistance is treated as an additional component of frictional resistance, appears to be feasible because of two considerations. First, the wave-making resistance, as demonstrated below, is small compared to the frictional resistance. Secondly, as shown by Seymour (1974), drag in random oscillatory flows has no Reynolds number dependence and scales approximately as Froude scaling, the same as the wave-making resistance.

The relative importance of the wave-making resistance can be deduced from the level of backscattered energy. In Table V, four experiments using the half-scale model and different wave climates, show the difference between the significant wave heights at the measurement station in front of the breakwater and at the same location with the breakwater removed. The measurement of the backscatter of narrow band waves from fixed surfaces requires that the wave measuring device be moved to a number of locations to

insure that reflected energy is not masked by the measurement point occurring at a node. In this system, however, a single location suffices because the signal is random and broad band, and because the reflecting body has a large number of reflecting surfaces all of which move randomly during the sampling interval.

The comparisons of the spectral plots for these same two spectra from each of the four experiments are shown in Figures 8, 9, 10 and 11. It is readily apparent from these figures and from Table V that the backscattered energy content is quite small. Since this is the only component of the free surface disturbance that can be measured easily, it is necessary to assume that the other components are also small.

Table V

Comparison of Incident Spectra With and Without Breakwater

Exp. No.	Tape No.	H_s (cm) Bare Channel	H_s (cm) With Breakwater*	Ratio H_s/H_s
L1	T1	7.26	7.75	1.07
L2	T2	10.70	10.79	1.01
L3	T3	11.93	12.01	1.01
L4	T4	9.52	9.66	1.01

6. EFFECTS OF VARYING FREEBOARD

Since the entire breakwater is expected to follow the surface to accommodate tides, storm surge and waves, some reserve buoyancy--or positive freeboard--must be provided. Experience has shown that a reserve volume roughly equivalent to 10% of the total float volume will assure that the breakwater does not totally submerge under reasonable combinations of large waves, mooring forces and currents. This can be most easily effected by making all tethers the same length and ballasting until the freeboard is approximately 20% of the diameter of the spherical float. This reduces the restoring force and the cross-sectional area compared to a zero freeboard condition at the same time that it increases the free surface disturbance. Therefore, alternative schemes were considered to improve performance.

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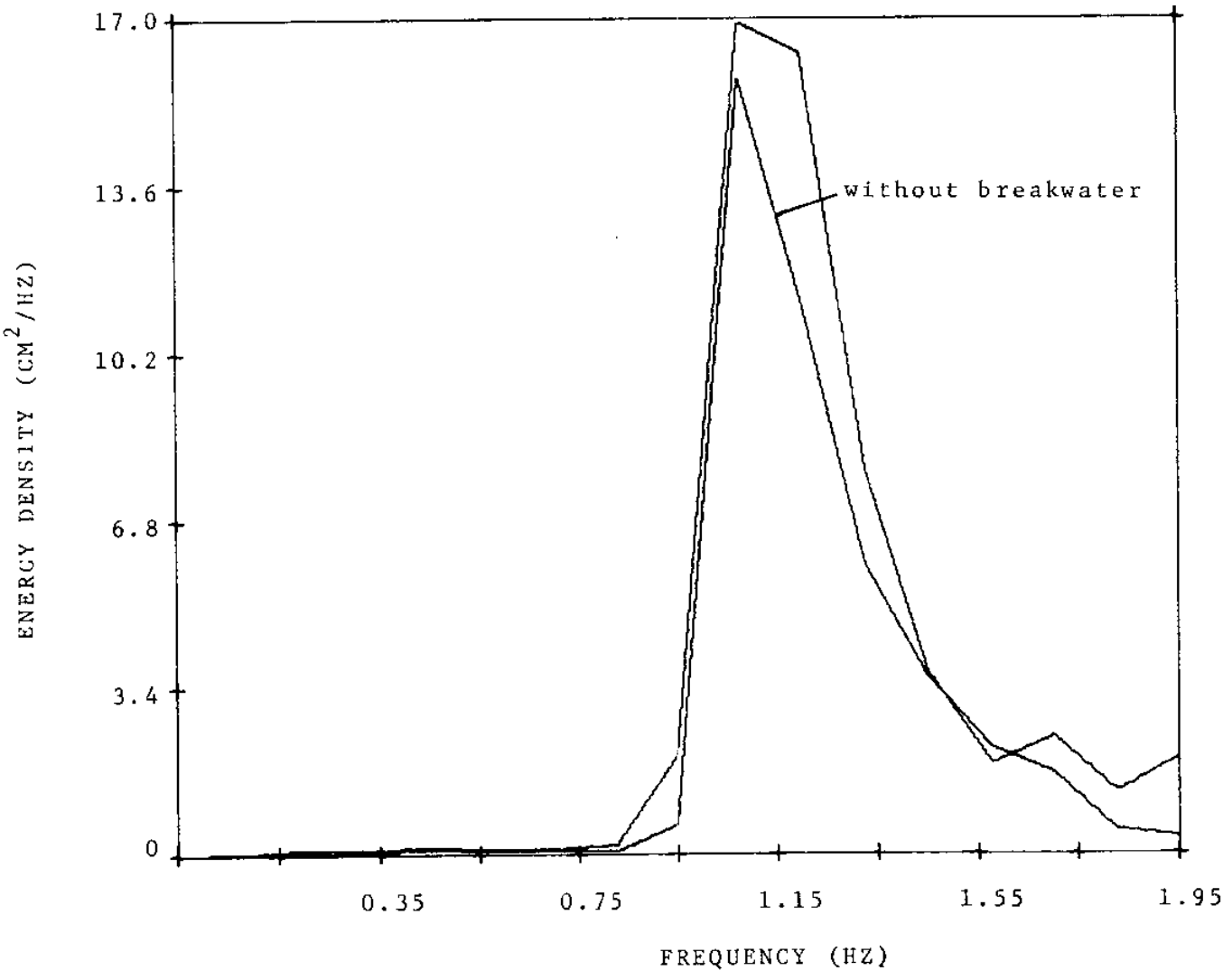
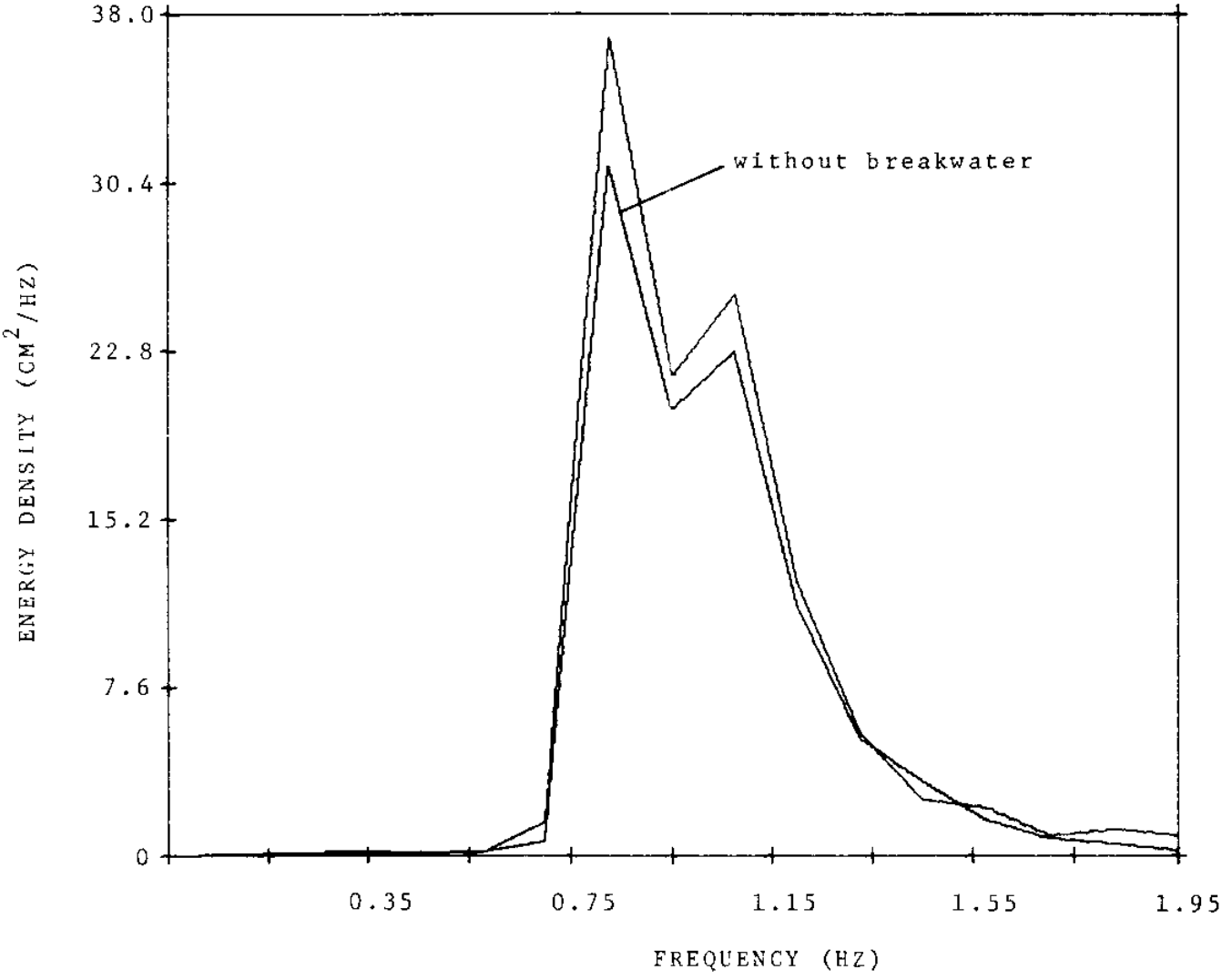
* Freeboard on all floats was -3.8 cm.



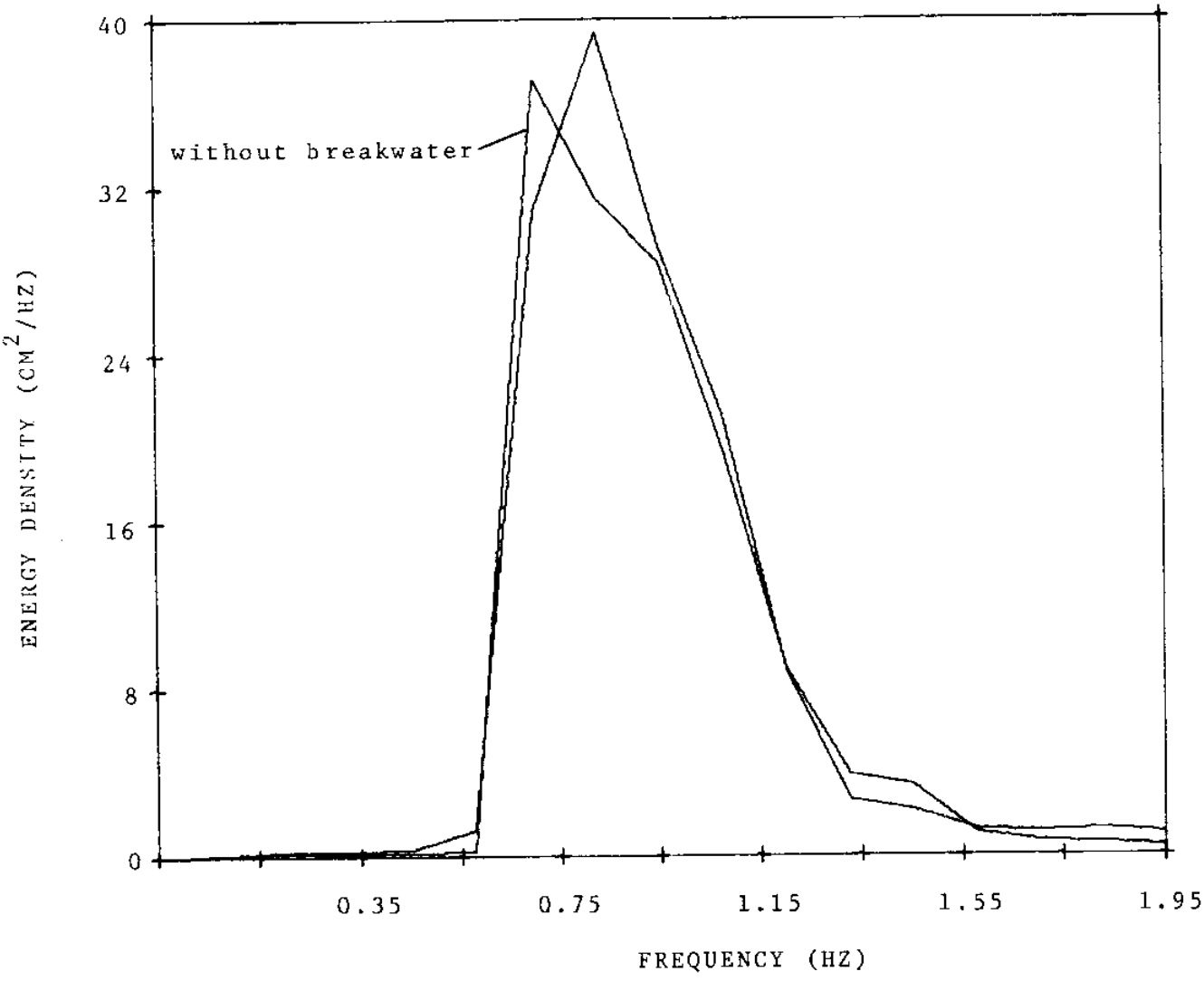
COMPARISON OF INCIDENT SPECTRA WITH
AND WITHOUT BREAKWATER - EXPERIMENT L1

FIGURE 8



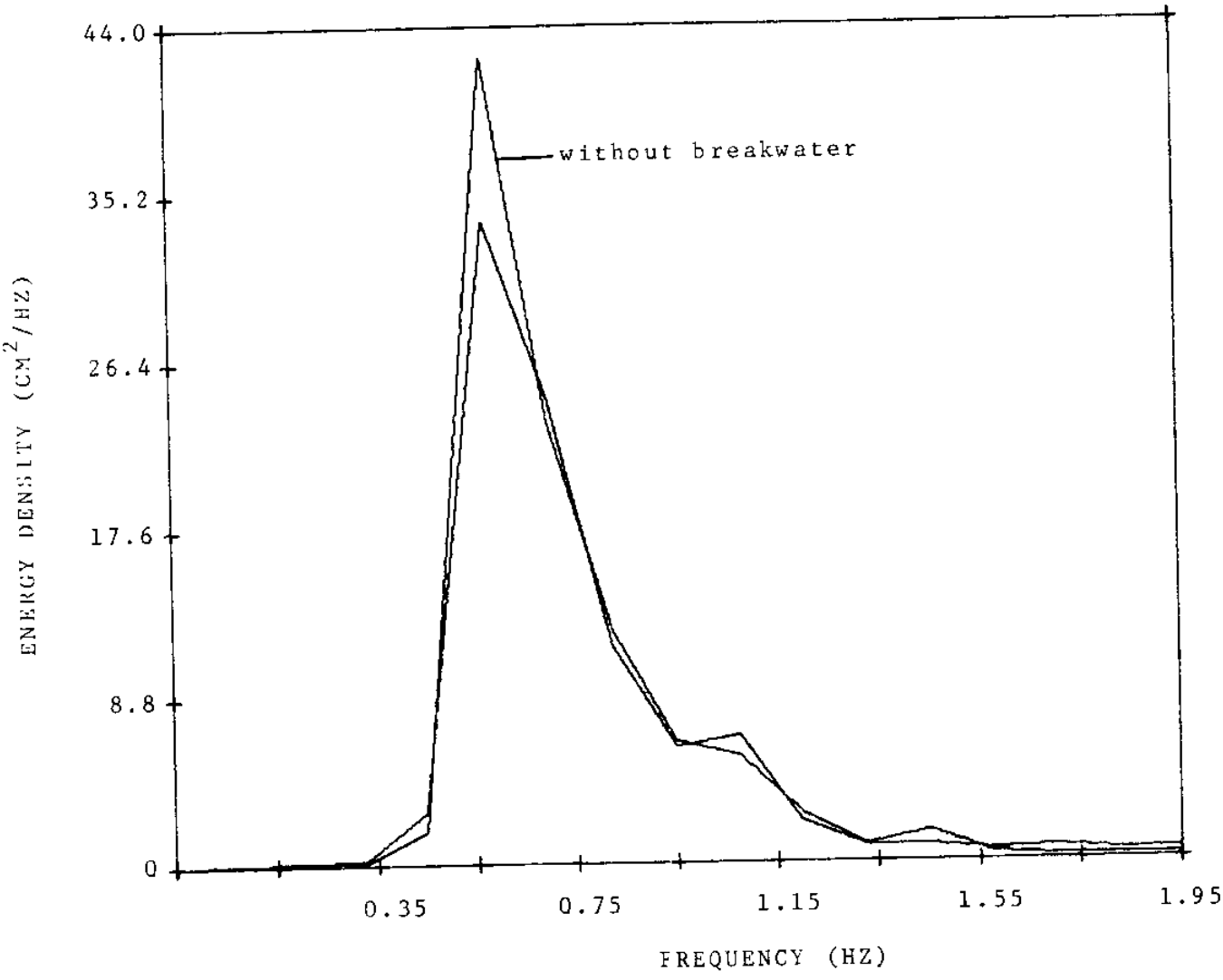
COMPARISON OF INCIDENT SPECTRA WITH
AND WITHOUT BREAKWATER - EXPERIMENT L2

FIGURE 9



COMPARISON OF INCIDENT SPECTRA WITH
AND WITHOUT BREAKWATER - EXPERIMENT L3

FIGURE 10



COMPARISON OF INCIDENT SPECTRA WITH
AND WITHOUT BREAKWATER - EXPERIMENT L4

FIGURE 11

In order to evaluate these concepts, it was necessary to measure the effects of varying freeboard on breakwater performance. To do this, the half-scale laboratory model was ballasted to produce a number of freeboard values. When the trim approached neutral buoyancy, or went negative, the breakwater was suspended at the proper depth by lines at the four corners of the ballast frame.

Defining a freeboard ratio for spherical floats

$$R = \text{freeboard/float diameter}$$

experiments were conducted at values of R between +0.21 and -0.50. A summary of the experiments is shown in Table VI.

Table VI

Variable Freeboard Experiments

Experiment Number	Tape Number	Freeboard Ratio, R	ETR
L1	T1	-0.25	.208
L2	T2	-0.25	.066
L3	T3	-0.25	.193
L8	T1	+0.21	.388
L9	T2	+0.21	.215
L10	T3	+0.21	.280
L11	T1	-0.17	.187
L12	T2	-0.17	.075
L13	T3	-0.17	.201
L14	T1	0	.191
L15	T2	0	.126
L16	T3	0	.249
L29	T1	- .33	.242
L30	T2	- .33	.081
L31	T3	- .33	.207
L32	T1	- .50	.537
L33	T2	- .50	.141
L34	T3	- .50	.247

The measured performance, defined by ETR, is tabulated in Table VI and plotted in Figure 12. It can be seen from Figure 12 that the minima in ETR (least energy transmitted) occur near a freeboard ratio of about -0.25.

Since the predictive model contains no consideration of free surface effects, it predicts best performance at R=0, where wave amplitudes are maximum. It is clear from Figure 12, however, that moving further away from the free surface compensates for the loss in the driving force amplitude to produce the minima observed. In the present form of the predictive model, therefore, it is necessary to accommodate these variations in performance efficiency by arbitrary adjustments of the resistance coefficients as discussed in Section 5, above.

The final operational configuration chosen for the field experiment had all of the reserve buoyancy provided by the front and rear rows (R=0.5). The central nine rows were submerged to the optimum (R=-0.25). This was handled in the predictive model by assuming 10 rows (rather than the actual 11) all submerged to R=-0.25. It was determined that this approximation--which consists of replacing the two outer, half-emerged rows with a single, optimally submerged row--gives very gratifying results in predicting performance. Laboratory experiments L5, L6 and L7 modeled this arrangement.

7. SELECTING C_r, C_d and C_m

Seymour (1974) showed for spheres and Sarpkaya (1976) for rough cylinders that drag and inertial coefficients are independent of Reynolds number and will be constant with Froude scaling. This suggests that, for geometrically similar models above a limiting critical size, a single set of these coefficients should be sufficient to predict the performance of any scale breakwater.

Therefore, the entire body of laboratory and field data of similar geometry could be explored to determine the best values of the coefficients. This was accomplished by means of a computer program which predicted the ETR and the transmitted spectrum for a particular experiment and compared these with the measured values. A normalized error function was established to compare the predicted and measured transmitted spectra in which the rms error was normalized by the standard deviation of the measured transmitted wave. The non-dimensional ETR values could be compared directly.

EFFECTS OF FREEBOARD RATIO
ON BREAKWATER PERFORMANCE

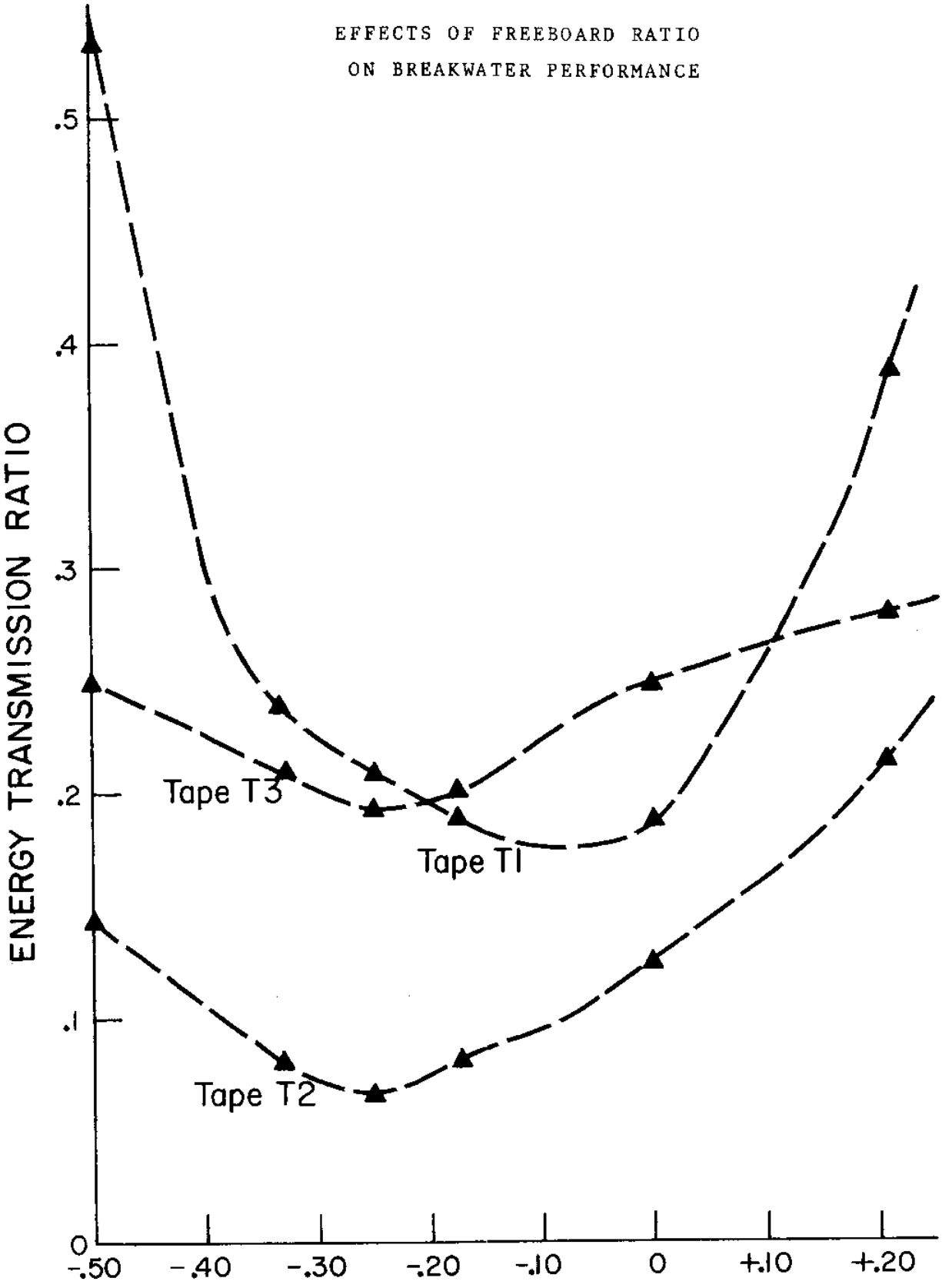


FIGURE 12

Values of C_r, C_d and C_m spanning the range of possible values were examined using a large number of the field and laboratory experiments. These results were evaluated subjectively to yield a set of coefficients giving minimum errors over the full range of conditions. Because of the wave climates involved, these data necessarily included experiments in which the incident waves exceeded the design optimum. The coefficient set selected to model breakwaters with the geometry employed in these experiments is:

$$C_d = 0.45$$

$$C_r = 0.55$$

$$C_m = 0.55$$

8. RESULTS OF LABORATORY MODELING

Figure 13 shows the comparison between measured and predicted performance (i.e., energy transmission ratio) for both the field and the laboratory experiments described in this report. The laboratory data are shown by triangles. The 25 laboratory experiments displayed ranged from an energy reduction of about 20% to a reduction of about 94%. Experiments L8 to L10, L14 to L16, and L32 to L34 were excluded from this plot, because their freeboard ratios were not sufficiently close to the prototype.

In Appendix A, the measured transmitted and incident spectra and the predicted transmitted spectrum are shown for each of the 34 laboratory experiments. A graphical comparison is also made of the measured and predicted energy transmission ratio (ETR) curves as functions of frequency. When comparing the two ETR curves it is important to refer to the incident wave spectrum in the plot above. In general, the agreement between the ETR curves is quite good over the frequency range where a significant amount of incident energy is present. The ETR curves have little physical significance in frequency regimes with small energies and are subject to considerable measurement error.

Appendix A also contains a table for each experiment showing the physical characteristics of the model and the performance estimates.

The standard error in estimating ETR for the 25 laboratory experiments plotted in Figure 13 is 0.0017. Since good agreement on an overall ETR is possible with very large, but

COMPARISON OF PREDICTED AND
MEASURED BREAKWATER PERFORMANCE

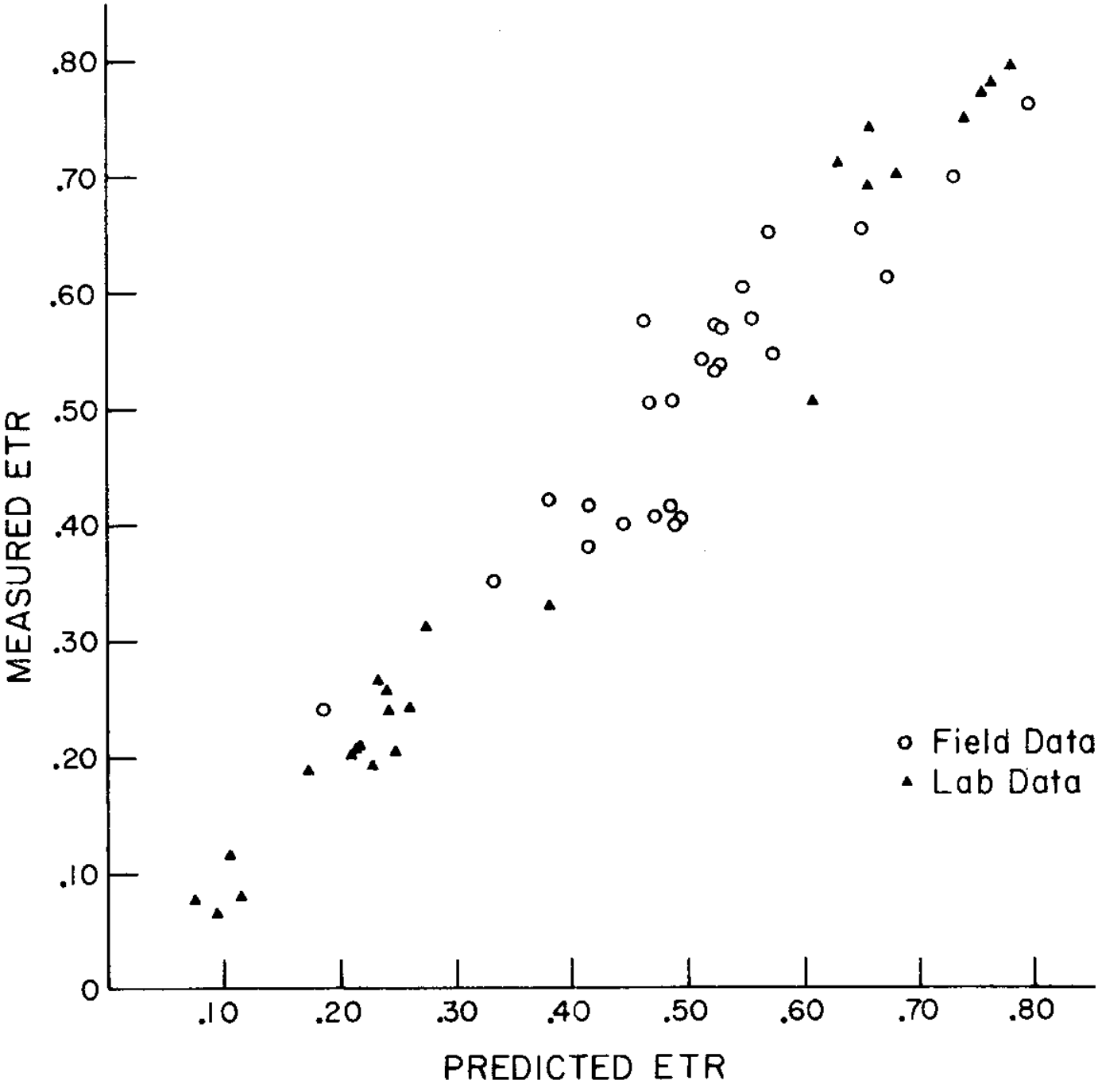


FIGURE 13

offsetting, errors in estimating the transmitted spectrum, a second criterion was developed to evaluate the quality of the estimation. A normalized error function was defined as

$$\Sigma(f) \quad \frac{E_{\text{transmitted measured}} - E_{\text{transmitted estimated}}}{E_{\text{incident}}}$$

The standard deviation of this function was calculated over all frequency bands. The resulting standard deviations are shown in the appropriate tables in Appendix A. The mean of all the standard deviations for the 25 laboratory experiments plotted was 0.066.

9. RESULTS OF FIELD EXPERIMENTS

The 26 field experiments are shown as open circles in Figure 13. These experiments cover a range of energy reductions from about 24% to about 76%. The spectra, ETR curve comparison and tabular data on these experiments are shown in Appendix B.

The standard error in estimating overall ETR for the 26 field experiments was 0.0027. The mean standard deviation of the error function was 0.061.

10. CONCLUSIONS

a) Lumped, single valued resistance coefficients applied to a linearized model for float motion can effectively predict the statistics of the response of the float to random wave excitation.

b) The values for the resistance coefficients, determined empirically by numerical curve fitting techniques for a particular freeboard ratio, apply over a broad range of both breakwater scales and wave climates.

c) The performance estimation technique predicts the transmitted spectrum, given the incident spectrum, with a mean rms normalized error of less than 0.07, and predicts total energy transmission within 3%.

d) The wave attenuation characteristics of the tethered float breakwater were satisfactorily demonstrated in a limited fetch application.

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APPENDIX A

RESULTS OF LABORATORY EXPERIMENTS

EXPERIMENT L1

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 11.43 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

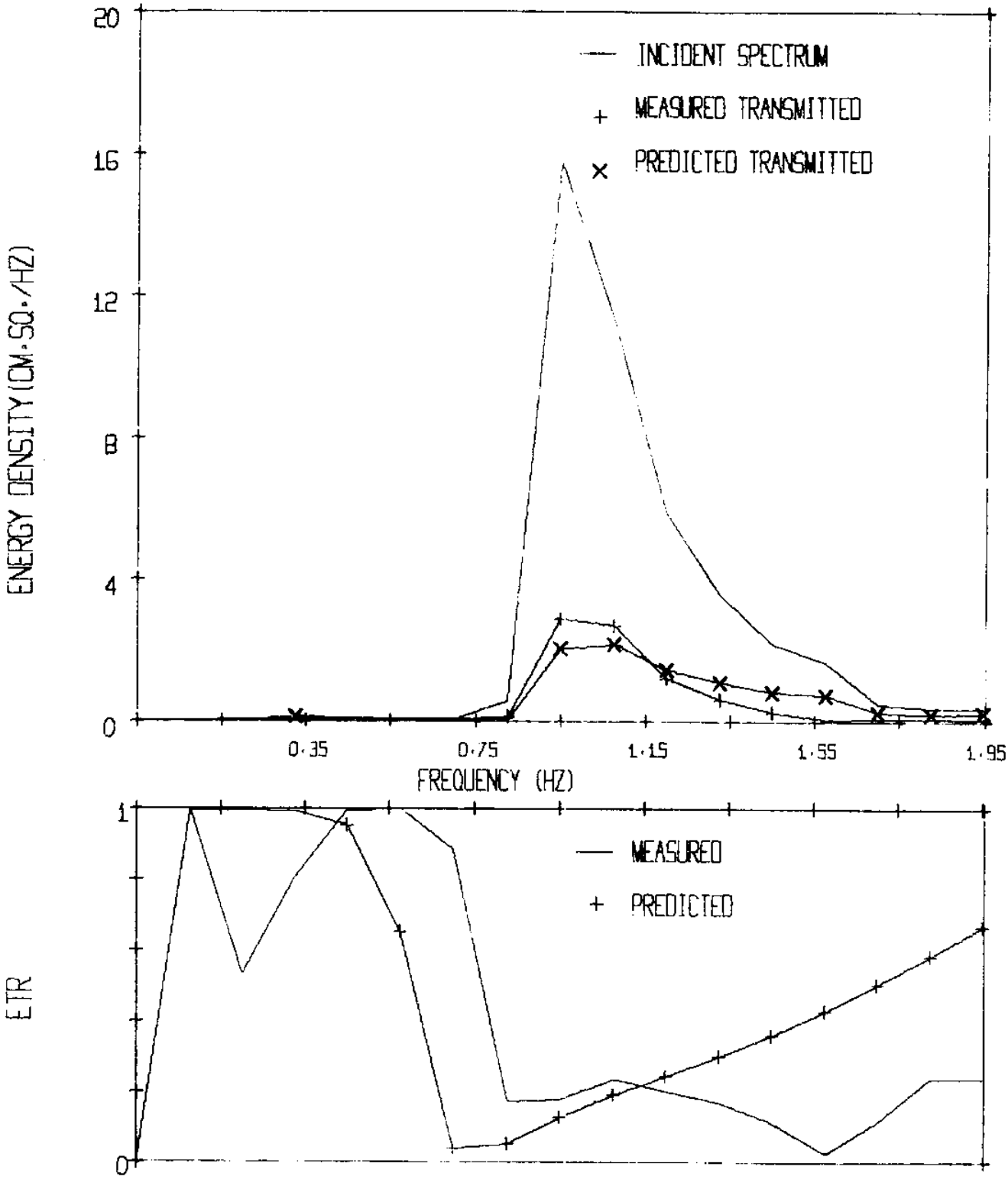
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.214
HEIGHT TRANSMISSION FACTOR = 0.462
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 3.0

RMS ERROR = 0.044

EXPERIMENT L1



EXPERIMENT L2

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 11.43 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

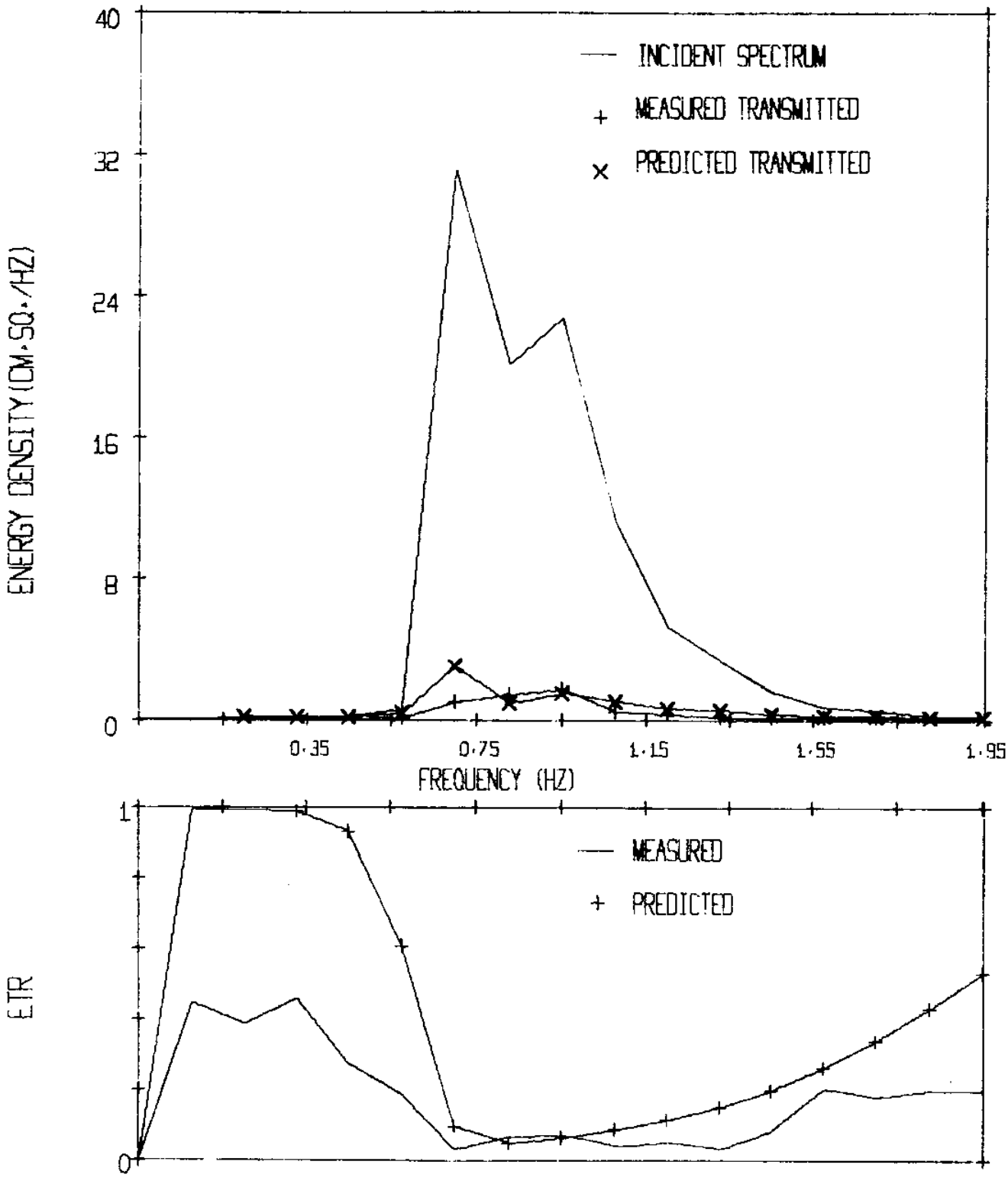
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.094
HEIGHT TRANSMISSION FACTOR = 0.307
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 3.0

RMS ERROR = 0.082

EXPERIMENT L2



EXPERIMENT L3

FLOAT DIAMETER = 15.24 CM	EFFECTIVE TETHER LENGTH = 83.8
X-SECTIONAL AREA = 182.4 CM.SQ.	VOLUME = 1853.3 CC
FLOAT SPACING = 30.48 CM	FLOAT DENSITY = 0.0400 GM/CC
DEPTH TO C.L. = 11.43 CM	WATER DEPTH = 177.8 CM
DELTF = 0.1250	NO. BANDS = 16
CD = 0.550 CM = 0.550	DCD = 0.450

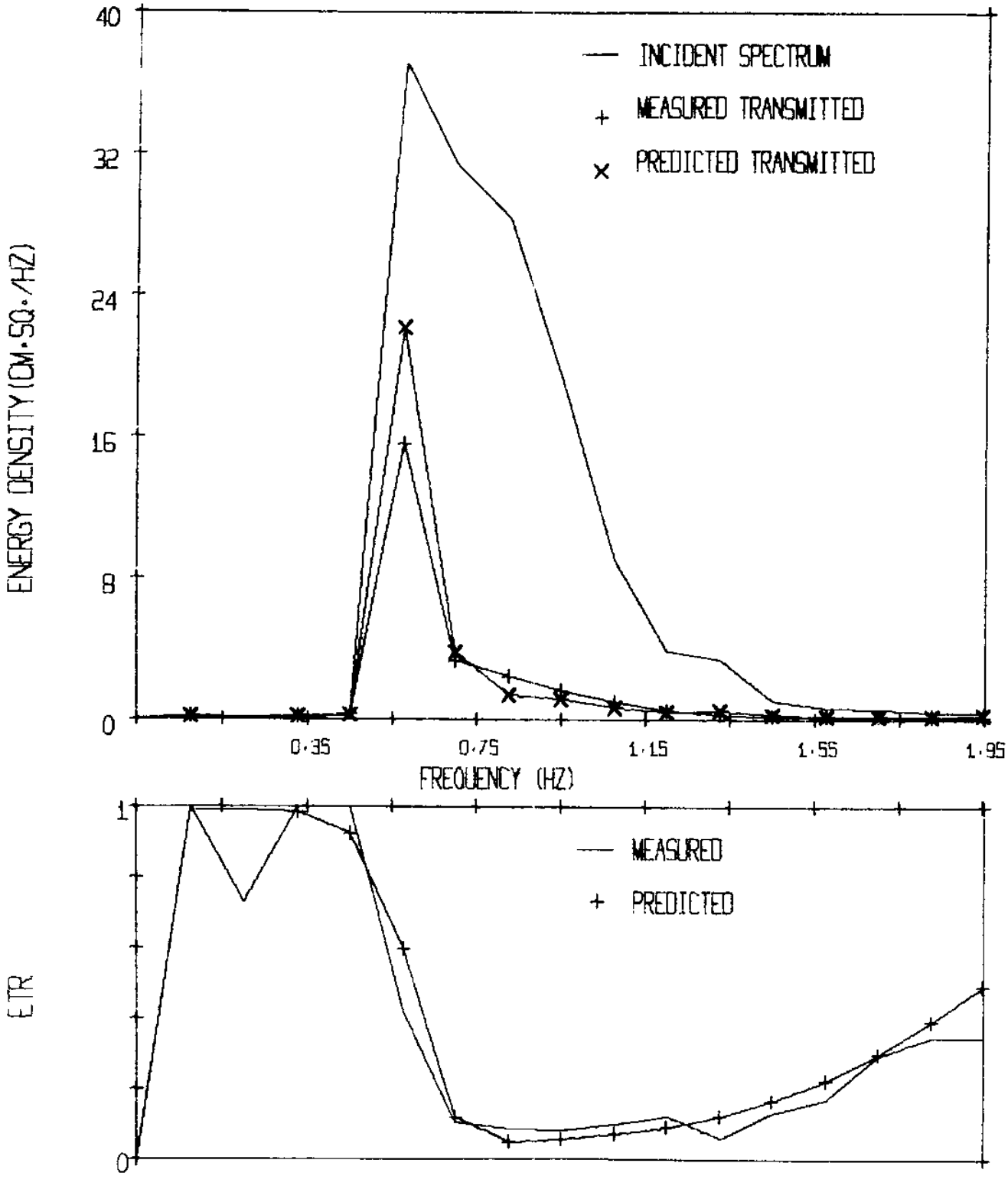
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.227
HEIGHT TRANSMISSION FACTOR = 0.477
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 5.5

RMS ERROR = 0.117

EXPERIMENT L3



EXPERIMENT L4

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.6
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	11.43 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

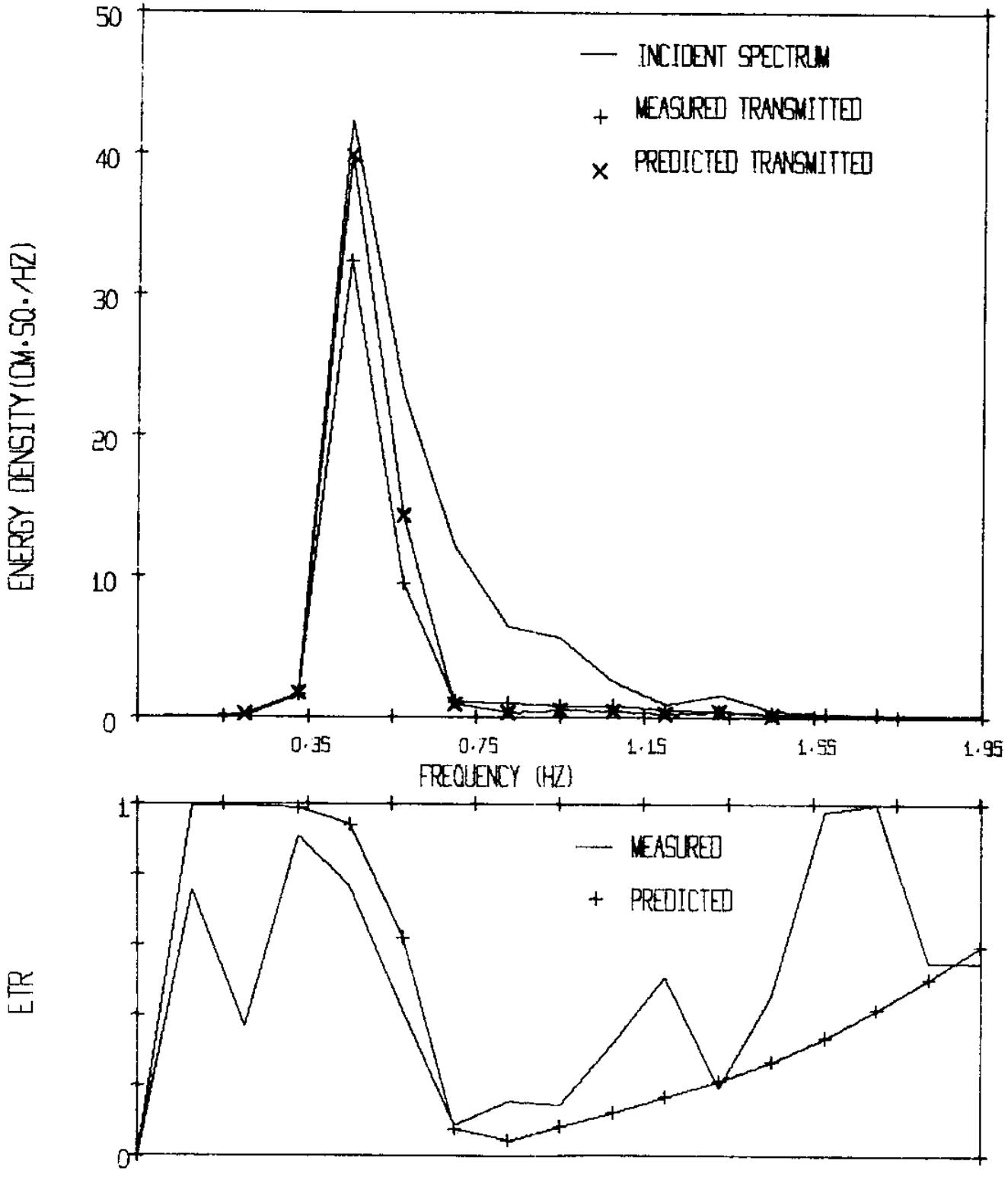
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.606
HEIGHT TRANSMISSION FACTOR =	0.778
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	9.8
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	7.6

RMS ERROR = 0.113

EXPERIMENT L4



EXPERIMENT L5

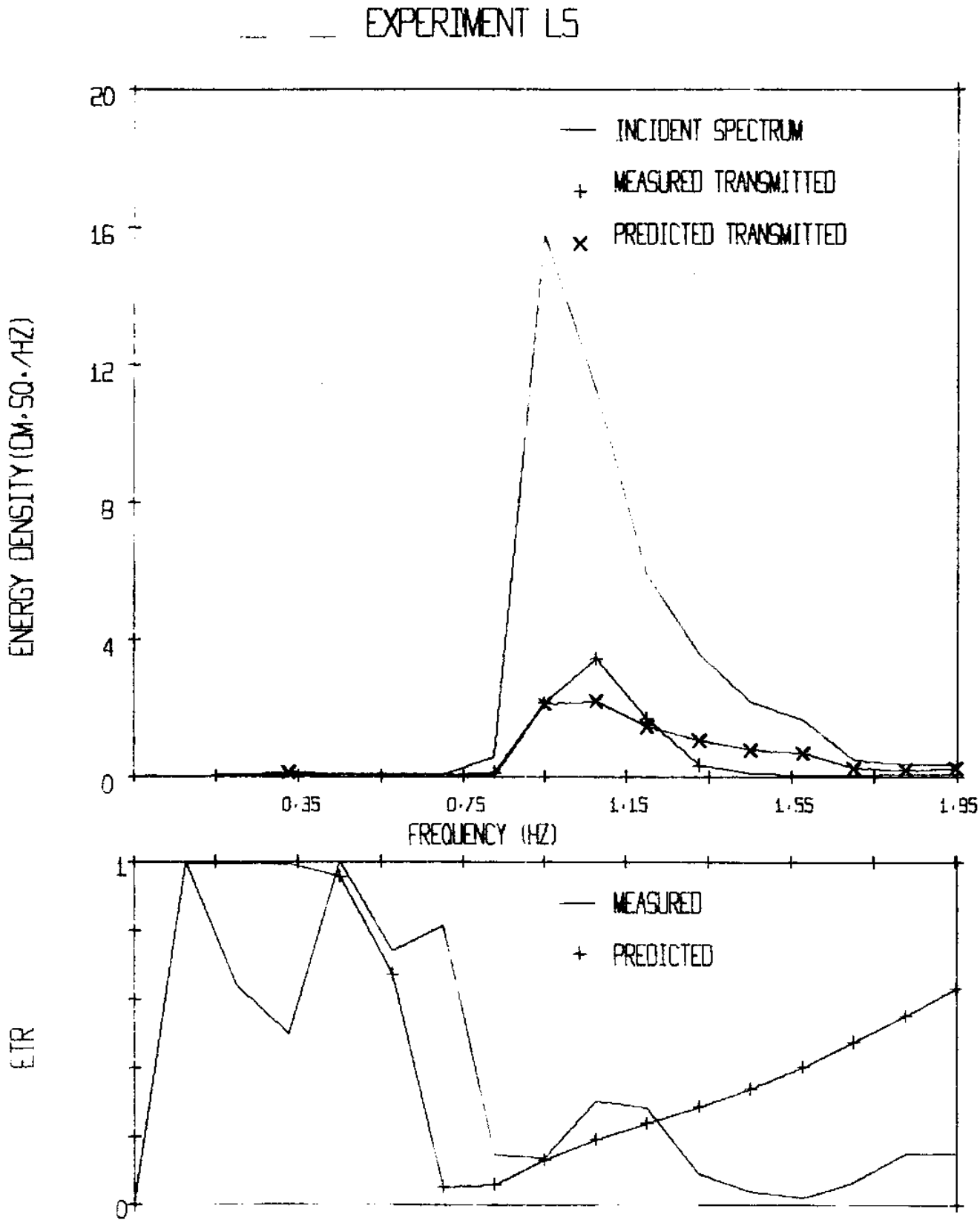
FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	10.83 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.212
HEIGHT TRANSMISSION FACTOR =	0.461
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	2.9

RMS ERROR = 0.054


EXPERIMENT L5
INCIDENT SPECTRUM
MEASURED TRANSMITTED
PREDICTED TRANSMITTED
ENERGY DENSITY(DM.SQ./HZ)
20
16
12
8
4
0
0.35
0.75
1.15
1.55
1.95
FREQUENCY (HZ)
ETR
MEASURED
PREDICTED
1
0

EXPERIMENT L6

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	10.83 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

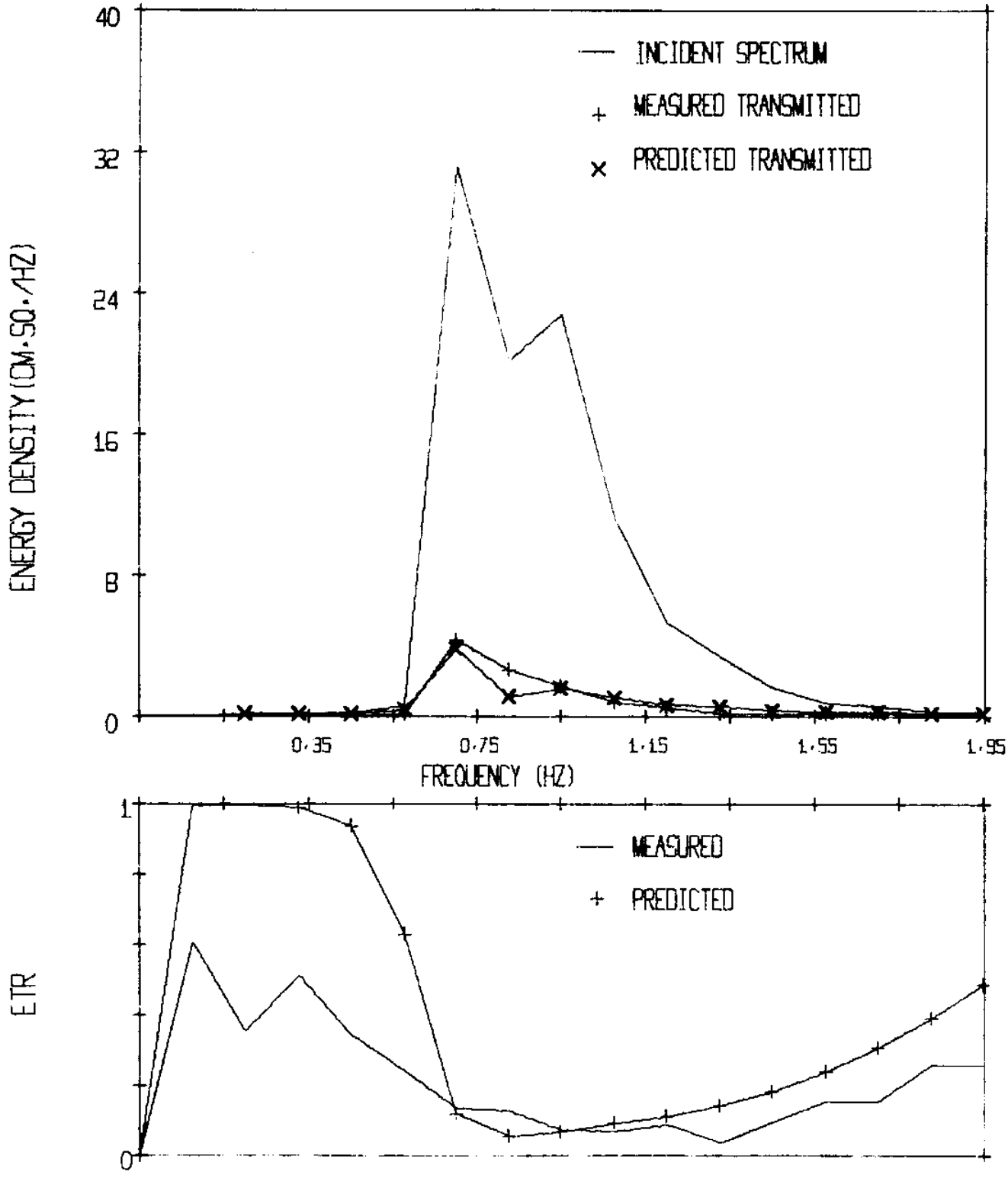
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.104
HEIGHT TRANSMISSION FACTOR =	0.322
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	3.1

RMS ERROR = 0.044

EXPERIMENT L6



EXPERIMENT L7

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.83 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

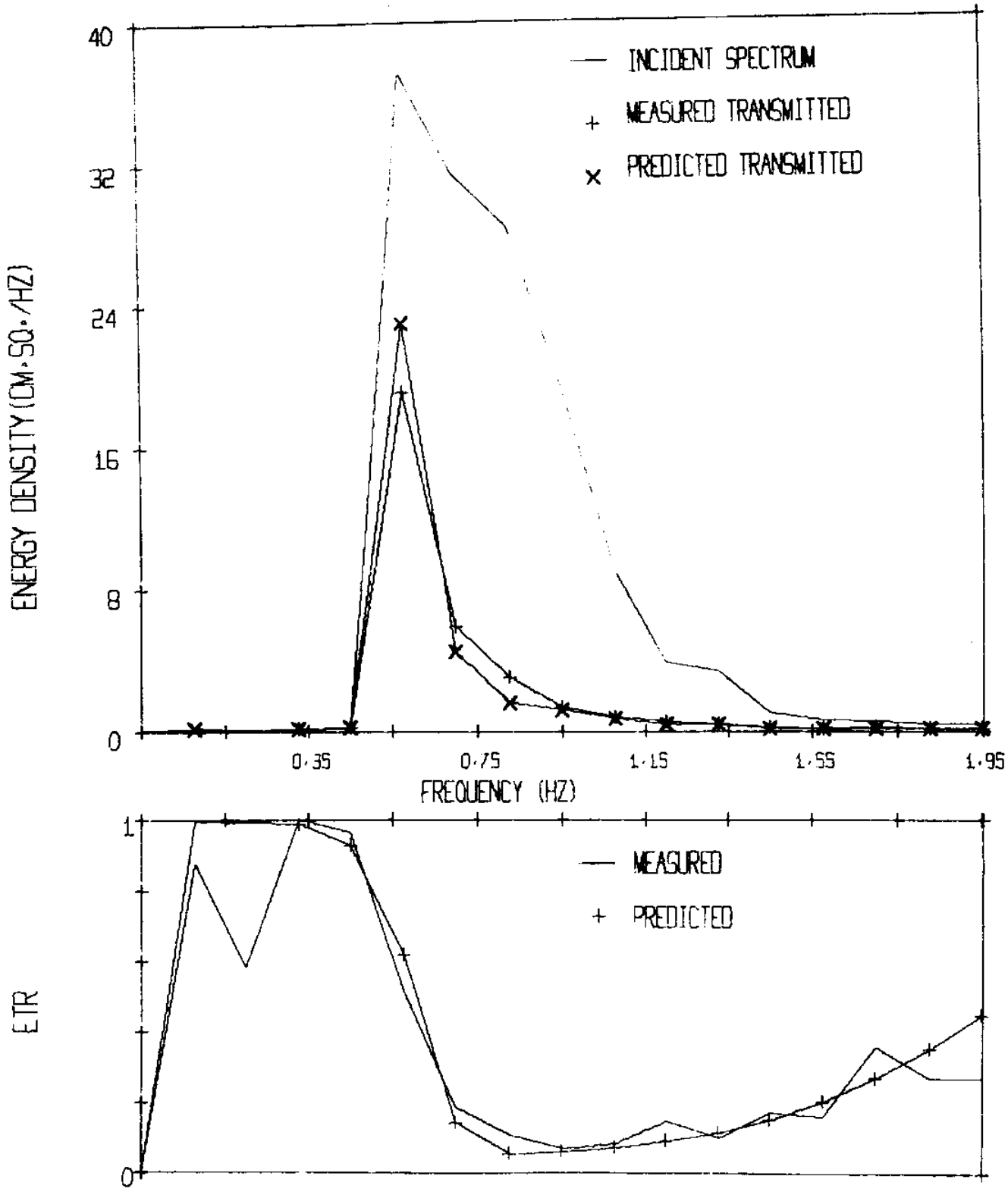
EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.241
HEIGHT TRANSMISSION FACTOR = 0.491
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 5.7

RMS ERROR = 0.068


EXPERIMENT L7
INCIDENT SPECTRUM
MEASURED TRANSMITTED
PREDICTED TRANSMITTED
ENERGY DENSITY (CM·SQ·/HZ)
40
32
24
16
8
0
0·35
0·75
1·15
1·55
1·95
FREQUENCY (HZ)
ETR
MEASURED
PREDICTED
1
0

EXPERIMENT L8

FLOAT DIAMETER = 14.71 CM
X-SECTIONAL AREA = 157.1 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 7.36 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1666.6 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

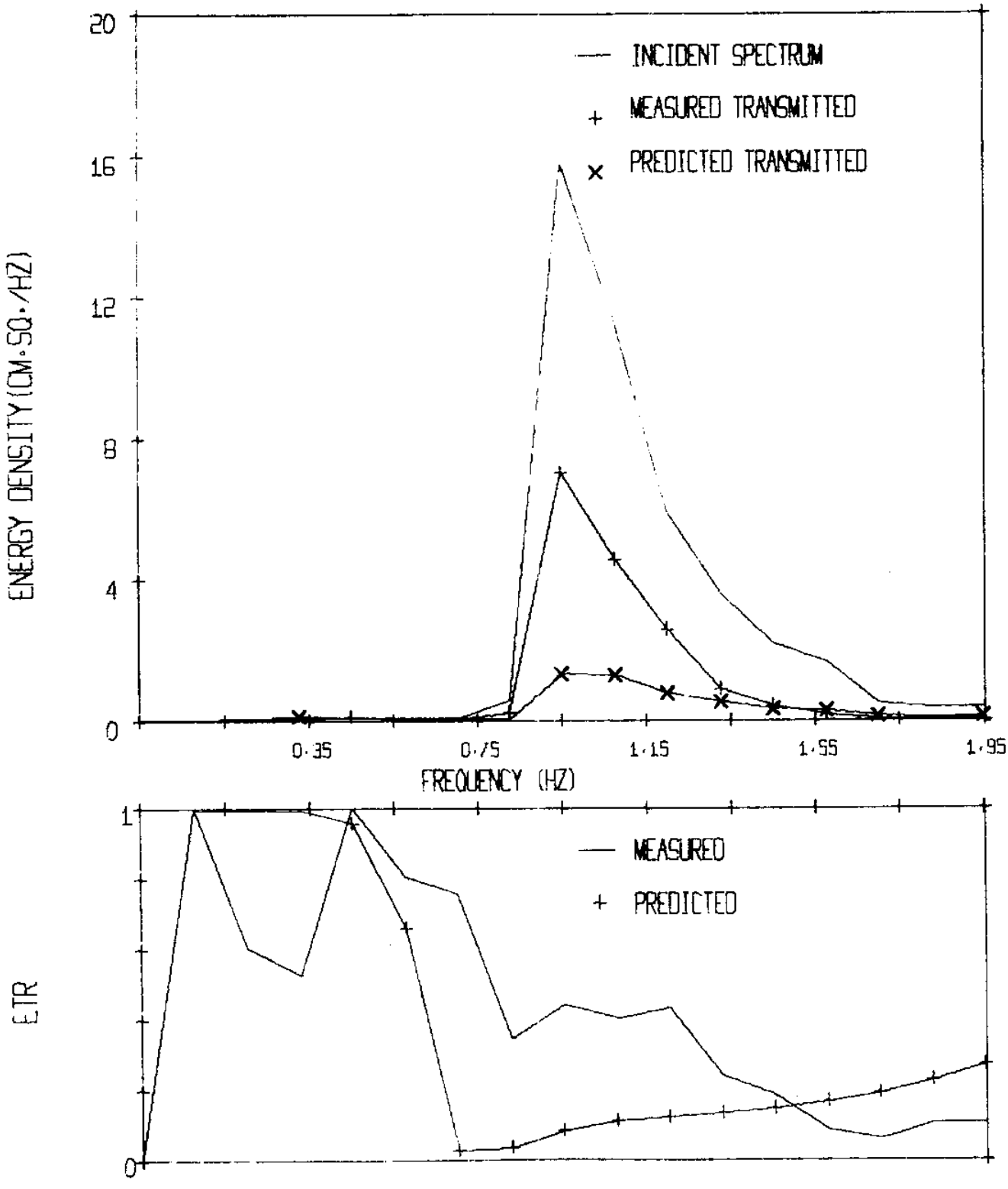
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.115
HEIGHT TRANSMISSION FACTOR = 0.340
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 2.2

RMS ERROR = 0.151

EXPERIMENT L8



EXPERIMENT L9

FLOAT DIAMETER = 14.71 CM
X-SECTIONAL AREA = 157.1 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 7.36 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1666.6 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

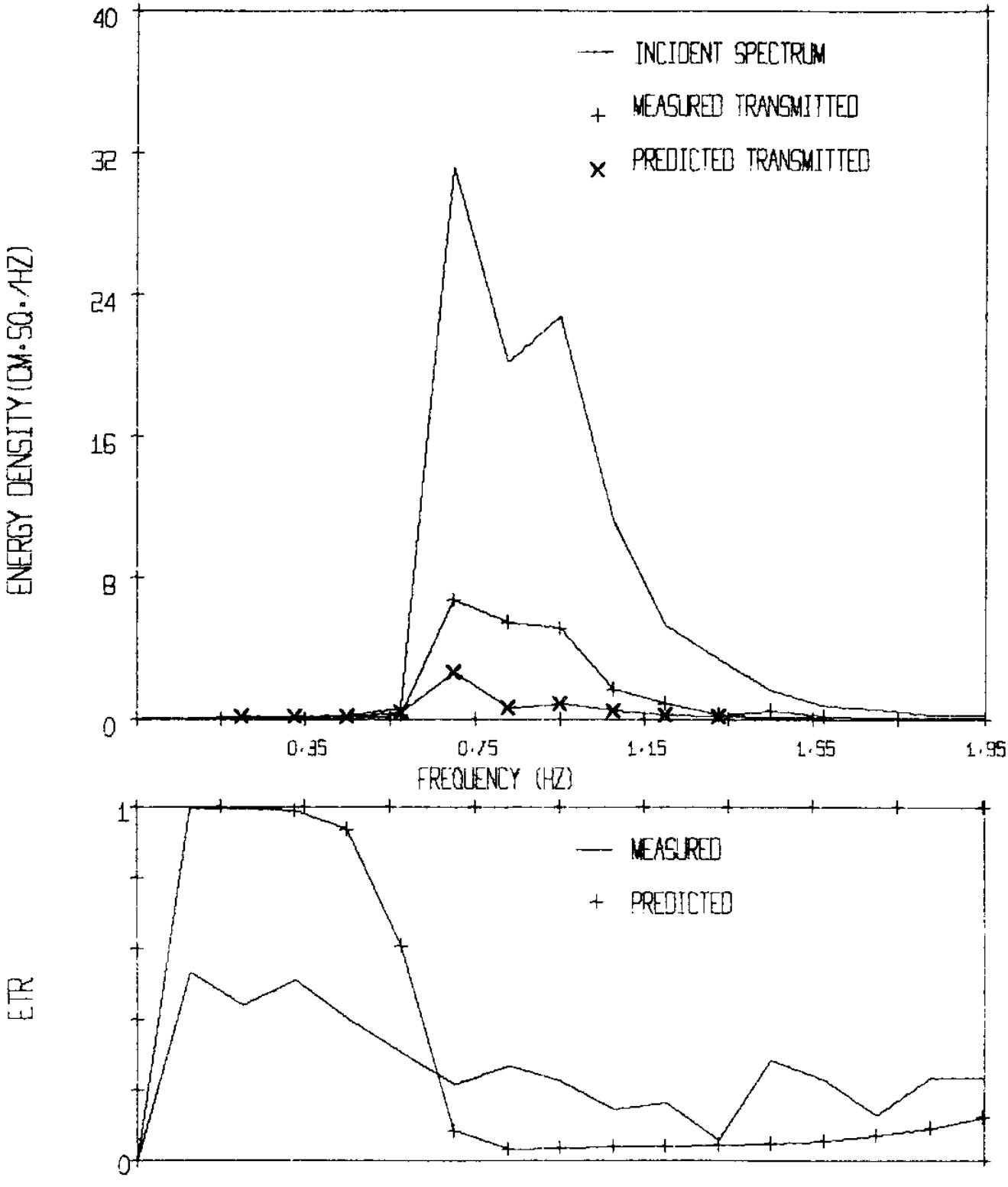
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.059
HEIGHT TRANSMISSION FACTOR = 0.243
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 2.4

RMS ERROR = 0.149

EXPERIMENT L9



EXPERIMENT L10

FLOAT DIAMETER =	14.71 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	157.1 CM.SQ.	VOLUME =	1666.6 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	7.36 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

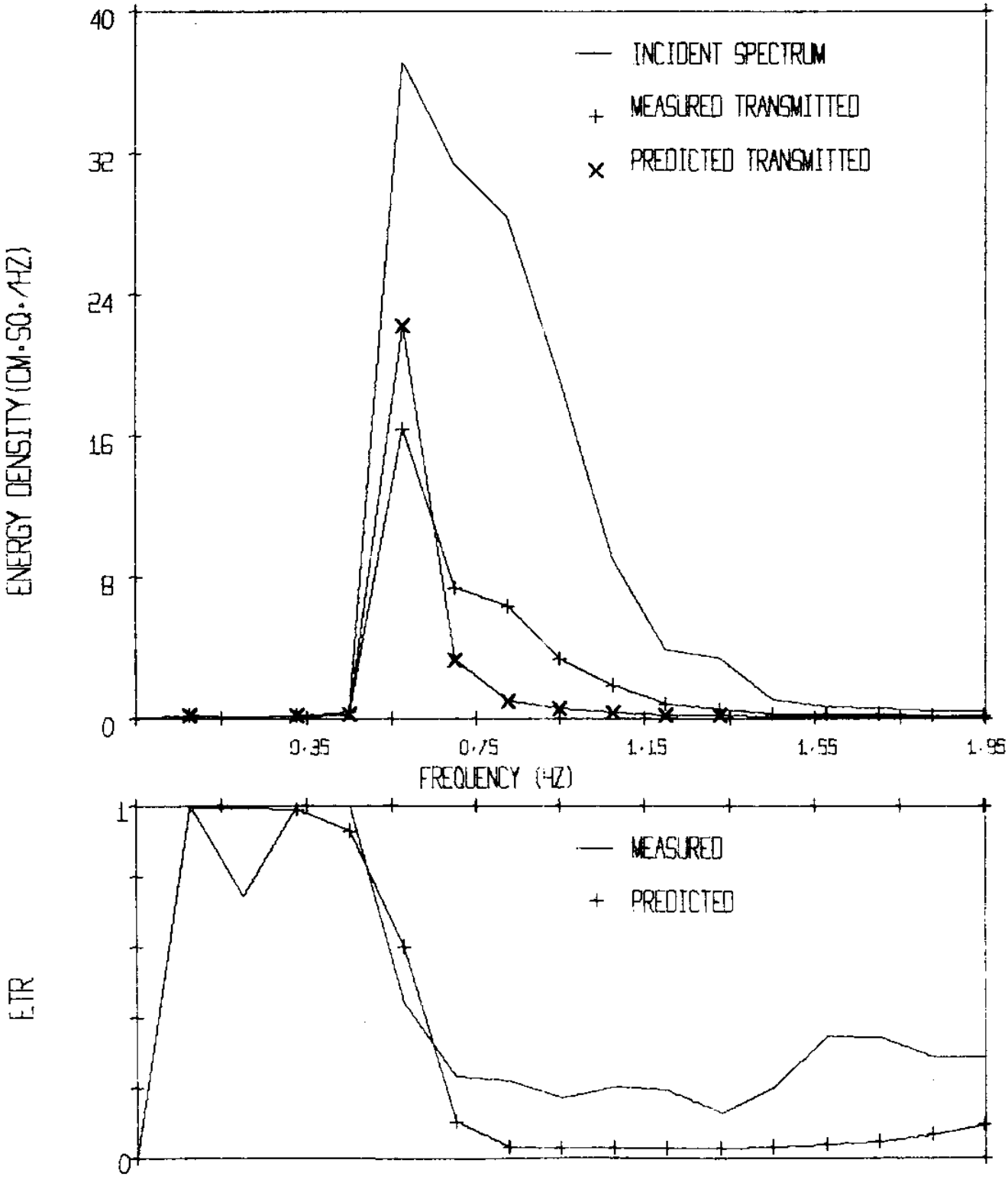
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.206
HEIGHT TRANSMISSION FACTOR =	0.454
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	5.2

RMS ERROR = 0.137

EXPERIMENT L10



EXPERIMENT L11

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.16 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

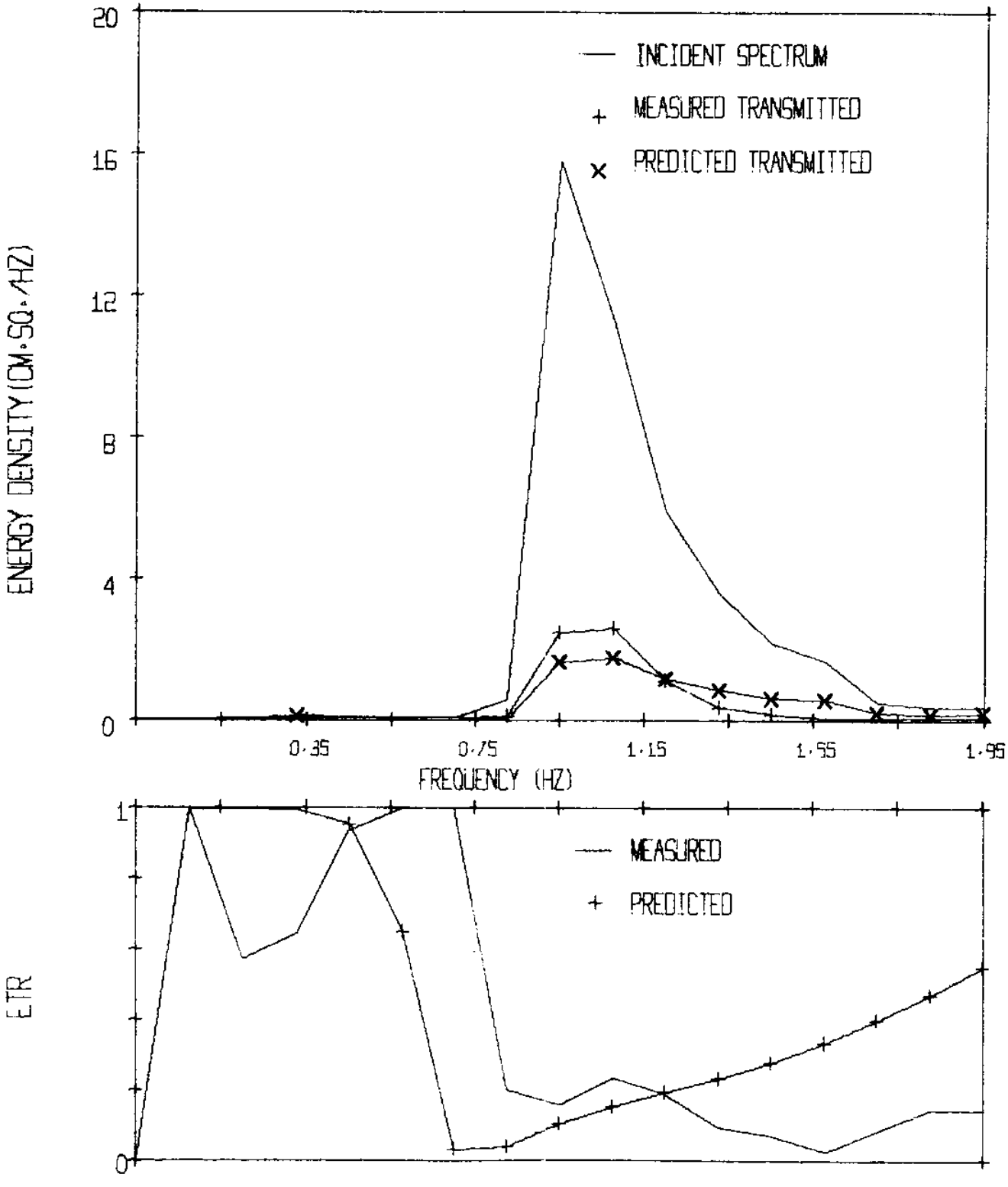
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.171
HEIGHT TRANSMISSION FACTOR = 0.413
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 2.6

RMS ERROR = 0.048

EXPERIMENT L11



EXPERIMENT L12

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.16 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

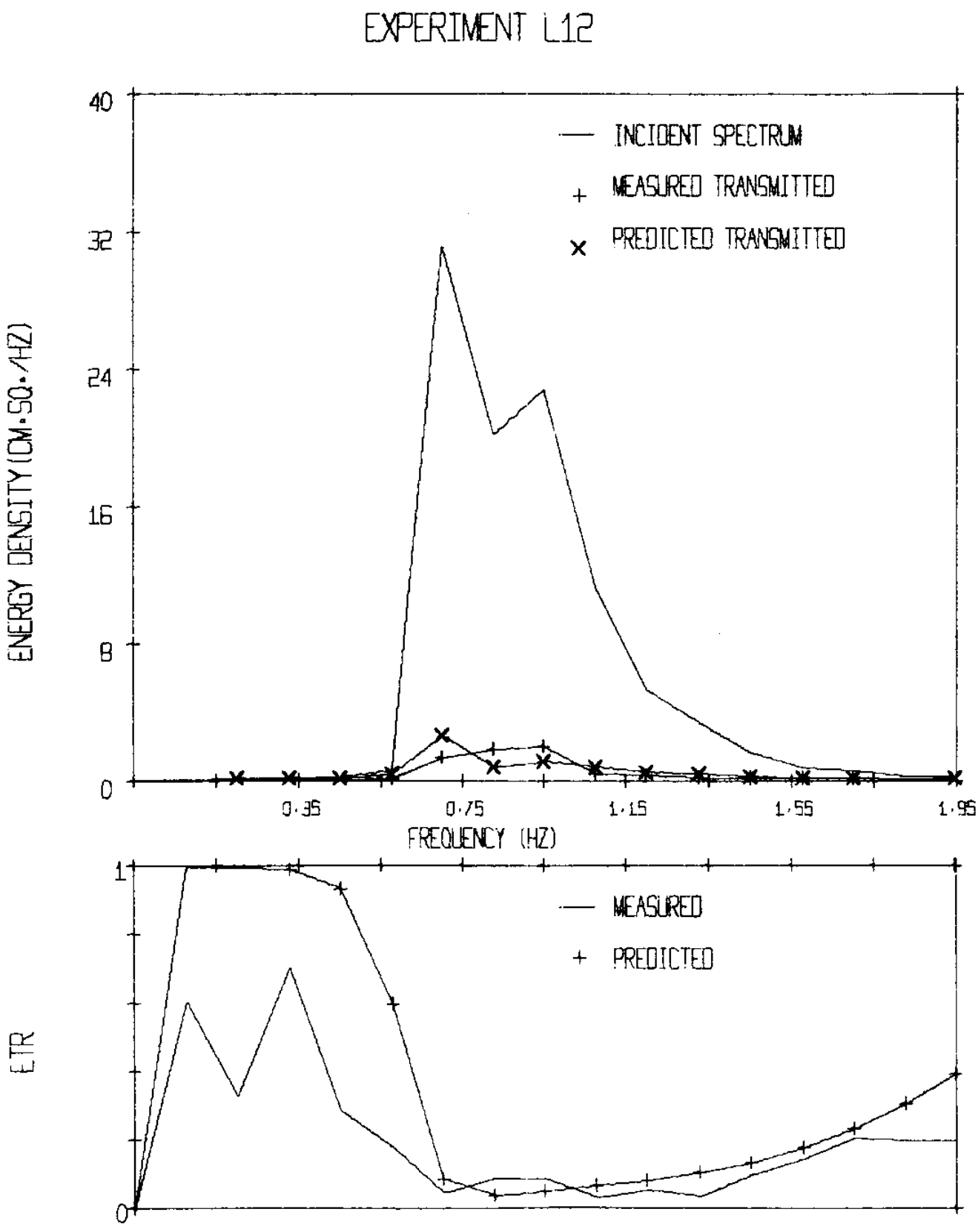
EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.075
HEIGHT TRANSMISSION FACTOR = 0.274
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 2.7

RMS ERROR = 0.065


EXPERIMENT L12
ENERGY DENSITY (CM·SQ·/HZ)
40
32
24
16
8
0
INCIDENT SPECTRUM
MEASURED TRANSMITTED
PREDICTED TRANSMITTED
0·35
0·75
1·15
1·55
1·95
FREQUENCY (HZ)
ETR
1
0
MEASURED
PREDICTED

EXPERIMENT L13

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.16 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

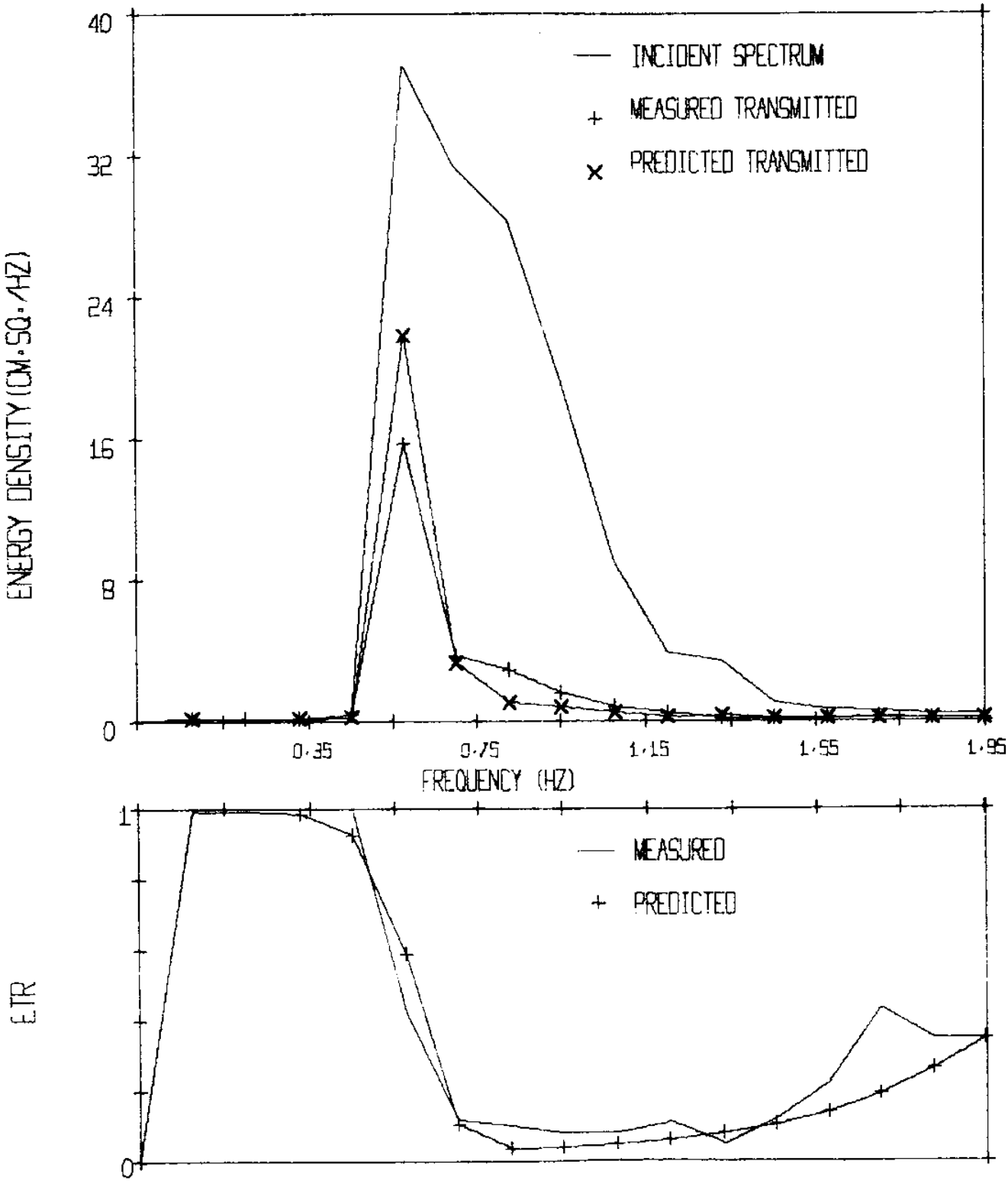
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.212
HEIGHT TRANSMISSION FACTOR = 0.460
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 5.3

RMS ERROR = 0.109

EXPERIMENT L13



EXPERIMENT L14

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	7.62 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

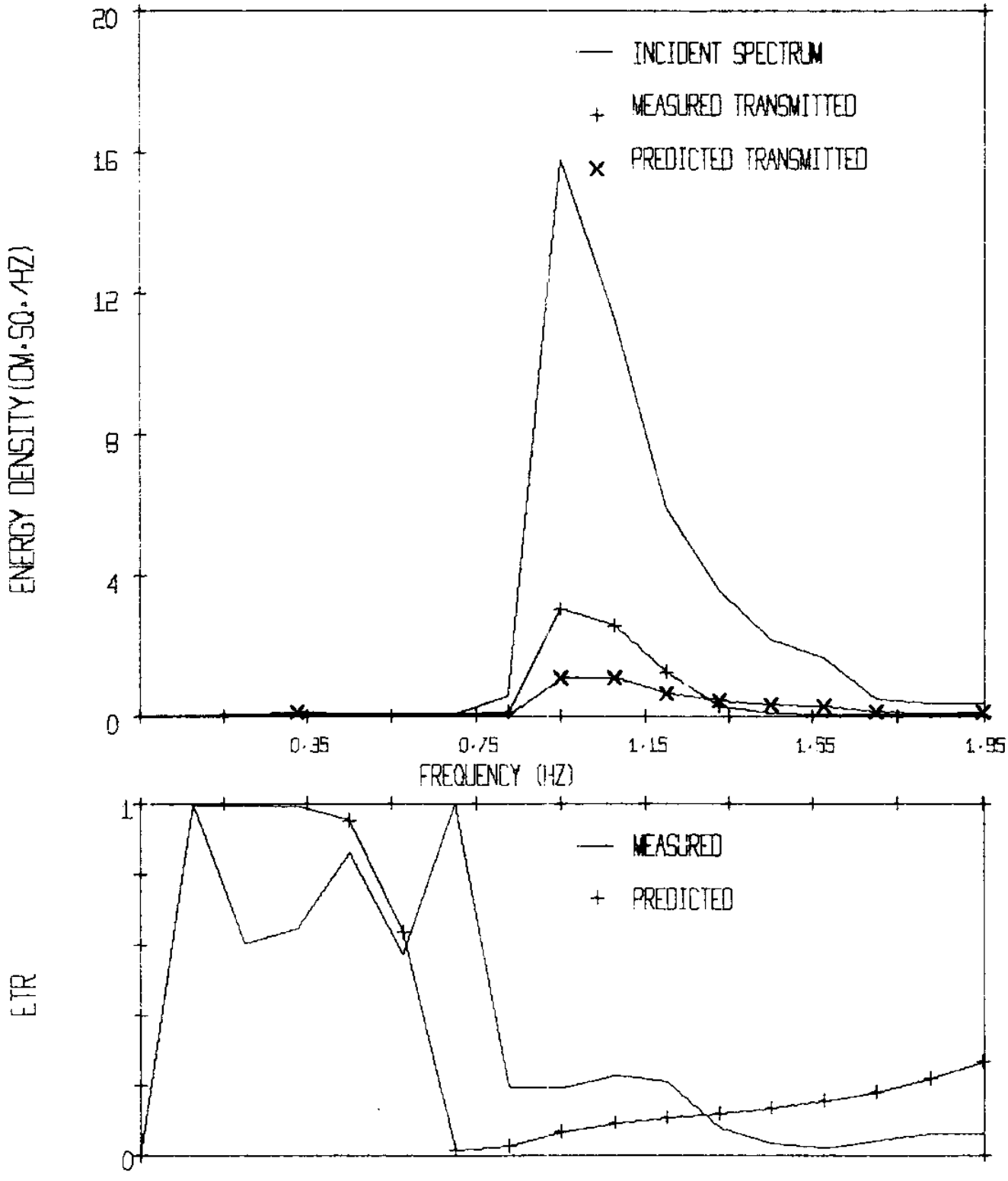
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.100
HEIGHT TRANSMISSION FACTOR = 0.316
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 2.0

RMS ERROR = 0.082

EXPERIMENT L14



EXPERIMENT L15

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 7.62 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

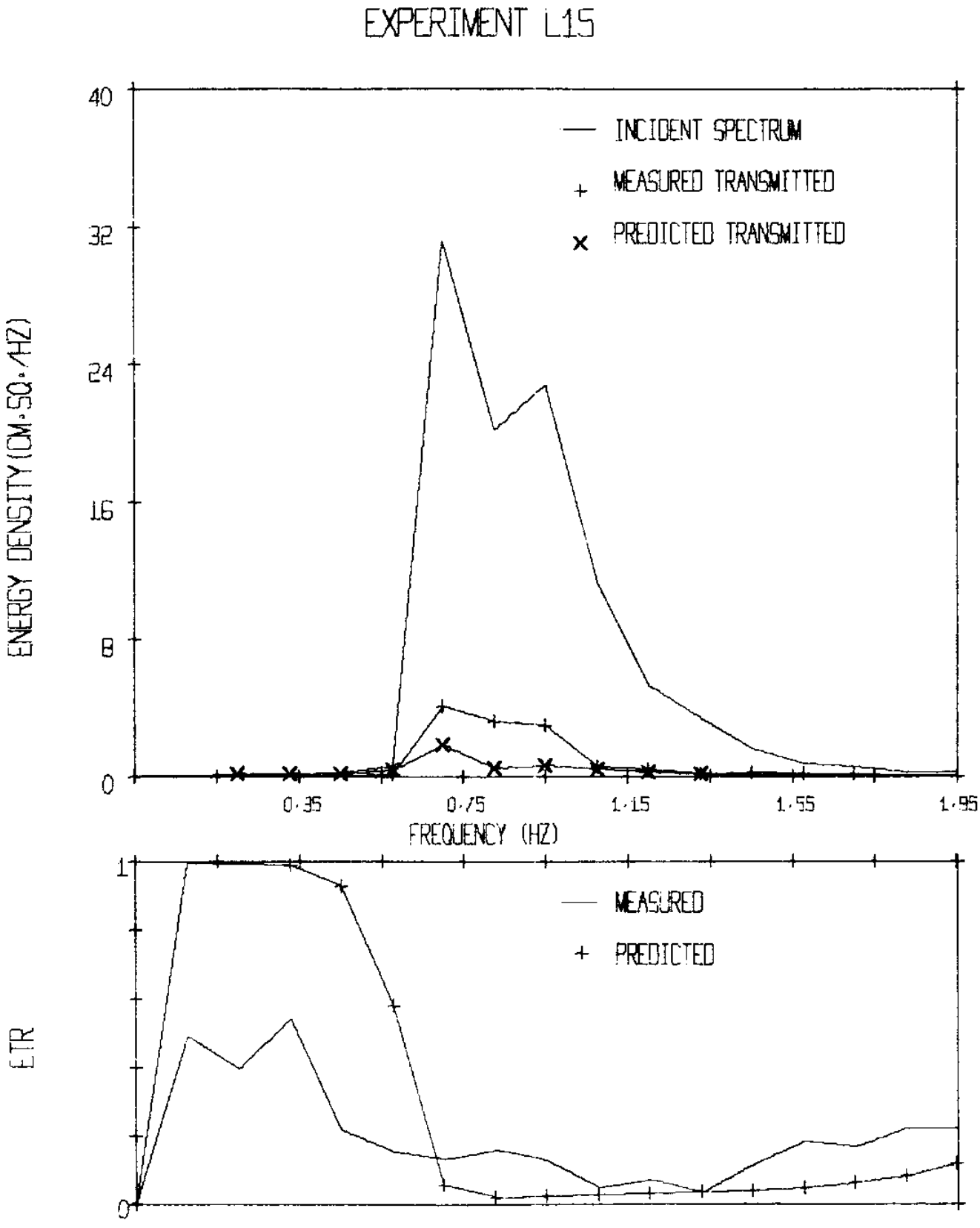
EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.044
HEIGHT TRANSMISSION FACTOR = 0.212
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 2.1

RMS ERROR = 0.110


EXPERIMENT L15
INCIDENT SPECTRUM
MEASURED TRANSMITTED
PREDICTED TRANSMITTED
ENERGY DENSITY(CM-SQ-/HZ)
40
32
24
16
8
0
0.35
0.75
1.15
1.55
1.95
FREQUENCY (HZ)
ETR
MEASURED
PREDICTED
1
0

EXPERIMENT L16

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 7.62 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

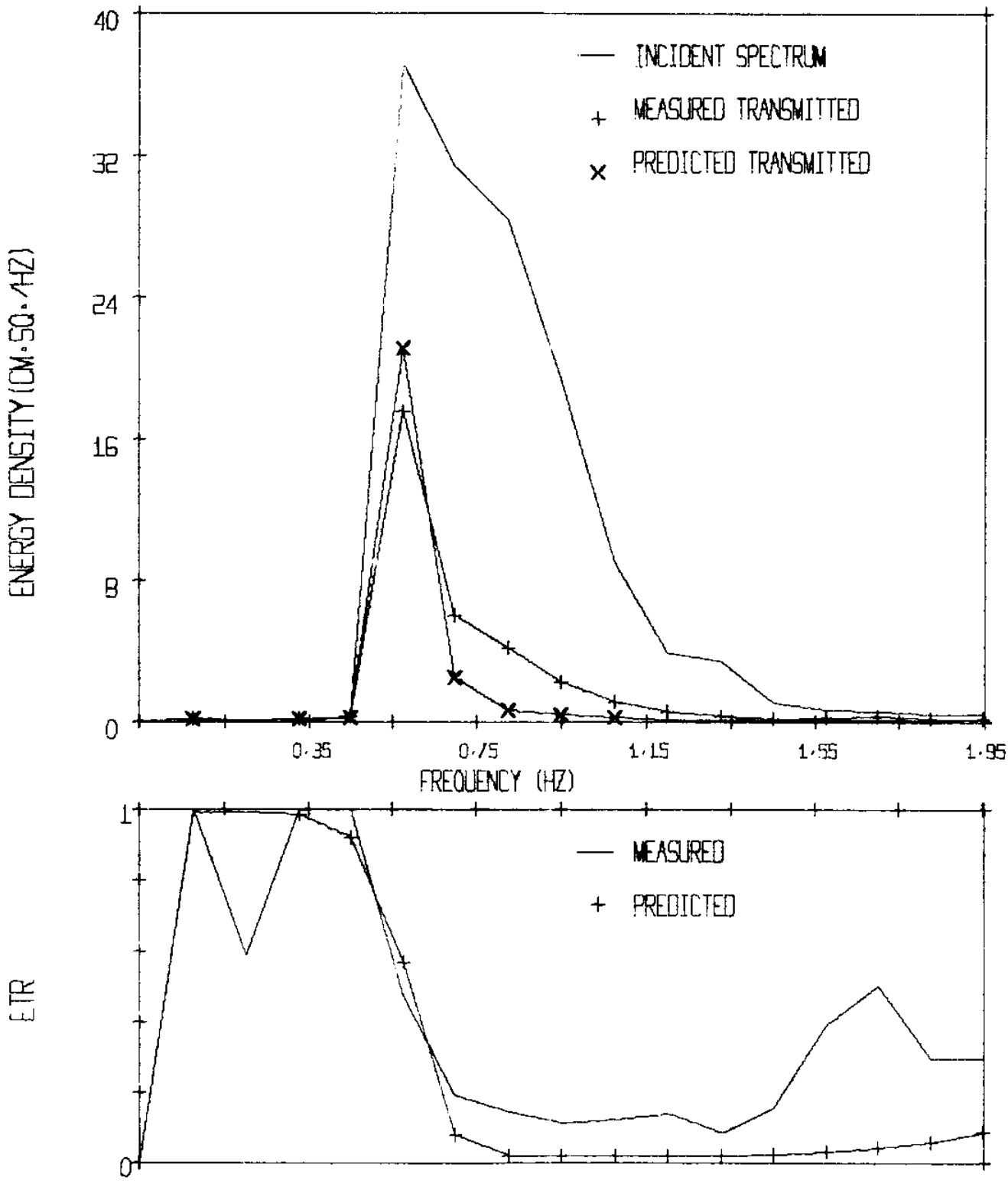
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.187
HEIGHT TRANSMISSION FACTOR = 0.432
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 5.0

RMS ERROR = 0.098

EXPERIMENT L16



EXPERIMENT L17

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	134.6
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	10.16 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

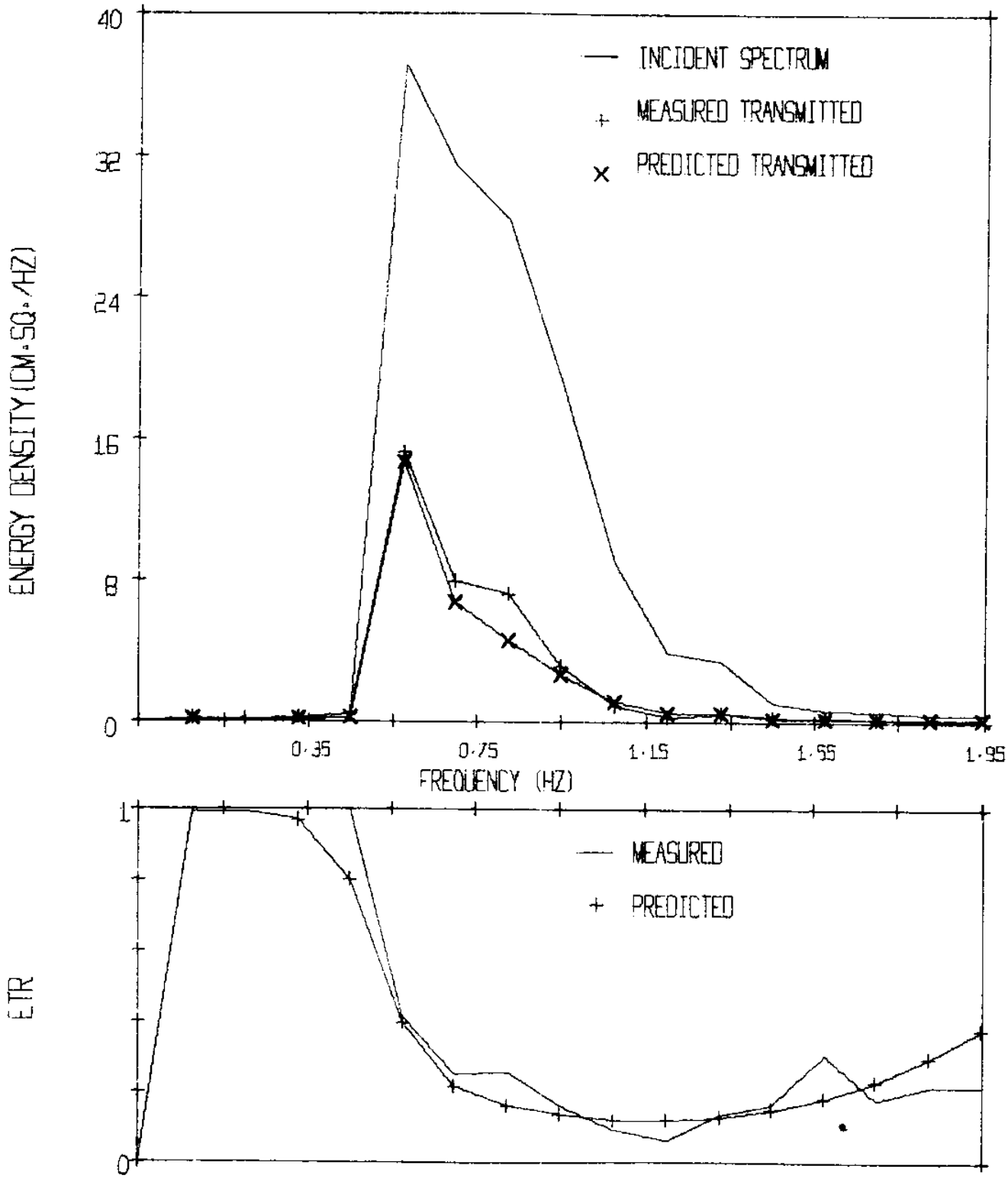
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.232
HEIGHT TRANSMISSION FACTOR = 0.482
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 5.6

RMS ERROR = 0.044

EXPERIMENT L17



EXPERIMENT L18

FLOAT DIAMETER = 15.24 CM	EFFECTIVE TETHER LENGTH = 134.6
X-SECTIONAL AREA = 182.4 CM.SQ.	VOLUME = 1853.3 CC
FLOAT SPACING = 30.48 CM	FLOAT DENSITY = 0.0400 GM/CC
DEPTH TO C.L. = 10.16 CM	WATER DEPTH = 177.8 CM
DELTF = 0.1250	NO. BANDS = 16
CD = 0.550 CM = 0.550	DCD = 0.450

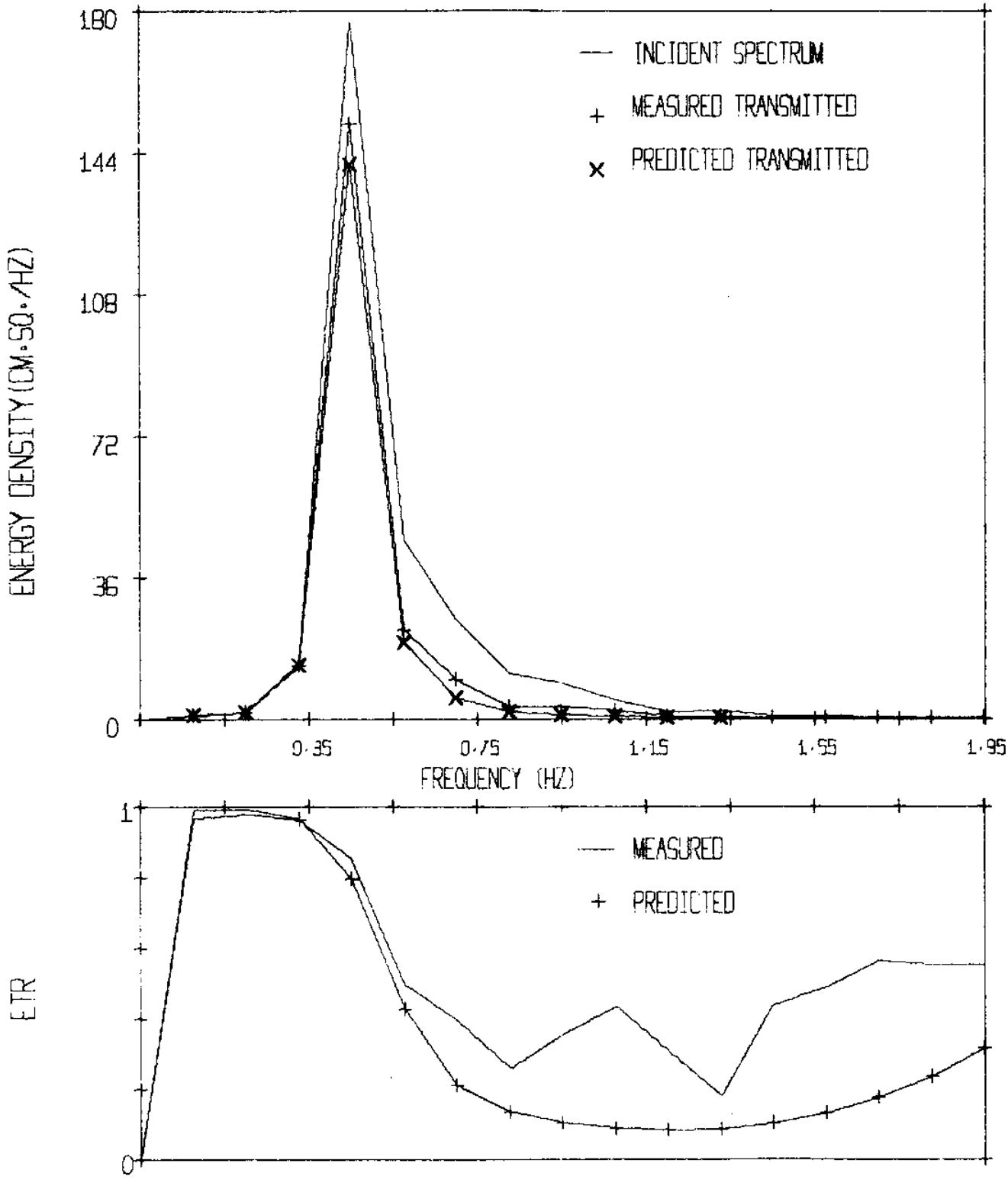
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.628
HEIGHT TRANSMISSION FACTOR = 0.793
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 17.1
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 13.6

RMS ERROR = 0.073

EXPERIMENT _18



EXPERIMENT L19

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	134.6
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	10.16 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

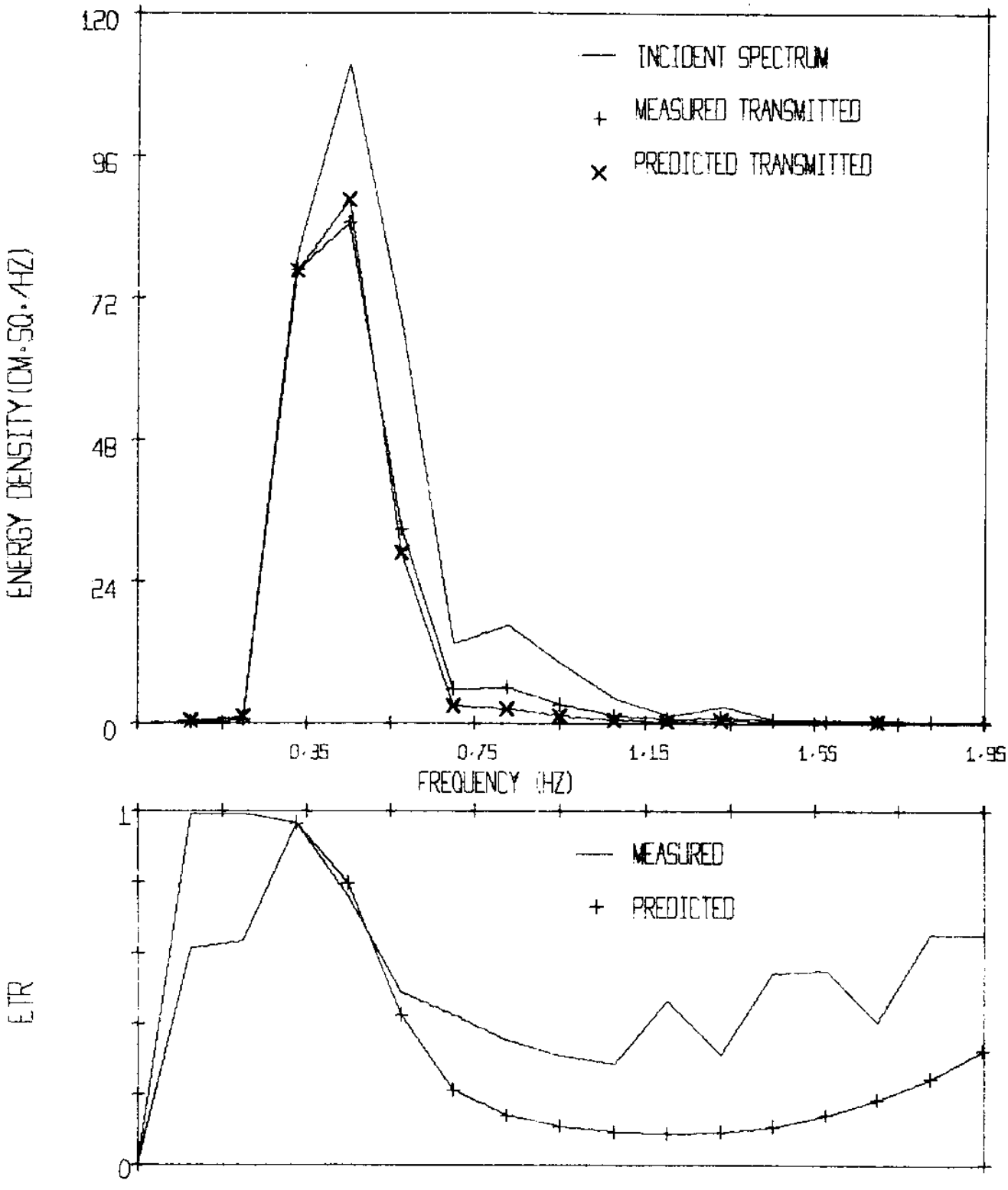
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.654
HEIGHT TRANSMISSION FACTOR = 0.808
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 17.5
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 14.2

RMS ERROR = 0.046

EXPERIMENT L19



EXPERIMENT L20

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.16 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

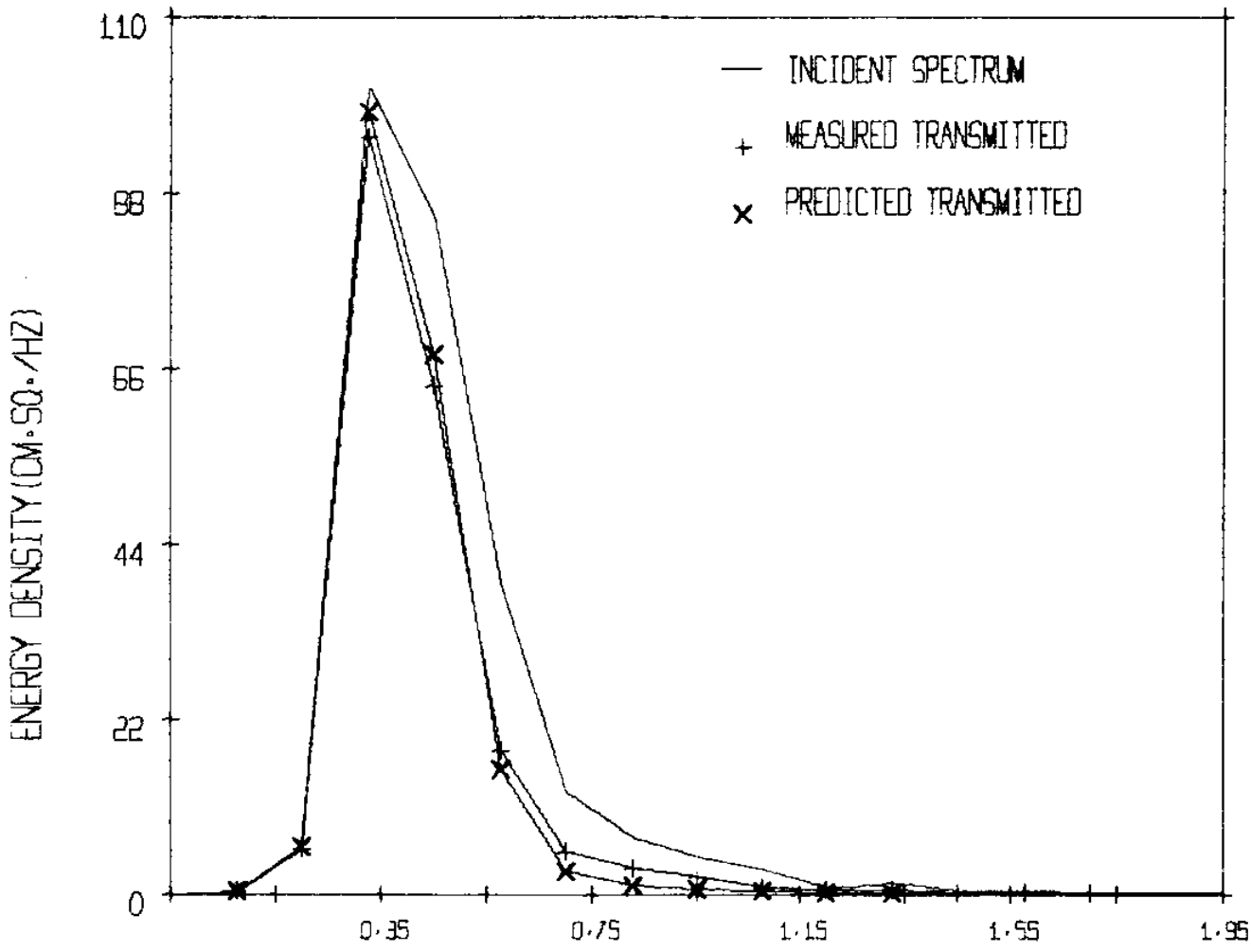
NUMBER OF ROWS = 11

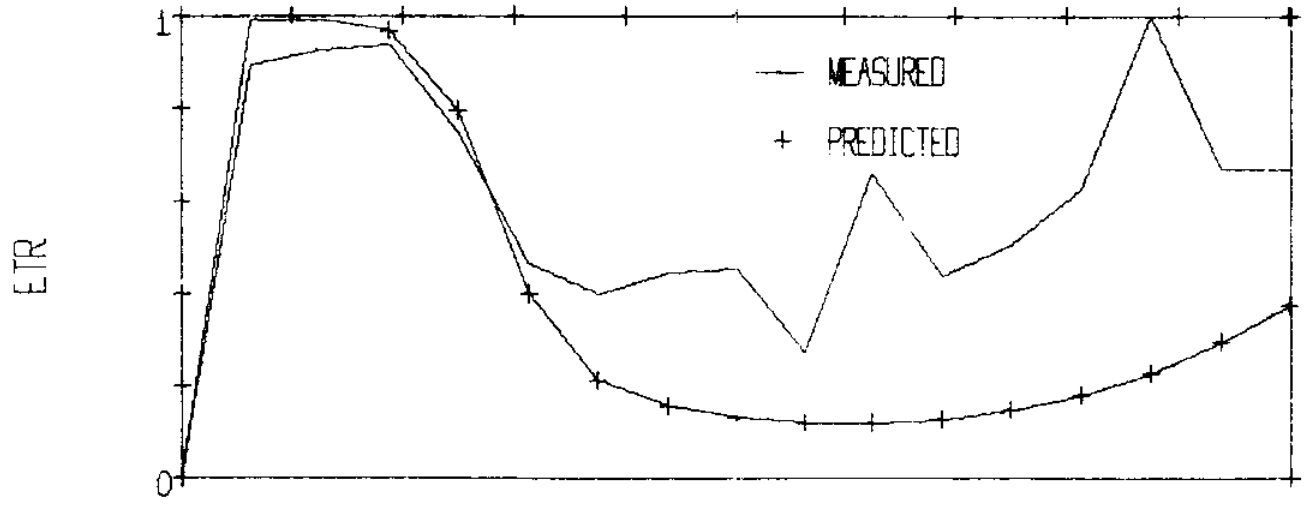
PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.737
HEIGHT TRANSMISSION FACTOR = 0.858
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 16.1
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 13.8

RMS ERROR = 0.042

EXPERIMENT L20





EXPERIMENT L21

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.16 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550
EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

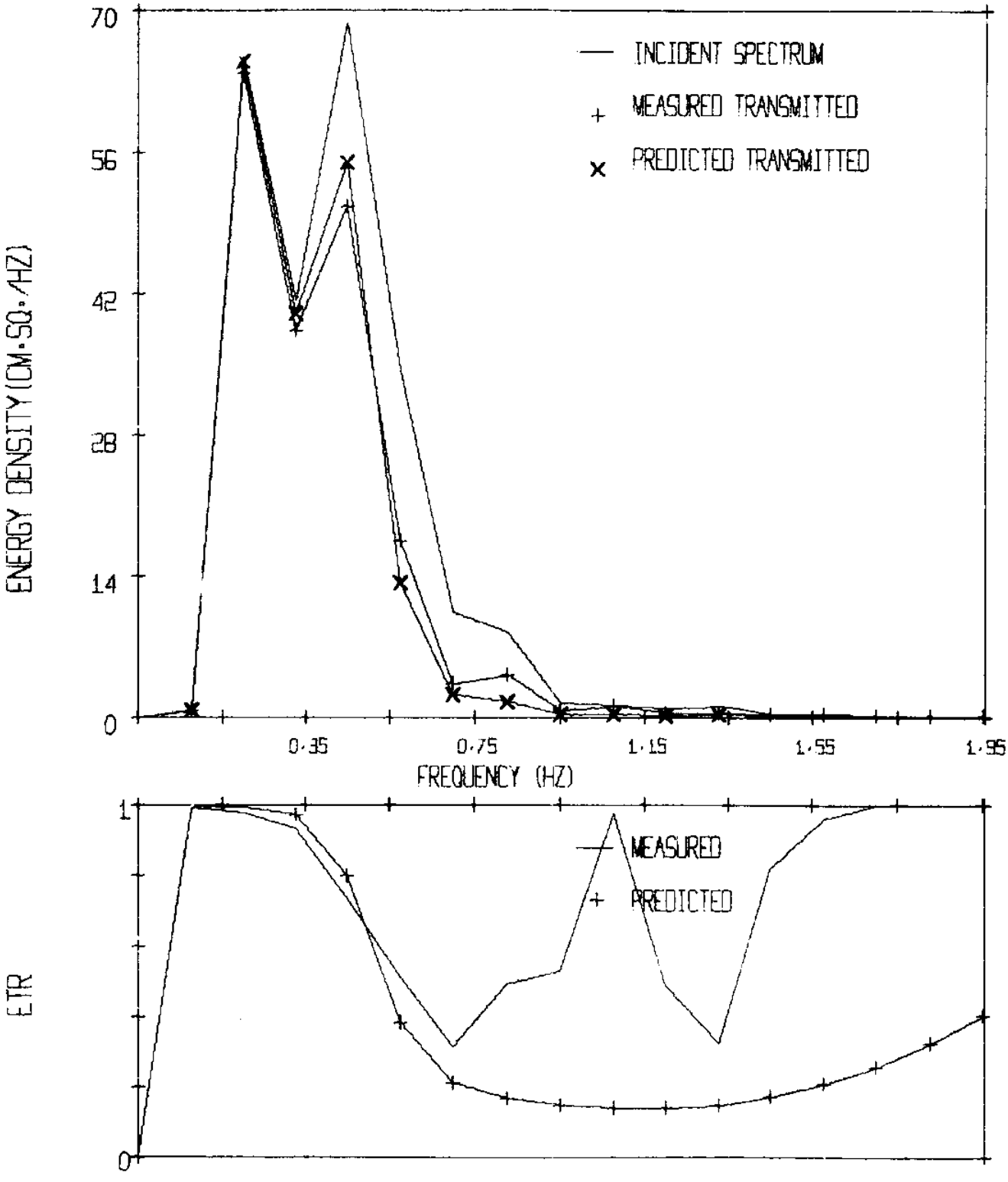
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.762
HEIGHT TRANSMISSION FACTOR = 0.873
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 15.2
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 13.3

RMS ERROR = 0.047

EXPERIMENT L21



EXPERIMENT L22

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.80 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

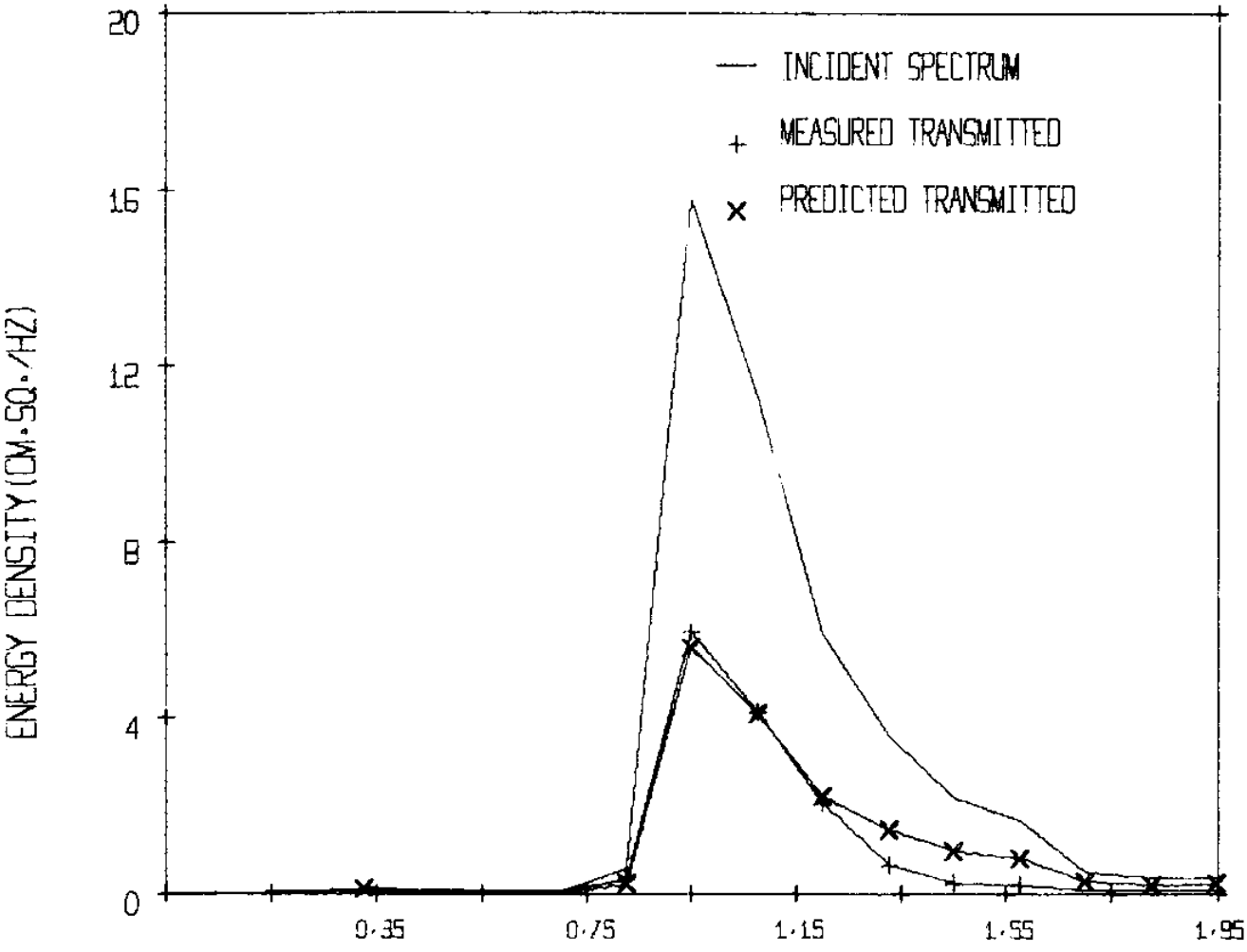
NUMBER OF ROWS = 10

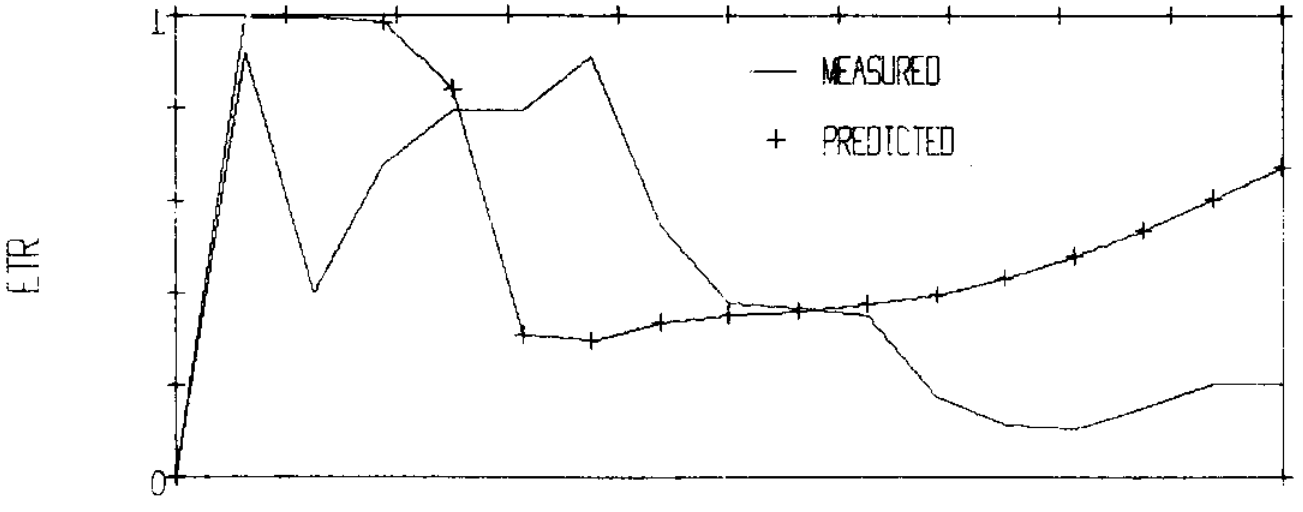
PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.380
HEIGHT TRANSMISSION FACTOR = 0.616
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 4.0

RMS ERROR = 0.031

EXPERIMENT L22





EXPERIMENT L23

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.80 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

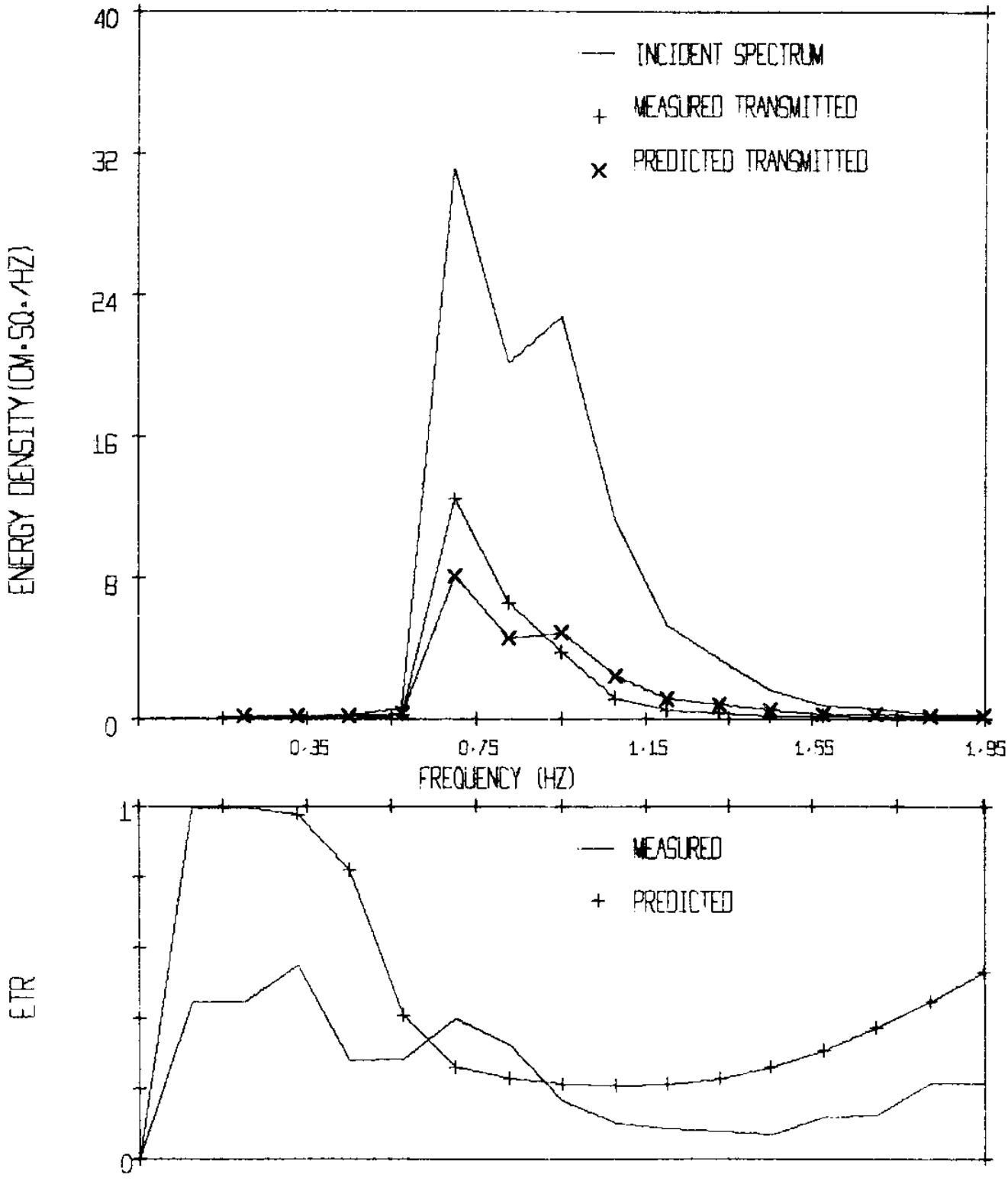
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.238
HEIGHT TRANSMISSION FACTOR = 0.488
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 4.8

RMS ERROR = 0.090

EXPERIMENT L23



EXPERIMENT L24

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.80 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

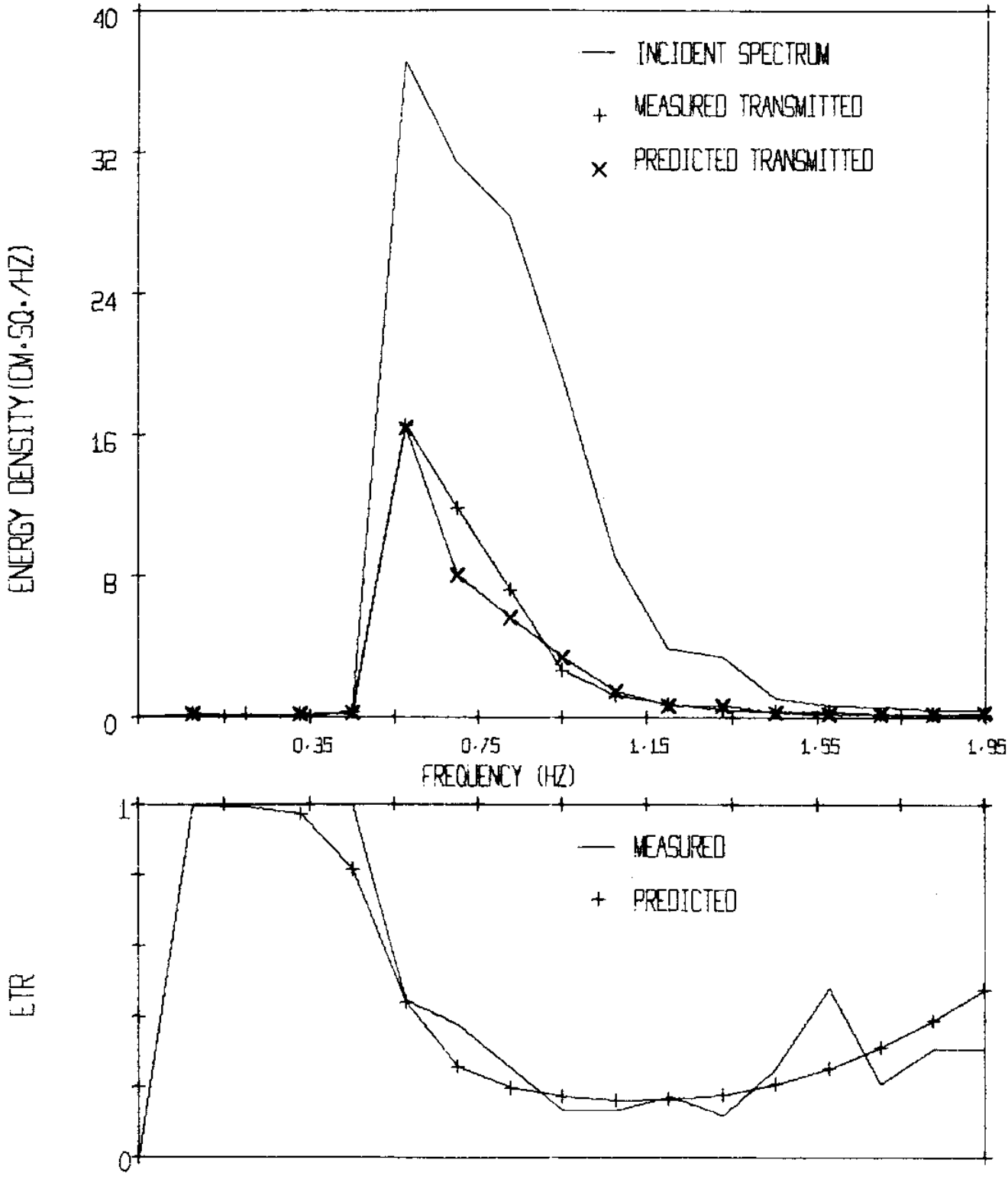
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.274
HEIGHT TRANSMISSION FACTOR = 0.523
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 6.0

RMS ERROR = 0.057

EXPERIMENT L24



EXPERIMENT L25

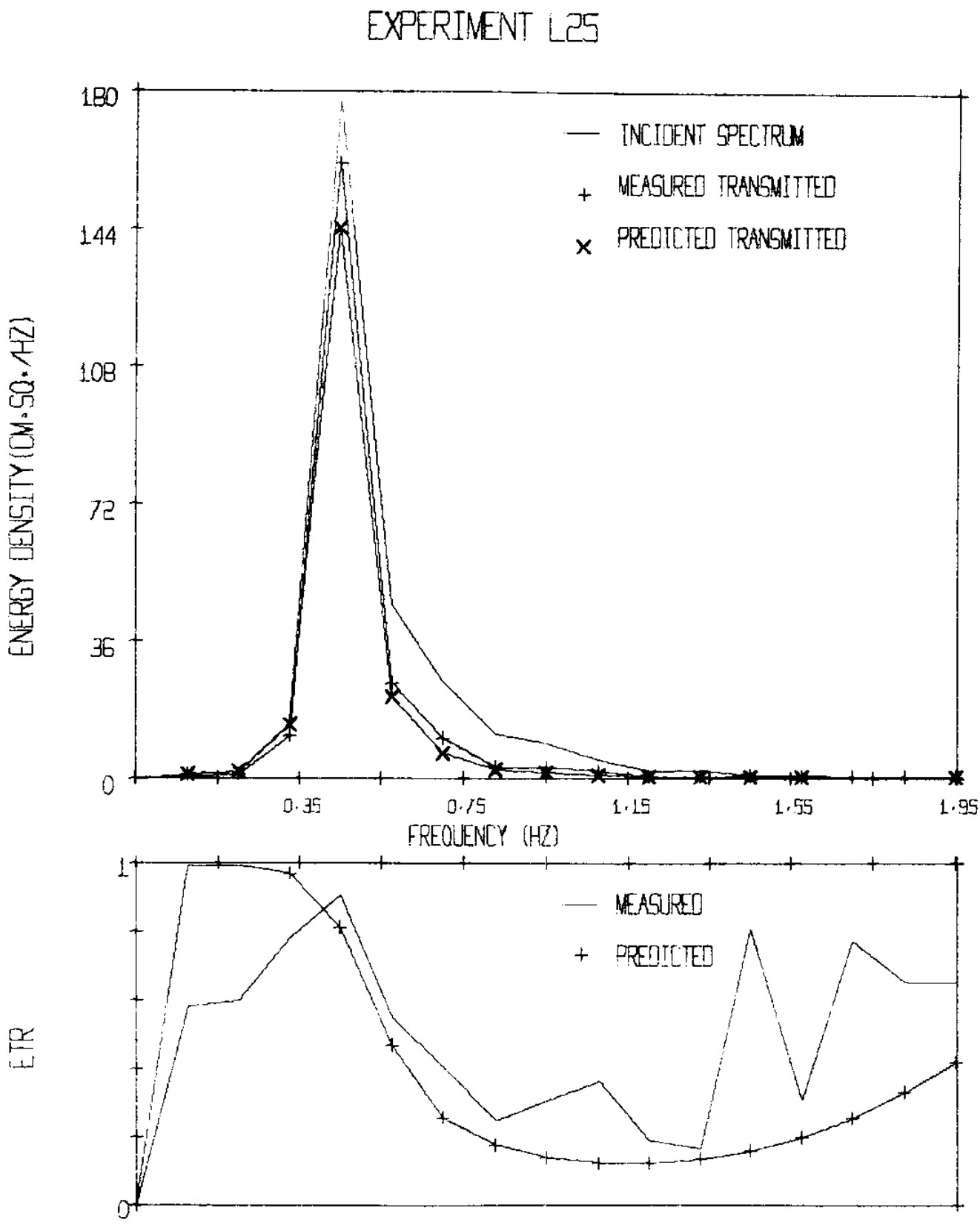
FLOAT DIAMETER = 15.24 CM	EFFECTIVE TETHER LENGTH = 134.6
X-SECTIONAL AREA = 182.4 CM.SQ.	VOLUME = 1853.3 CC
FLOAT SPACING = 30.48 CM	FLOAT DENSITY = 0.0400 GM/CC
DEPTH TO C.L. = 10.80 CM	WATER DEPTH = 177.8 CM
DELTF = 0.1250	NO. BANDS = 16
CD = 0.550 CM = 0.550	DCD = 0.450

NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.654
HEIGHT TRANSMISSION FACTOR = 0.808
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 17.1
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 13.8

RMS ERROR = 0.107


EXPERIMENT L25
180
144
108
72
36
0
ENERGY DENSITY (OM·SQ·/HZ)
INCIDENT SPECTRUM
MEASURED TRANSMITTED
PREDICTED TRANSMITTED
0.35
0.75
1.15
1.55
1.95
FREQUENCY (HZ)
1
0
ETR
MEASURED
PREDICTED

EXPERIMENT L26

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.80 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

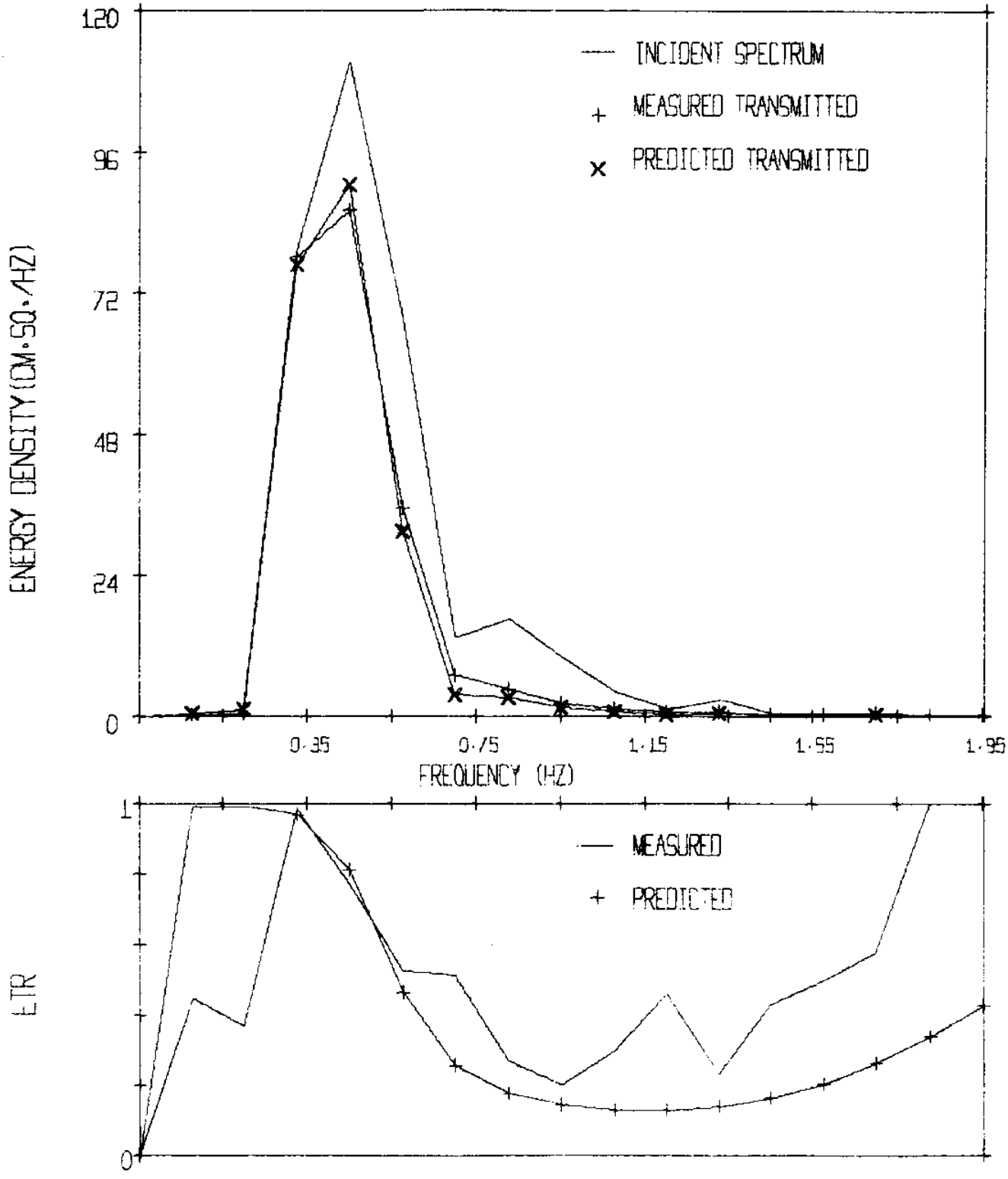
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.677
HEIGHT TRANSMISSION FACTOR = 0.823
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 17.5
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 14.4

RMS ERROR = 0.043

EXPERIMENT L26



EXPERIMENT L27

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	134.6
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	10.80 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

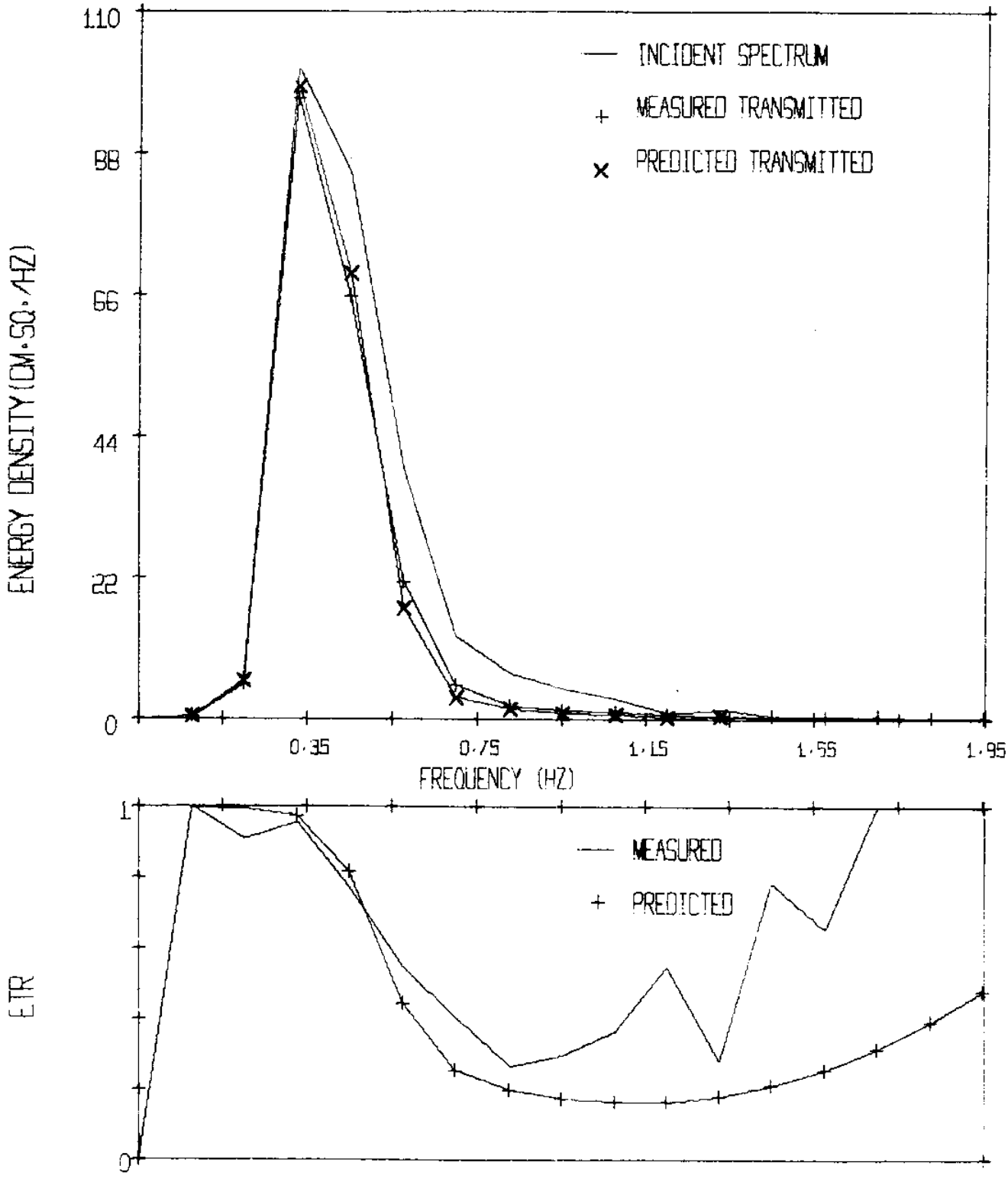
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.755
HEIGHT TRANSMISSION FACTOR =	0.869
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	16.1
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	14.0

RMS ERROR = 0.038

EXPERIMENT L27



EXPERIMENT L28

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 10.60 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 134.6
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

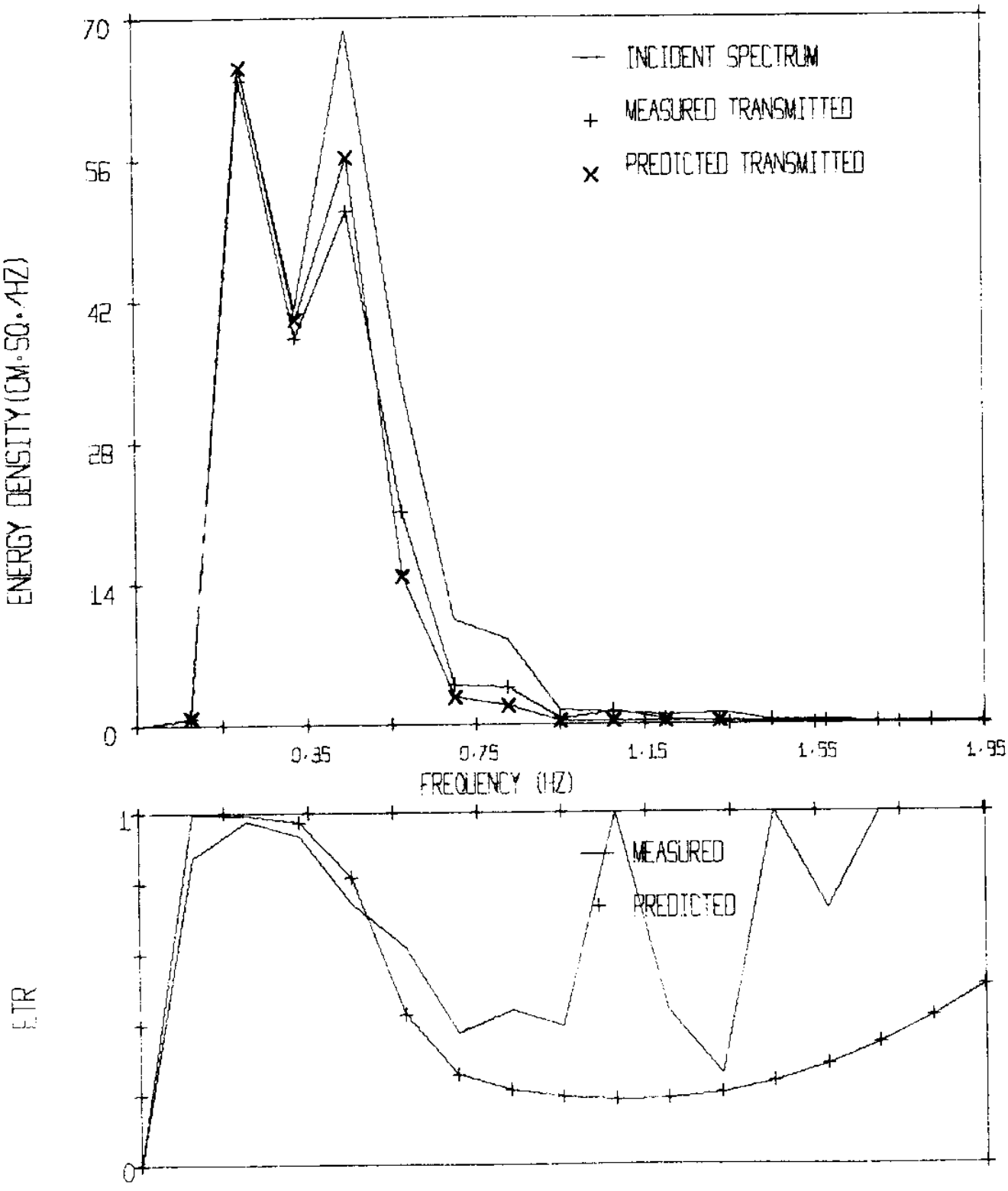
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.778
HEIGHT TRANSMISSION FACTOR = 0.882
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 15.2
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 13.4

RMS ERROR = 0.058

EXPERIMENT L28



EXPERIMENT L29

FLOAT DIAMETER = 15.24 CM	EFFECTIVE TETHER LENGTH = 83.8
X-SECTIONAL AREA = 182.4 CM.SQ.	VOLUME = 1853.3 CC
FLOAT SPACING = 30.48 CM	FLOAT DENSITY = 0.0400 GM/CC
DEPTH TO C.L. = 12.70 CM	WATER DEPTH = 177.8 CM
DELTF = 0.1250	NO. BANDS = 16
CD = 0.550 CM = 0.550	DCD = 0.450

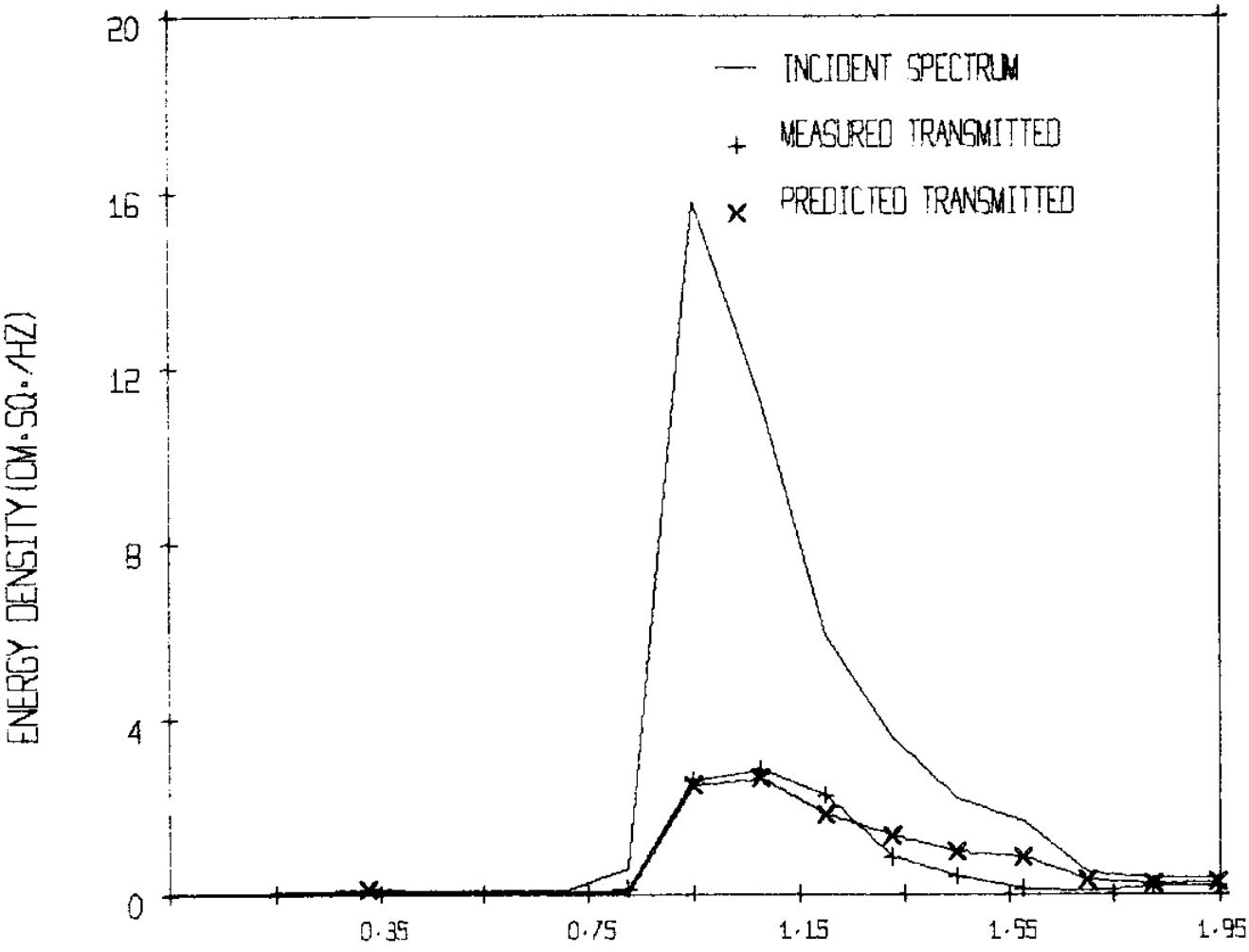
NUMBER OF ROWS = 11

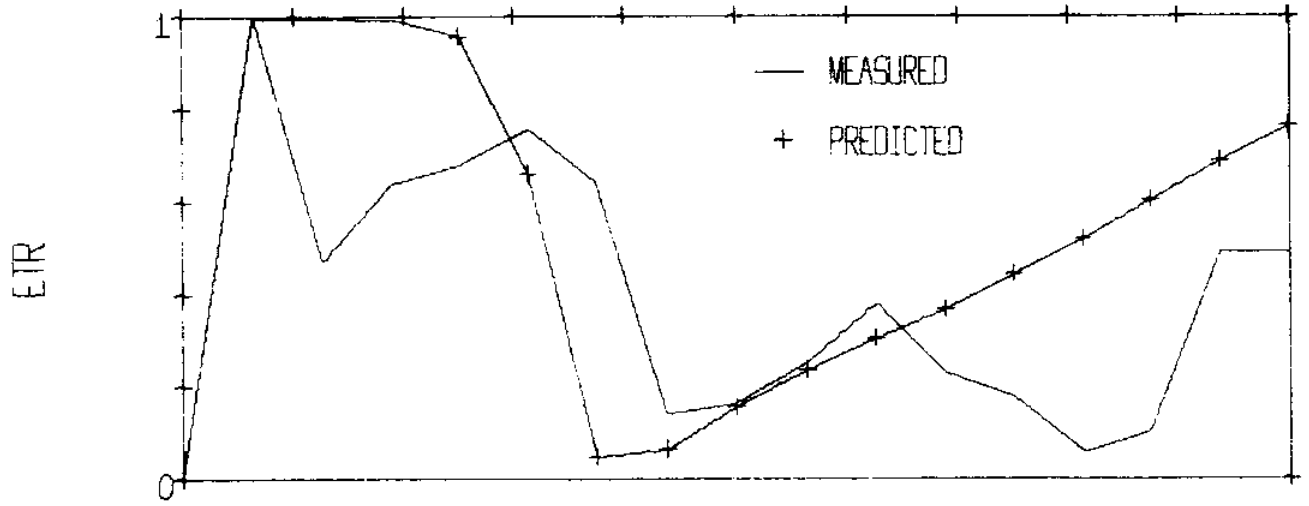
PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.260
HEIGHT TRANSMISSION FACTOR = 0.510
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 3.3

RMS ERROR = 0.034

EXPERIMENT L29





EXPERIMENT L30

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 12.70 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0400 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

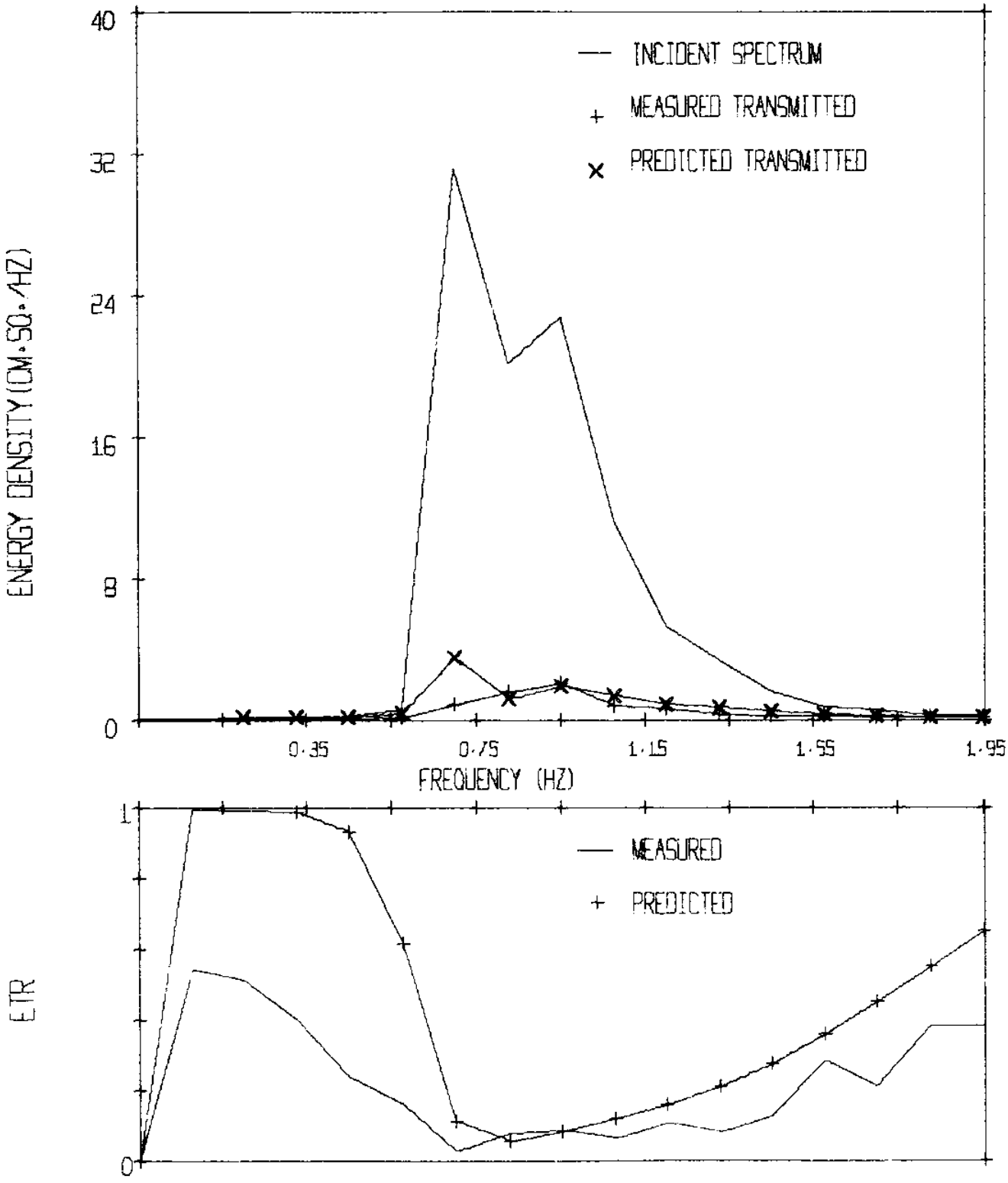
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.116
HEIGHT TRANSMISSION FACTOR = 0.341
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 3.3

RMS ERROR = 0.093

EXPERIMENT L30



EXPERIMENT L31

FLOAT DIAMETER = 15.24 CM
X-SECTIONAL AREA = 182.4 CM.SQ.
FLOAT SPACING = 30.48 CM
DEPTH TO C.L. = 12.70 CM
DELTF = 0.1250
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 83.8
VOLUME = 1853.3 CC
FLOAT DENSITY = 0.0409 GM/CC
WATER DEPTH = 177.8 CM
NO. BANDS = 16
DCD = 0.450

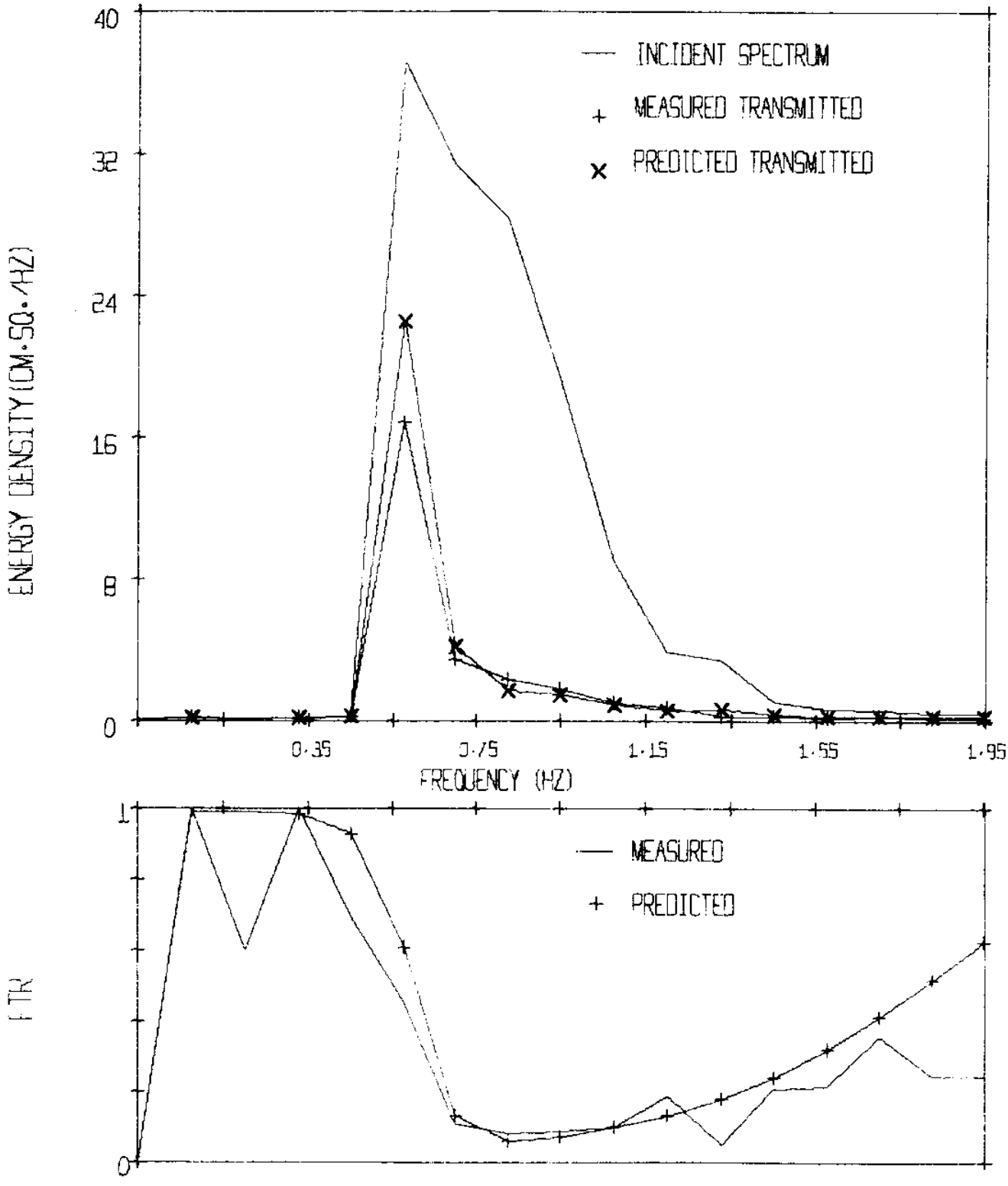
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.245
HEIGHT TRANSMISSION FACTOR = 0.495
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 5.7

RMS ERROR = 0.098

EXPERIMENT L31



EXPERIMENT L32

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	15.24 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

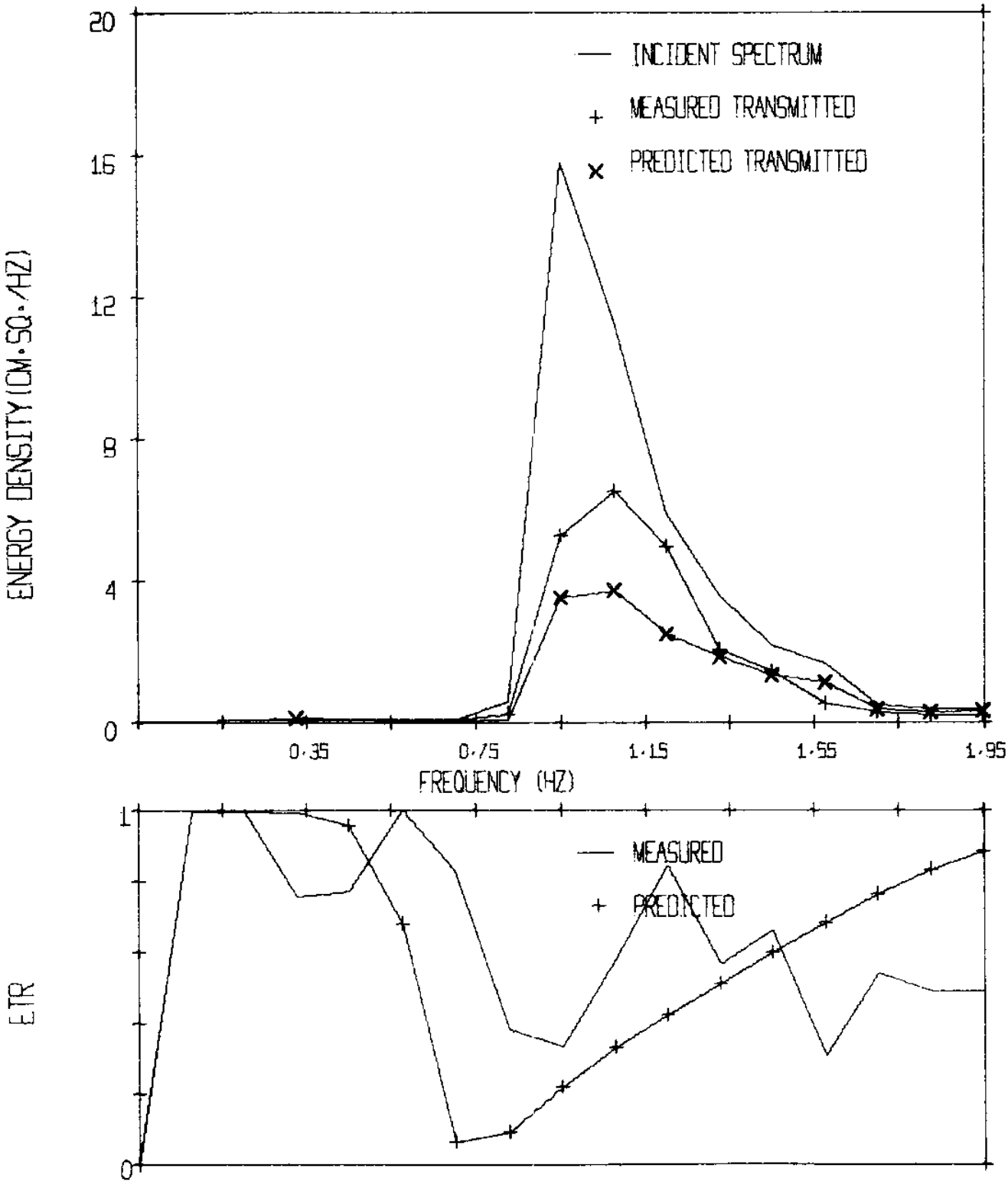
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.357
HEIGHT TRANSMISSION FACTOR = 0.598
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 6.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 3.8

RMS ERROR = 0.079

EXPERIMENT L32



EXPERIMENT L33

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	15.24 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

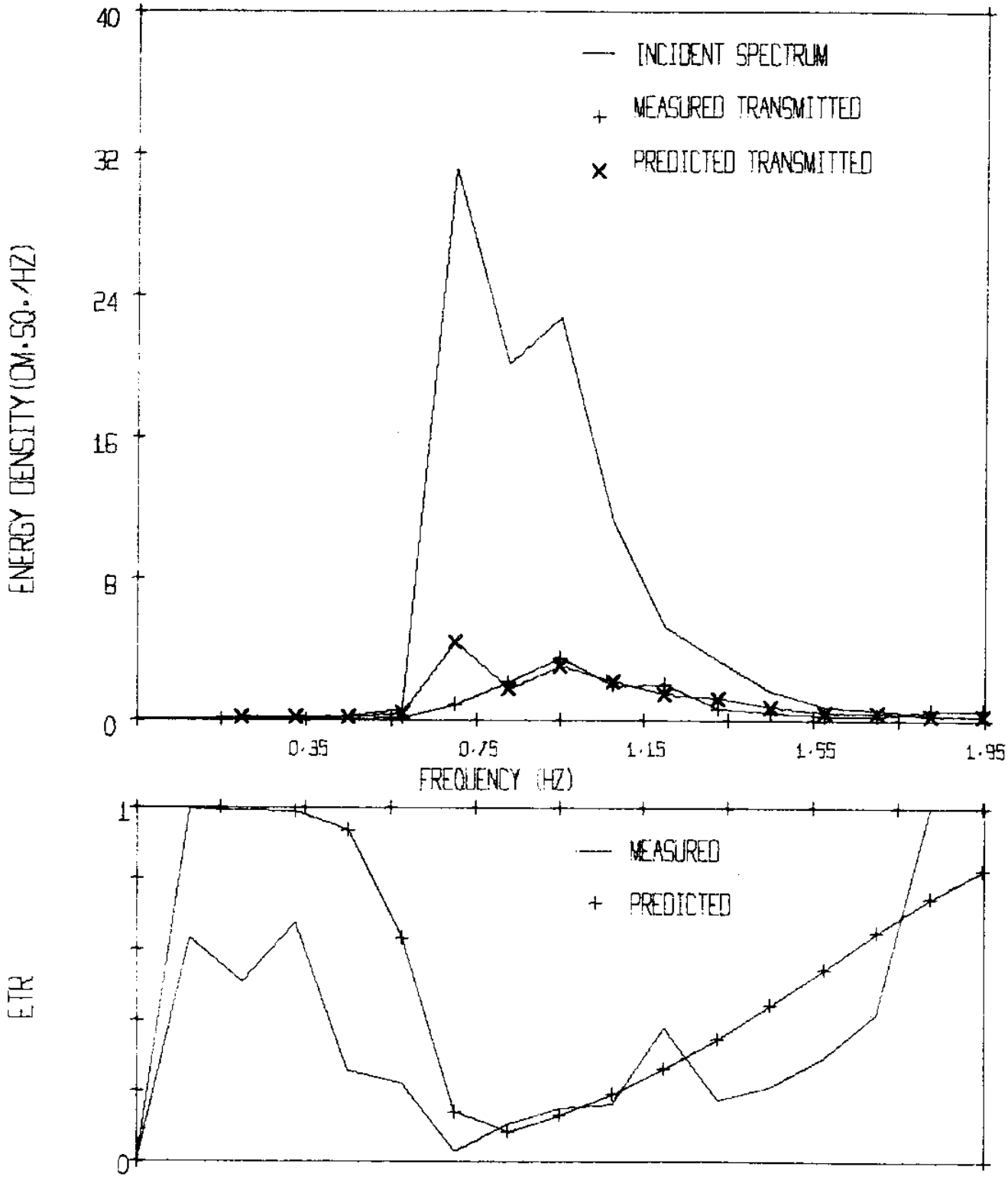
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.167
HEIGHT TRANSMISSION FACTOR =	0.408
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	9.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	4.0

RMS ERROR = 0.091

EXPERIMENT L33



EXPERIMENT L34

FLOAT DIAMETER =	15.24 CM	EFFECTIVE TETHER LENGTH =	83.8
X-SECTIONAL AREA =	182.4 CM.SQ.	VOLUME =	1853.3 CC
FLOAT SPACING =	30.48 CM	FLOAT DENSITY =	0.0400 GM/CC
DEPTH TO C.L. =	15.24 CM	WATER DEPTH =	177.8 CM
DELTF = 0.1250		NO. BANDS =	16
CD = 0.550	CM = 0.550	DCD = 0.450	

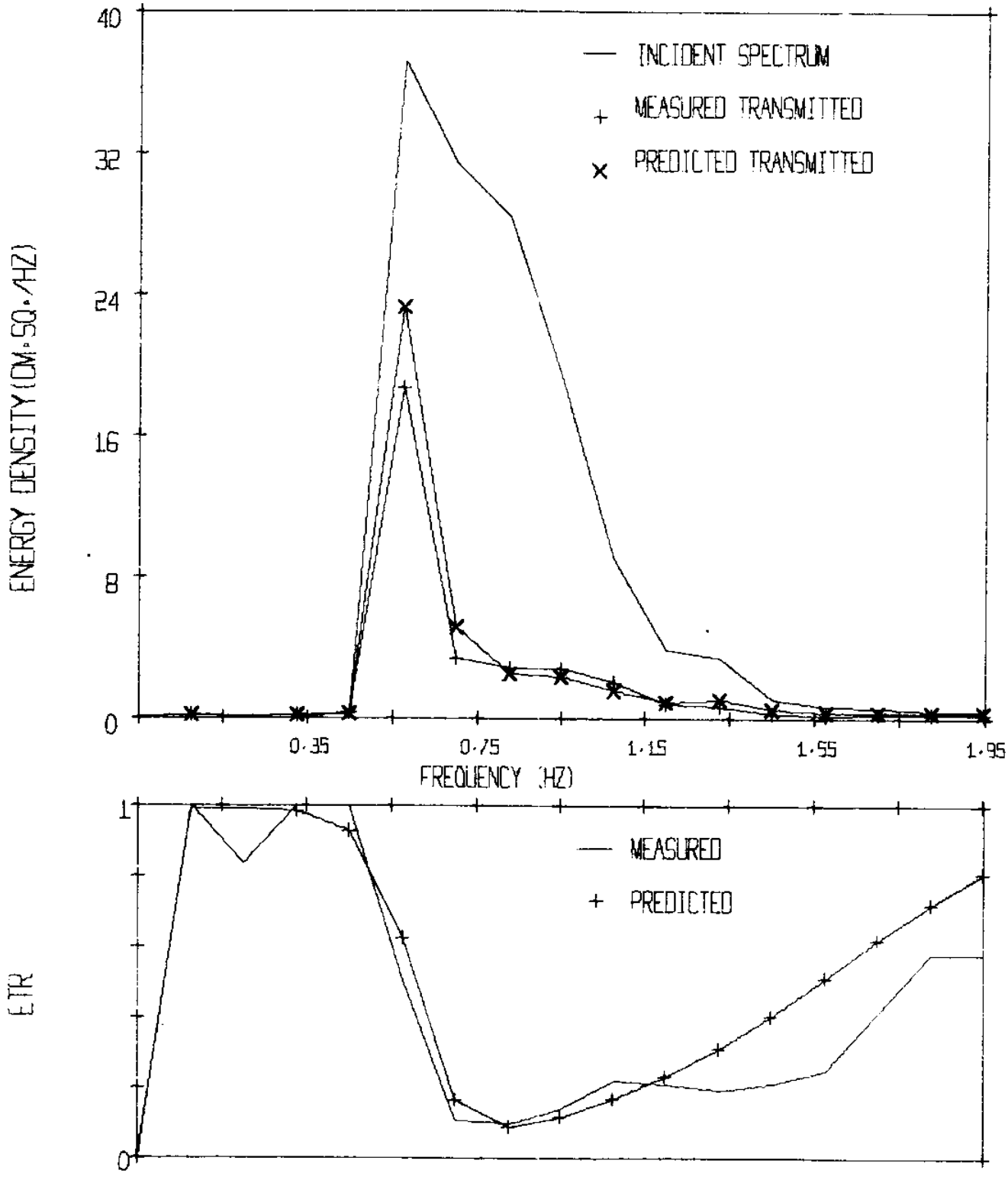
NUMBER OF ROWS = 11

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR =	0.283
HEIGHT TRANSMISSION FACTOR =	0.532
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) =	11.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) =	6.1

RMS ERROR = 0.077

EXPERIMENT L34



APPENDIX B

RESULTS OF FIELD EXPERIMENTS

EXPERIMENT S1

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CV = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

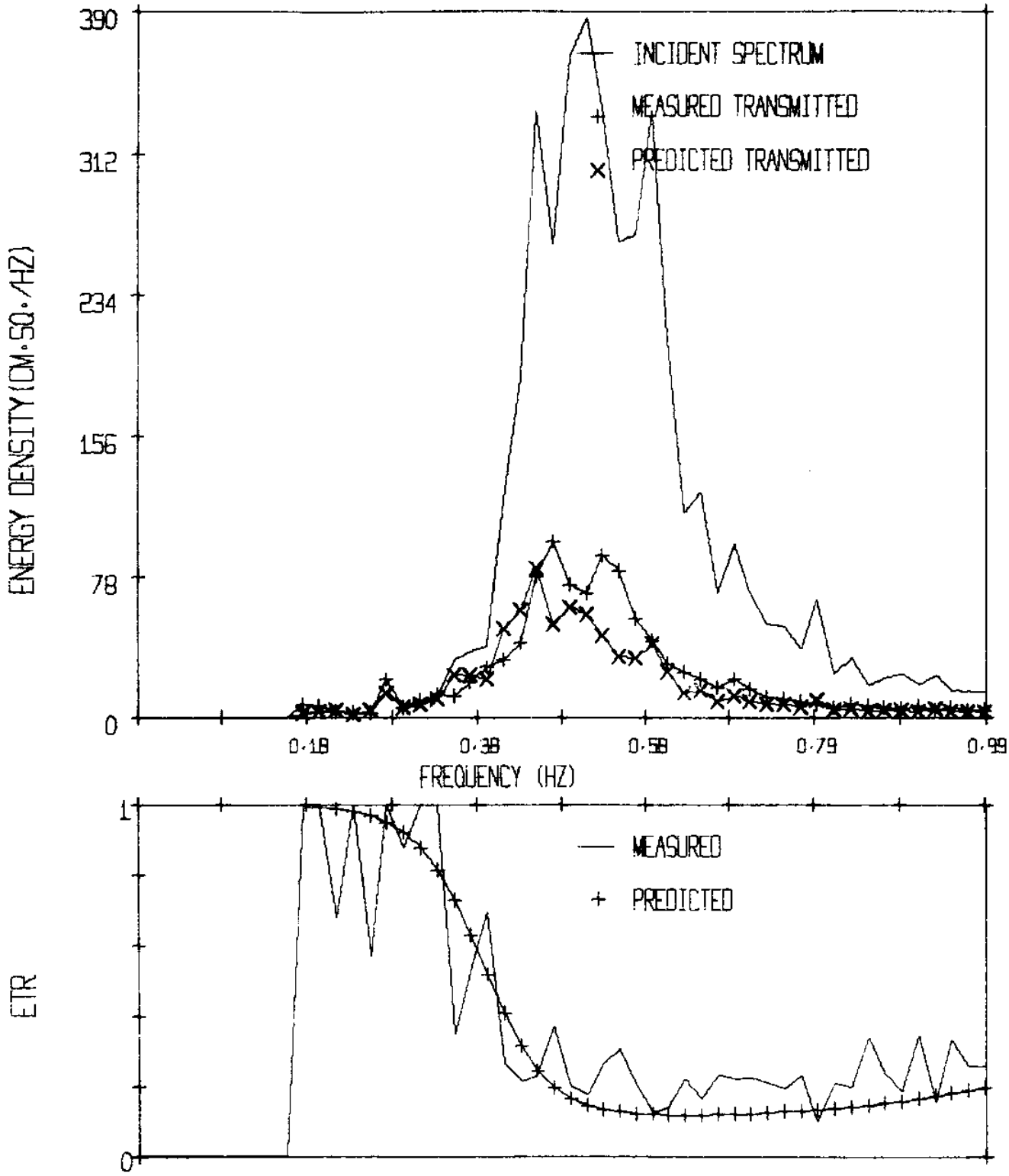
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.185
HEIGHT TRANSMISSION FACTOR = 0.430
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 25.5
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 10.9

RMS ERROR = 0.058

EXPERIMENT S1



EXPERIMENT S2

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CV = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

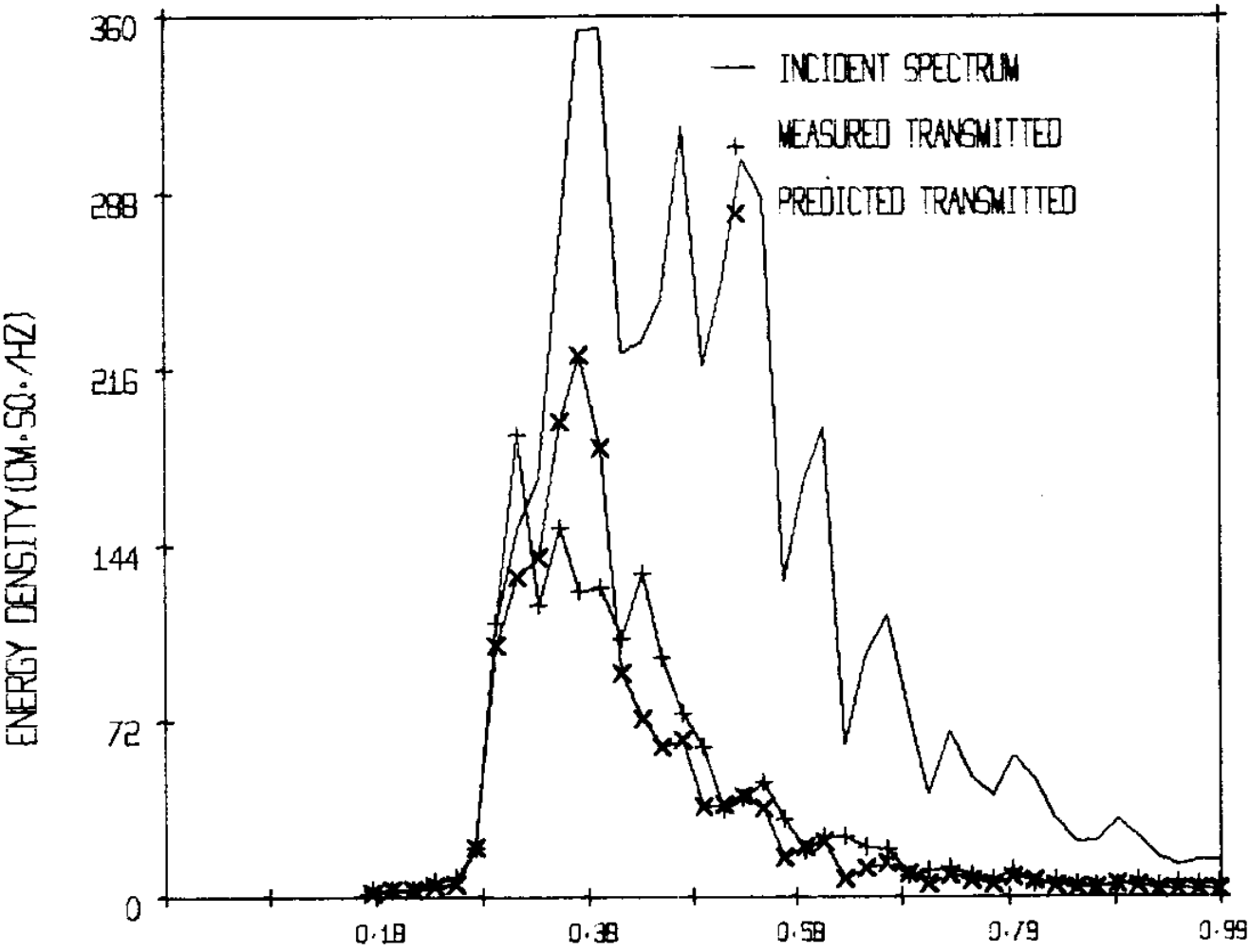
NUMBER OF ROWS = 10

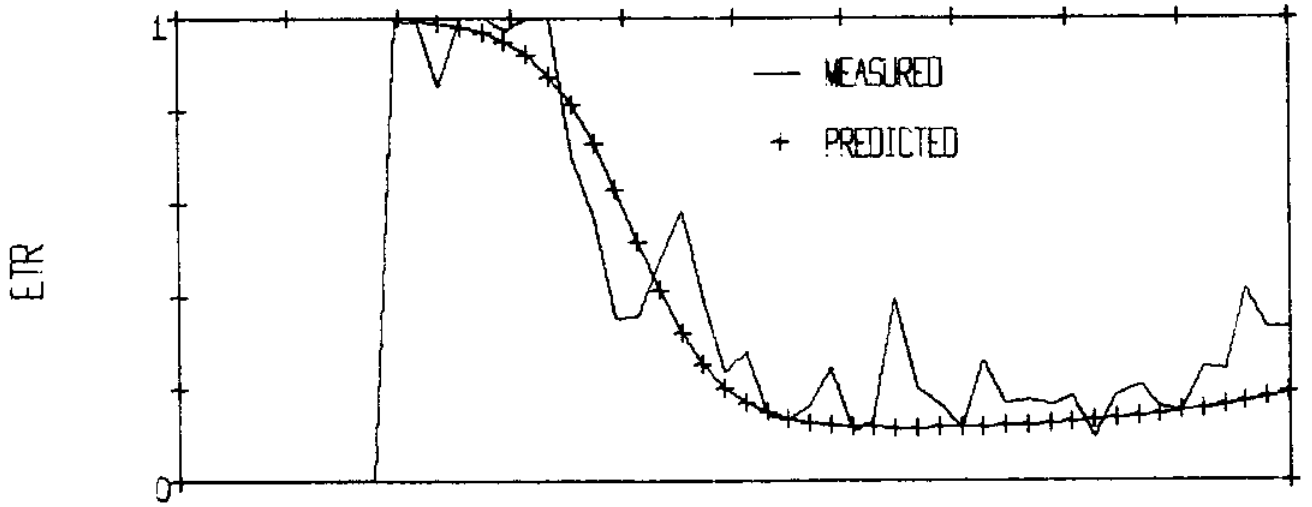
PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.332
HEIGHT TRANSMISSION FACTOR = 0.576
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 27.7
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 15.9

RMS ERROR = 0.075

EXPERIMENT S2





EXPERIMENT S3

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

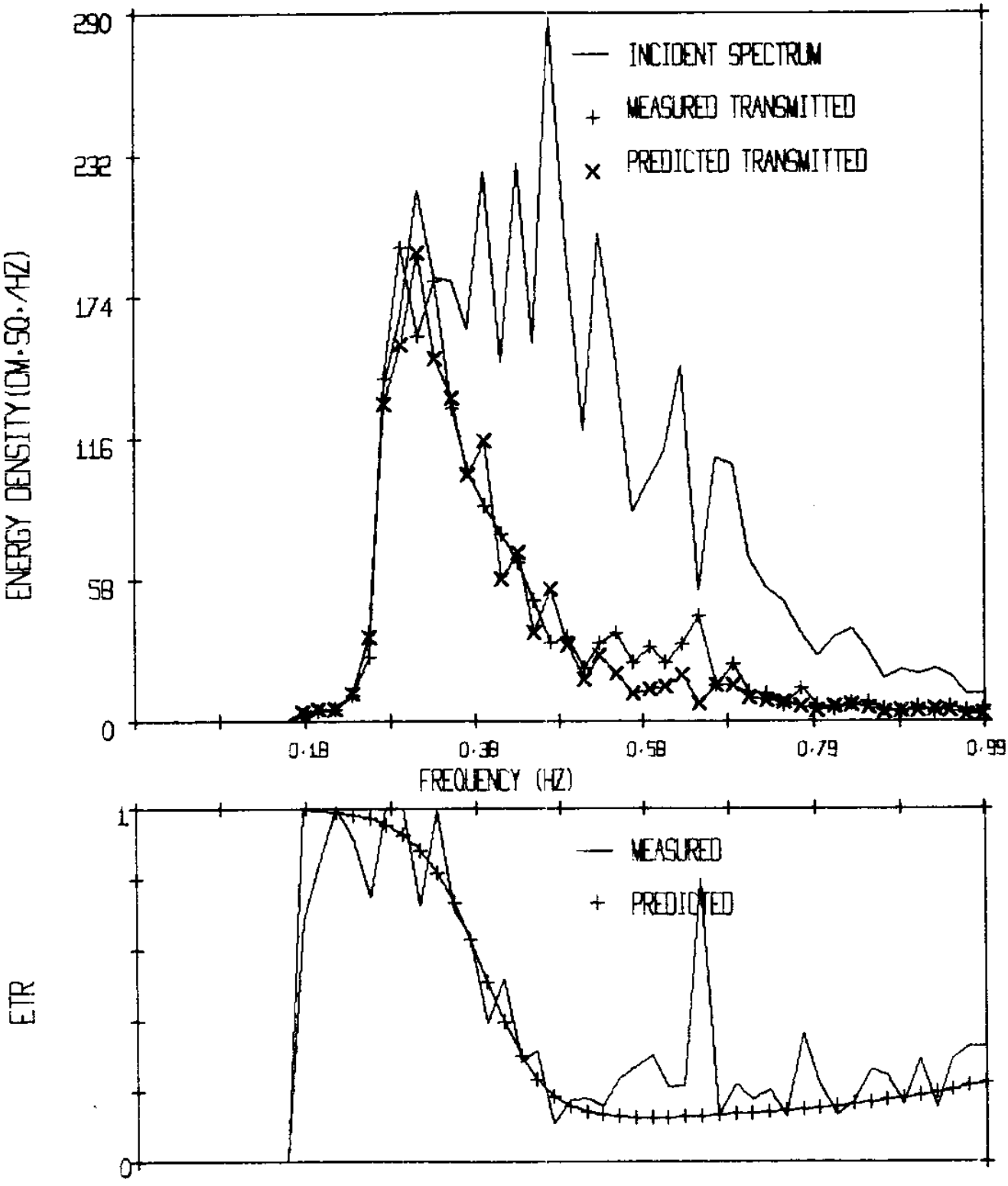
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.378
HEIGHT TRANSMISSION FACTOR = 0.615
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 25.1
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 15.4

RMS ERROR = 0.043

EXPERIMENT S3



EXPERIMENT S4

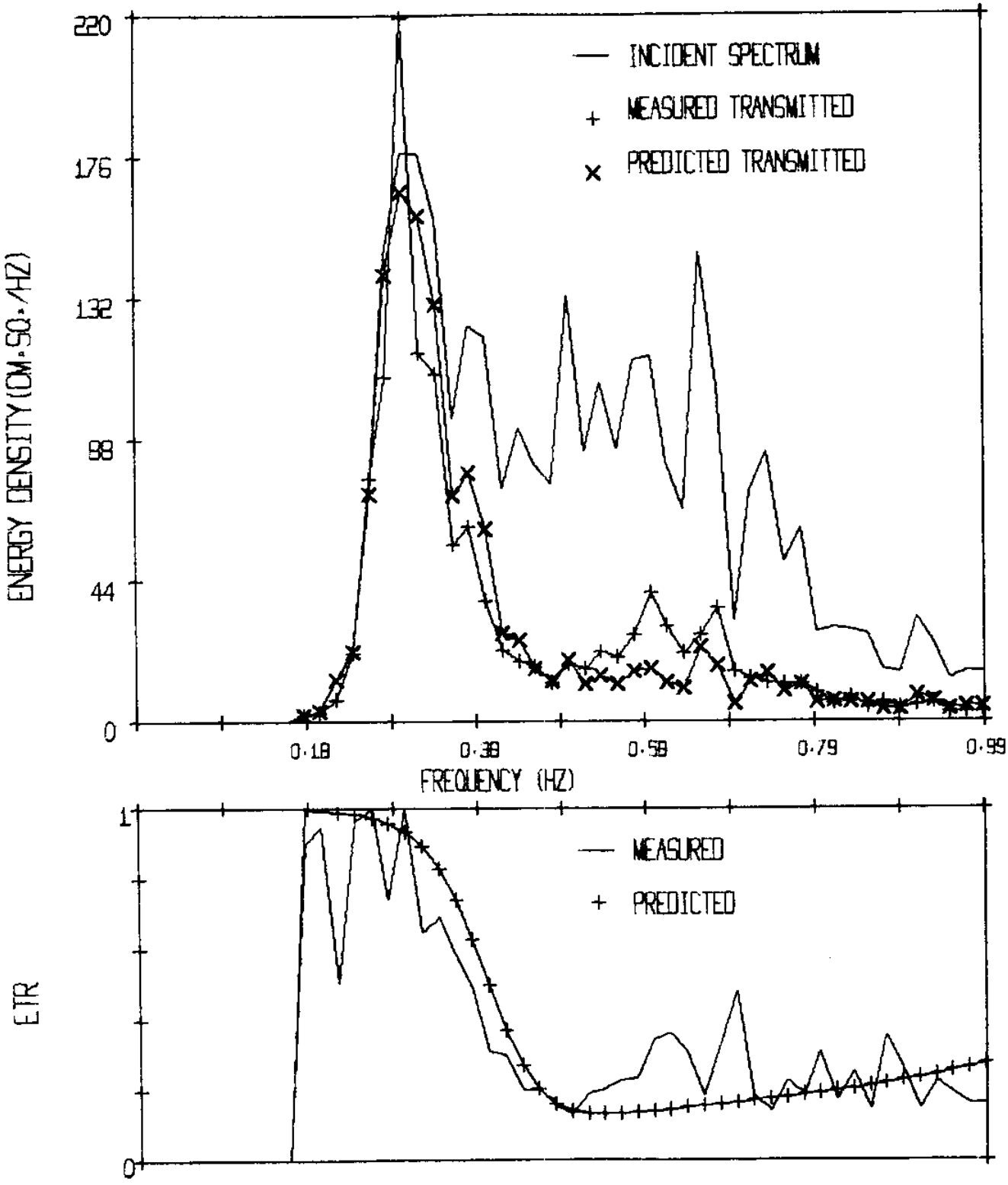
FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CM = 0.550	DCD = 0.450	

NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.415
HEIGHT TRANSMISSION FACTOR = 0.644
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 21.8
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 14.0

EXPERIMENT 54



EXPERIMENT S5

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

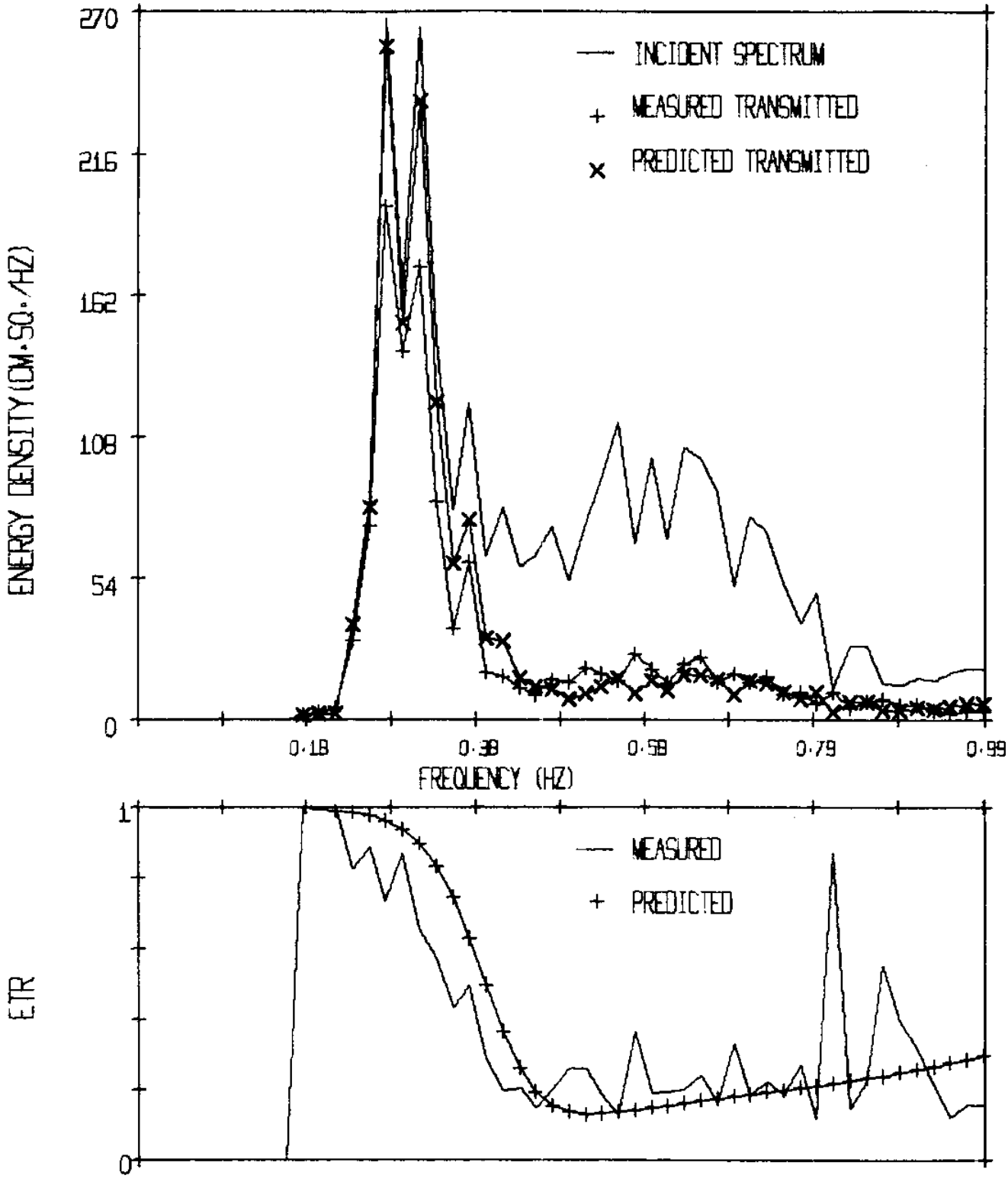
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.472
HEIGHT TRANSMISSION FACTOR = 0.687
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 21.3
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 14.6

RMS ERROR = 0.061

EXPERIMENT 55



EXPERIMENT S6

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CV = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

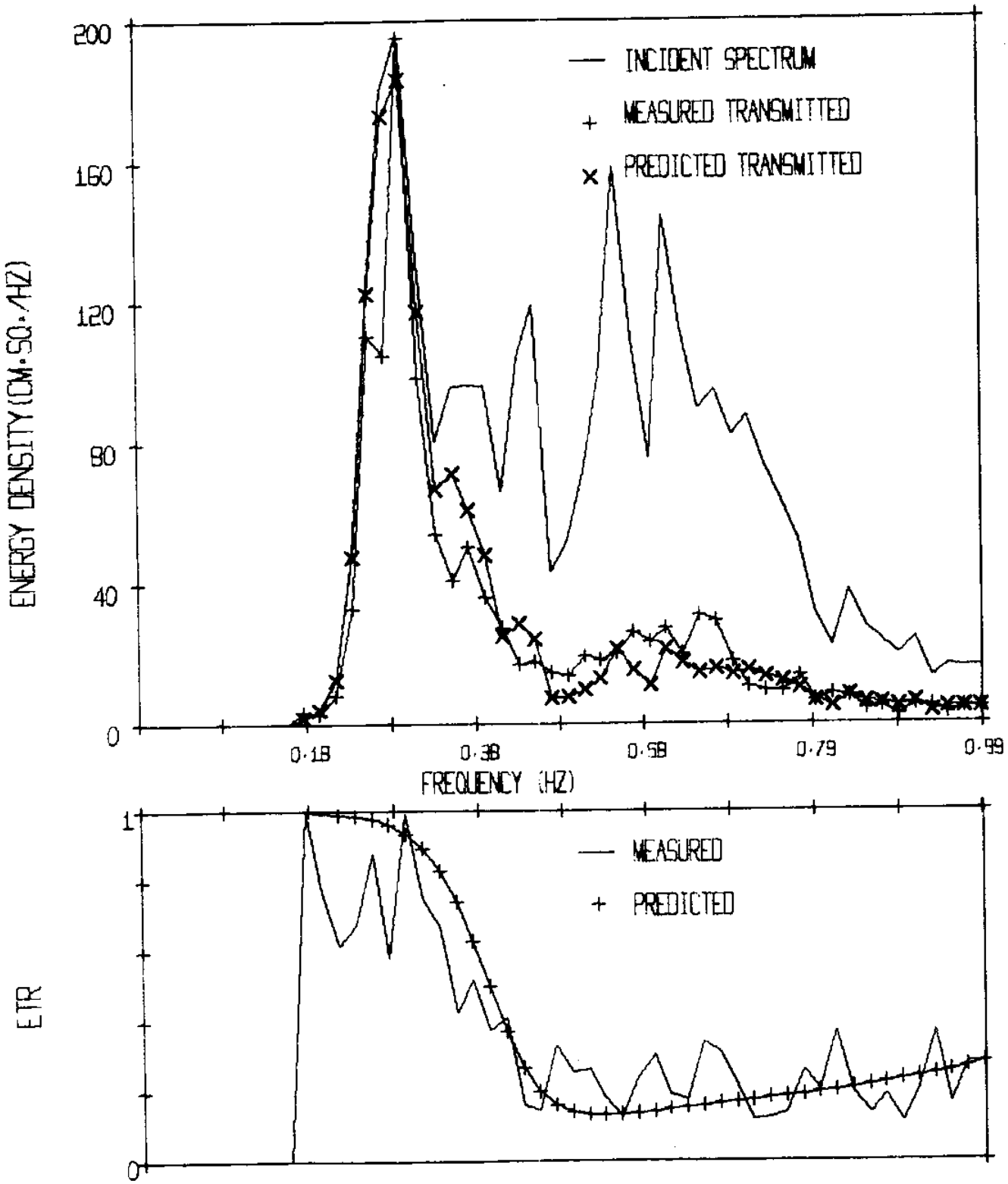
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.416
HEIGHT TRANSMISSION FACTOR = 0.645
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 21.8
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 14.1

RMS ERROR = 0.052

EXPERIMENT 56



EXPERIMENT S7

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

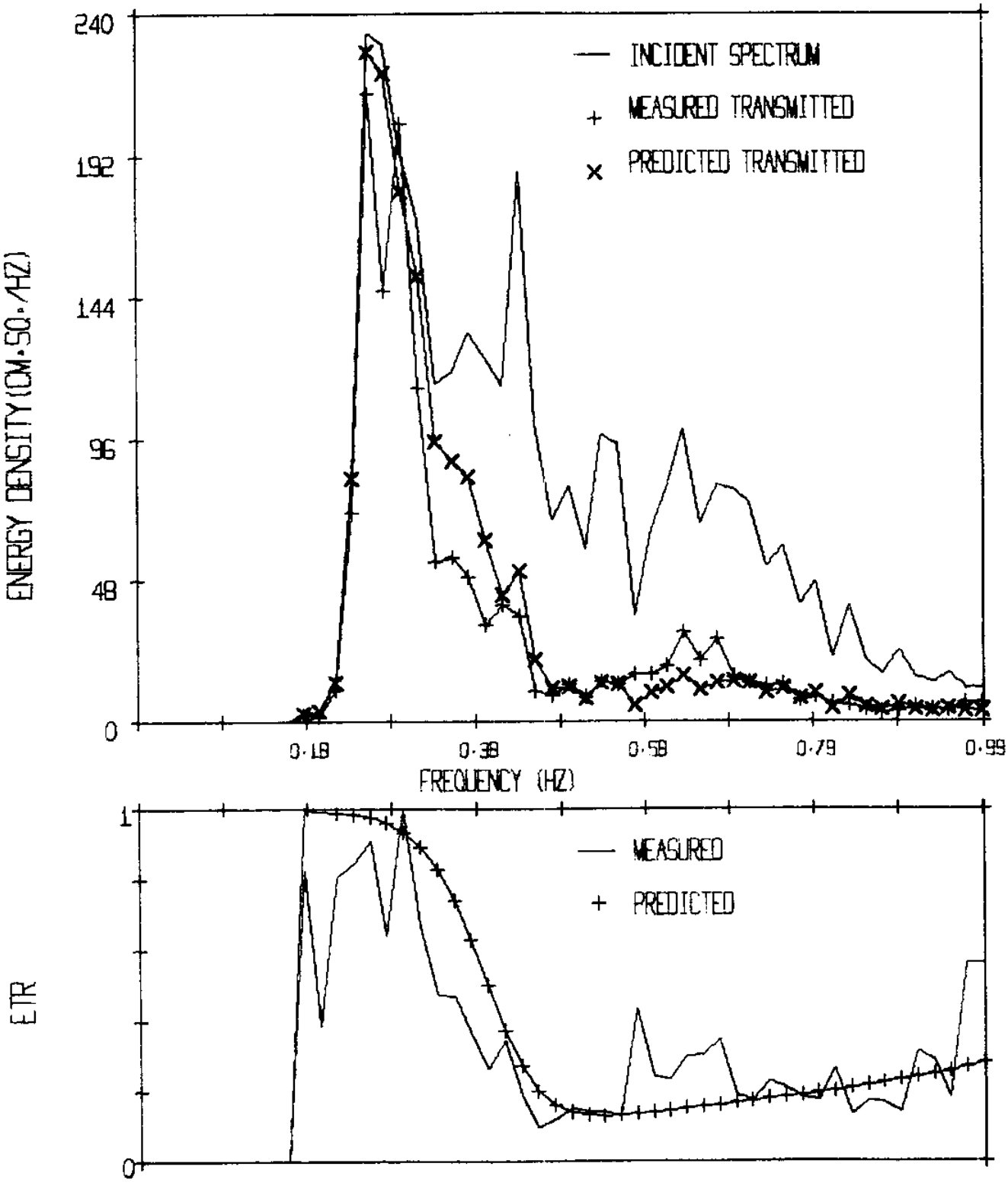
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.485
HEIGHT TRANSMISSION FACTOR = 0.696
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 22.4
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 15.6

RMS ERROR = 0.063

EXPERIMENT 57



EXPERIMENT 58

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

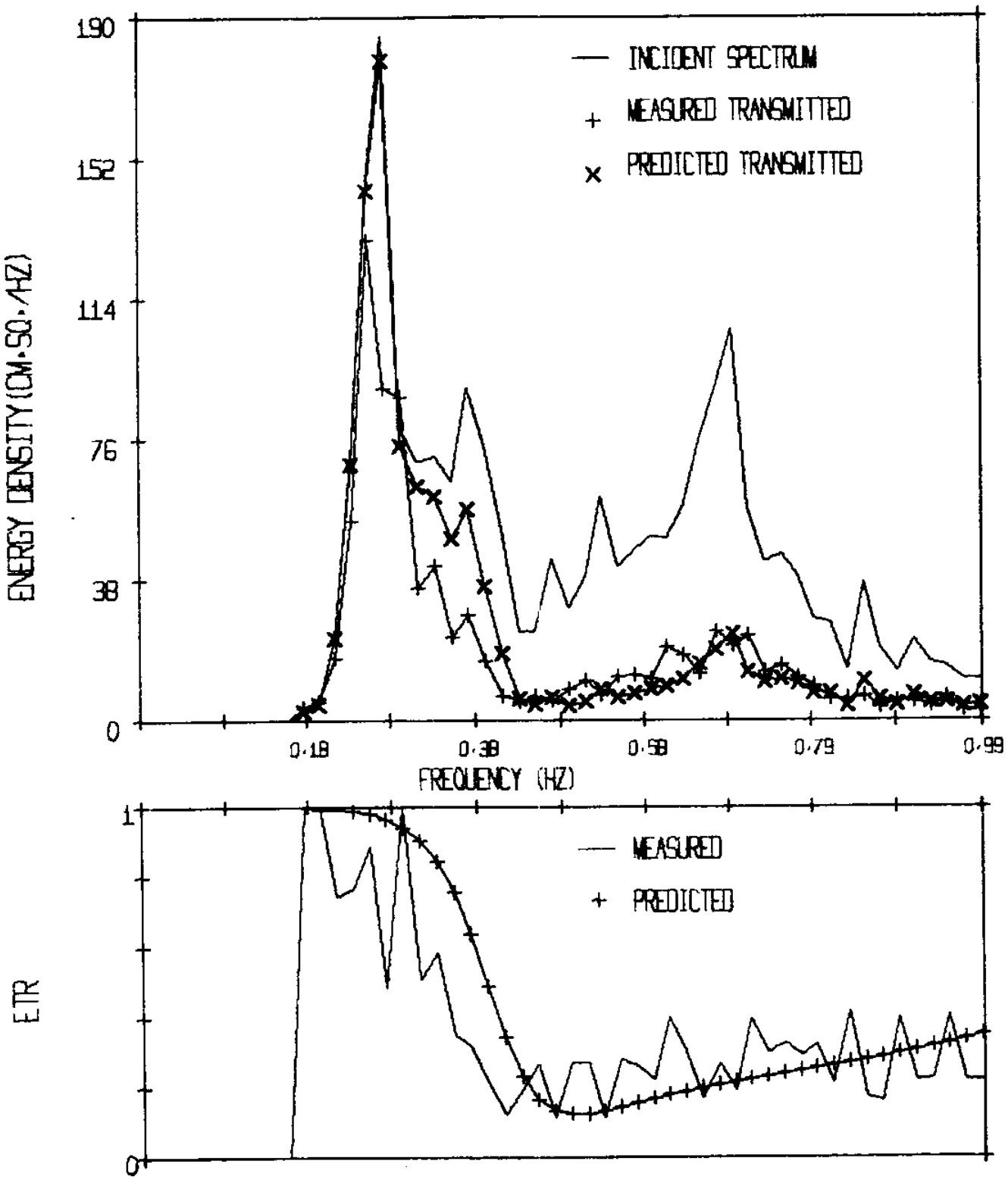
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.491
HEIGHT TRANSMISSION FACTOR = 0.701
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 18.0
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 12.6

RMS ERROR = 0.076

EXPERIMENT 58



EXPERIMENT S9

FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CM = 0.550	DCD = 0.450	

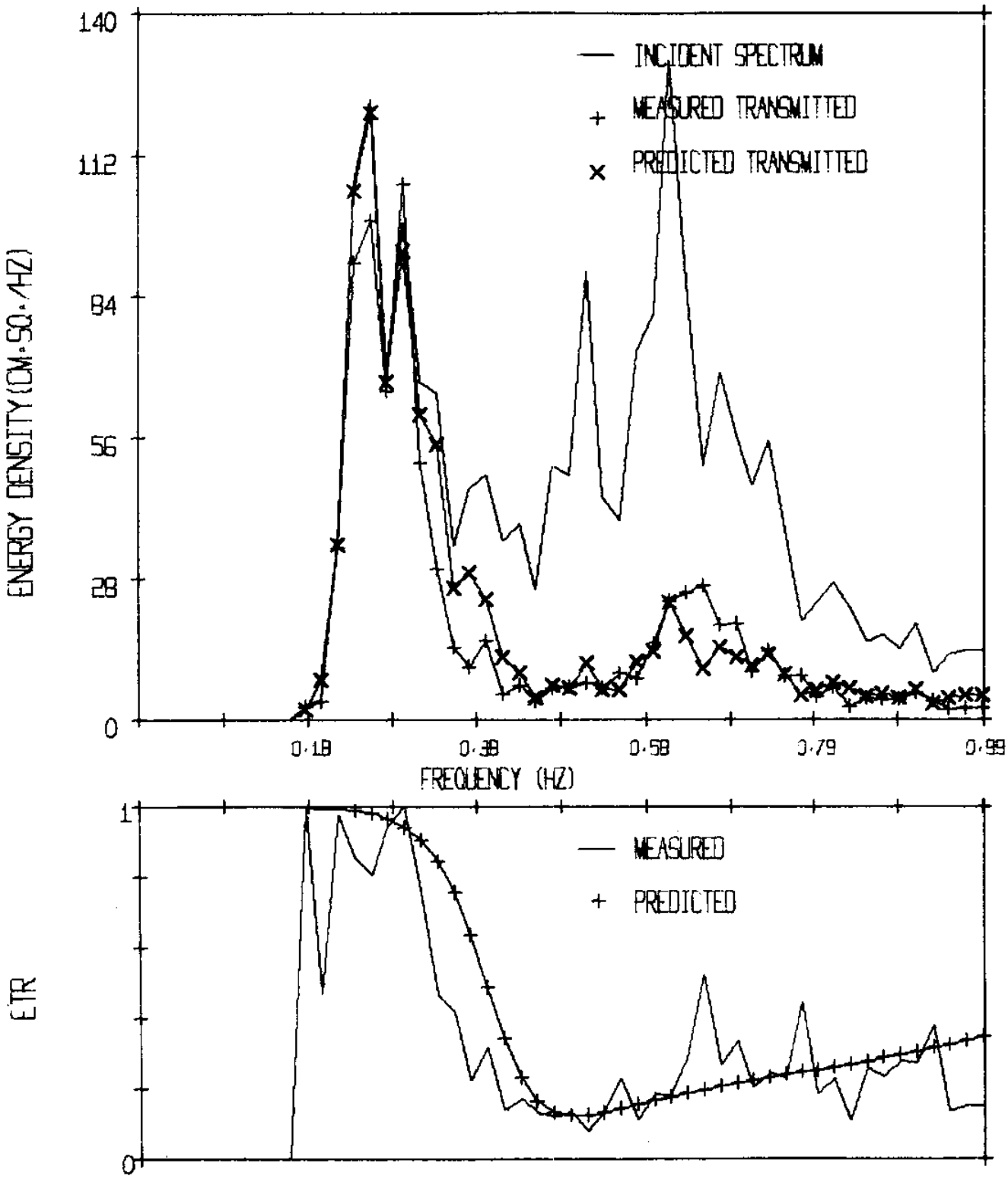
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.445
HEIGHT TRANSMISSION FACTOR = 0.667
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 17.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 11.7

RMS ERROR = 0.036

EXPERIMENT 59



EXPERIMENT 510

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

NUMBER OF ROWS = 10

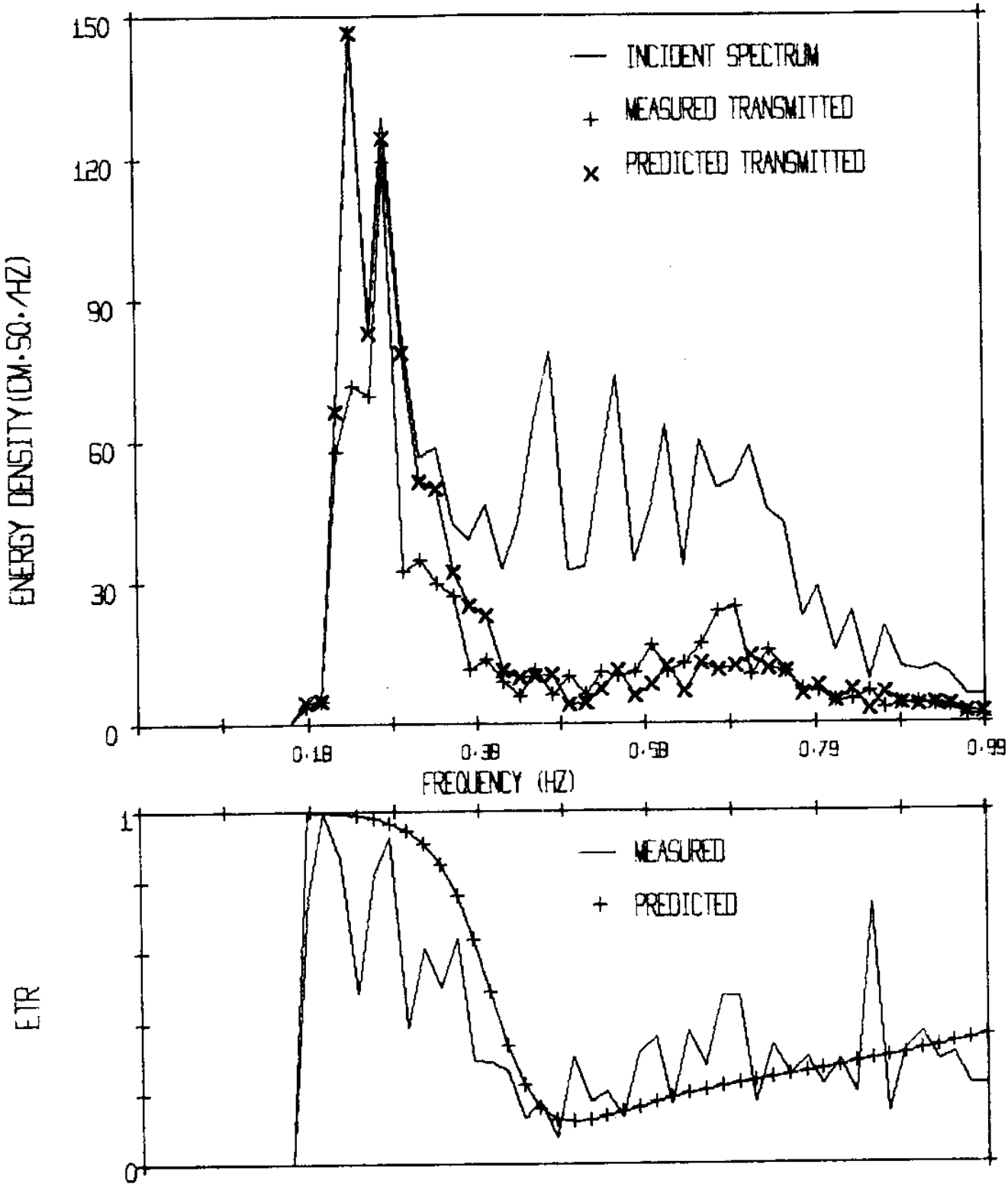
EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.496
HEIGHT TRANSMISSION FACTOR = 0.704
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 17.0
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 12.0

RMS ERROR = 0.071

EXPERIMENT S10



EXPERIMENT S11

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

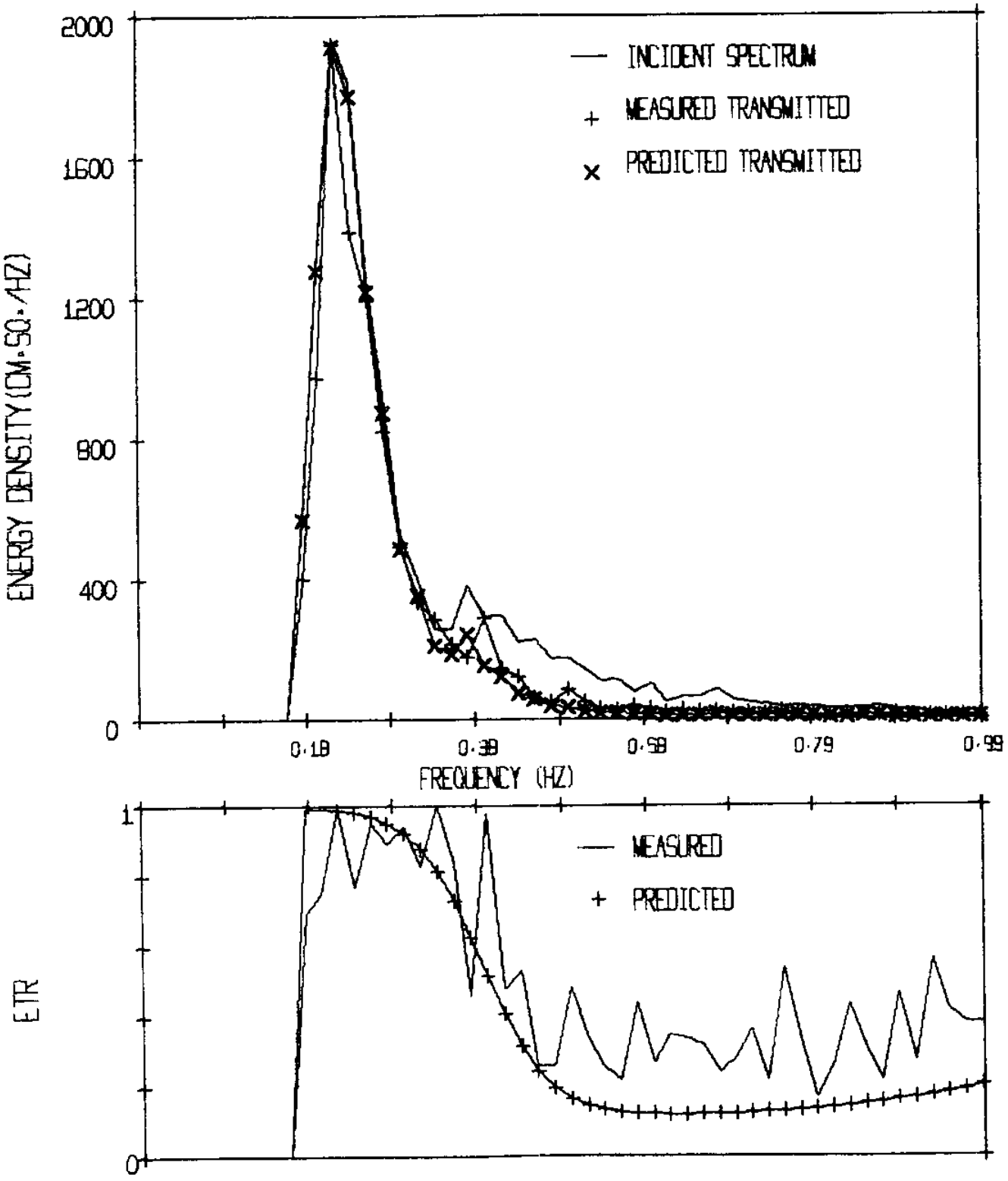
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.796
HEIGHT TRANSMISSION FACTOR = 0.892
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 43.9
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 39.2

RMS ERROR = 0.114

EXPERIMENT S11



EXPERIMENT S12

FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CM = 0.550	DCD = 0.450	

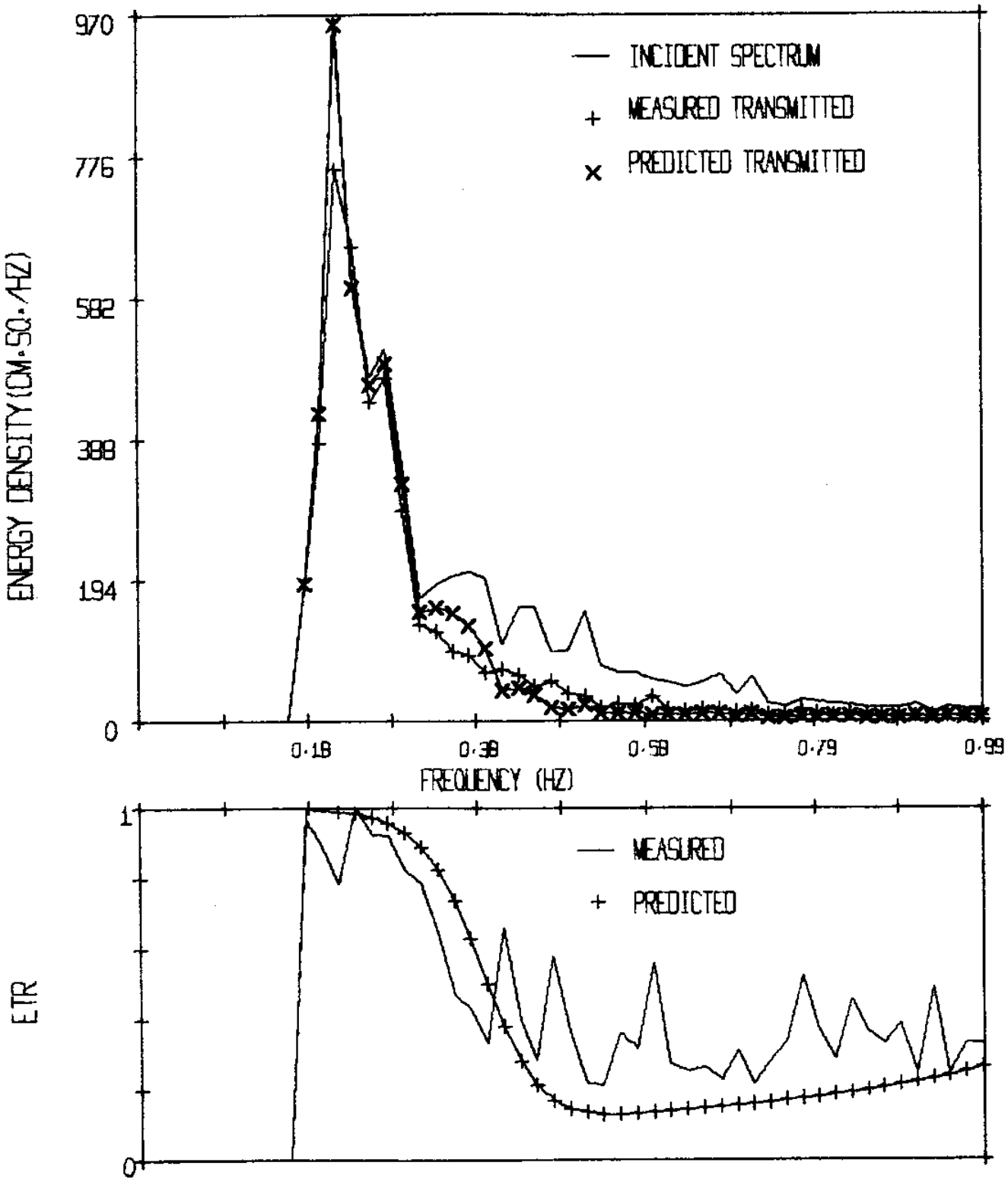
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.727
HEIGHT TRANSMISSION FACTOR = 0.853
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 31.0
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 26.5

RMS ERROR = 0.073

EXPERIMENT S12



EXPERIMENT 513

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

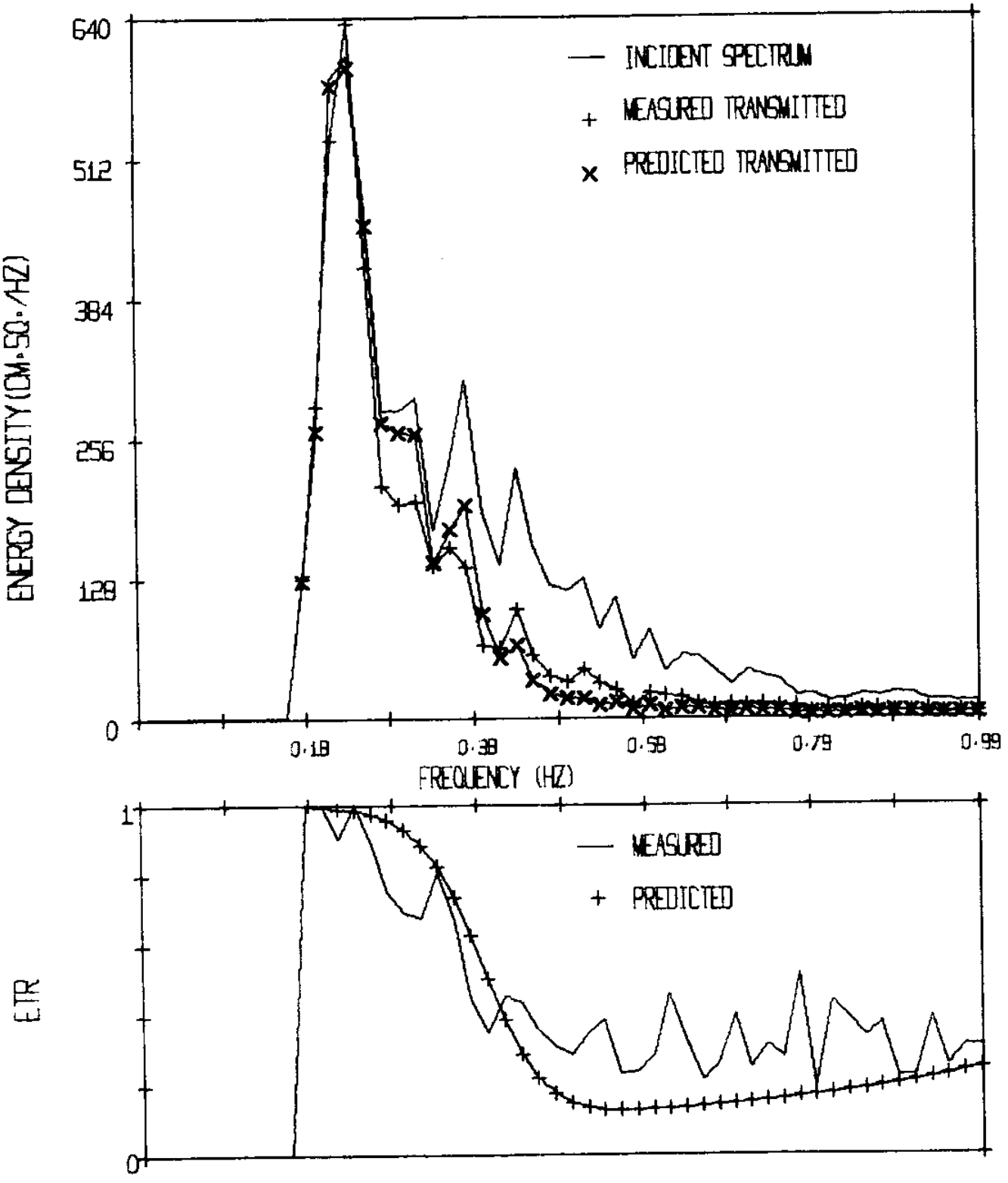
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.672
HEIGHT TRANSMISSION FACTOR = 0.820
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 29.7
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 24.4

RMS ERROR = 0.052

EXPERIMENT S13



EXPERIMENT S14

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

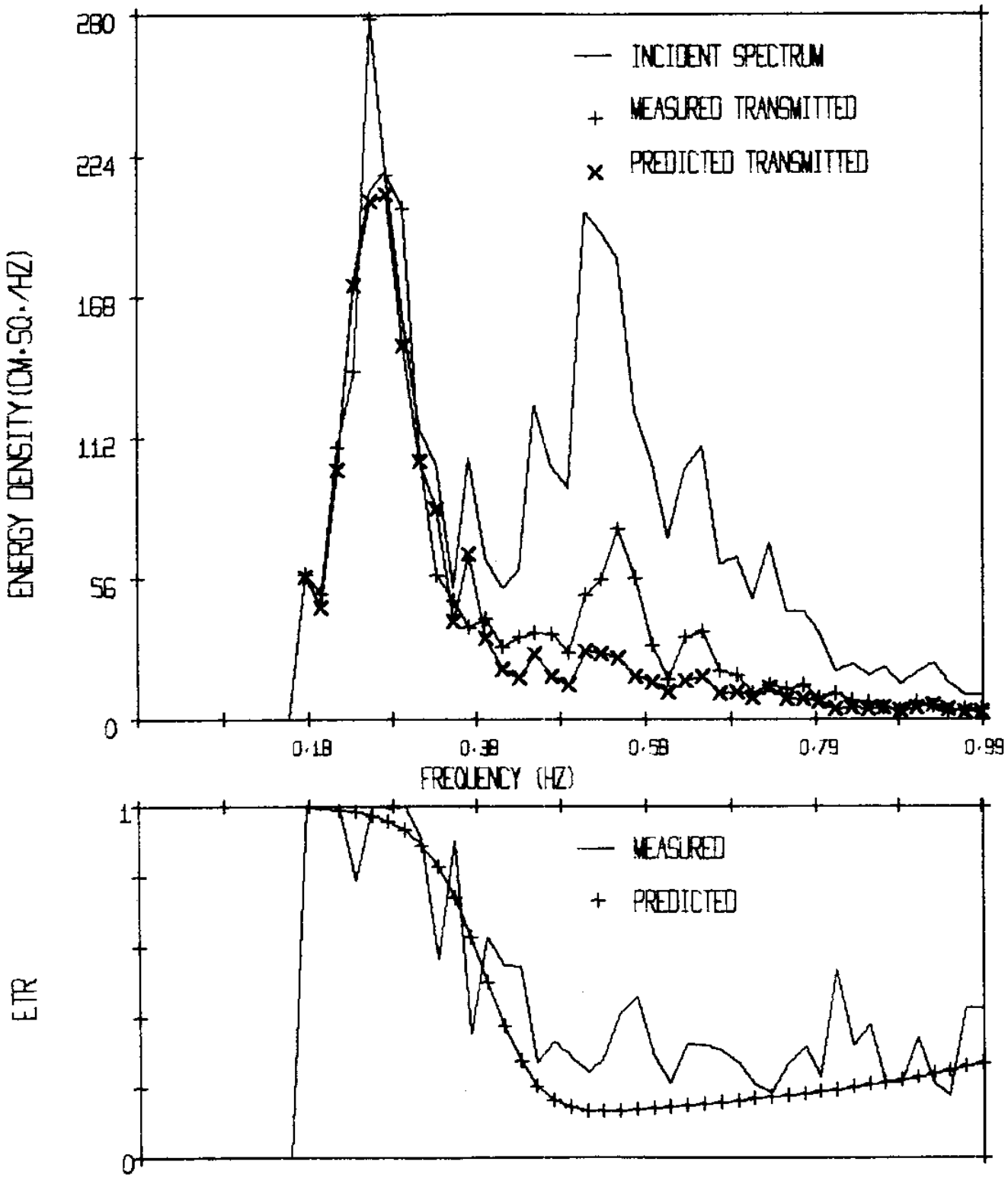
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.463
HEIGHT TRANSMISSION FACTOR = 0.680
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 23.3
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 15.9

RMS ERROR = 0.060

EXPERIMENT S14



EXPERIMENT S15

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

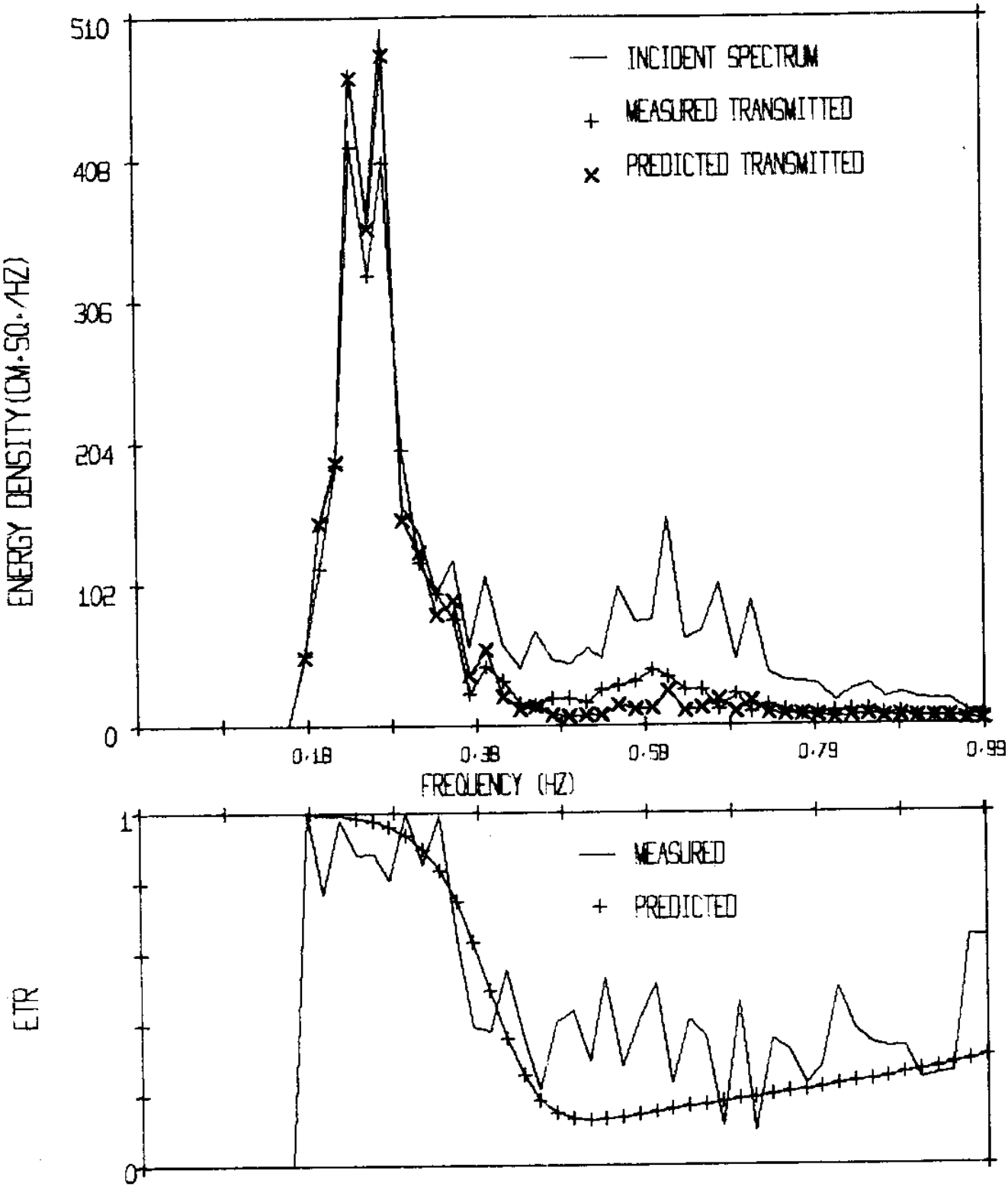
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.649
HEIGHT TRANSMISSION FACTOR = 0.805
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 24.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 19.8

RMS ERROR = 0.051

EXPERIMENT S15



EXPERIMENT S16

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

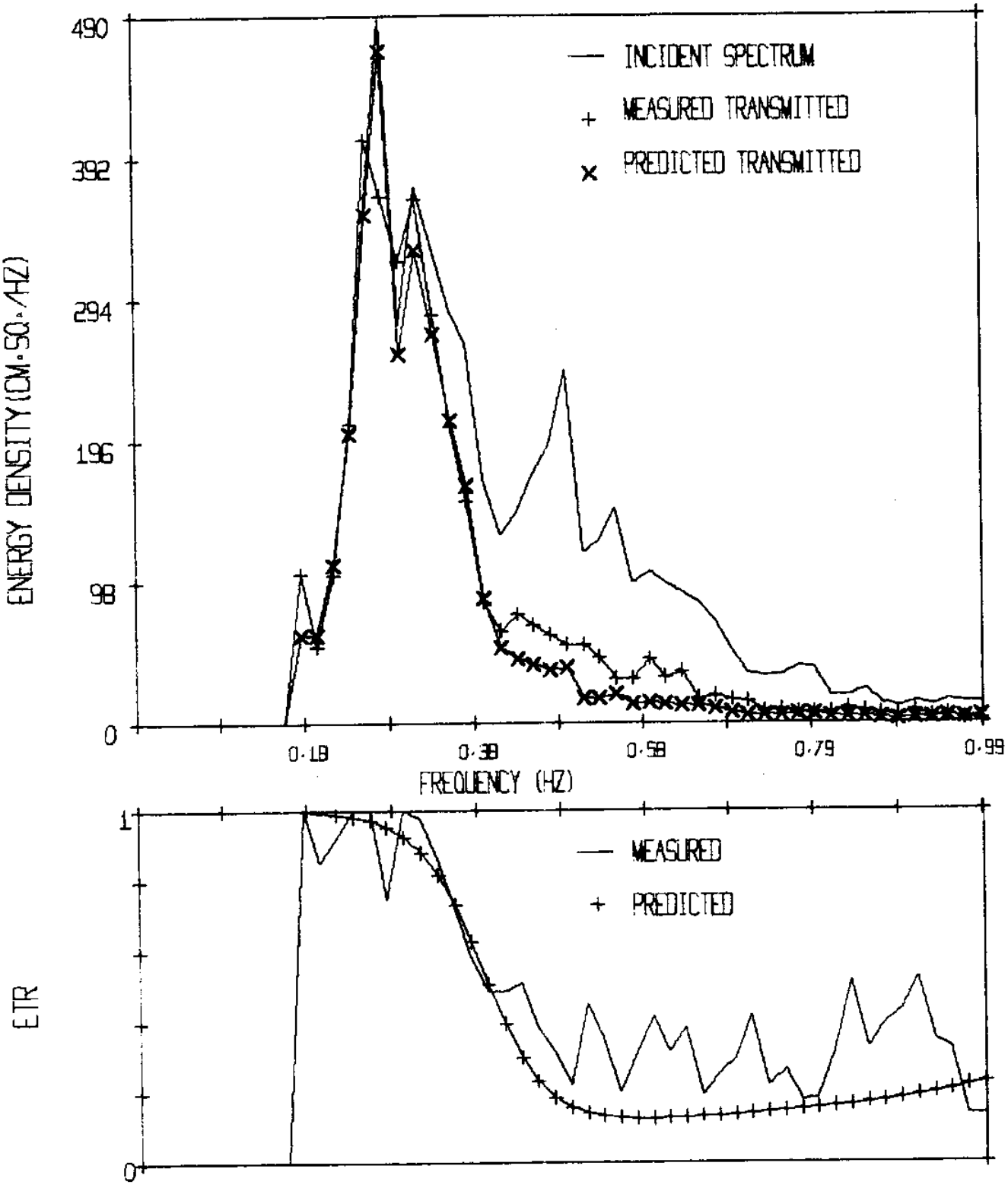
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.569
HEIGHT TRANSMISSION FACTOR = 0.754
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 28.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 21.6

RMS ERROR = 0.056

EXPERIMENT 516



EXPERIMENT S17

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

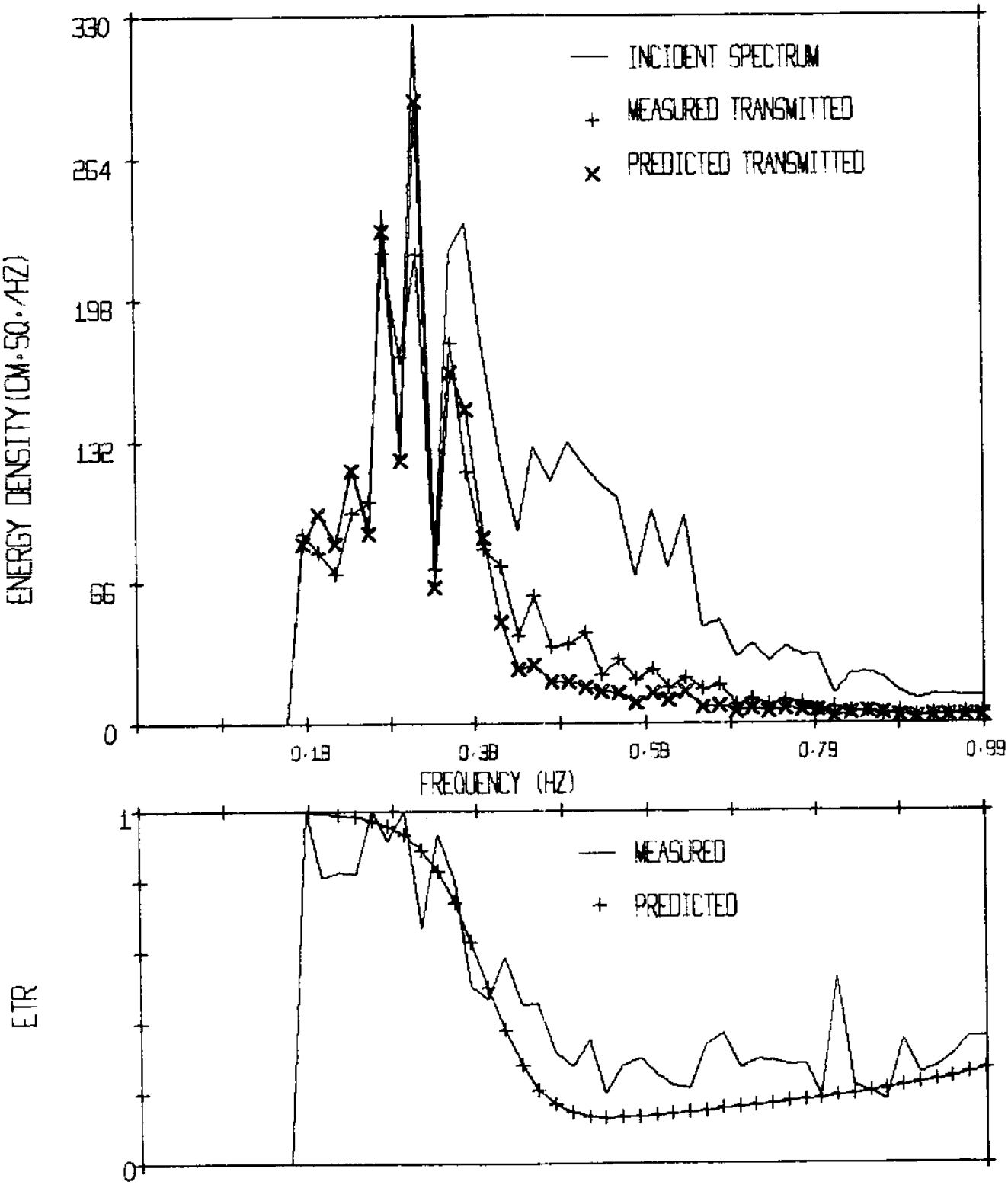
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.525
HEIGHT TRANSMISSION FACTOR = 0.724
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 23.8
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 17.2

RMS ERROR = 0.051

EXPERIMENT S17



EXPERIMENT S1R

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

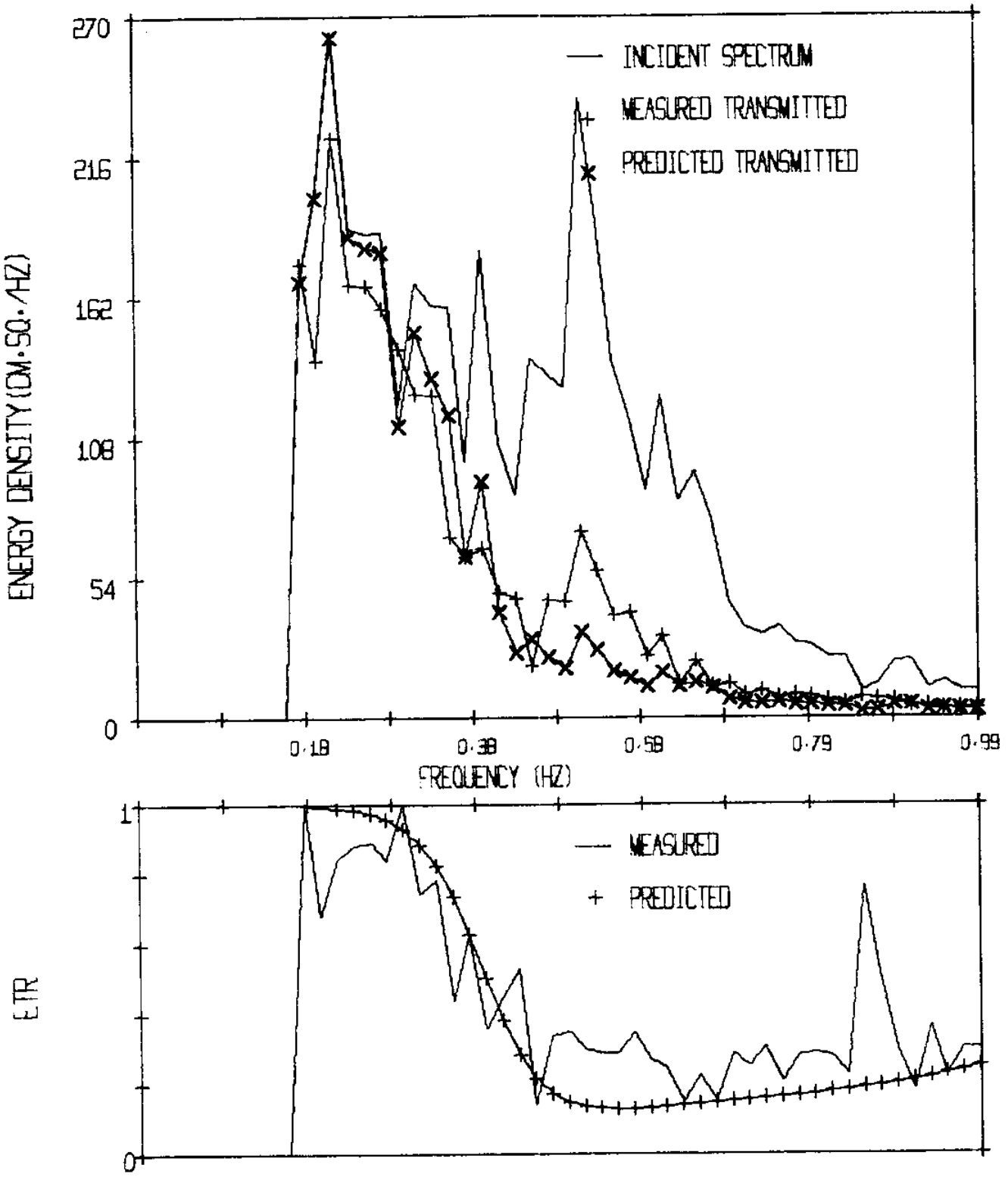
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.524
HEIGHT TRANSMISSION FACTOR = 0.724
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 25.7
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 18.6

RMS ERROR = 0.054

EXPERIMENT S18



EXPERIMENT S19

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

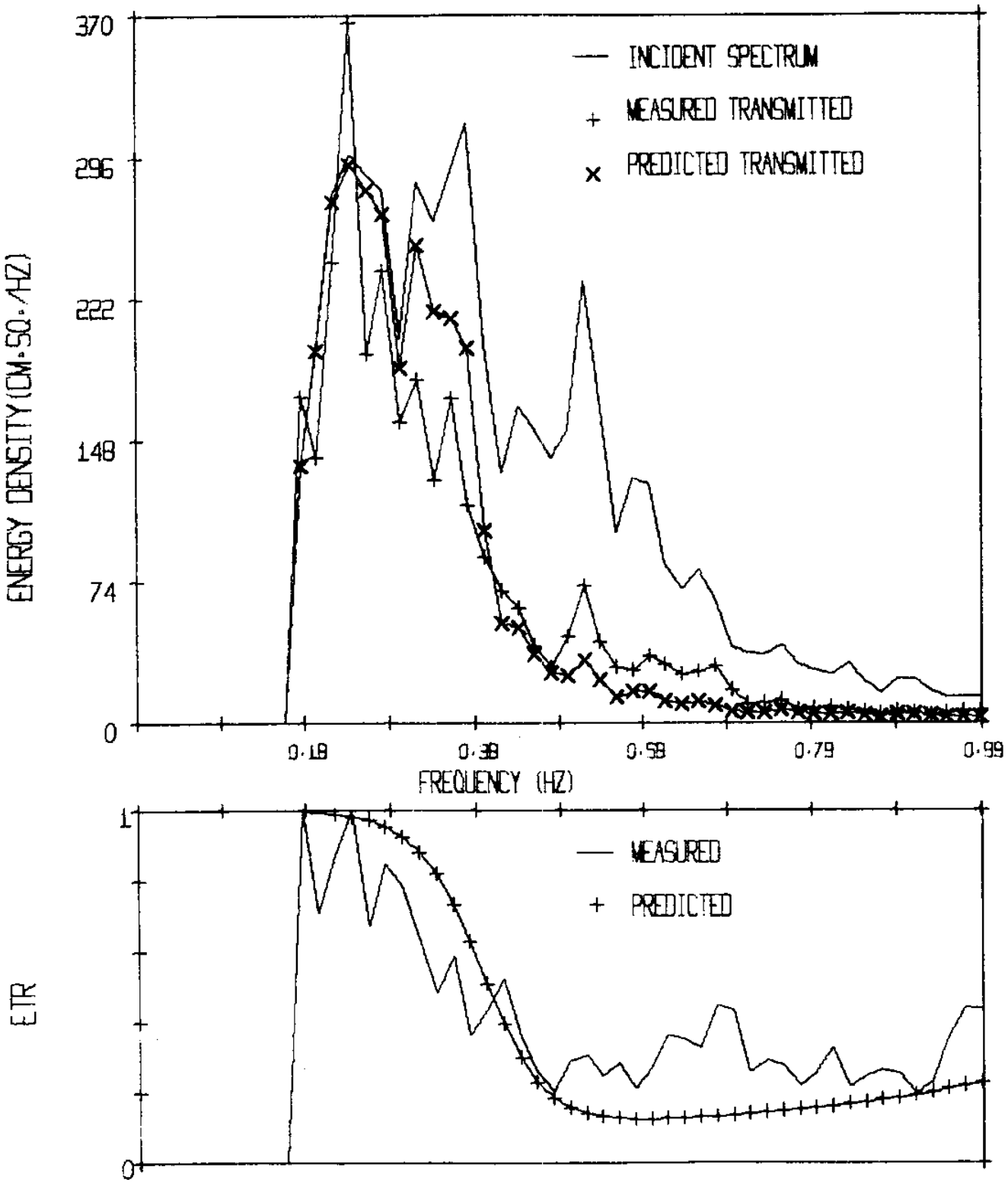
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.573
HEIGHT TRANSMISSION FACTOR = 0.757
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 28.7
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 21.7

RMS ERROR = 0.079

EXPERIMENT S19



EXPERIMENT S20

FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CM = 0.550	DCD = 0.450	

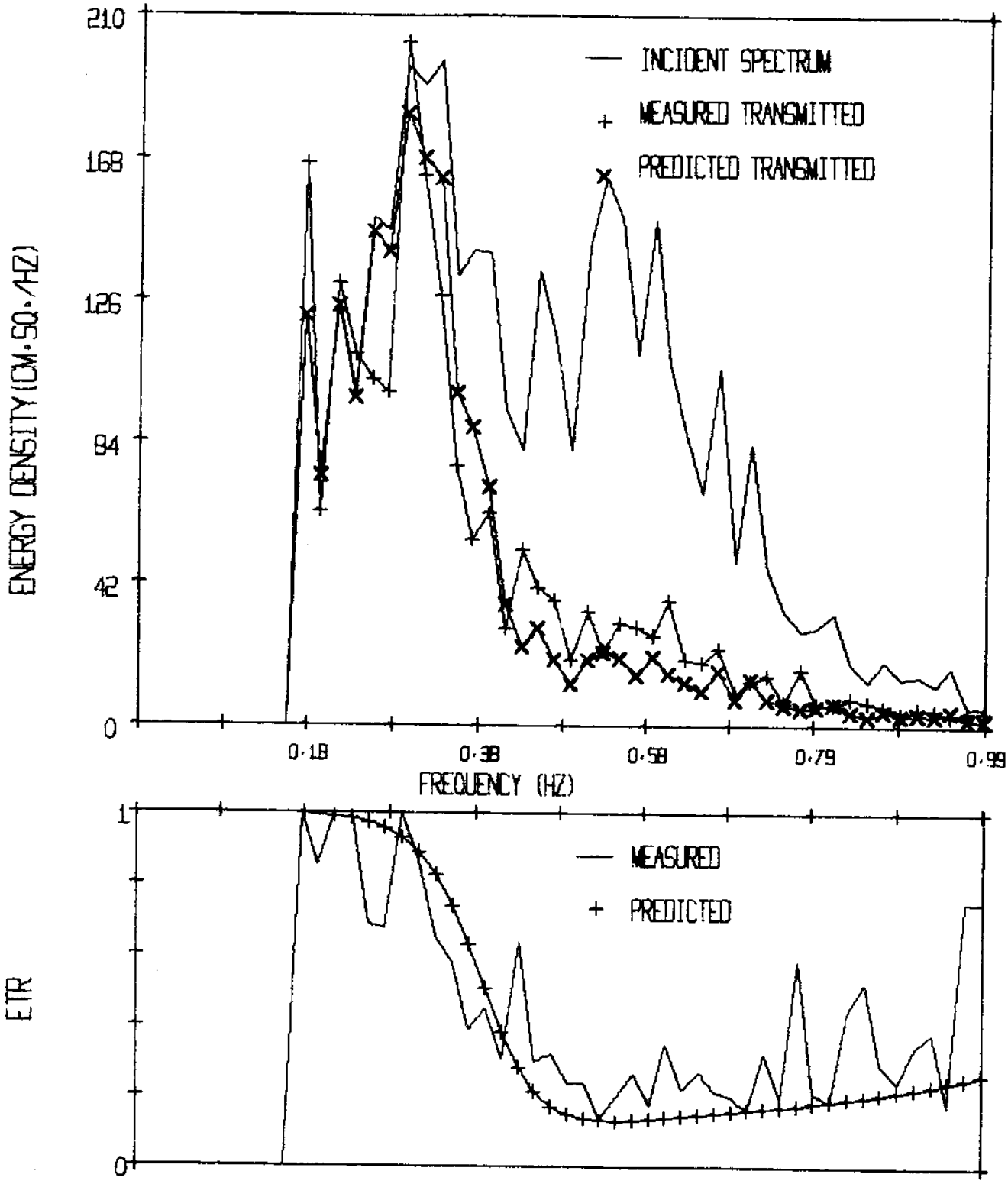
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.487
HEIGHT TRANSMISSION FACTOR = 0.698
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 24.3
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 16.9

RMS ERROR = 0.050

EXPERIMENT 520



EXPERIMENT S21

FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CM = 0.550	DCD = 0.450	

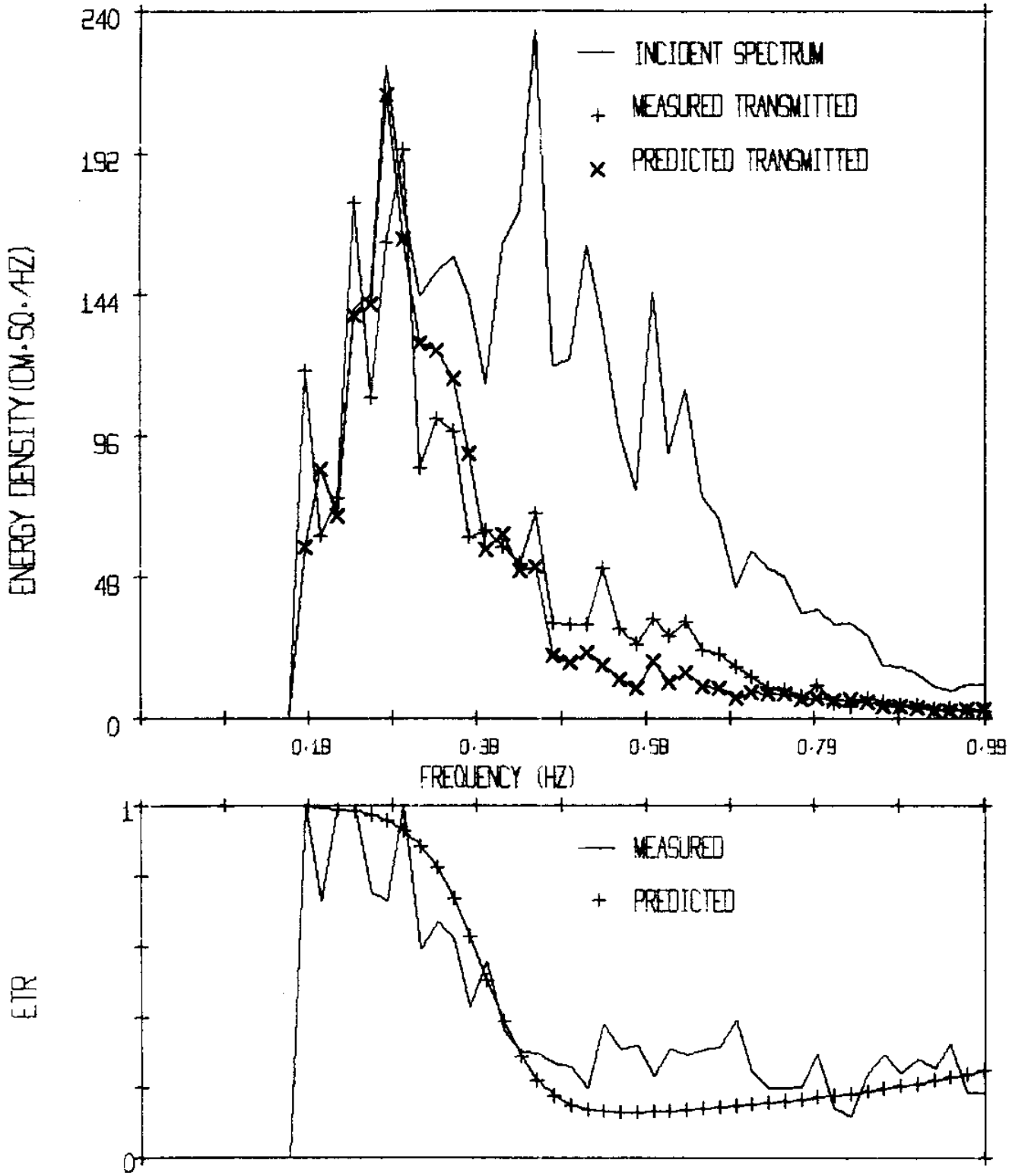
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.467
HEIGHT TRANSMISSION FACTOR = 0.683
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 24.6
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 16.8

RMS ERROR = 0.059

EXPERIMENT S21



EXPERIMENT S22

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 157.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

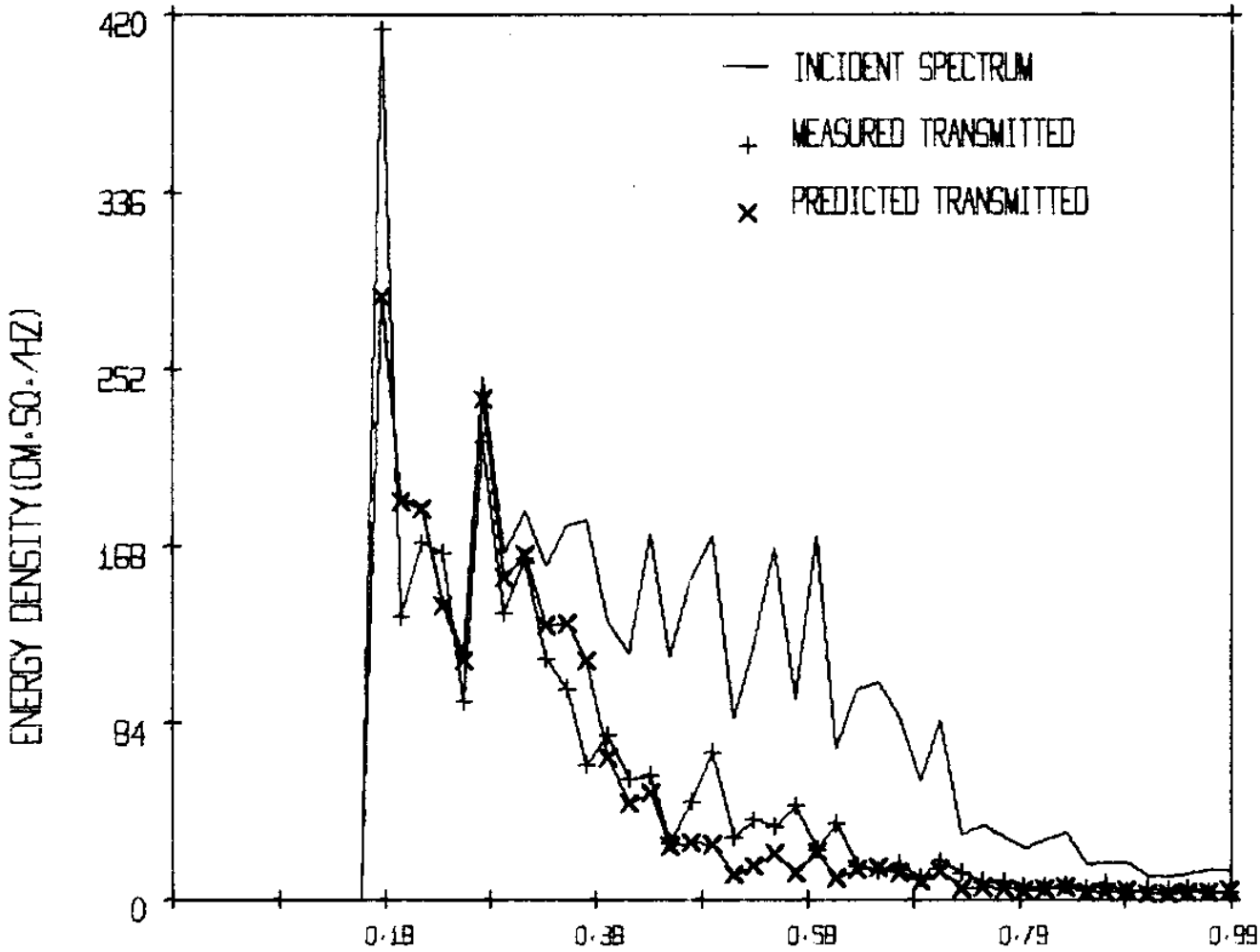
NUMBER OF ROWS = 10

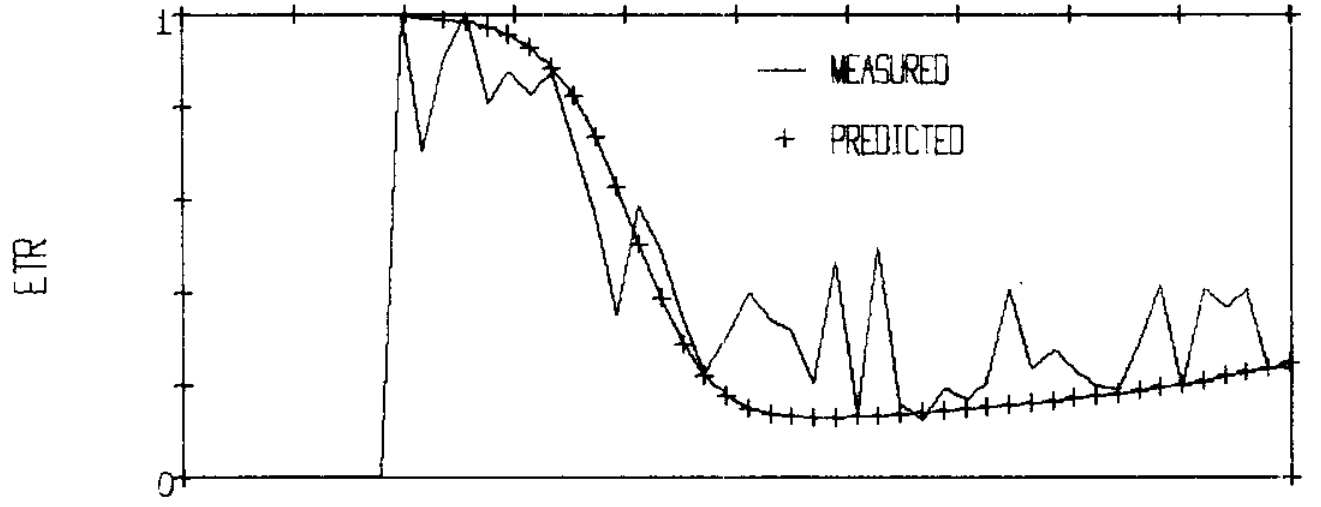
PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.528
HEIGHT TRANSMISSION FACTOR = 0.726
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 26.2
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 19.0

RMS ERROR = 0.068

EXPERIMENT S22





EXPERIMENT 523

FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CV = 0.550	DCD = 0.450	

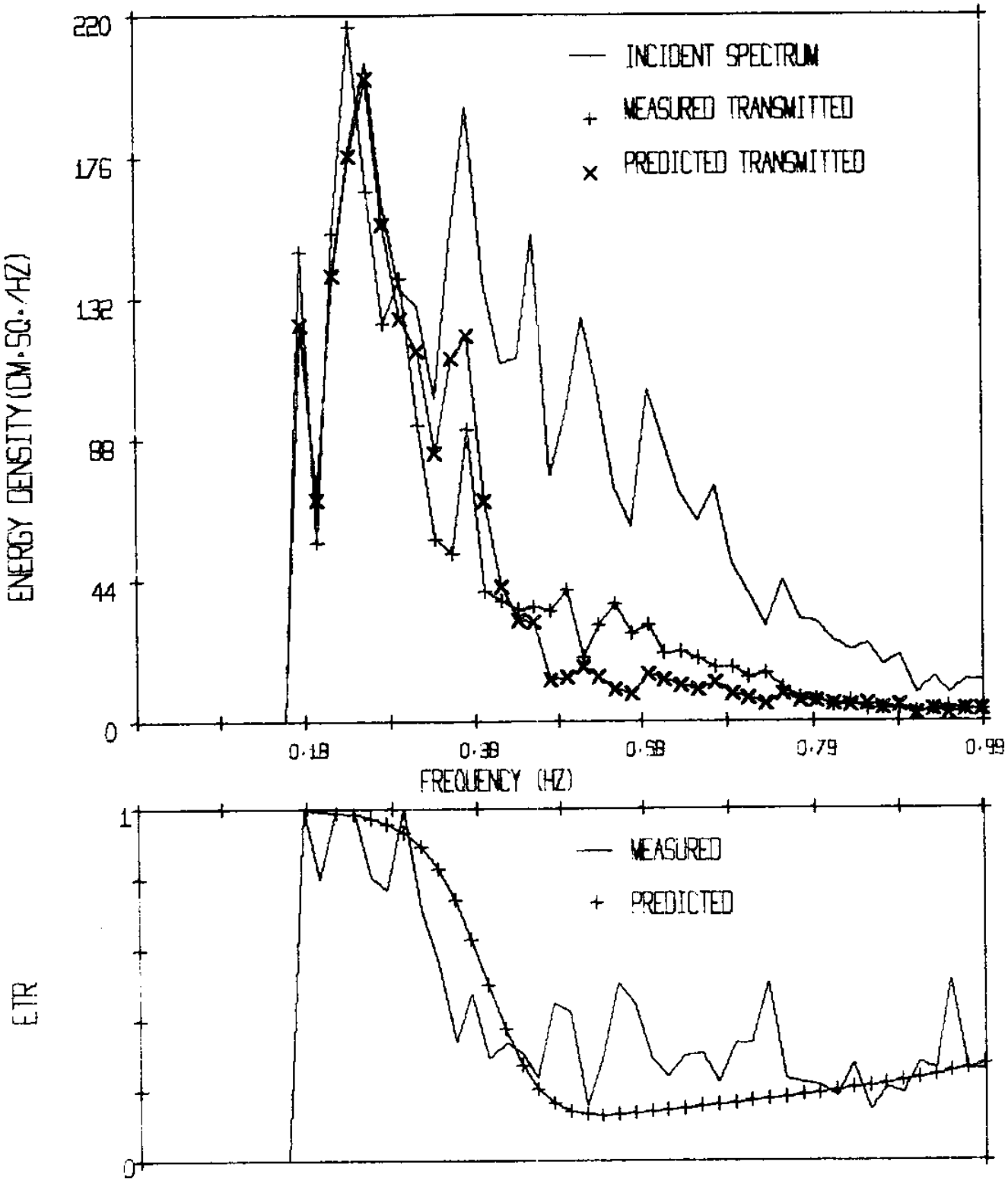
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.526
HEIGHT TRANSMISSION FACTOR = 0.725
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 23.3
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 16.9

RMS ERROR = 0.056

EXPERIMENT 523



EXPERIMENT 524

FLOAT DIAMETER =	29.21 CM	EFFECTIVE TETHER LENGTH =	167.0
X-SECTIONAL AREA =	670.1 CM.SQ.	VOLUME =	13049.4 CC
FLOAT SPACING =	58.41 CM	FLOAT DENSITY =	0.0870 GM/CC
DEPTH TO C.L. =	21.90 CM	WATER DEPTH =	600.0 CM
DELTF = 0.0199		NO. BANDS =	51
CD = 0.550	CM = 0.550	DCD = 0.450	

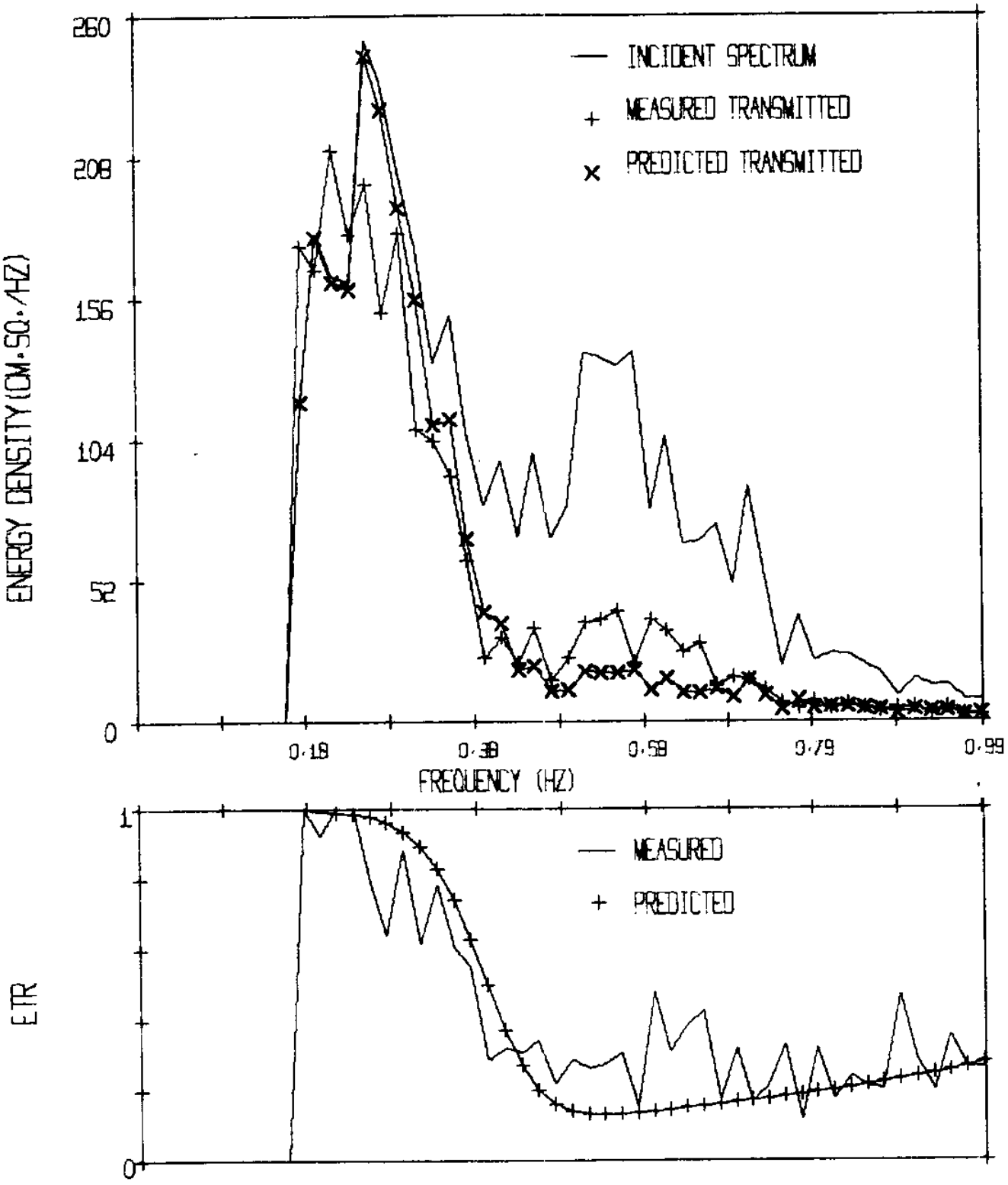
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.556
HEIGHT TRANSMISSION FACTOR = 0.746
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 24.2
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 18.1

RMS ERROR = 0.061

EXPERIMENT S24



EXPERIMENT S25

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

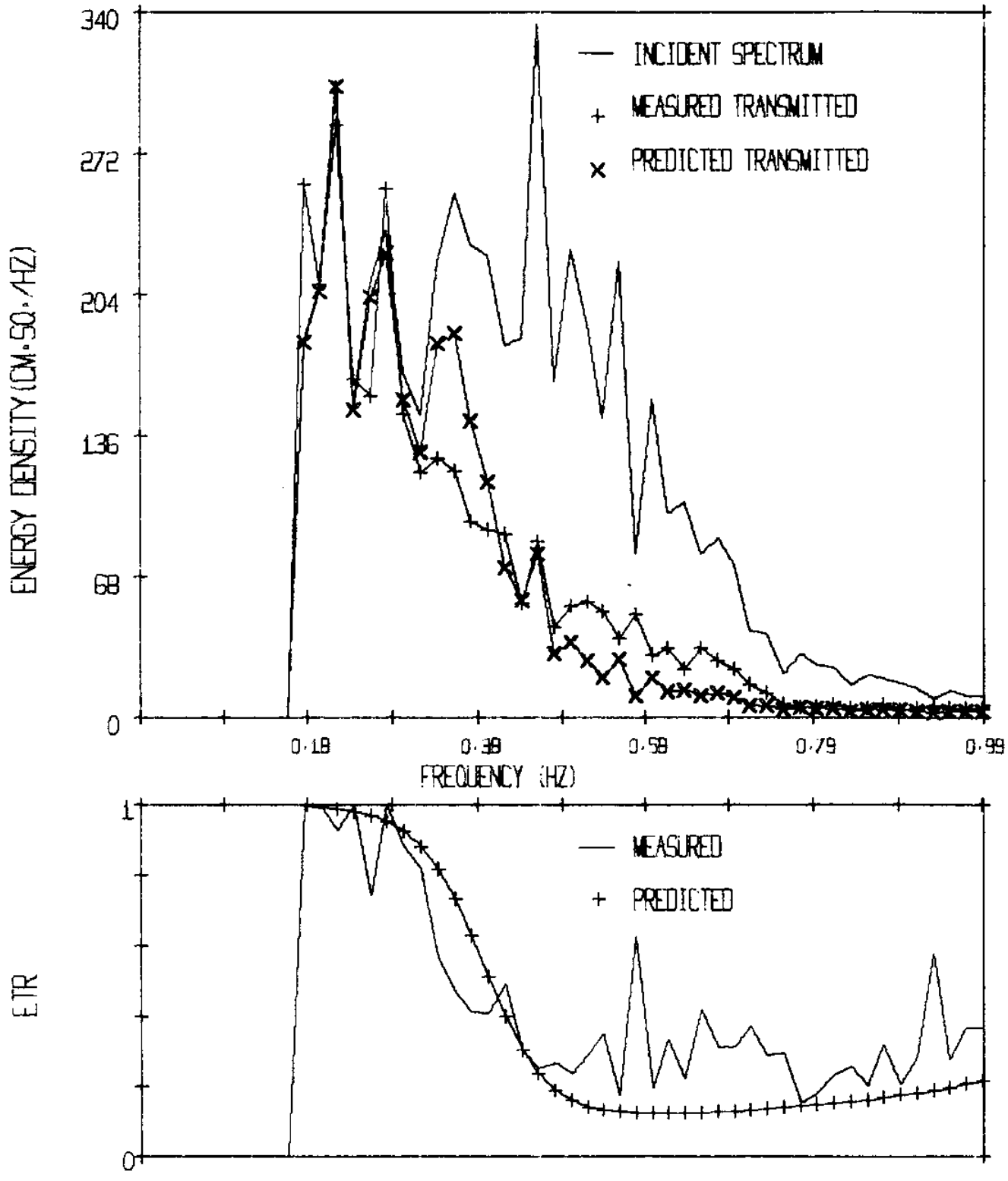
NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.514
HEIGHT TRANSMISSION FACTOR = 0.717
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 28.5
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 20.5

RMS ERROR = 0.060

EXPERIMENT S25



EXPERIMENT S26

FLOAT DIAMETER = 29.21 CM
X-SECTIONAL AREA = 670.1 CM.SQ.
FLOAT SPACING = 58.41 CM
DEPTH TO C.L. = 21.90 CM
DELTF = 0.0199
CD = 0.550 CM = 0.550

EFFECTIVE TETHER LENGTH = 167.0
VOLUME = 13049.4 CC
FLOAT DENSITY = 0.0870 GM/CC
WATER DEPTH = 600.0 CM
NO. BANDS = 51
DCD = 0.450

NUMBER OF ROWS = 10

PERFORMANCE ESTIMATES

ENERGY TRANSMISSION FACTOR = 0.548
HEIGHT TRANSMISSION FACTOR = 0.740
SIGNIFICANT WAVE HEIGHT, INCIDENT (CM) = 25.7
SIGNIFICANT WAVE HEIGHT, TRANSMITTED (CM) = 19.0

RMS ERROR = 0.056

EXPERIMENT 526