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# HAWAII DEEP WATER CABLE PROGRAM

## PHASE II

## HIGH FREQUENCY WAVE ANALYSIS FOR THE ALENUIHAHA CHANNEL

United States of America
Department of Energy

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# HAWAII DEEP WATER CABLE PROGRAM

# PHASE II

## HIGH FREQUENCY WAVE ANALYSIS
## FOR THE
## ALENUIHAHA CHANNEL

Prepared by

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(Report No. EKN-1028-R-4-1)

Prepared for
Hawaiian Dredging and Construction Company
The Ralph M. Parsons Company
Hawaiian Electric Co., Inc.
and the
U.S. Department of Energy

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# 1. INTRODUCTION

The Hawaii Deep Water Cable Program (HDWCP) is a jointly sponsored research and development effort by the U.S. Department of Energy (DOE) and the State of Hawaii through the Department of Planning and Economic Development. A major goal of the HDWCP is to determine the feasibility of deploying and operating, over a service life of thirty years, submarine power transmission cables between the islands of Hawaii and Oahu.

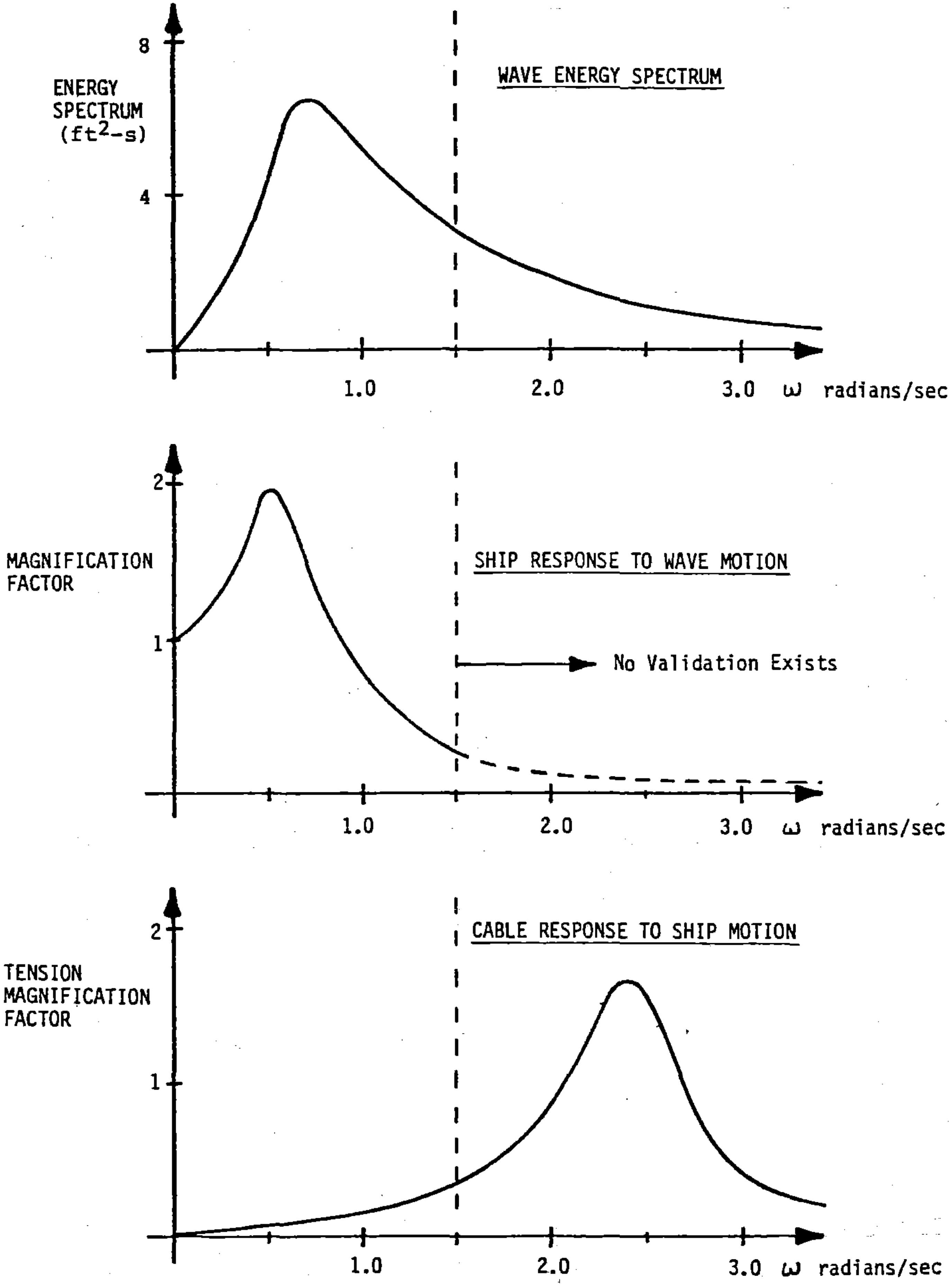
One of the major obstacles in the design and deployment of this power cable system is the Alenuihaha Channel located between the islands of Hawaii and Maui. Not only is the 1,920m (6,300 ft) depth of the channel a significant constraint, but the Alenuihaha Channel is well renowned for its severe wind and wave environment.

As part of the HDWCP, a study was performed involving the dynamic response of the coupled cable/deployment-vessel system to the dynamic ocean environment during cable laying operations in the Alenuihaha Channel. This report is by Vega, L., G. Nihous, J. Hoech, J. Van Ryzin and A. Resnick entitled "Systems Analysis and Parametric Study" dated August 1984. The deployment vessel modeled in this report is a barge of varying generic dimensions. One of the conclusions from this report is that "considerable dynamic motions and tensions are excited in the cables at frequencies in the range of 1 to 3 rad/sec (6.3 to 2.1 second periods)". Since the cable response is excited through the wave-induced barge motions, the barge motions must be modeled for frequencies beyond the standard 1 rad/sec (6.3 second period) and as high as 3 rad/sec (2.1 second period).

In the Vega et al. (1984) study, the dynamic response of the cable/barge system (Section 6.0) was analyzed using assumed theoretical wave energy spectra. It was noted that while these model spectra define the wave energy field for all wave frequencies, in the high frequency range of interest between frequencies of 2 to 3 rad/sec (3.1 to 2.1 second periods) there was no validation of the spectra with direct field measurements. Figure 1 provides a schematic representation of the situation. In Figure 1, the region to the right of the vertical dotted line represents a region where little or no verification data is available. In general, for typical engineering applications, this high frequency region is not of major interest since the energy content of the waves are very small as compared to waves in the larger wave period band. For the case of the coupled barge-cable system as shown in Figure 1, while the input wave spectrum and the resulting barge response are small in the high frequency wave band, the cable peak response is within this high frequency range and thus, this region is an area of concern.

The recent report entitled "Wave and Near-Surface Current Measurement Program in the Alenuihaha Channel" by Edward K. Noda and Associates (Report No. EKN-1028-R-3-2, October 1986, revised)

Figure 1: SCHEMATIC DESCRIPTION OF CABLE-BARGE SYSTEM RESPONSE TO HIGH-FREQUENCY SURFACE WAVES



describes the results of two years of wave measurements off Upolu Point, Hawaii for the HDWCP. The wave data was acquired using a subsurface pressure sensor, taut-moored a minimum of about 9 meters (30 ft) below the ocean surface. Surface wave height data were obtained by applying linear wave theory transfer functions to Fourier frequency components of decomposed subsurface dynamic pressure records. The problem with this technique is that high frequency wave energy is rapidly attenuated by the water column above the subsurface sensor, with the result that the wave energy spectrum obtained must be truncated at a frequency (cutoff period) that is a function of the mean depth of the sensor. The mean depth of the pressure sensor varies with the mean ocean current, increasing with stronger currents due to the drag force on the taut support cable and the buoyancy modules. For the minimum sensor depth of about 9 meters (30 ft), the cutoff wave period is 3.4 seconds, and for a depth of 30 meters (100 ft), which is not uncommon due to the very high current speeds in the Alenuihaha Channel, it is 6.3 seconds. Sea surface energy of waves shorter than the cutoff wave period are thus, irretrievably lost and the resulting energy spectrum is only an approximation of the true surface spectrum. While this truncation of the high frequency waves is not of significant concern for typical engineering applications, particularly due to the generally low levels of energy in this region, for the cable-barge dynamic response problem, this becomes of major concern. Thus, the above described wave measurement program can not provide validation data for the high frequency cable-barge dynamic analysis.

In order to quantify the magnitude of wave energy in the high frequency region, a surface wave measurement program was initiated and is herein described. The purpose of this measurement and analysis effort was two fold. First, high frequency wave measurements were to be obtained and compared with the theoretical spectrum models used by Vega et al. (1984) for verification and validation purposes. If the measured high frequency wave energy characteristics were significantly different from the theoretical spectra, then the second objective was to develop an analytical representation for the high frequency energy region which could then be applied to future cable-barge dynamic simulations. As part of this second objective, the analytical representation of the high frequency wave spectrum should be of a form generally utilized for dynamic analysis input.

## 2. SURFACE WAVE MEASUREMENT FIELD PROGRAM

To obtain accurate sea surface time history records, it was decided to utilize a surface following Waverider wave measuring buoy that incorporates accelerometers to measure the surface elevation and which telemeters the data via a radio signal to a shore receiver. Originally, it was planned to moor the Waverider at the same location in the Alenuihaha Channel as the nearsurface wave measuring instrument, but the logistics proved too difficult. A simpler solution was to receive the data transmitted by an existing Waverider moored in 390 feet of water, 5 miles due east of Makapuu Pt., Oahu in the Kaiwi Channel between Oahu and Molokai. This buoy is part of the Coastal Data Information Program sponsored by the U.S. Army Corps of Engineers, and operated and maintained by Scripps Institution of Oceanography. Its location exposes it to a wave environment similar to that in the Alenuihaha Channel.

Since high frequency waves (2 to 3 rad/sec) are seldom of interest to ocean researchers, the Waverider system as normally configured and operated is not optimized for such frequencies. In fact, two factors make its high frequency response decidedly nonlinear. The first factor is the physical interaction between the buoy and the water. The buoy is 0.9 meters (3 feet) in diameter and a published manufacturer's response curve indicates that it begins to resonate when forced by waves of about a 2 second period, with peak response at about a 1.4 second period. However, discussions with engineers having extensive experience with Waverider buoys indicates that resonance is seldom actually observed, and if present is readily seen on spectral plots. In this study, no evidence of buoy resonance was observed.

The other factor that introduces nonlinearity at high frequencies is the response of the antialiasing filter in the Waverider receiver. The receiver is a complex electronic device that receives the telemetered data and converts it to a sea surface record. It has a strip chart recorder and an analog voltage output for external recording and digitization. Normally, the analog signal passes through an antialiasing filter with a response that goes nonlinear at either a 5 or 2.5 second period, depending on the filter installed. The purpose of the filter is to minimize digitization errors when the analog output is sampled at a slow rate, e.g., 1 Hz sampling. The receiver that is used by the Coastal Data Information Program for the Makapuu Point Waverider system is located at Makai Pier, Waimanalo and incorporates the 5 second antialiasing filter. Thus, the data it provides is cutoff at a period of 5 seconds and is of no value to the present high freqency wave study.

In order to measure waves with periods as short as 2 seconds, it was necessary to obtain a separate Waverider receiver and modify it by bypassing the antialiasing filter. To minimize aliasing without the filter, it was further necessary to digitize the analog output signal at a fast rate. The digitizing was done by a Hewlett-Packard (HP) 3456 digital voltmeter (DVM) sampling at a rate of 5.5 Hz, which is 0.181 seconds between samples. For this sampling interval the maximum spectral frequency (Nyquist frequency) is 2.76 Hz ($T = 2 \times 0.181 = 0.362$ seconds), well above the 0.5 Hz maximum freqency required ($T = 2$ seconds). An HP-9826 computer controlled the DVM and recorded the data. Due to data array limitations in the computer, continuous data could be recorded for only about 90 minutes. This 90 minute record was separated into three 30 minute records for analysis.

The data acquisition system consisting of the Waverider reciever, DVM, and computer was transported to Makai Pier (facilities provided by Makai Ocean Engineering, Inc.) where it was set up to receive and record data from the Makapuu Waverider. This was done on four days, April 30, and July 17,22,& 23, 1986. Table 1 lists the eleven 30 minute data sets obtained on these days, the significant wave height $H_s$ (feet), and the wind conditions existing. The first two days represent typical tradewind conditions that might be expected to exist during cable deployment operations in the Alenuihaha Channel. The last two consecutive days where when Hurricane Estelle was moving in a westward direction south of the island of Hawaii. This produced moderate southerly wind and surf on Oahu, representative of "Kona" weather. Only 60 minutes of data was obtained on the last day because of a DVM failure.

Table 1. KAIWI CHANNEL DATA SETS, $H_s$ AND WIND CONDITIONS

| Data Set (Date-Time) | $H_s$ (feet) | Wind Conditions |
|---|---|---|
| AP30861400 | 7.14 | moderate (15-20 mph) |
| AP30861430 | 7.56 | NE tradewinds |
| AP30861500 | 6.90 | |
| JL17861400 | 6.09 | moderate NE tradewinds |
| JL17861430 | 6.31 | |
| JL17861500 | 6.32 | |
| JL22861600 | 7.58 | moderate southerly winds, |
| JL22861630 | 7.74 | Hurricane Estelle south |
| JL22861700 | 8.00 | of the island of Hawaii |
| JL23860900 | 9.24 | moderate southerly winds, |
| JL23860930 | 8.77 | Hurricane Estelle southwest |
| | | of the island of Hawaii |

In the Appendix, five of the measured spectra are plotted along with spectra from the Coastal Data Information Program (CDIP). Note that the CDIP or Corps' spectra are generally recorded every six hours but sometimes only one per day is obtained. Thus, the times of the two spectra plotted together are not identical but are the closest available. In no case do the times coincide.

## 3. WAVE DATA REDUCTION

Each of the eleven 30 minute data sets is a 10,240 point sea surface time-history record. Analysis of a record consists of two steps. First, a zero-up-crossing (ZUC) analysis of the wave record is performed to determine the average height and period of the one-third largest waves and the average wave period for all waves designated by:

$H_{sz}$ = zero-up-crossing significant wave height,

$T_{sz}$ = zero-up-crossing significant wave period, and

$T_{zz}$ = zero-up-crossing average wave period for all waves.

The third letter, z, in each designation indicates that it came from the ZUC analysis. The second step involves computing the wave energy (variance) spectrum. This is performed by breaking the 10,240 point time-history into 40-256 point records, computing 40 Fast Fourier Transforms (FFT) and averaging the 128 frequency components from the 40 spectra. Of the 128 frequency components in the averaged spectrum, only the first 24 are of importance because they define the region of interest from wave periods of T=46.4 to T=1.93 seconds. The amount of total spectral energy lost by truncating the spectrum at 1.93 seconds is no more than 2% for the 11 spectra measured and analyzed in this study.

Once the spectrum of interest is computed, three statistical parameters are calculated. These are:

$H_s$ = spectral significant wave height,
$= 4\ (V)^{1/2}$

where V is the area under the spectrum, called the variance,

$T_a$ = average wave period,
$= M_0/M_1$

and

$T_z$ = average apparent wave period.
$= (M_0/M_2)^{1/2}$

where the $n^{th}$ spectral moment $M_n$ is defined by

$$M_n = \int f^n\ S(f)df$$

where f is the frequency and S(f) is the spectral ordinate at f. The variance V, which is the area under the spectrum is the zeroth spectral moment given by

$$V = M_0 = \int S(f)df.$$

$T_a$ is seen to be the centroid (CG) of the spectrum and $T_z$ closely approximates the ZUC average wave period $T_{zz}$. Another wave period of interest which is calculated is

$T_p$ = the period of the peak spectral ordinate.

Table 2 lists the wave period statistics from the ZUC and

## Table 2. COMPARISON OF ZERO-UP-CROSSING (ZUC) AND SPECTRAL WAVE STATISTICS

| | ZUC Statistics | | Spectral Statistics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Data Set | Tsz | Tzz | Tp | Ta | Tz | Tsz/Tp | Tzz/Tp | Tsz/Ta | Tzz/Tz |
| AP30861400 | 6.79 | 5.00 | 7.74 | 5.89 | 5.35 | .88 | .65 | 1.15 | .93 |
| AP30861430 | 6.96 | 5.25 | 9.29 | 6.06 | 5.49 | .75 | .57 | 1.15 | .96 |
| AP30861500 | 6.66 | 4.84 | 7.74 | 6.90 | 5.20 | .86 | .63 | .97 | .93 |
| JL17861400 | 6.44 | 4.91 | 7.74 | 5.63 | 5.11 | .83 | .63 | 1.14 | .96 |
| JL17861430 | 6.43 | 5.03 | 7.74 | 5.56 | 5.07 | .83 | .65 | 1.16 | .99 |
| JL17861500 | 6.16 | 4.88 | 7.74 | 5.61 | 5.12 | .80 | .63 | 1.10 | .95 |
| JL22861600 | 7.49 | 5.38 | 15.47 | 6.57 | 5.73 | .48 | .35 | 1.14 | .94 |
| JL22861630 | 7.21 | 5.39 | 11.61 | 6.56 | 5.75 | .62 | .46 | 1.10 | .94 |
| JL22861700 | 8.23 | 5.81 | 15.47 | 6.92 | 6.03 | .53 | .38 | 1.19 | .96 |
| JL23860900 | 8.07 | 6.38 | 11.61 | 7.09 | 6.39 | .70 | .55 | 1.14 | 1.00 |
| JL23860930 | 8.22 | 6.14 | 11.61 | 6.93 | 6.24 | .71 | .53 | 1.19 | .98 |
| | | | | | Average = | .73 | .55 | 1.13 | .96 |
| | | | | | Std. Deviation = | .13 | .11 | .06 | .02 |

## Table 3. COMPARISON OF RESULTS WITH THOSE OF OTHER SOURCES

| Ratio | Table 2 | ISSC | Wiegel | Black | Goda * | Haring * | Manohar * |
|---|---|---|---|---|---|---|---|
| Tsz/Tp | .73 ± .13 | .95 | .88 | .71 ± .12 | .94 | .75 | .78 |
| Tzz/Tp | .55 ± .11 | -- | -- | .46 ± .08 | .75 | .52 | -- |
| Tsz/Ta | 1.13 ± .06 | -- | -- | 1.29 ± .06 | 1.30 | 1.33 | -- |
| Tzz/Tz | .96 ± .02 | -- | -- | 1.16 ± .03 | 1.20 | 1.15 | -- |

* Referenced by Black

spectral analyses and some wave period ratios between the two methods. In Table 3, these ratios are compared with those from other published sources. For the present effort, the ratio of most importance is that between the ZUC average wave period and the spectral average apparent wave period, $T_{zz}/T_z$. The average value of $T_{zz}/T_z = 0.96$ which indicates that the spectral value $T_z$ is very nearly equal to the ZUC average wave period $T_{zz}$.

## 4. FITTING THEORETICAL SPECTRA

To model wave conditions in the Alenuihaha Channel as an input into the cable/barge dynamic analysis program, Vega et al. (1984) selected the theoretical spectral formulation recommended by the International Ship Structures Congress (ISSC) for wave loads and ship motion calculations. The ISSC spectrum is defined by two parameters, the significant wave height H and the average wave period T, and is given by,

$$S(f) = 0.11\ H^2\ T(Tf)^{-5}\ \exp[-.44(Tf)^{-4}]$$

where f is frequency.

The present high frequency wave data reduction yields two characteristic wave heights and three wave period values that could be used as parameters in the ISSC spectrum. These are $H_{sz}$ and $T_{zz}$ from the ZUC analysis, and $H_s$, $T_a$, and $T_z$ from the spectral analysis. Figures 2a through 12c are plots of the 11 measured spectra with the theoretical ISSC spectrum overplotted (dotted line). In Figures _a the ISSC spectrum is defined by parameters $H_{sz}$ and $T_{zz}$ from the ZUC analysis, in Figures _b it is defined by $H_s$ and $T_a$ from the spectral analysis, and in Figures _c it is defined by $H_s$ and $T_z$ from the spectral analysis. Table 4 lists the ZUC and spectral statistics and the ratio $H_{sz}/H_s$ which indicates that on average $H_{sz}$ is 93% of $H_s$. Thus, the ISSC spectra defined by $H_s$ are larger than those defined by $H_{sz}$, as is observed in the figures.

Table 5 summarizes how well the three theoretical ISSC spectra fit the measured spectrum in terms of the average percent difference between the two over the period range 2 to 6 seconds. It is seen that when averaged over the 11 measured spectra, the best fit is provided by using parameters $H_{sz}$ and $T_{zz}$ from the ZUC analysis and $H_s$ and $T_z$ from the spectral analysis, the difference being 7%. Since $H_{sz}$ and $H_s$ are very nearly equal and similarly for $T_{zz}$ and $T_z$, it is not surprising that the fit is essentially the same. Using $H_s$ and $T_a$, however, yields a difference of 36%.

The significance of this is that the readily computed spectral statistics calculated from the spectral moments, $H_s$ and $T_z$, define an ISSC spectrum that fits well to the high frequency portion of the 11 surface measured spectra.

Fig.2a. Makapuu Waverider AP30861400: Hs=7.14 Ta=5.89 Tz=5.35

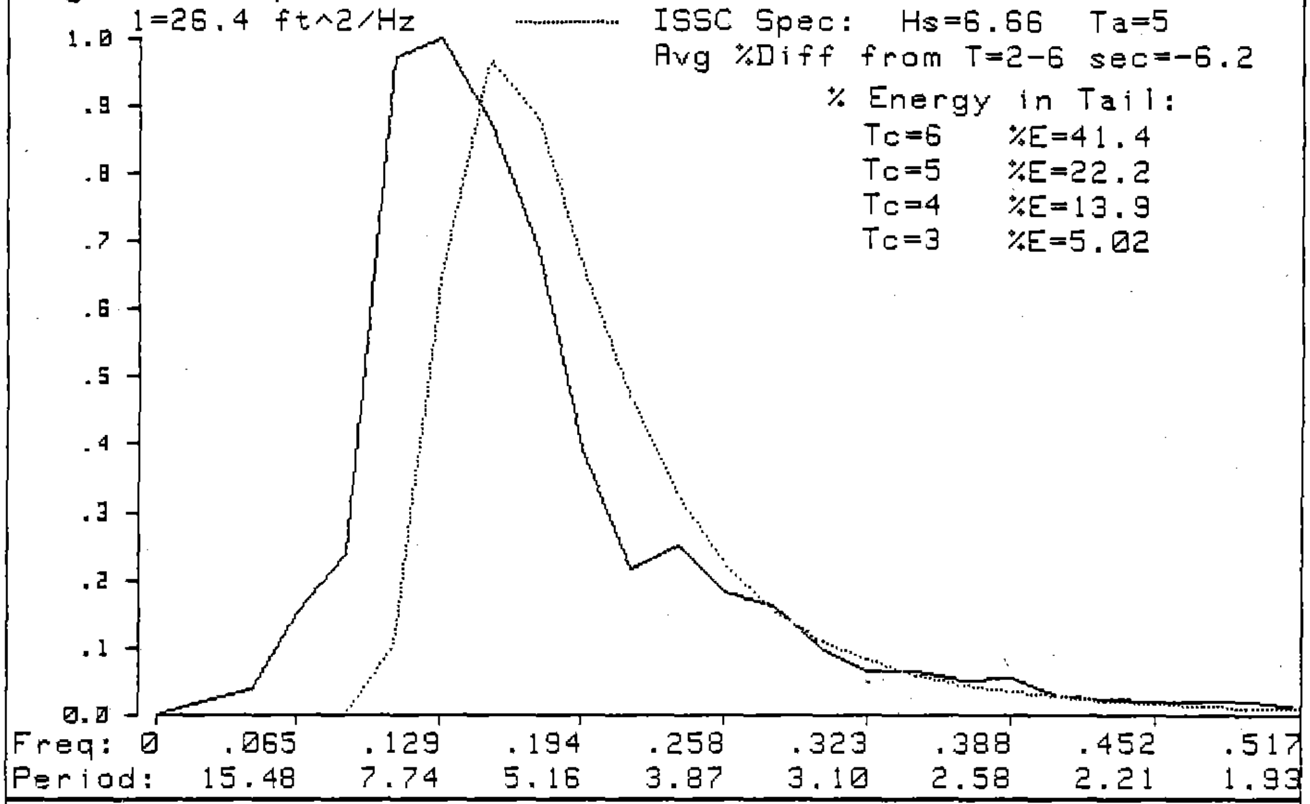
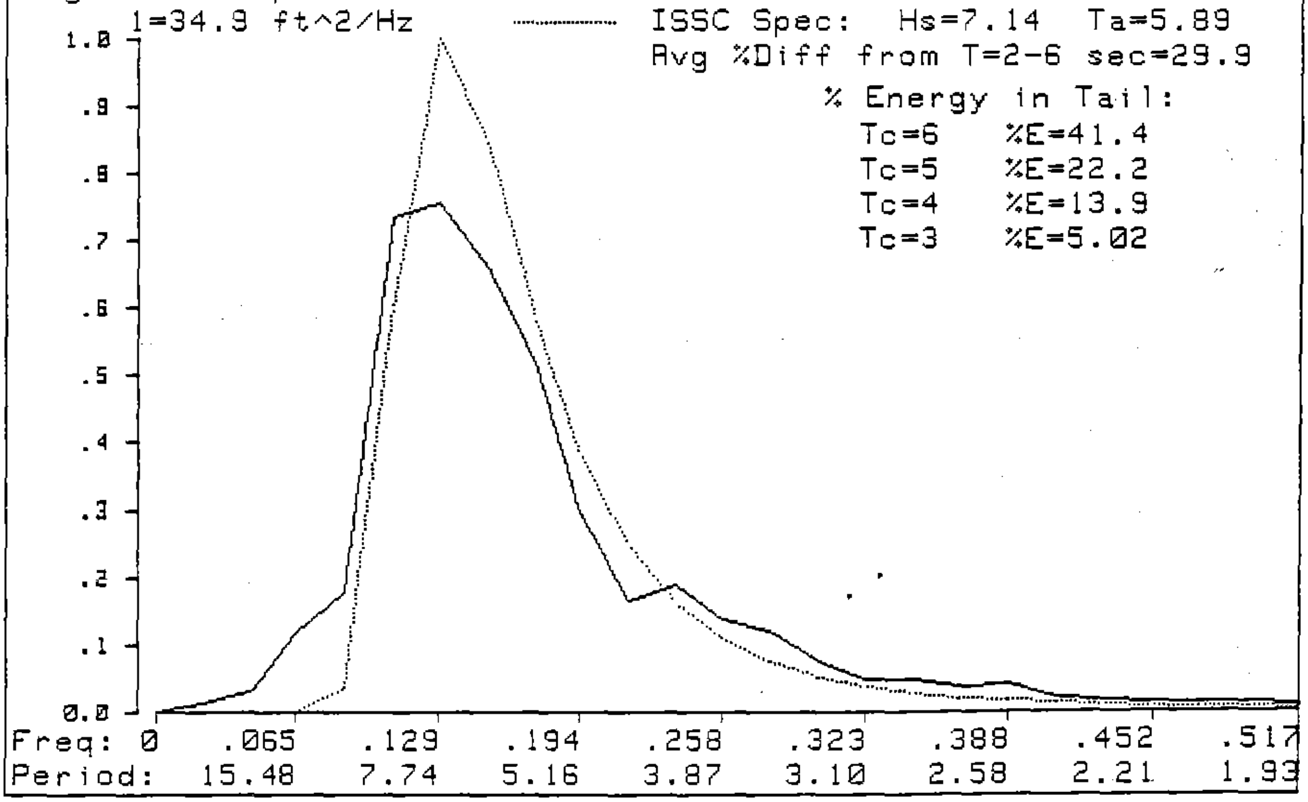


Fig.2b. Makapuu Waverider AP30861400: Hs=7.14 Ta=5.89 Tz=5.35



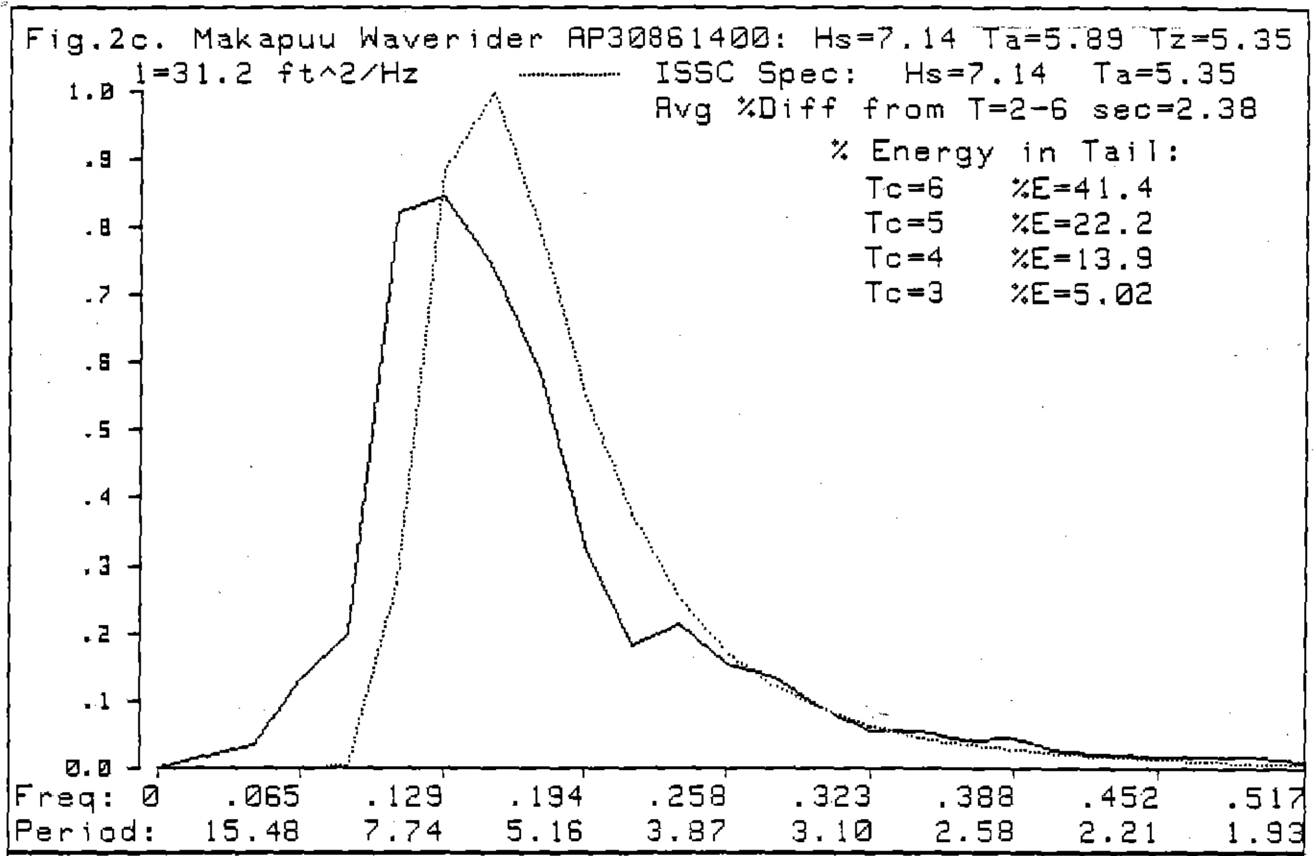


Fig.2c. Makapuu Waverider AP30861400: Hs=7.14 Ta=5.89 Tz=5.35

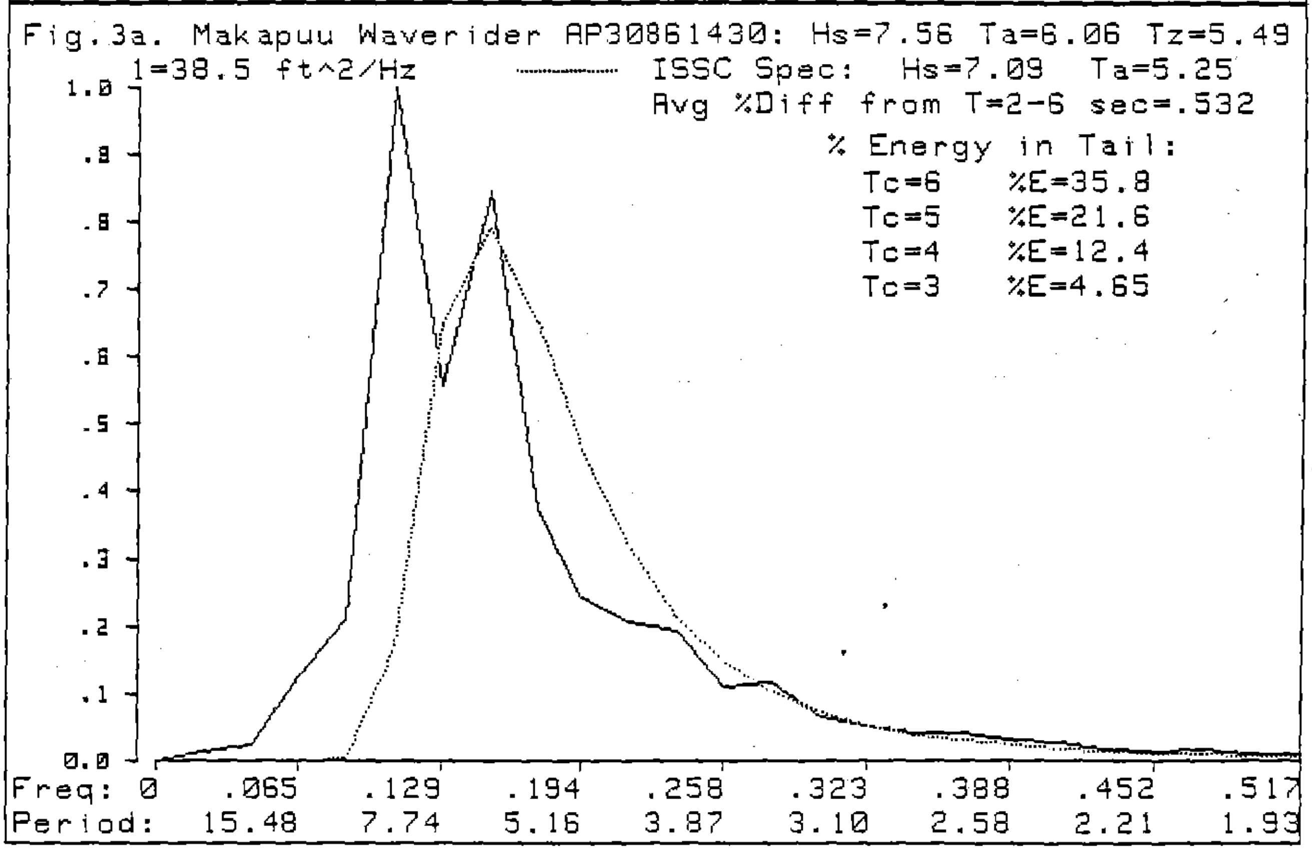


Fig.3a. Makapuu Waverider AP30861430: Hs=7.56 Ta=6.06 Tz=5.49

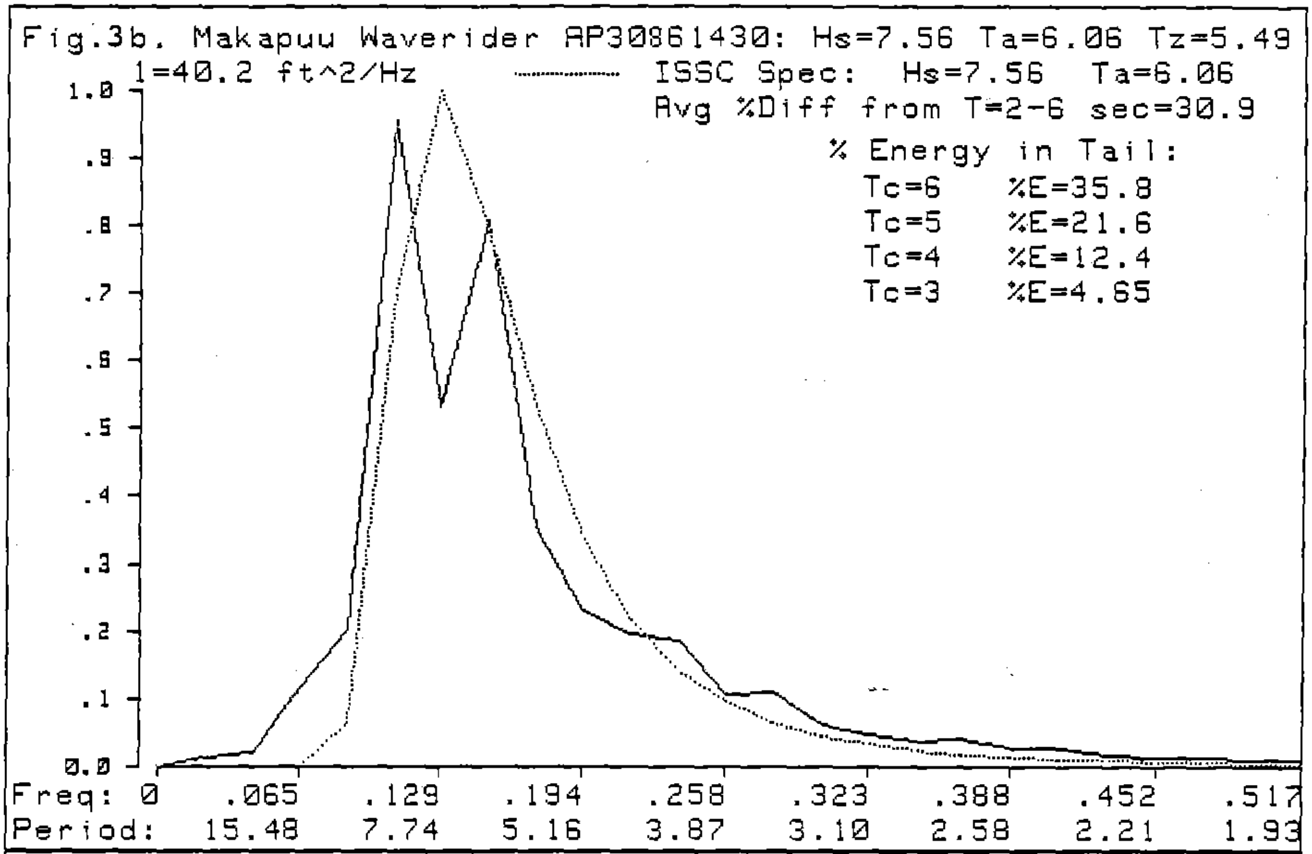


Fig.3b. Makapuu Waverider AP30861430: Hs=7.56 Ta=6.06 Tz=5.49

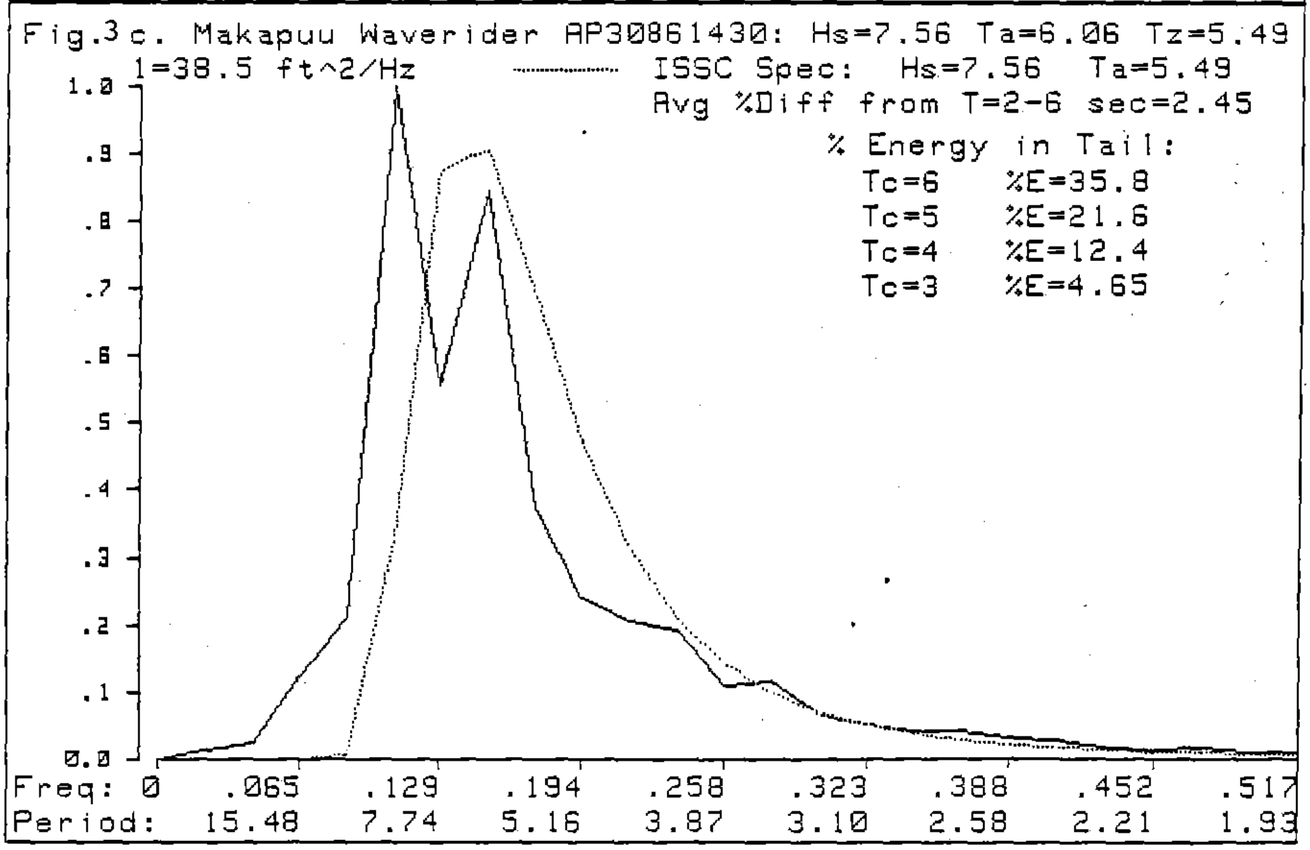


Fig.3c. Makapuu Waverider AP30861430: Hs=7.56 Ta=6.06 Tz=5.49

Fig.4a. Makapuu Waverider AP30861500: Hs=6.90 Ta=5.75 Tz=5.20

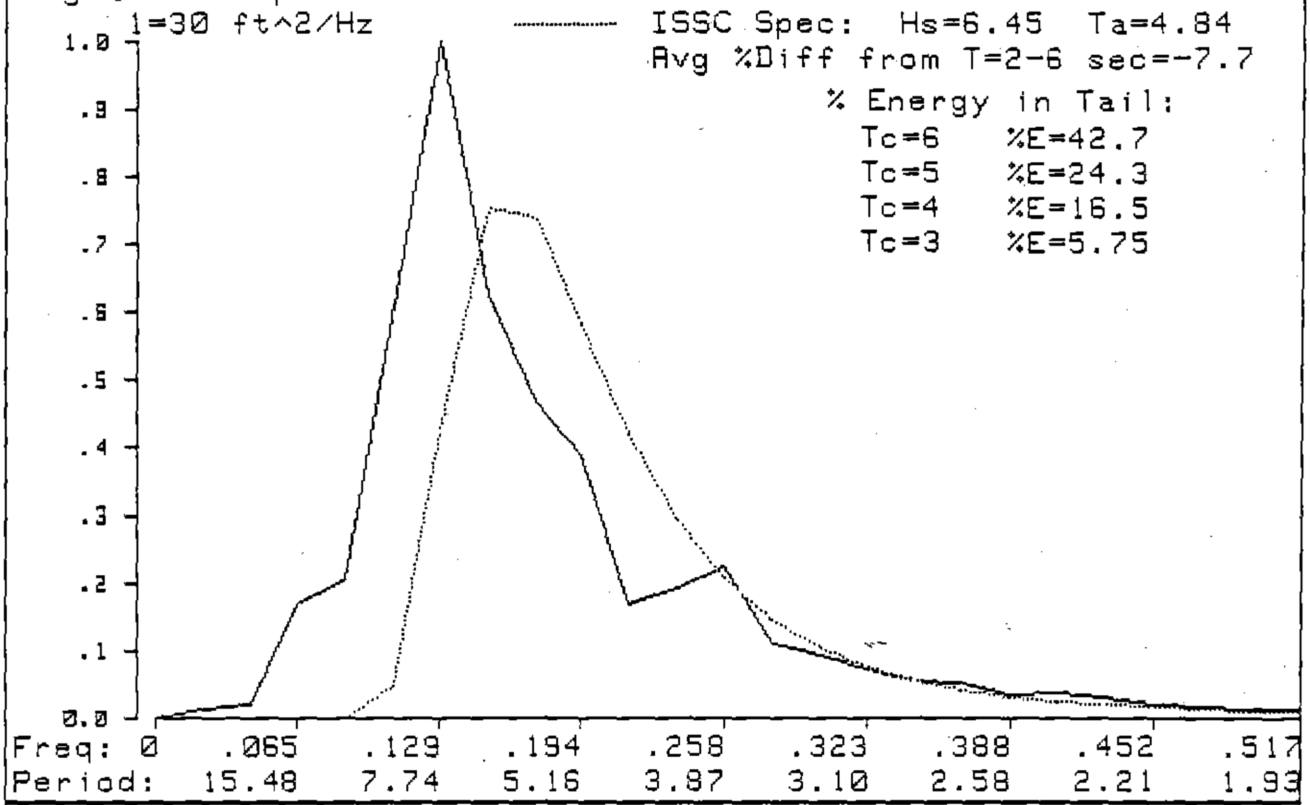


Fig.4b. Makapuu Waverider AP30861500: Hs=6.90 Ta=5.75 Tz=5.20

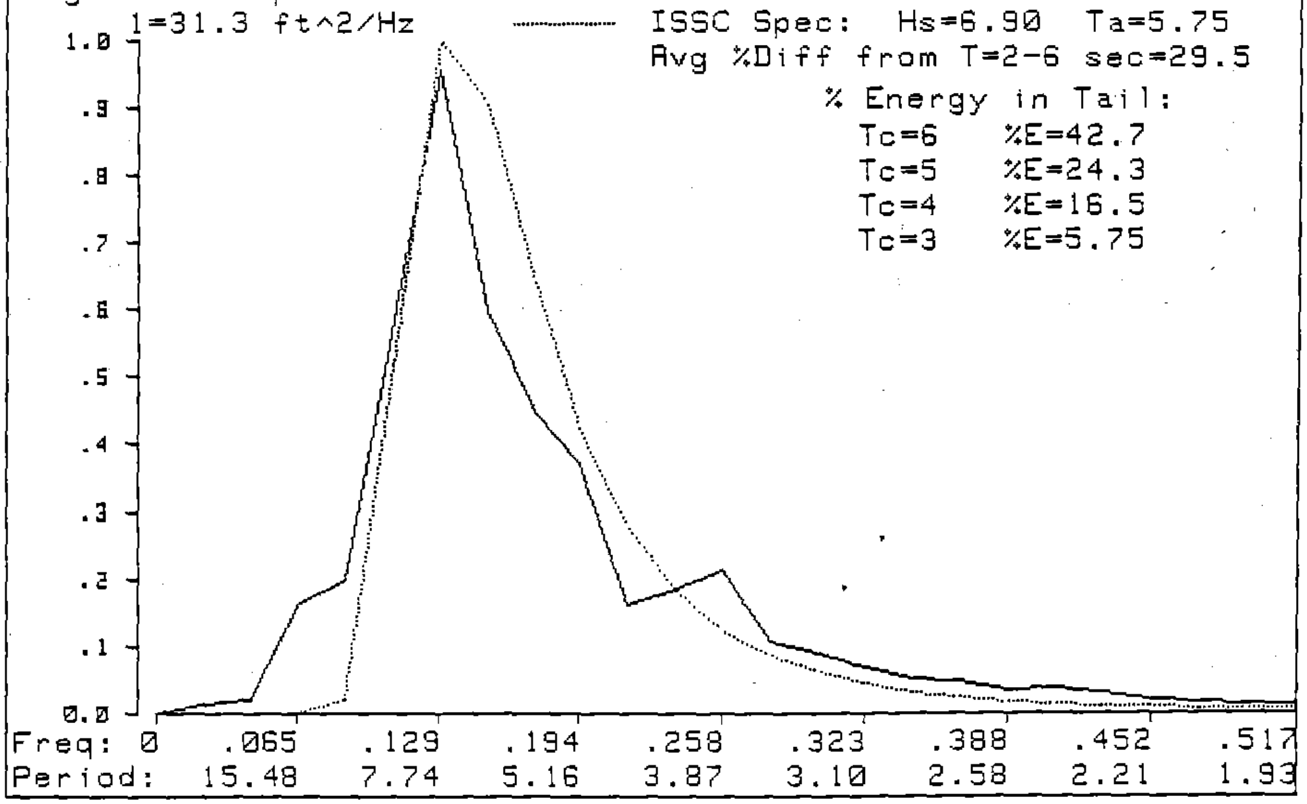


Fig.4c. Makapuu Waverider AP30861500: Hs=6.90 Ta=5.75 Tz=5.20

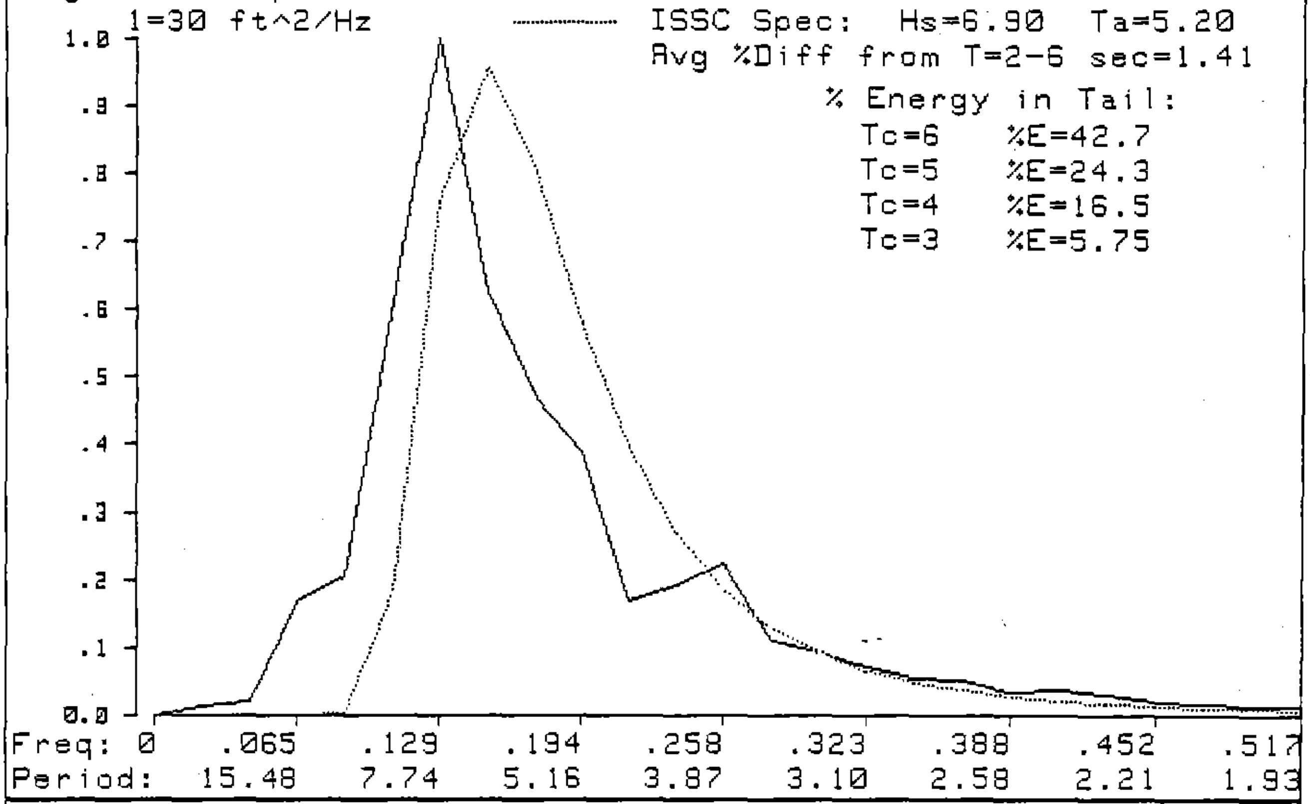
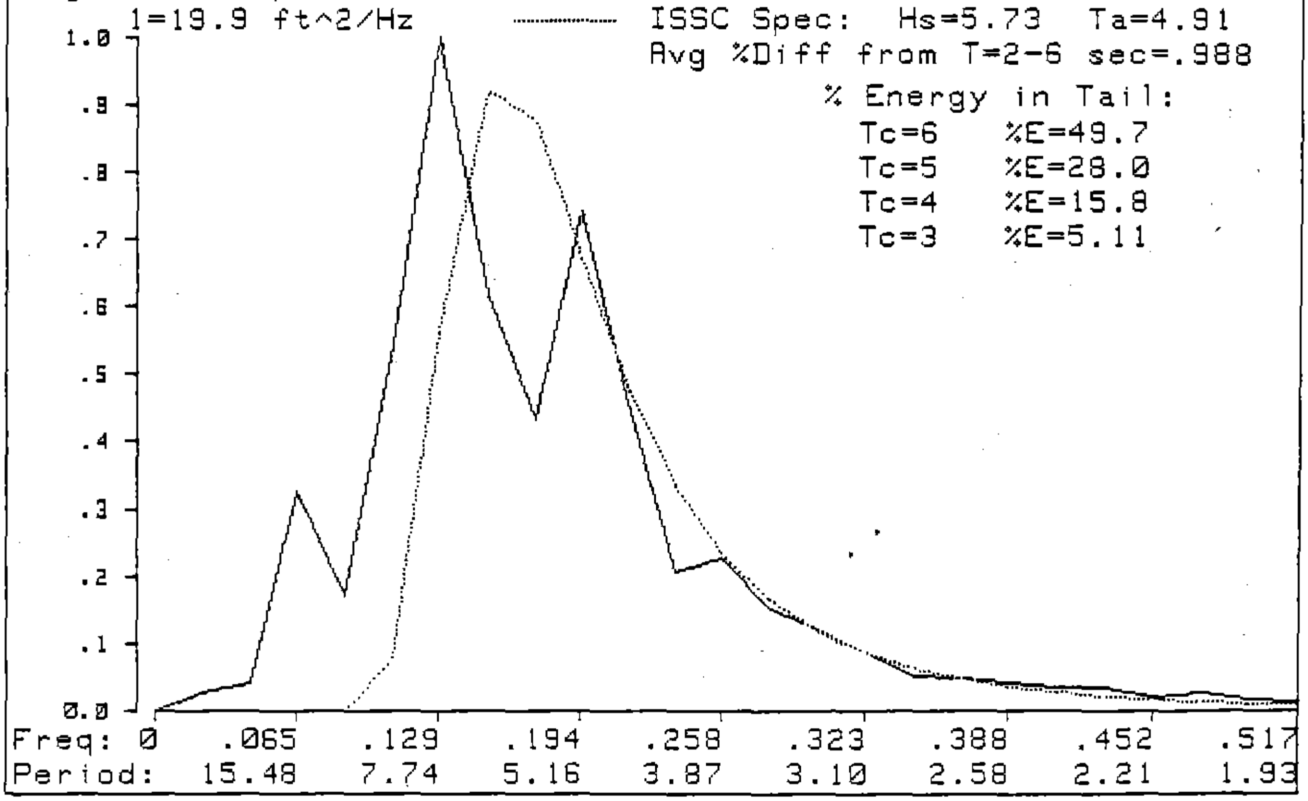


Fig.5a. Makapuu Waverider JL17861400: Hs=6.09 Ta=5.63 Tz=5.11



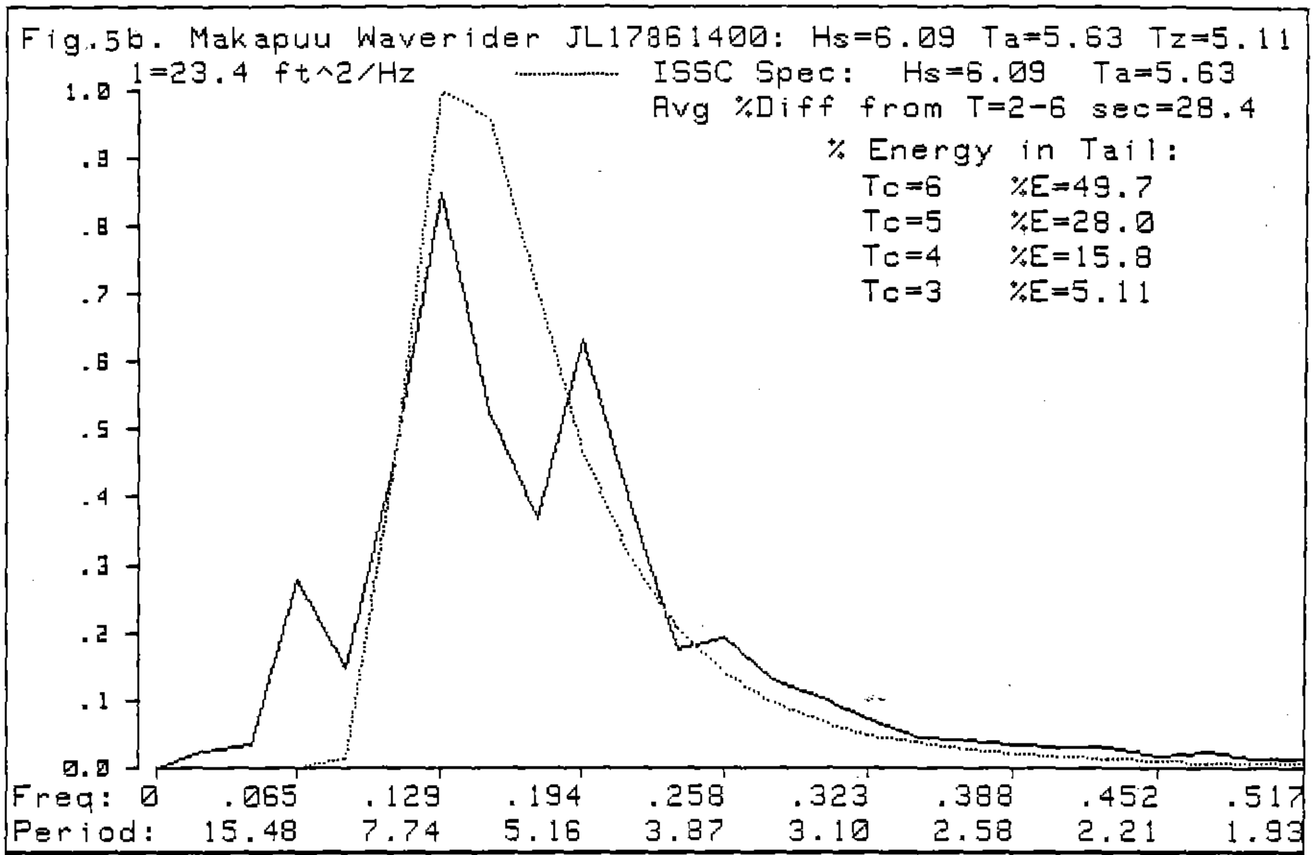


Fig.5b. Makapuu Waverider JL17861400: Hs=6.09 Ta=5.63 Tz=5.11

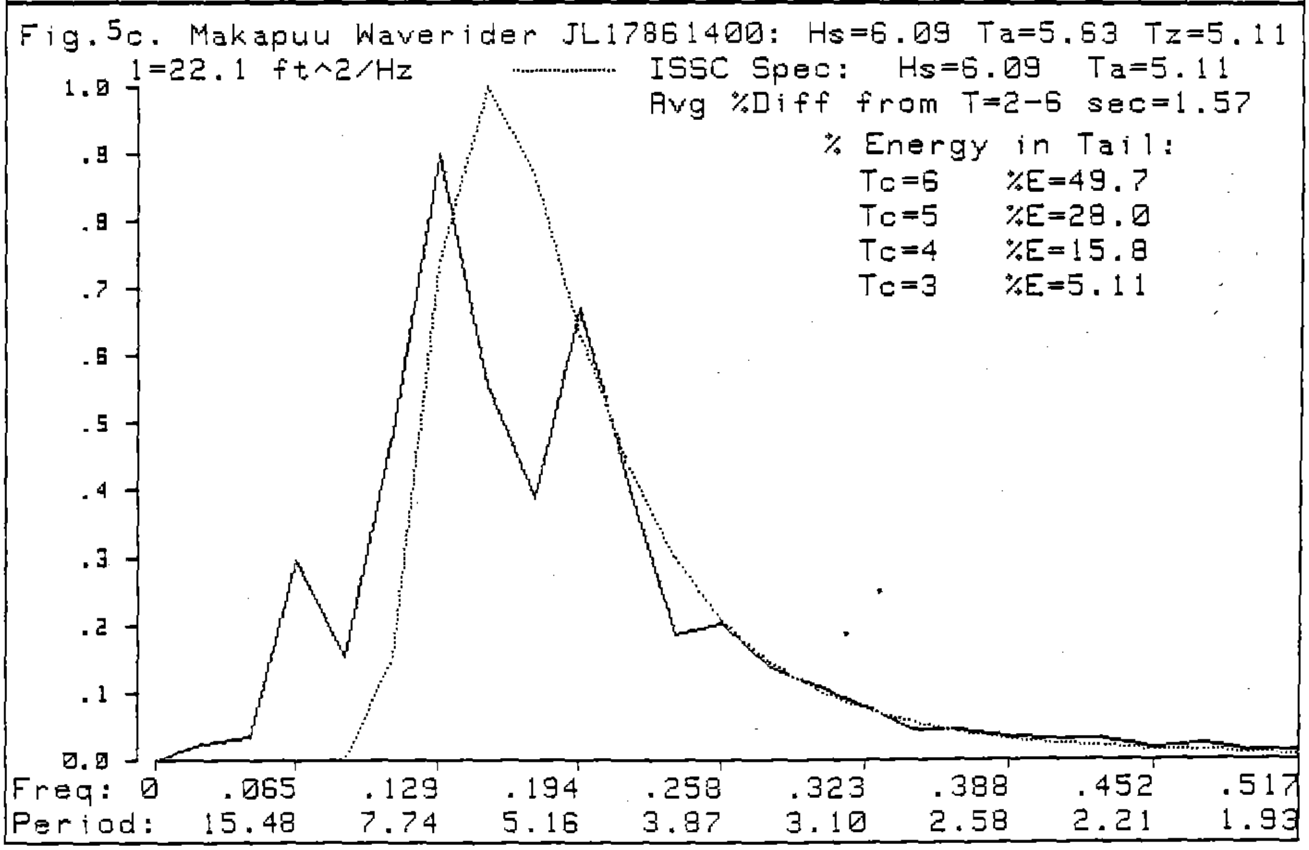


Fig.5c. Makapuu Waverider JL17861400: Hs=6.09 Ta=5.63 Tz=5.11

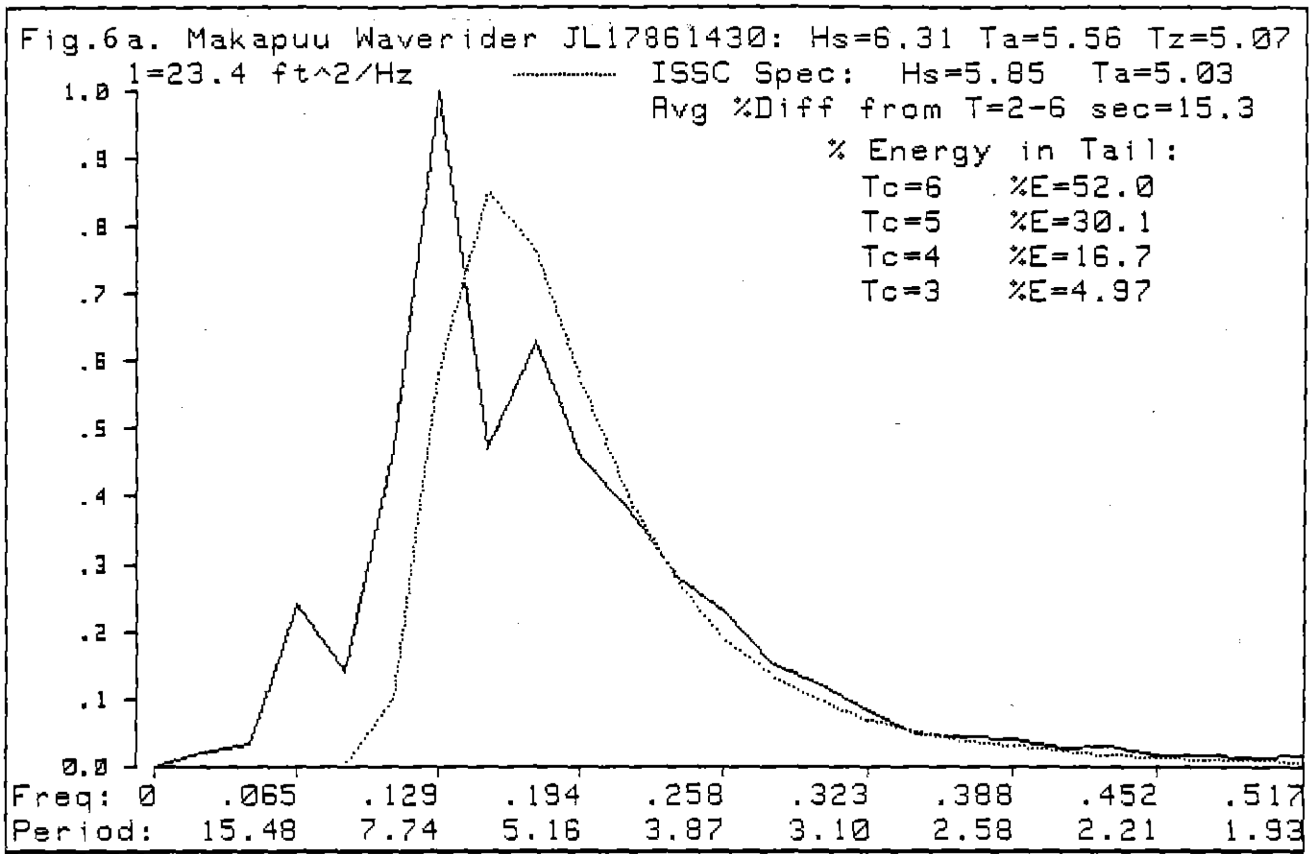


Fig.6a. Makapuu Waverider JL17861430: Hs=6.31 Ta=5.56 Tz=5.07

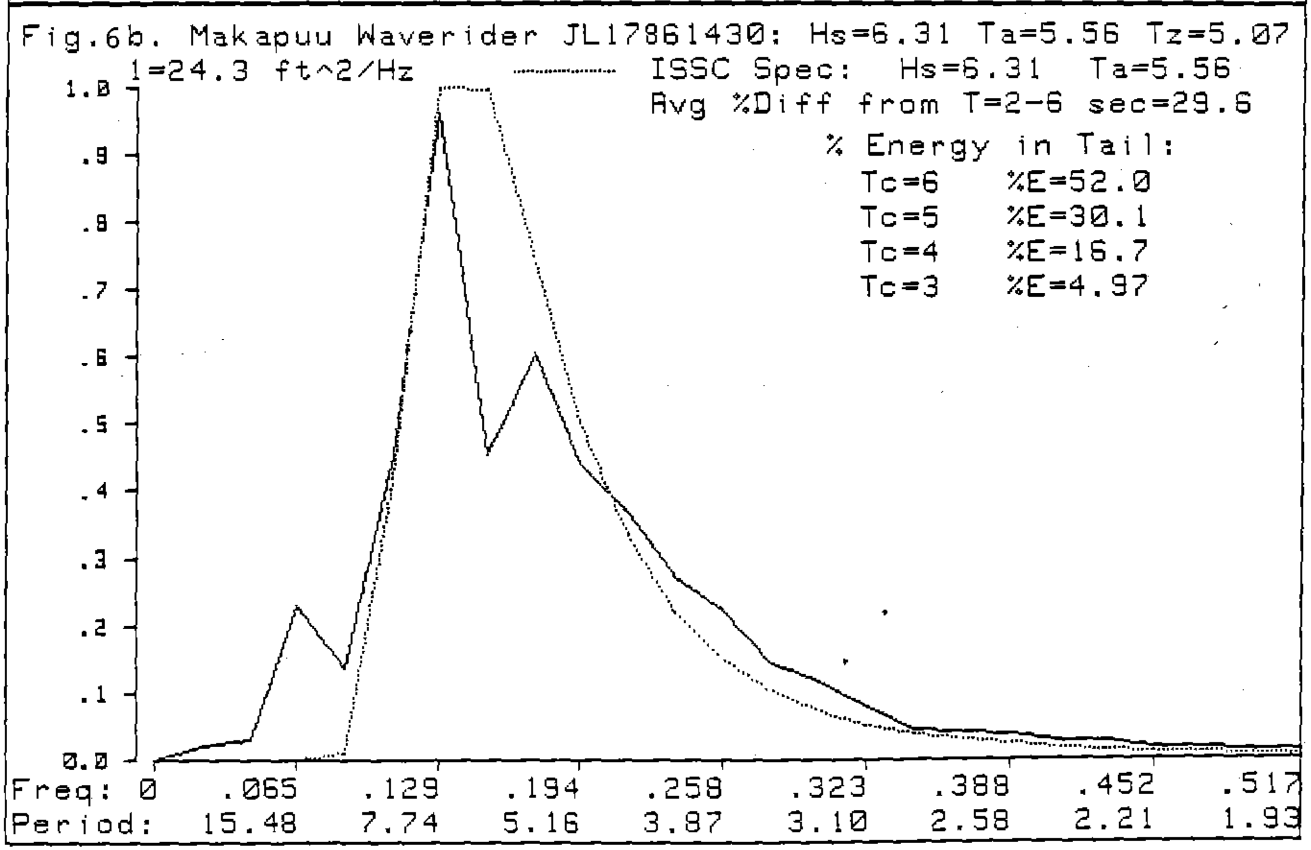


Fig.6b. Makapuu Waverider JL17861430: Hs=6.31 Ta=5.56 Tz=5.07

Fig.6c. Makapuu Waverider JL17861430: Hs=6.31 Ta=5.56 Tz=5.07

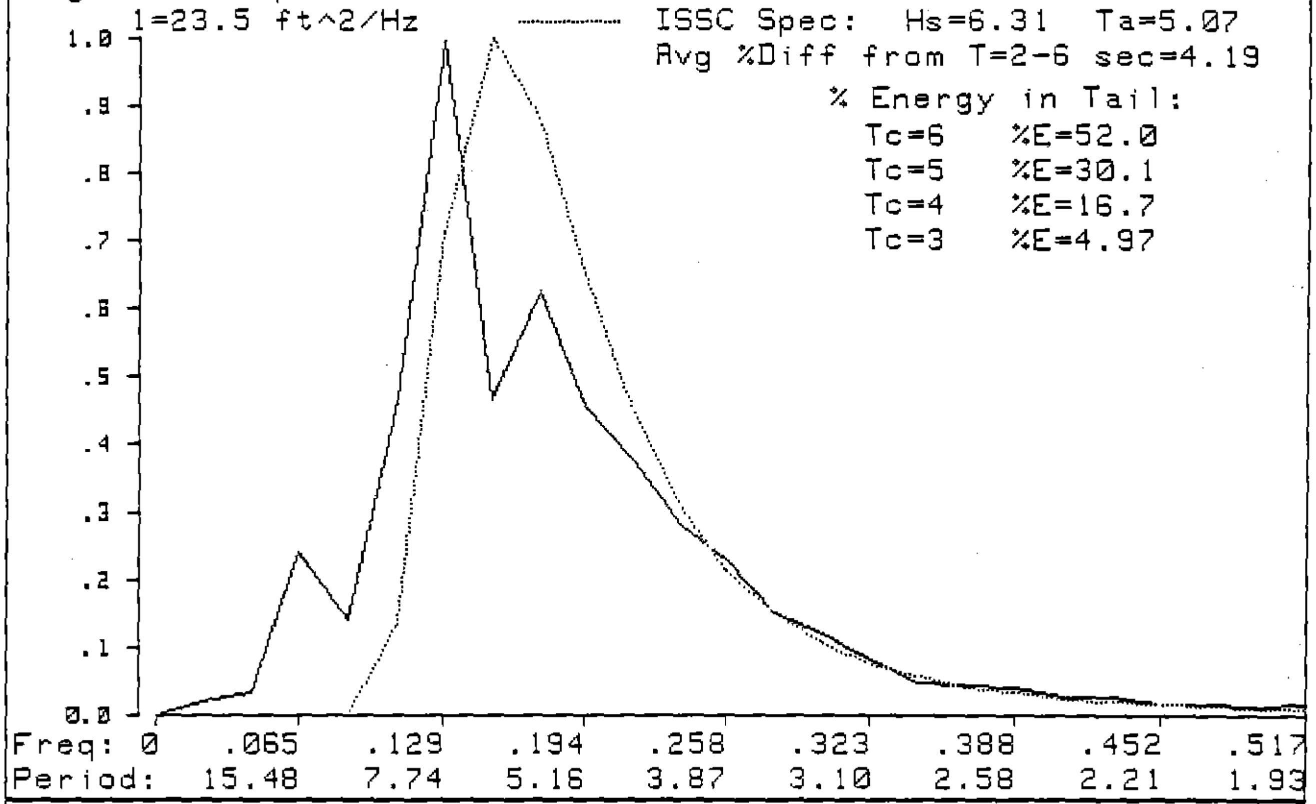
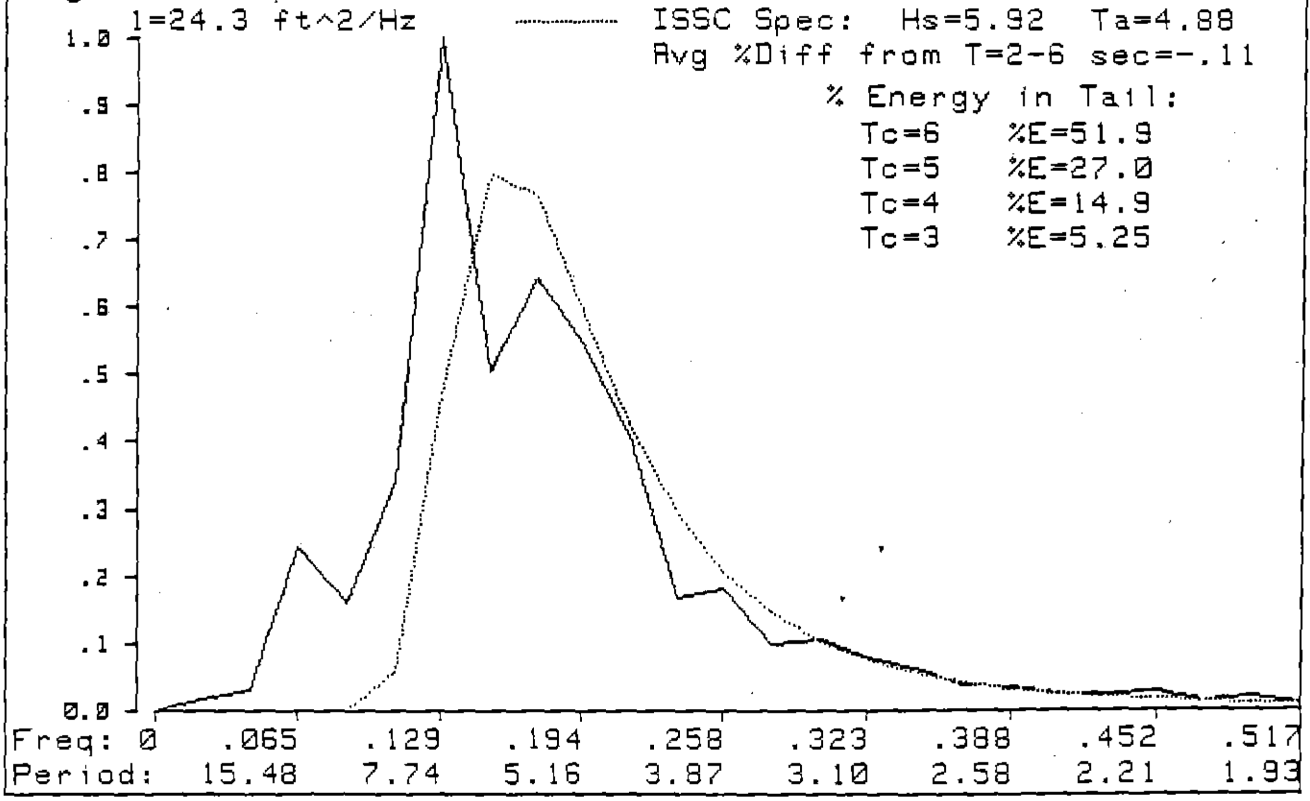


Fig.7a. Makapuu Waverider JL17861500: Hs=6.32 Ta=5.61 Tz=5.12



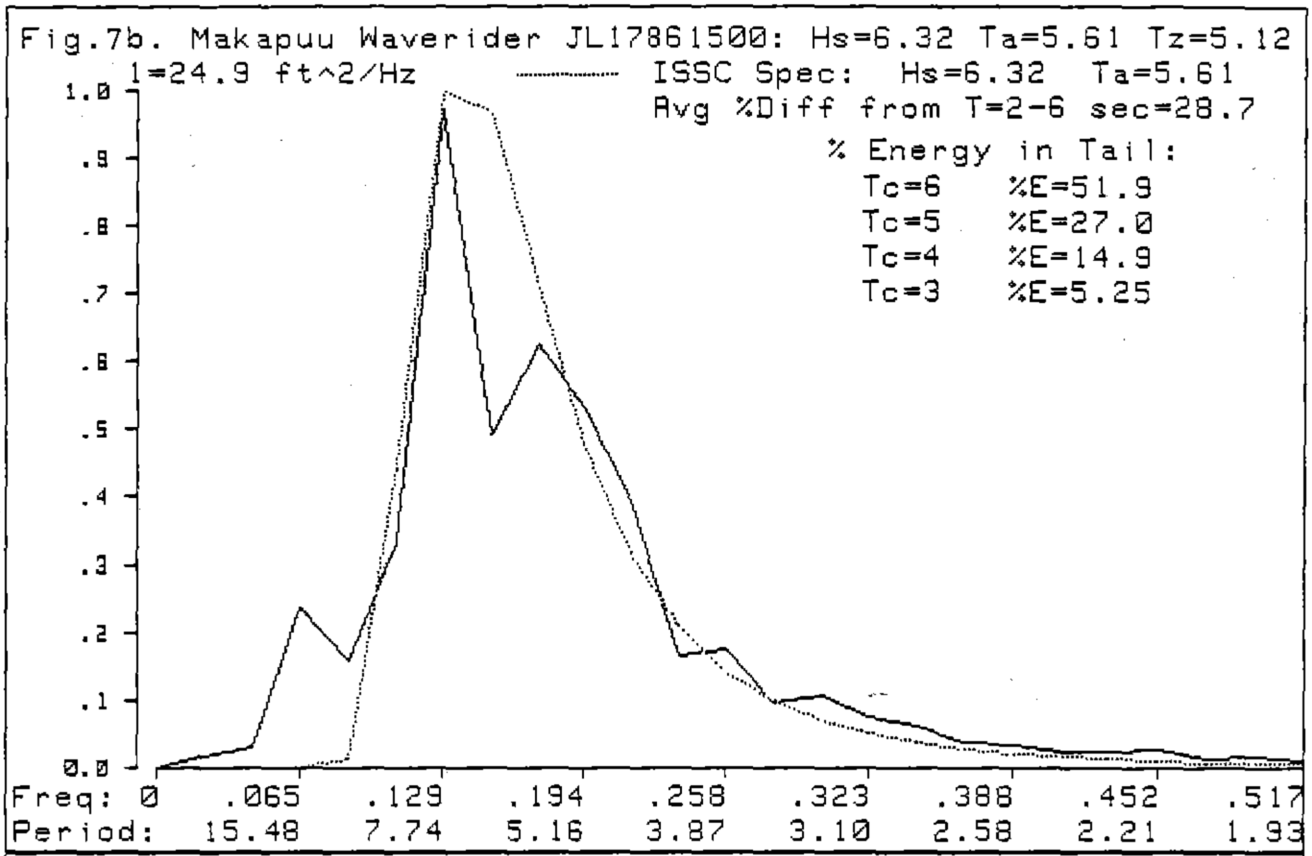


Fig.7b. Makapuu Waverider JL17861500: Hs=6.32 Ta=5.61 Tz=5.12

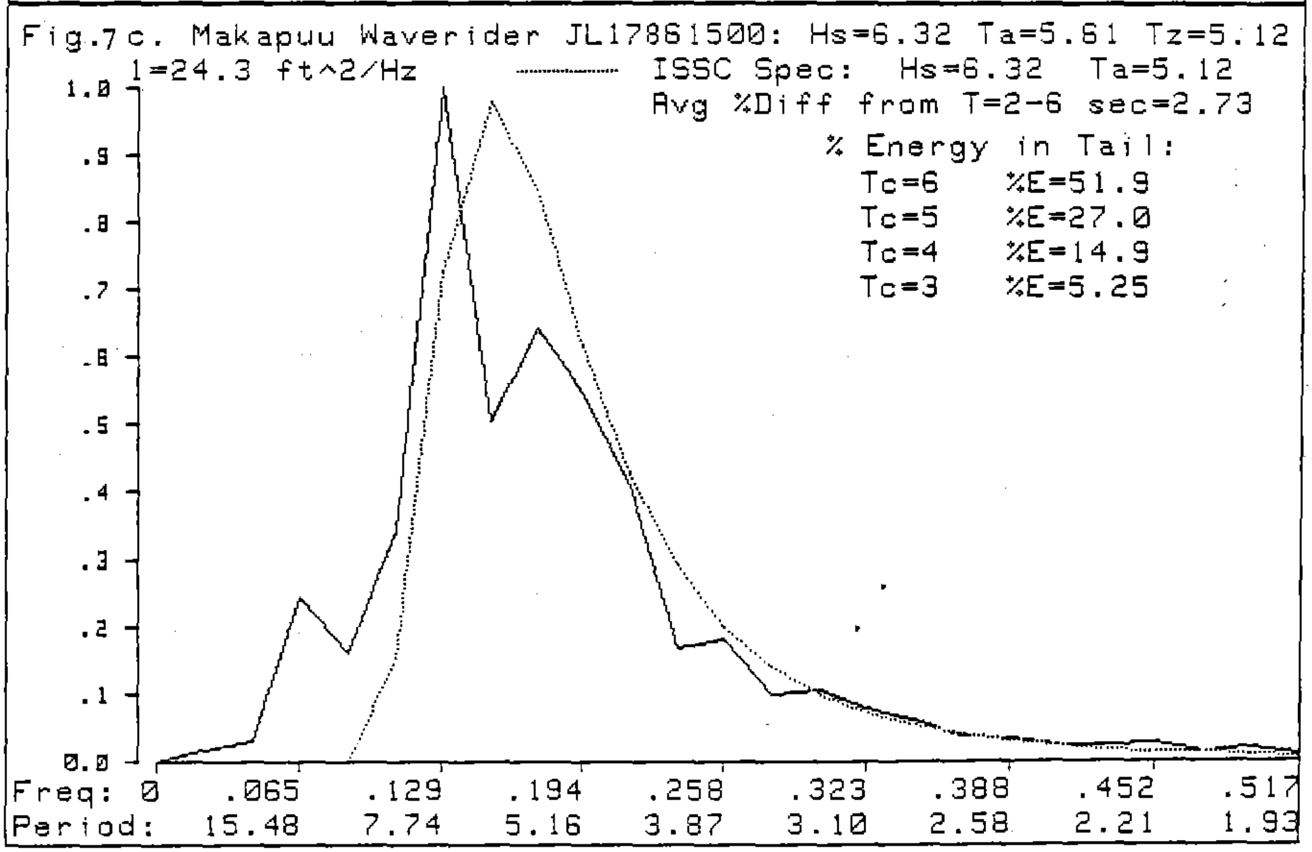


Fig.7c. Makapuu Waverider JL17861500: Hs=6.32 Ta=5.61 Tz=5.12

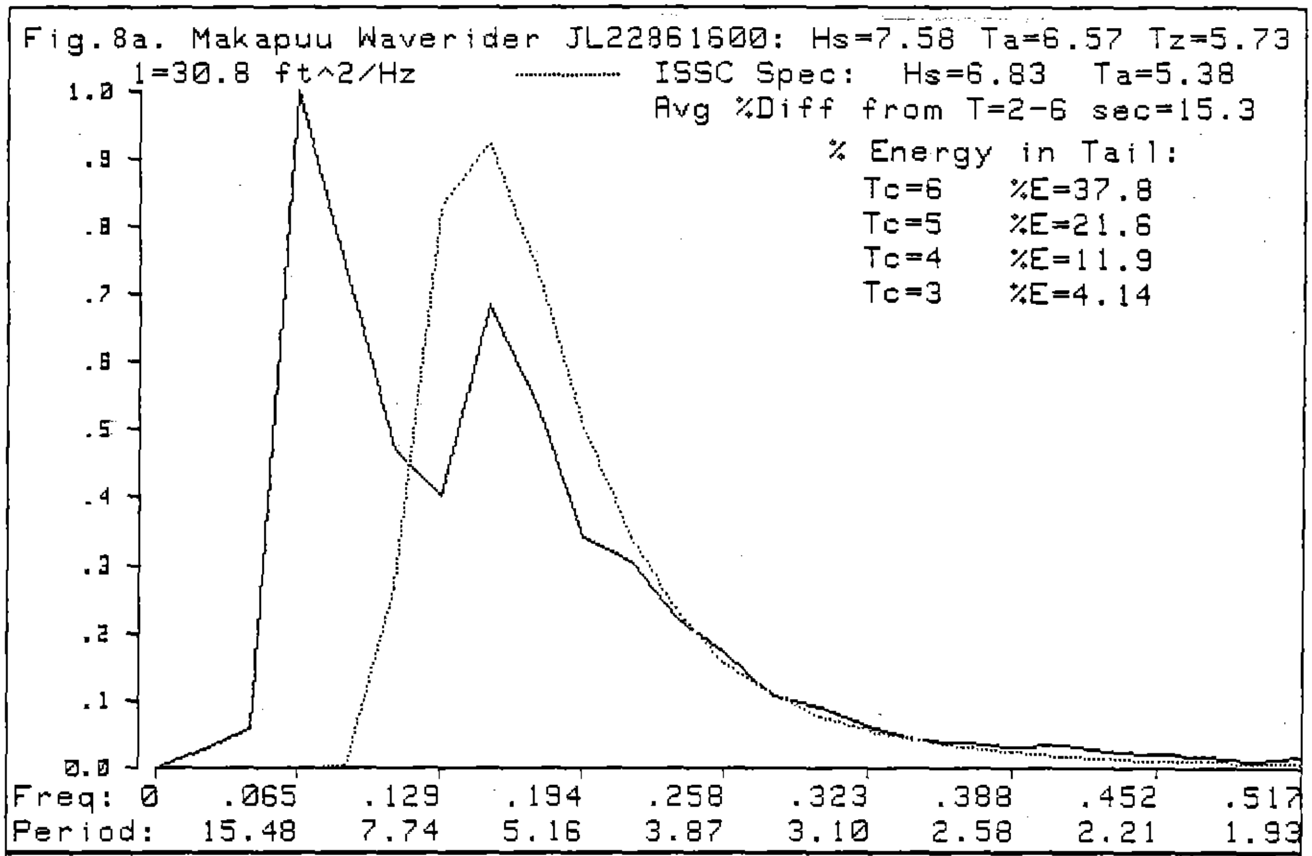


Fig.8a. Makapuu Waverider JL22861600: Hs=7.58 Ta=6.57 Tz=5.73

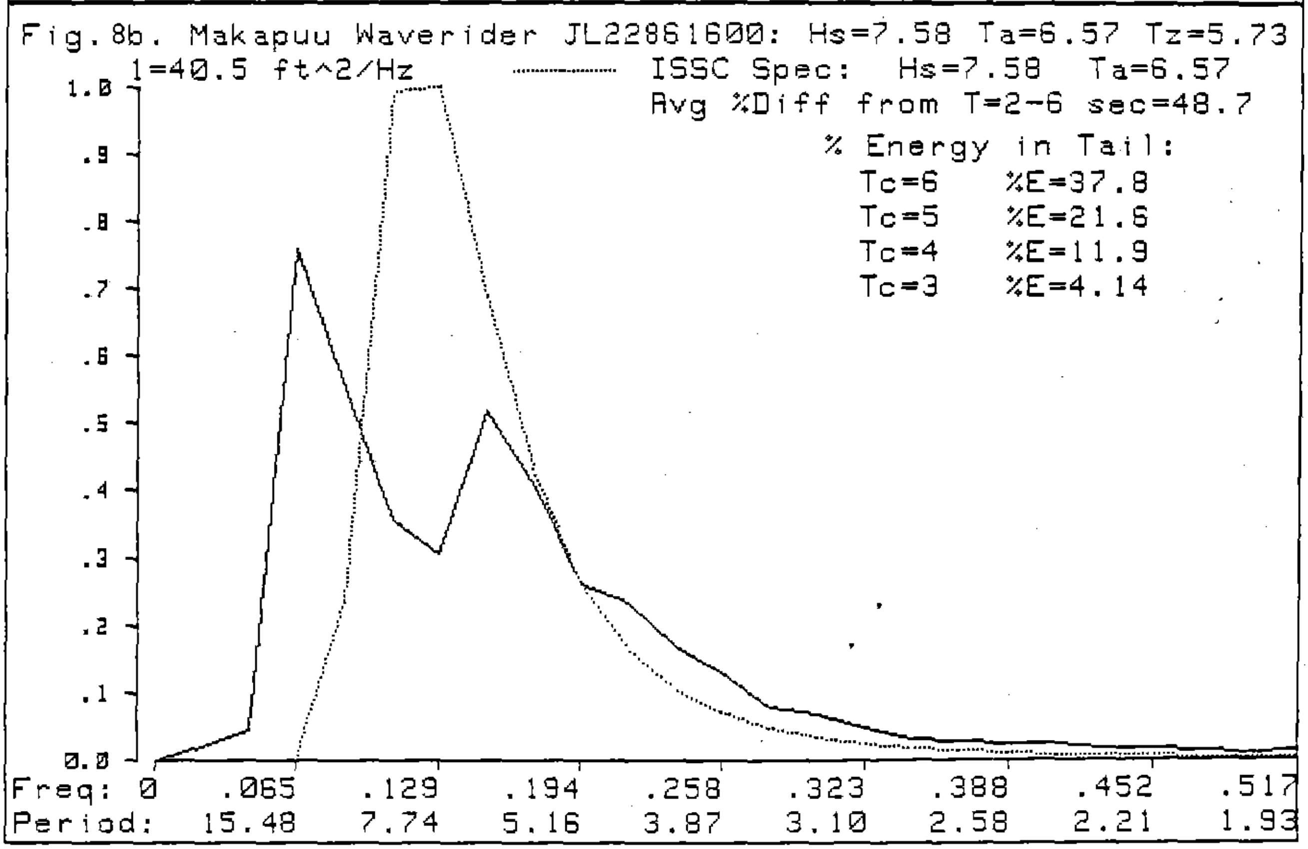


Fig.8b. Makapuu Waverider JL22861600: Hs=7.58 Ta=6.57 Tz=5.73

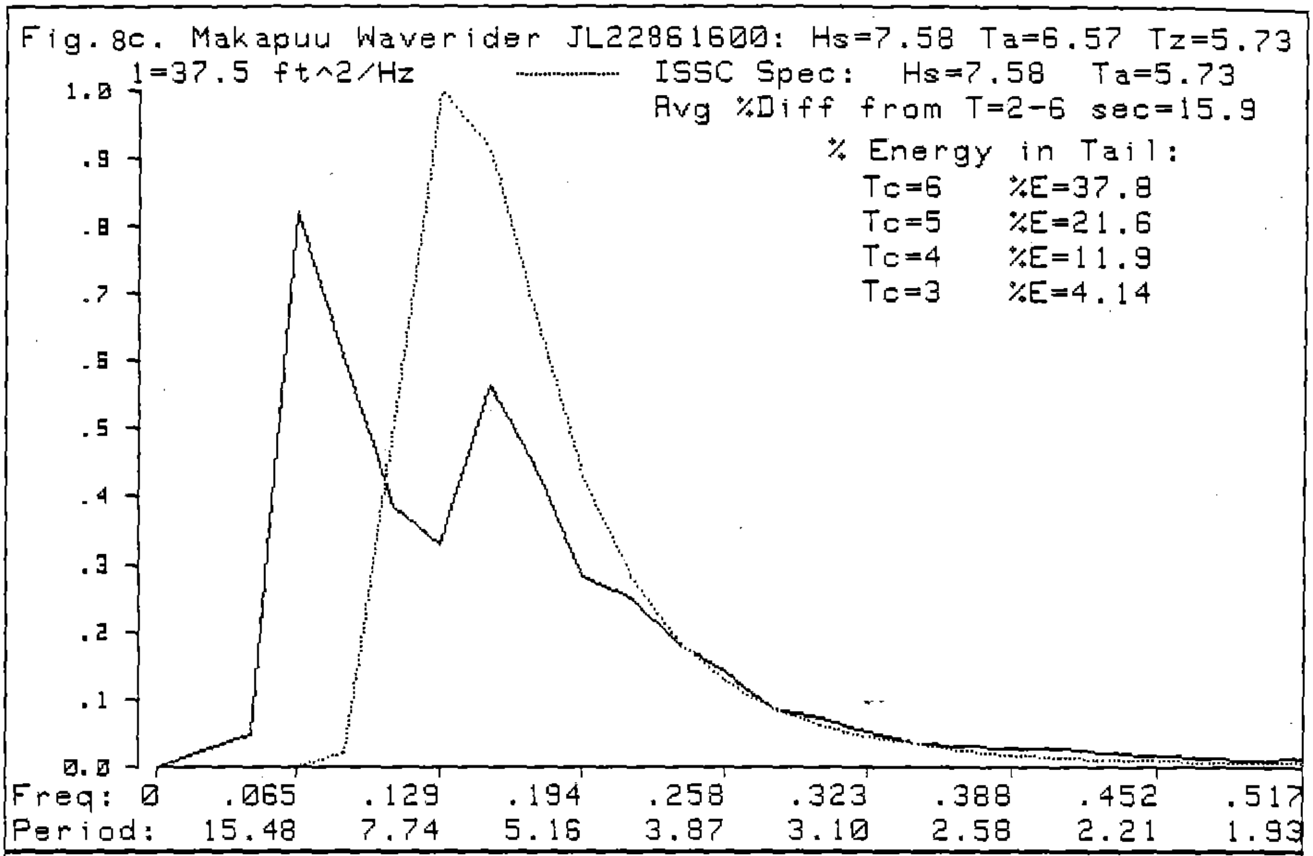


Fig. 8c. Makapuu Waverider JL22861600: Hs=7.58 Ta=6.57 Tz=5.73

1=37.5 ft^2/Hz ········ ISSC Spec: Hs=7.58 Ta=5.73

Avg %Diff from T=2-6 sec=15.9

% Energy in Tail:

Tc=6 %E=37.8

Tc=5 %E=21.6

Tc=4 %E=11.9

Tc=3 %E=4.14

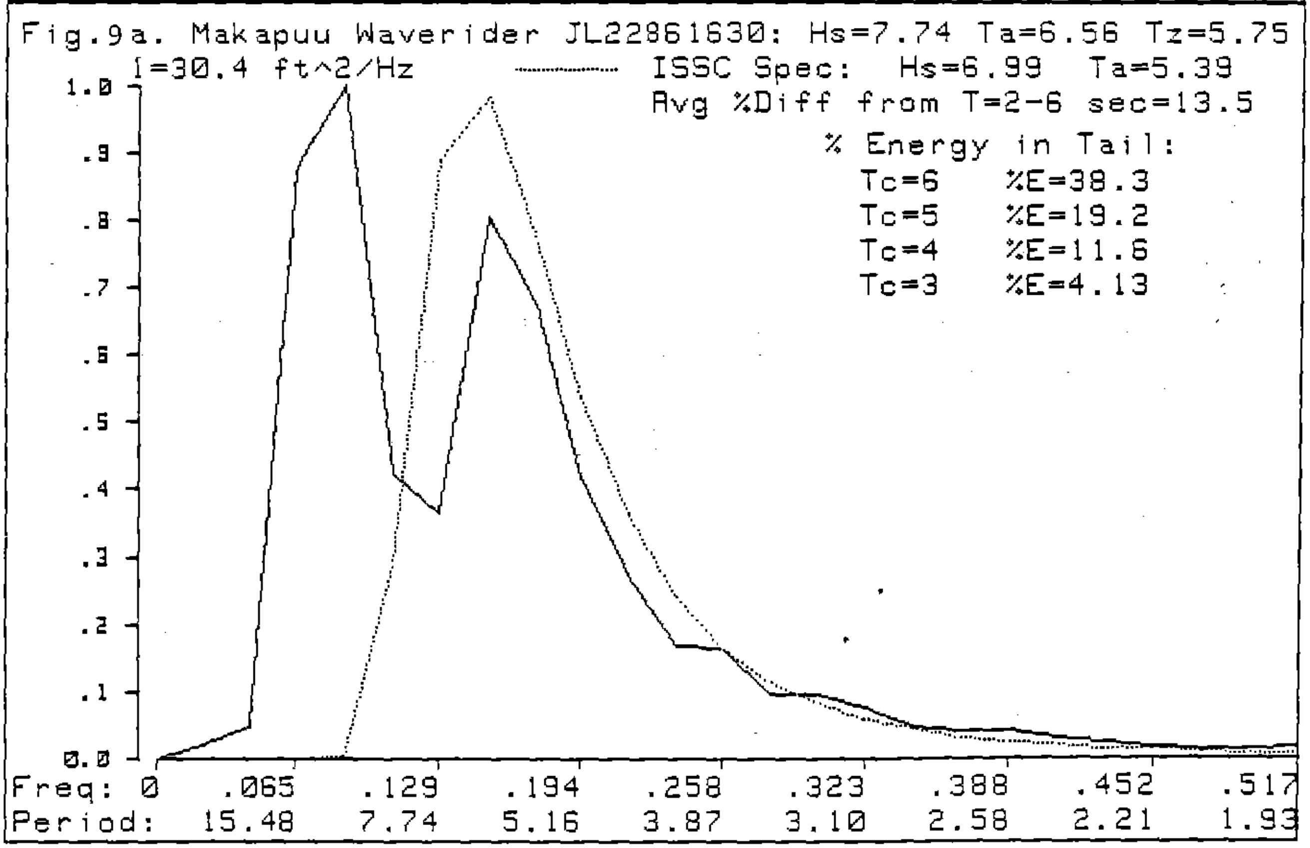


Fig.9a. Makapuu Waverider JL22861630: Hs=7.74 Ta=6.56 Tz=5.75

1=30.4 ft^2/Hz ········ ISSC Spec: Hs=6.99 Ta=5.39

Avg %Diff from T=2-6 sec=13.5

% Energy in Tail:

Tc=6 %E=38.3

Tc=5 %E=19.2

Tc=4 %E=11.6

Tc=3 %E=4.13

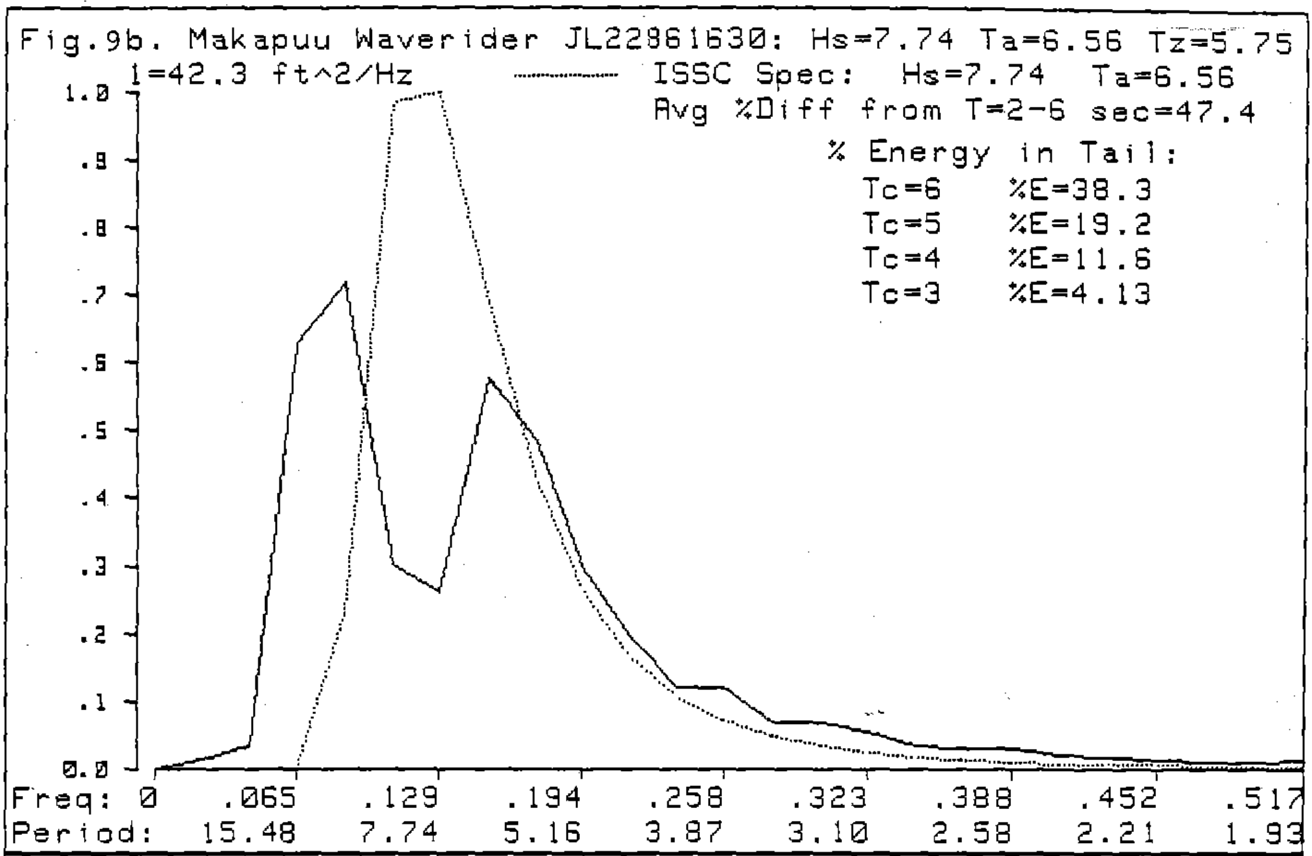


Fig.9b. Makapuu Waverider JL22861630: Hs=7.74 Ta=6.56 Tz=5.75

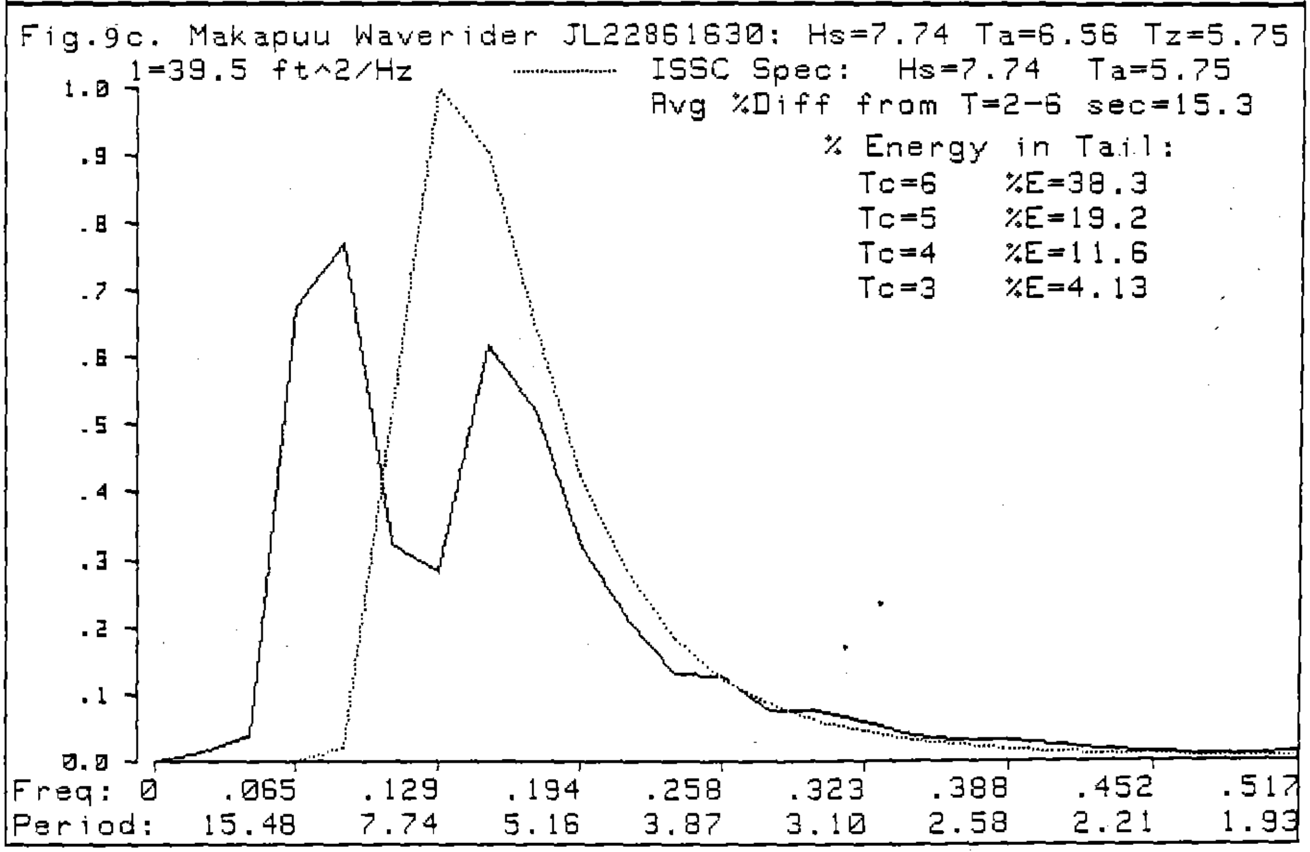


Fig.9c. Makapuu Waverider JL22861630: Hs=7.74 Ta=6.56 Tz=5.75

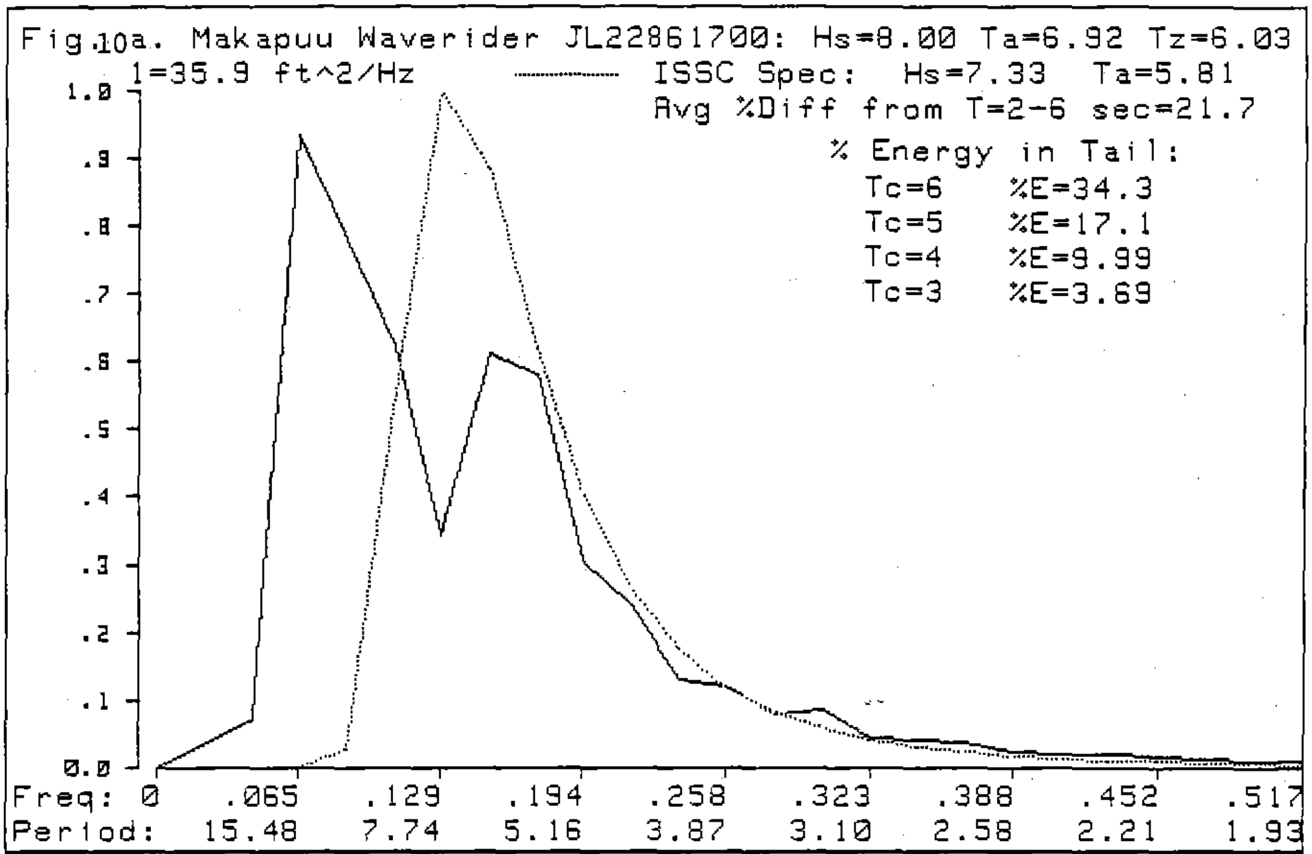


Fig.10a. Makapuu Waverider JL22861700: Hs=8.00 Ta=6.92 Tz=6.03

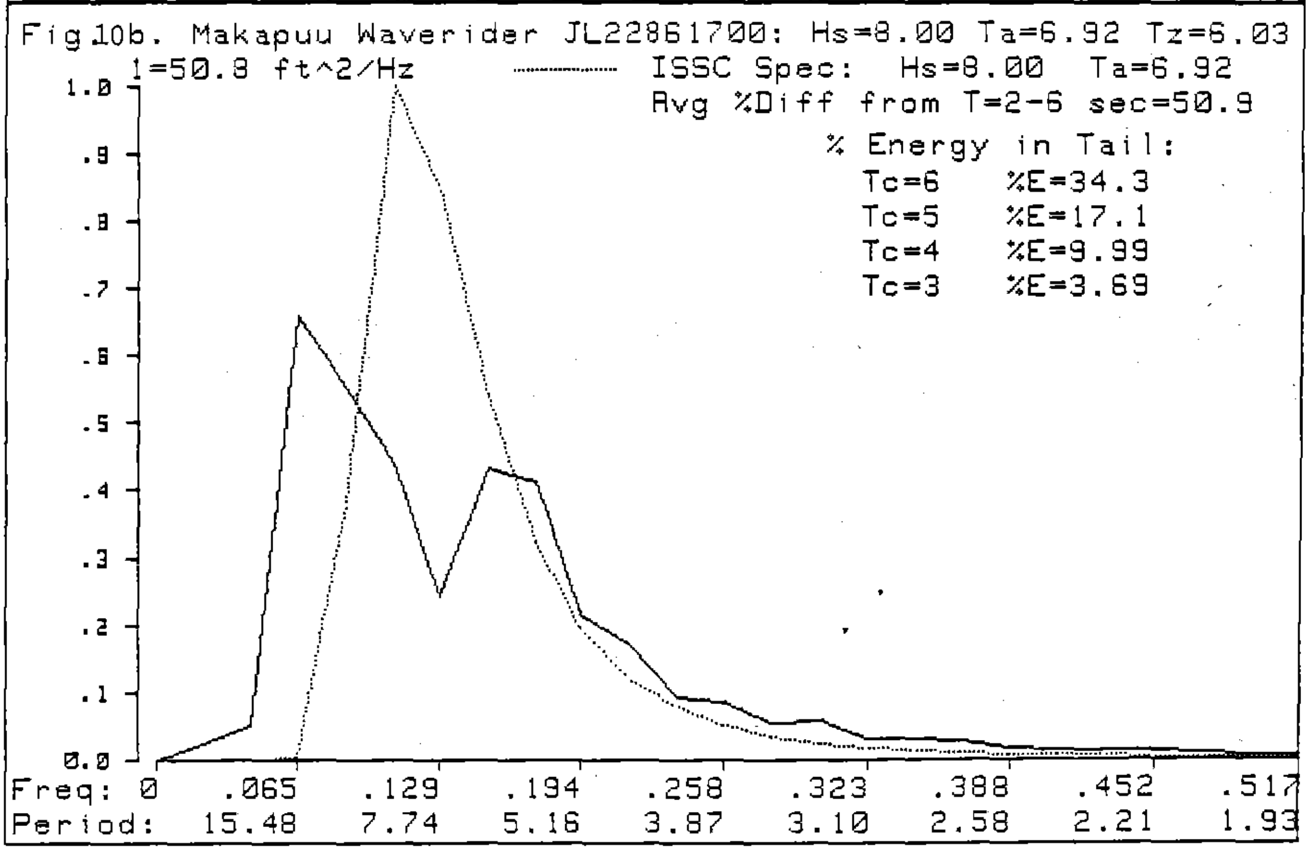


Fig.10b. Makapuu Waverider JL22861700: Hs=8.00 Ta=6.92 Tz=6.03

Fig.10c. Makapuu Waverider JL22861700: Hs=8.00 Ta=6.92 Tz=6.03

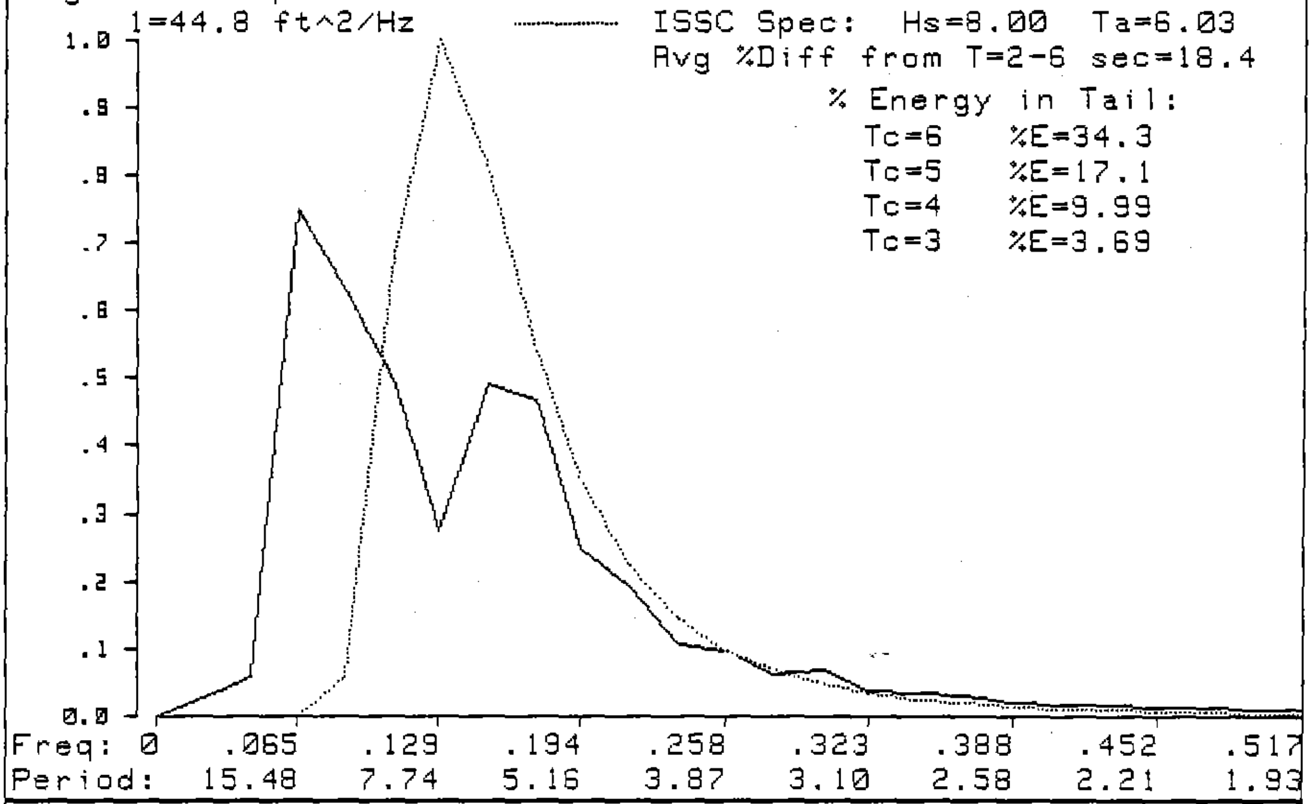


Fig.11 a. Makapuu Waverider JL23860900: Hs=9.24 Ta=7.09 Tz=6.39

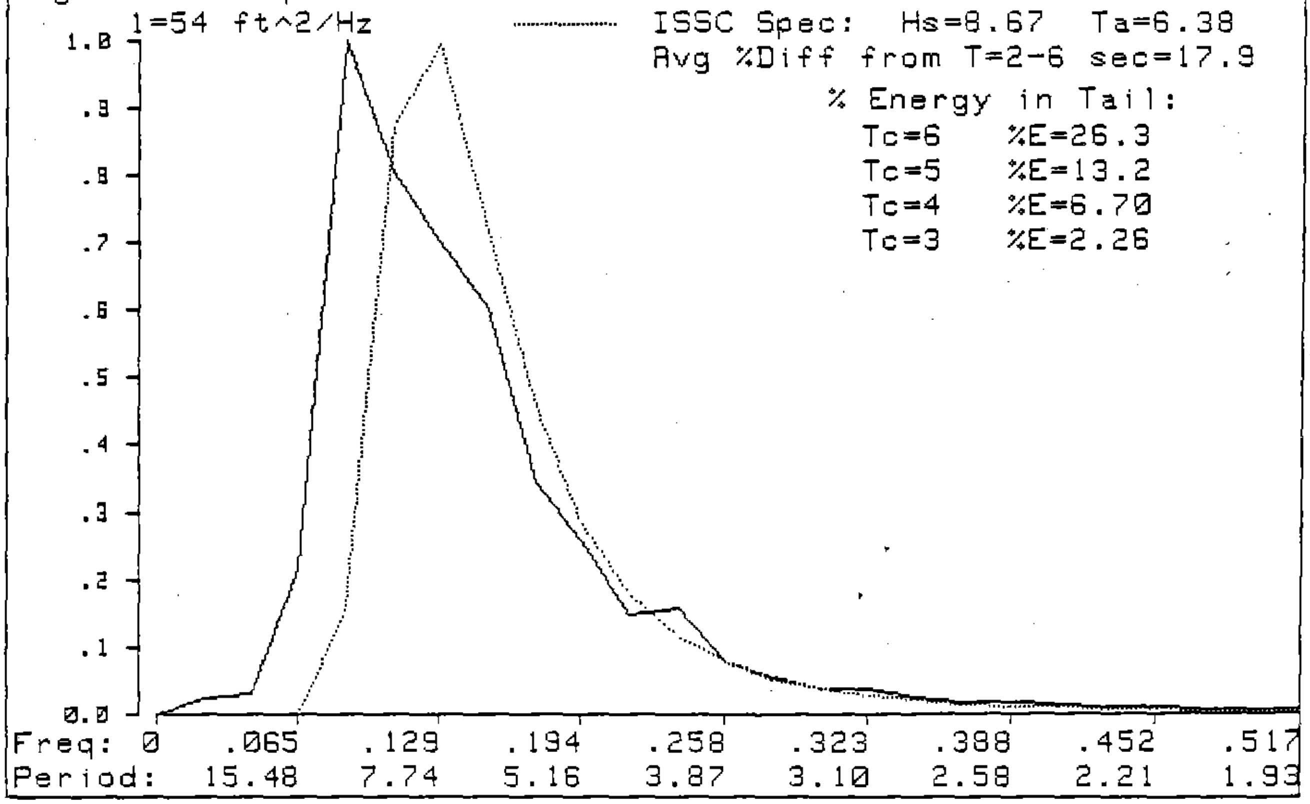


Fig.11b. Makapuu Waverider JL23860900: Hs=9.24 Ta=7.09 Tz=6.39

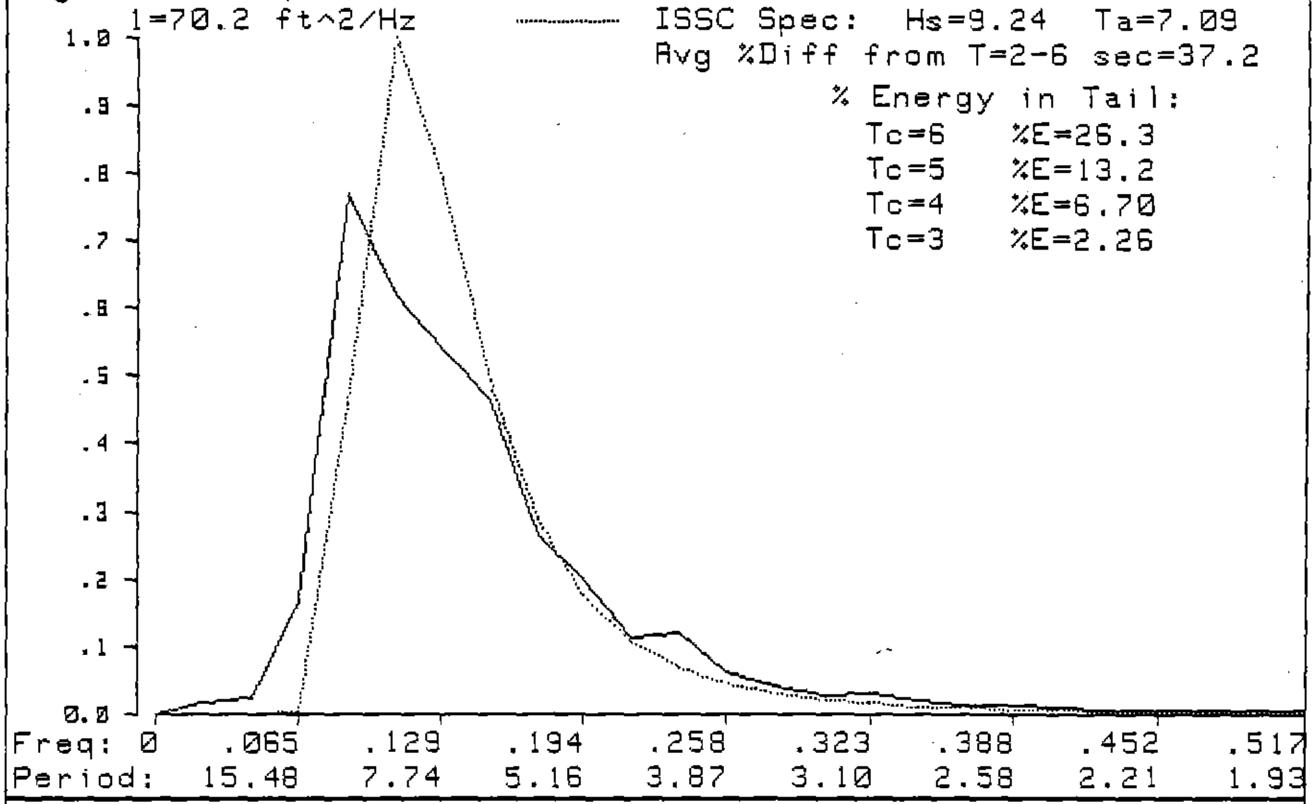


Fig.11c. Makapuu Waverider JL23860900: Hs=9.24 Ta=7.09 Tz=6.39

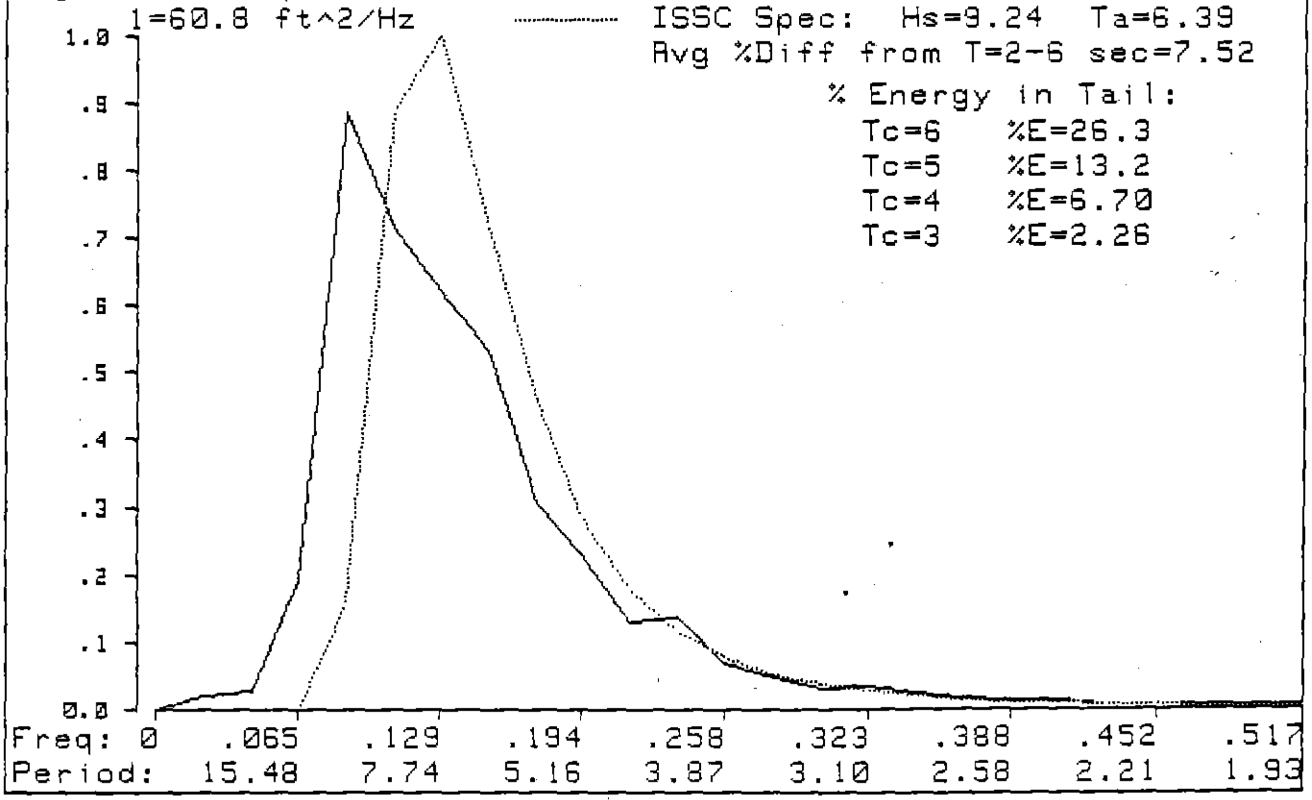


Fig.12a. Makapuu Waverider JL23860930: Hs=8.77 Ta=6.93 Tz=6.24

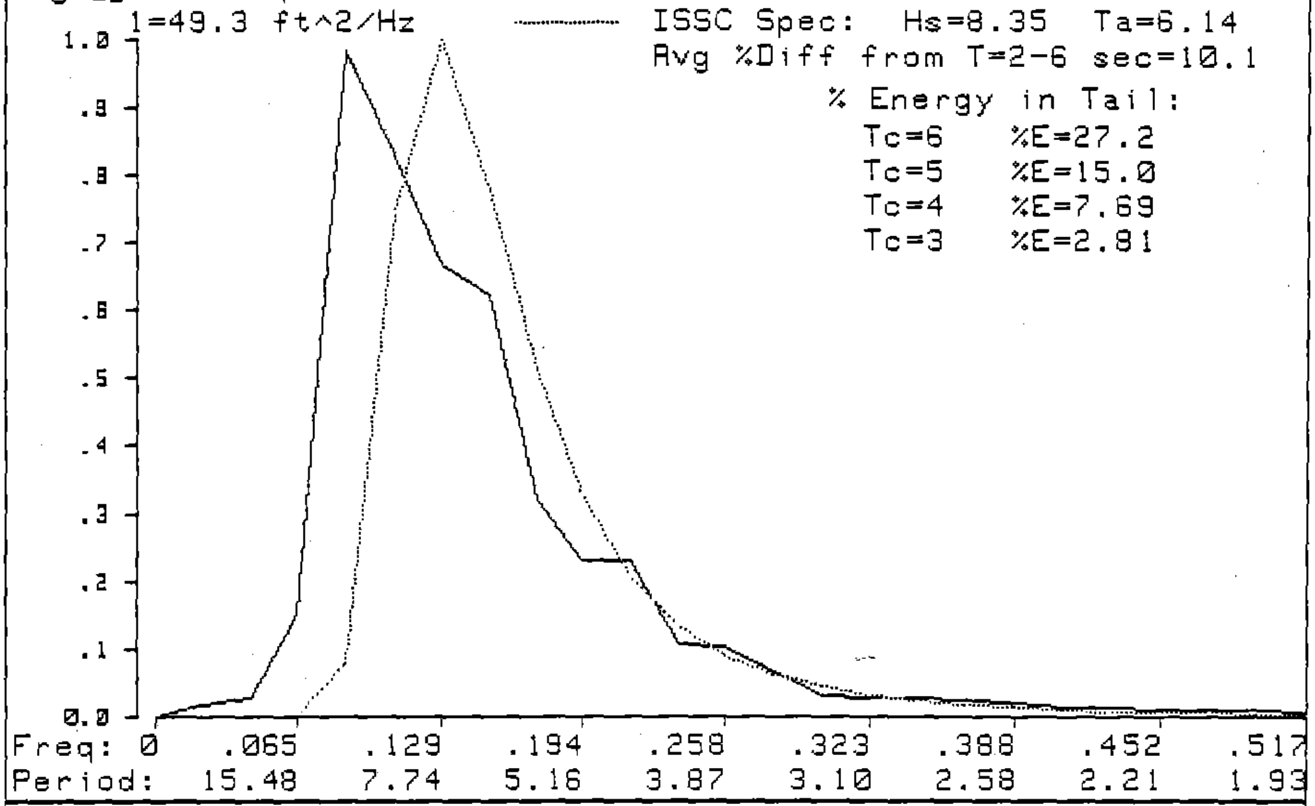
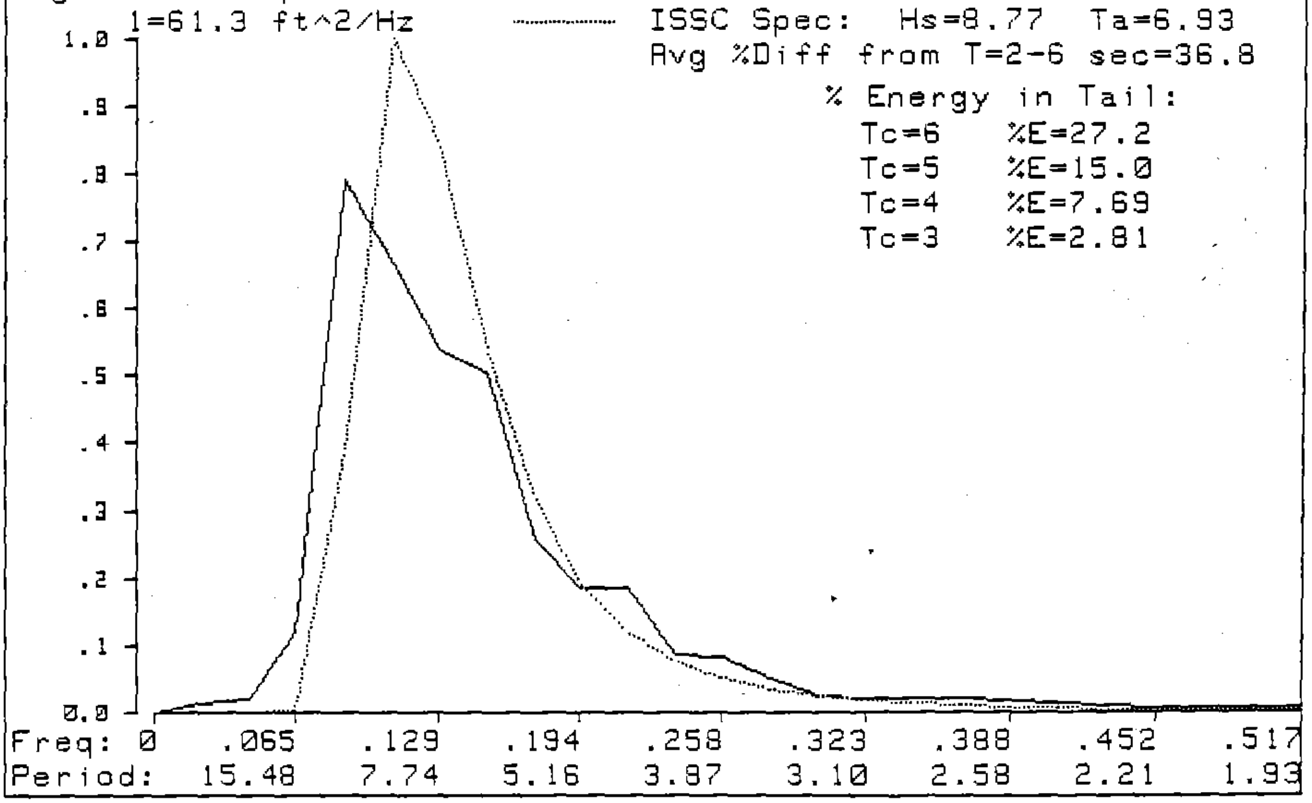


Fig.12b. Makapuu Waverider JL23860930: Hs=8.77 Ta=6.93 Tz=6.24



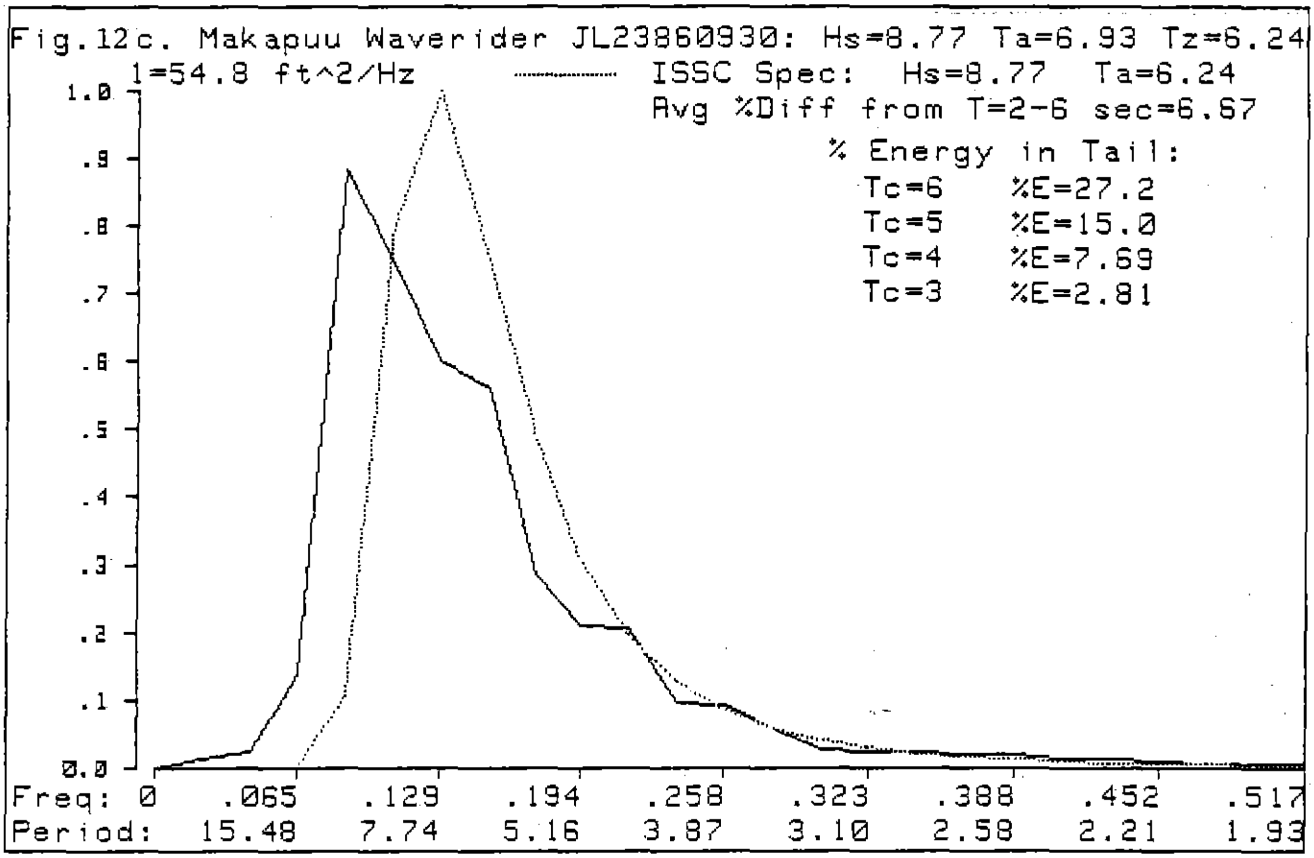


Fig.12c. Makapuu Waverider JL23860930: Hs=8.77 Ta=6.93 Tz=6.24

## Table 4. ZERO-UP-CROSSING (ZUC) AND SPECTRAL WAVE STATISTICS

| | ZUC STATISTICS | | | SPECTRAL STATISTICS | | | | |
|---|---|---|---|---|---|---|---|---|
| Data Set | Hsz | Tsz | Tzz | Hs | Tp | Ta | Tz | Hsz/Hs |
| AP30861400 | 6.66 | 6.79 | 5.00 | 7.14 | 7.74 | 5.89 | 5.35 | .93 |
| AP30861430 | 7.09 | 6.96 | 5.25 | 7.56 | 9.29 | 6.06 | 5.49 | .94 |
| AP30861500 | 6.45 | 6.66 | 4.84 | 6.90 | 7.74 | 6.90 | 5.20 | .93 |
| JL17861400 | 5.73 | 6.44 | 4.91 | 6.09 | 7.74 | 5.63 | 5.11 | .94 |
| JL17861430 | 5.85 | 6.43 | 5.03 | 6.31 | 7.74 | 5.56 | 5.07 | .93 |
| JL17861500 | 5.92 | 6.16 | 4.88 | 6.32 | 7.74 | 5.61 | 5.12 | .94 |
| JL22861600 | 6.83 | 7.49 | 5.38 | 7.58 | 15.47 | 6.57 | 5.73 | .90 |
| JL22861630 | 6.99 | 7.21 | 5.39 | 7.74 | 11.61 | 6.56 | 5.75 | .90 |
| JL22861700 | 7.33 | 8.23 | 5.81 | 8.00 | 15.47 | 6.92 | 6.03 | .92 |
| JL23860900 | 8.67 | 8.07 | 6.38 | 9.24 | 11.61 | 7.09 | 6.39 | .94 |
| JL23860930 | 8.35 | 8.22 | 6.14 | 8.77 | 11.61 | 6.93 | 6.24 | .95 |

Average = .93 ± .02

## Table 5. ISSC SPECTRAL FIT COMPARISON AND HIGH FREQUENCY WAVE ENERGY

| | Avg % Diff for T = 2 to 6 sec. | | | % Energy in Tail for Cutoff Period Shown | | | | |
|---|---|---|---|---|---|---|---|---|
| | ISSC Parameters | | | | | | | |
| Data Set | Hsz, Tzz | Hs, Ta | Hs, Tz | Tc = 6 | Tc = 5 | Tc = 4 | Tc = 3 | Modal |
| AP30861400 | -6% | 30% | 2% | 41% | 22% | 14% | 5% | uni |
| AP30861430 | 1% | 31% | 2% | 36% | 22% | 12% | 5% | bi |
| AP30861500 | -8% | 30% | 1% | 43% | 24% | 17% | 6% | bi |
| JL17861400 | 1% | 28% | 2% | 50% | 28% | 16% | 5% | tri |
| JL17861430 | 15% | 30% | 4% | 52% | 30% | 17% | 5% | tri |
| JL17861500 | 0% | 29% | 3% | 52% | 27% | 15% | 5% | tri |
| JL22861600 | 15% | 49% | 16% | 38% | 22% | 12% | 4% | bi |
| JL22861630 | 14% | 47% | 15% | 38% | 19% | 12% | 4% | bi |
| JL22861700 | 22% | 51% | 18% | 34% | 17% | 10% | 4% | bi |
| JL23860900 | 18% | 37% | 8% | 26% | 13% | 7% | 2% | uni |
| JL23860930 | 10% | 37% | 7% | 27% | 15% | 8% | 3% | uni |
| Average = | 7% | 36% | 7% | 40% | 22% | 13% | 4% | |
| Std. Deviation = | 10% | 9% | 6% | 9% | 5% | 3% | 1% | |

Note: H in feet

## 5. SPECTRAL MODALITY AND ENERGY

One thing that is readily observed in the spectral figures is that the measured spectra are seldom unimodal, that is single peaked. In fact, only three of the 11 spectra are unimodal, which is not surprising since the two year Alenuihaha wave measurement program observed unimodal spectra only about 10% of the time. The fact that the tradewinds blow most of the time and the channels receive swell from the north and south Pacific mean that most measured spectra are multimodal with at least short period wind sea and long period swell components. Soares (1984) has reported on fitting JONSWAP type theoretical spectra, of which the ISSC spectrum is a derivative, to double-peaked spectra, a procedure that involves the linear superposition of two theoretical spectra. In his report, Soares recommended criteria for determining spectral modality, and these criteria were applied to the 11 measured spectra and the determined modality is reported in Table 5. Note that on July 17 the three spectra were trimodal, as is readily observed in the appropriate figures. Even those spectra identified as unimodal are most likely bimodal but the spectral peaks are too close together to be distinguished.

Also presented in Table 5 is the amount of total spectral energy that is contained in the high frequency tail for different cutoff periods $T_c$. It is seen that in three of the spectra for $T_c = 6$ seconds, at least half of the energy is in the cutoff tail. The amount of energy in the tail is a function of the spectral modality and the distribution of wave energy between the components. For example, an ISSC spectrum in which the peak period and the cutoff period coincided would have about 75% of its energy in the cutoff tail.

## 6. THE ALENUIHAHA WAVE DATA

As discussed in the introduction, the spectra measured by the two year Alenuihaha wave measurement program are cutoff at periods that are functions of sensor depth. In order to estimate the missing high frequency tails, a technique similar to that presented by Soares(1984) is applied to fit JONSWAP type spectra to measured spectral shapes. Once that is done, the spectral statistics $H_s$ and $T_s$ are readily calculated, and these parameters have been tabulated in the data report, EKN-1028-R-3-2. It was demonstrated that for the surface spectra measured in the Kaiwi Channel off Oahu, these two parameters define an ISSC spectrum that provides a good envelope fit to the high frequency portion of the spectrum between wave periods of T= 2 to 6 seconds. However, note in Table 5 that this fit is not very good for the spectra measured on July 22, 1986, with an average percent difference of 15%. This is attributed to the fact that, relative to the spectra measured on other days, the two large bimodal peaks are farther apart which results in a larger $H_s$, and consequently an ISSC spectrum that overestimates the high frequency wave energy. The consequence of this for the Alenuihaha bimodal spectra is that when the spectral peaks are not close together, and especially when the swell (longer period) peak dominates the spectrum, the high frequency ISSC spectrum tends to overestimate the high frequency wave energy.

In order to more accurately quantify the high frequency wave energy in the Alenuihaha Channel, the measured spectra, as represented by the theoretical ISSC spectra fitted to them, were examined to identify those with the greatest high frequency wave energy and an overall $H_s$ close to that chosen by Vega et al. (1984) for the dynamic response sensitivity analysis. In the Section 6.0 analysis, Vega et al. utilized as representative of wave conditions in the Alenuihaha Channel an ISSC spectrum with the parameters $H_s = 8$ feet and $T_a = 5.53$ seconds. Also used was an ISSC spectrum with the parameters $H_s = 6$ feet and $T_a = 4.81$ seconds.

In examining the approximately 2100 Alenuihaha spectra, four spectra with an $H_s$ of about 8 feet and one with an $H_s$ of 6 feet were selected which represented measured spectra with the greatest high frequency energy content. All of the spectra except one were bimodal, and are plotted in Figures 13 through 17, along with the appropriate ISSC spectrum (broken line) utilized by Vega et al. Figure 13, the only unimodal spectrum, was measured on August 21, 1985 at 0500 hours (0821850500) and is an ISSC spectrum with the parameters $H_s = 8.5$ feet and $T_a = 4.1$ seconds. This spectrum is judged to be significant because it represents a greater concentration of high frequency wave energy in the T= 2 to 6 second wave period band than does the ISSC spectrum assumed by Vega et al. This spectrum can be scaled up or down by choosing the Hs desired. Figures 14 through 16 are bimodal spectra with large concentrations of high frequency wave energy and overall $H_s$'s of 7.8, 7.6 and 7.5 feet, respectively. Note that the complete bimodal spectrum is the linear superposition (addition) of two ISSC spectra (dotted lines) with the parameters indicated. Figure 17 is a bimodal spectrum of $H_s = 6.0$ feet, selected because it represents a greater density of high frequency wave energy than does that assumed by Vega et al. The concept of using $H_s$ and $T_z$ to define a high frequency ISSC envelope spectrum does not apply in these cases because the spectra are inherently high frequency.

## 7. CONCLUSION

The high frequency wave study successfully measured sea surface wave spectra to wave periods as short as 2 seconds. It was found that a significant portion of the wave energy was contained in the high frequency portion of the spectrum for wave periods between T = 2 to 6 seconds.

From direct measurements of wave spectra in the high frequency region between wave periods of T = 2 to 6 seconds in a

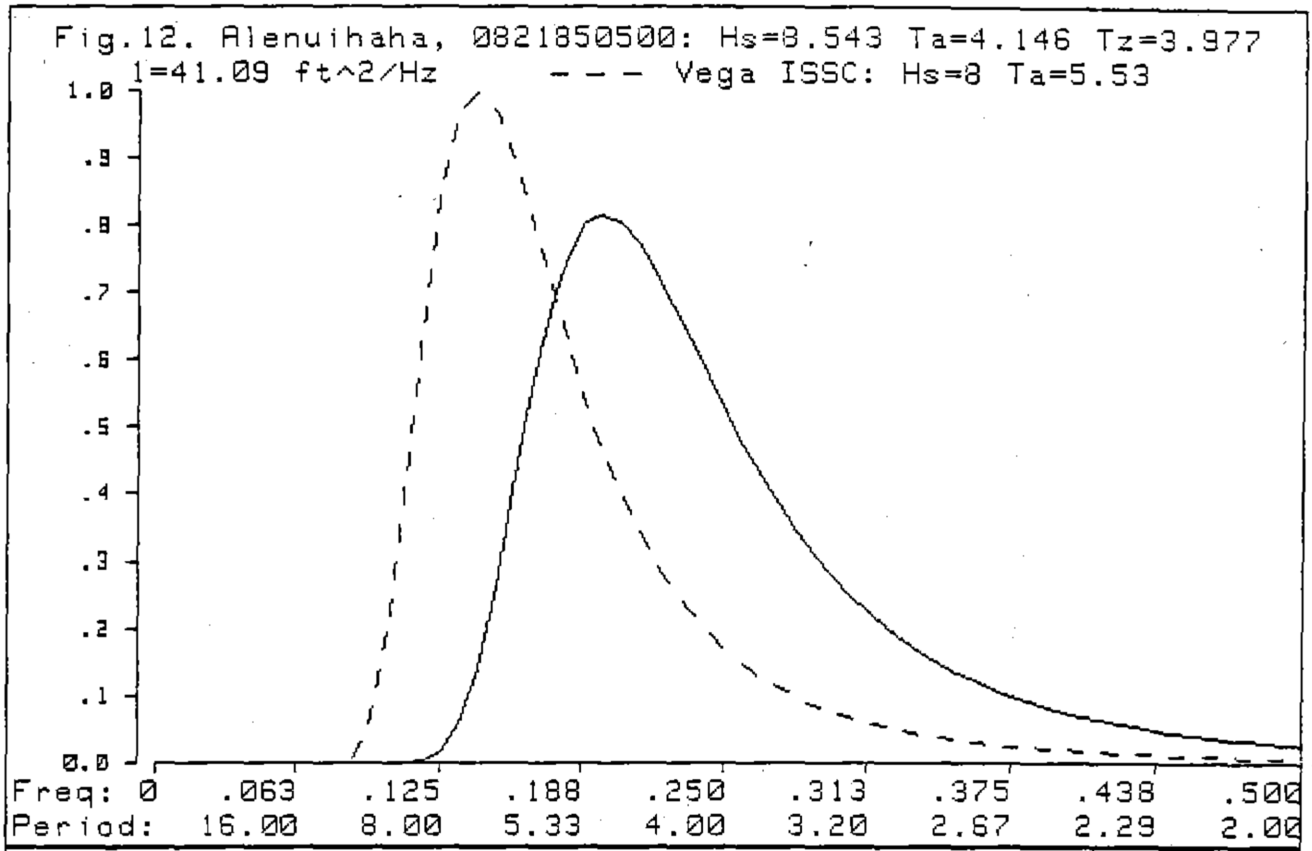


Fig.12. Alenuihaha, 0821850500: Hs=8.543 Ta=4.146 Tz=3.977

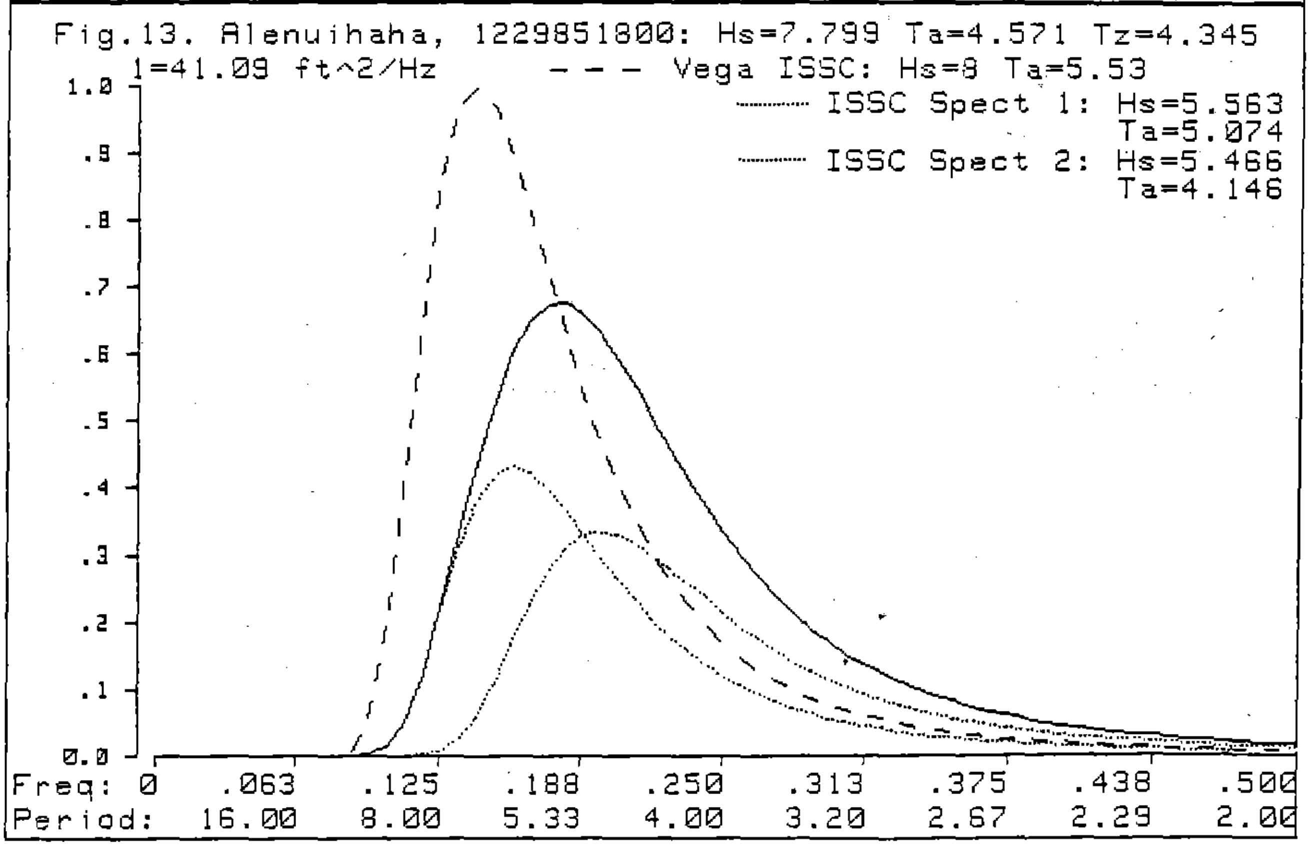


Fig.13. Alenuihaha, 1229851800: Hs=7.799 Ta=4.571 Tz=4.345

Fig.14. Alenuihaha, 1225851000: Hs=7.599 Ta=5.344 Tz=4.764

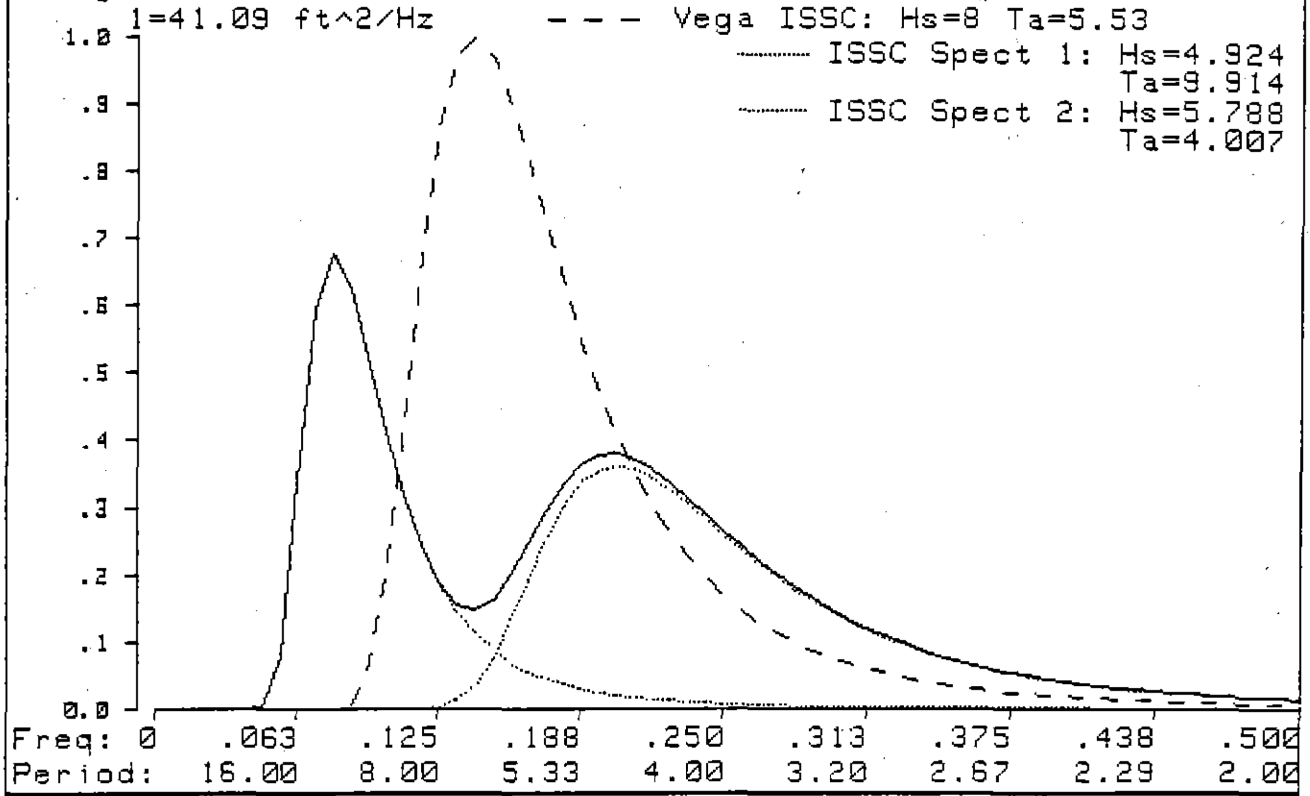
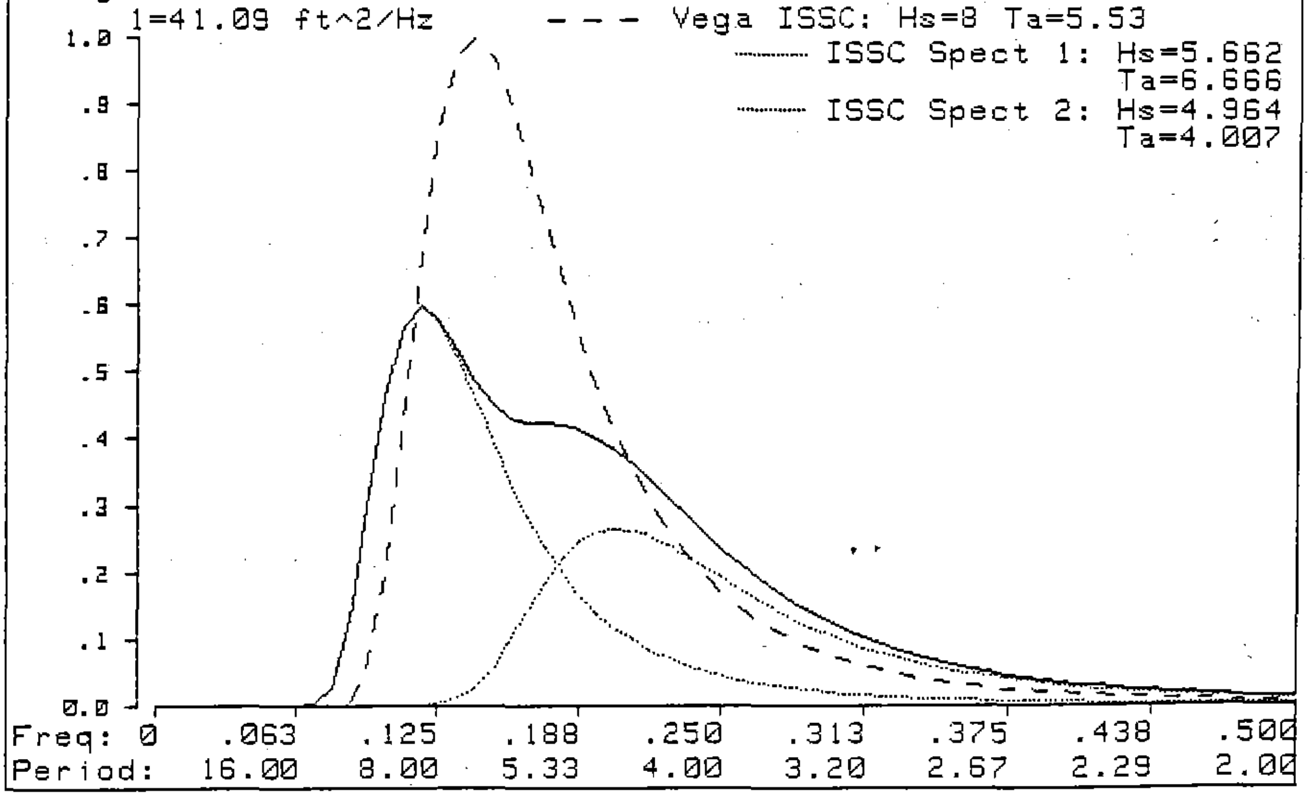


Fig.15. Alenuihaha, 0331860400: Hs=7.530 Ta=5.174 Tz=4.783



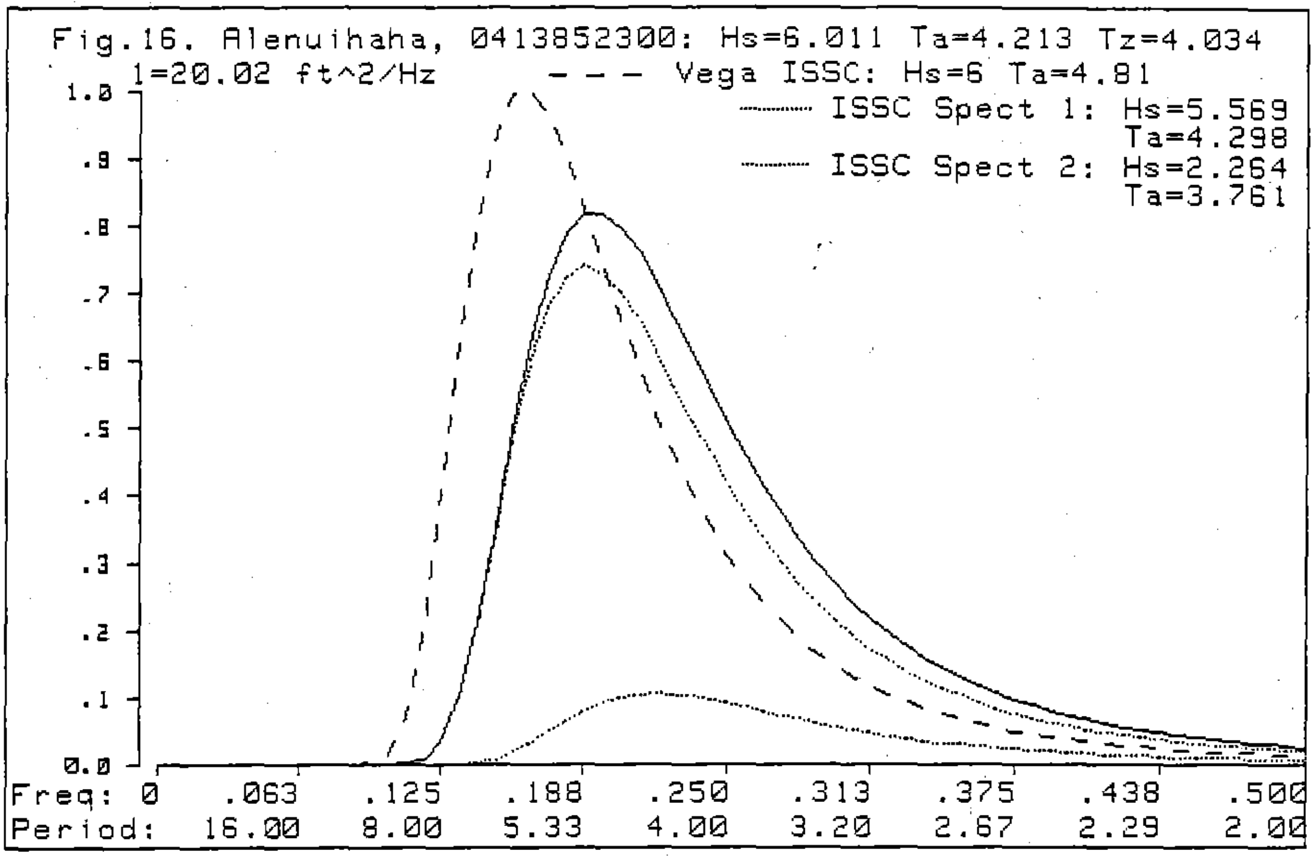


Fig.16. Alenuihaha, 0413852300: Hs=6.011 Ta=4.213 Tz=4.034

location representative of the Alenuihaha Channel, an analytical technique has been developed to accurately represent this high frequency portion of the spectrum. An ISSC spectrum defined by the spectral statistics $H_s$ and $T_z$ provides a good envelope fit to the high frequency portion of the spectrum, provided the qualitative considerations presented in Section 6. are observed to avoid overestimating the high frequency wave energy. It does not, however, by itself fit the entire measured spectrum well. In Hawaiian waters, approximately 90% of the spectra are at least bimodal and thus, must be fitted with more than one spectrum. Given a cutoff measured spectrum, it is necessary to approximate the cutoff tail with a JONSWAP type theoretical spectrum and then compute the spectral statistics $H_s$ and $T_z$, which then defines the high frequency ISSC spectrum.

Two conclusions related to the ISSC spectrum model representation of high frequency surface waves have been obtained. First, from the limited direct measurements of the high frequency wave energy spectra obtained from the Makapuu Point, Oahu Waverider buoy, comparisons with the theoretical ISSC spectrum for the appropriate wave height and period pair indicates good correlation. In other words, the ISSC model spectrum is a reasonable representation of the high frequency energy content of waves in Hawaiian waters.

A second conclusion is related to the validity of the "design" ISSC spectra utilized by Vega et al. (1984) as surface wave inputs for the cable-barge dynamic analysis. While the ISSC spectrum may reasonably represent the high frequency wave energy character, are the "design" ISSC spectra utilized by Vega et al. as characterized by the selected wave height and period pairs, indicative of the significant high frequency wave events in the Alenuihaha Channel? In order to answer this question, all the near-surface wave spectra obtained from the HDWCP sponsored wave measurement program (Edward K. Noda and Associates, 1986) were examined. Specific spectra were selected which showed significant energy in the high frequency region. On the basis of the present high frequency wave analysis results, the truncated high frequency region of the selected Alenuihaha Channel wave data was reestablished, using fitted unimodal and bimodal theoretical ISSC spectra. These were then compared with the design ISSC spectra utilized by Vega et al. (Section 6.0) and it was found that the measured data contained greater concentrations of high frequency wave energy. In other words, the ISSC design wave spectra utilized by Vega et al. (1984) can underestimate the high frequency region (between 1 to 3 rad/sec) of wave spectra in the Alenuihaha Channel.

Should it be necessary to perform additional dynamic response analysis of cable-vessel systems, it is recommended that the herein described technique to model surface wave spectra be utilized to more accurately represent design high frequency wave energy conditions in the Alenuihaha Channel.

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# APPENDIX:

## Comparison Of Measured High Frequency Wave Spectra With Coastal Data Information Program Spectra

Fig. A-1. Makapuu Waverider, AP30861400: Hs=7.14 Ts=6.79

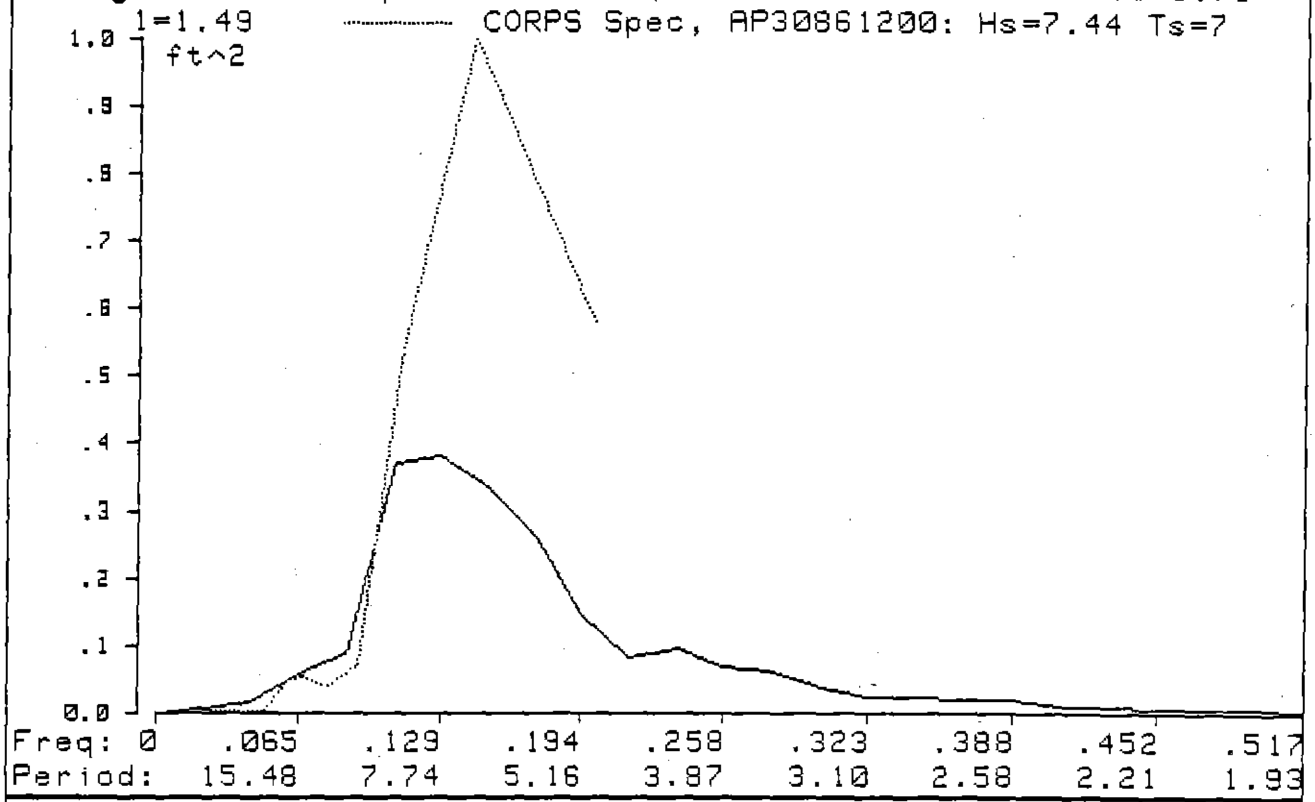


Fig. A-2. Makapuu Waverider, AP30861500: Hs=6.90 Ts=6.66

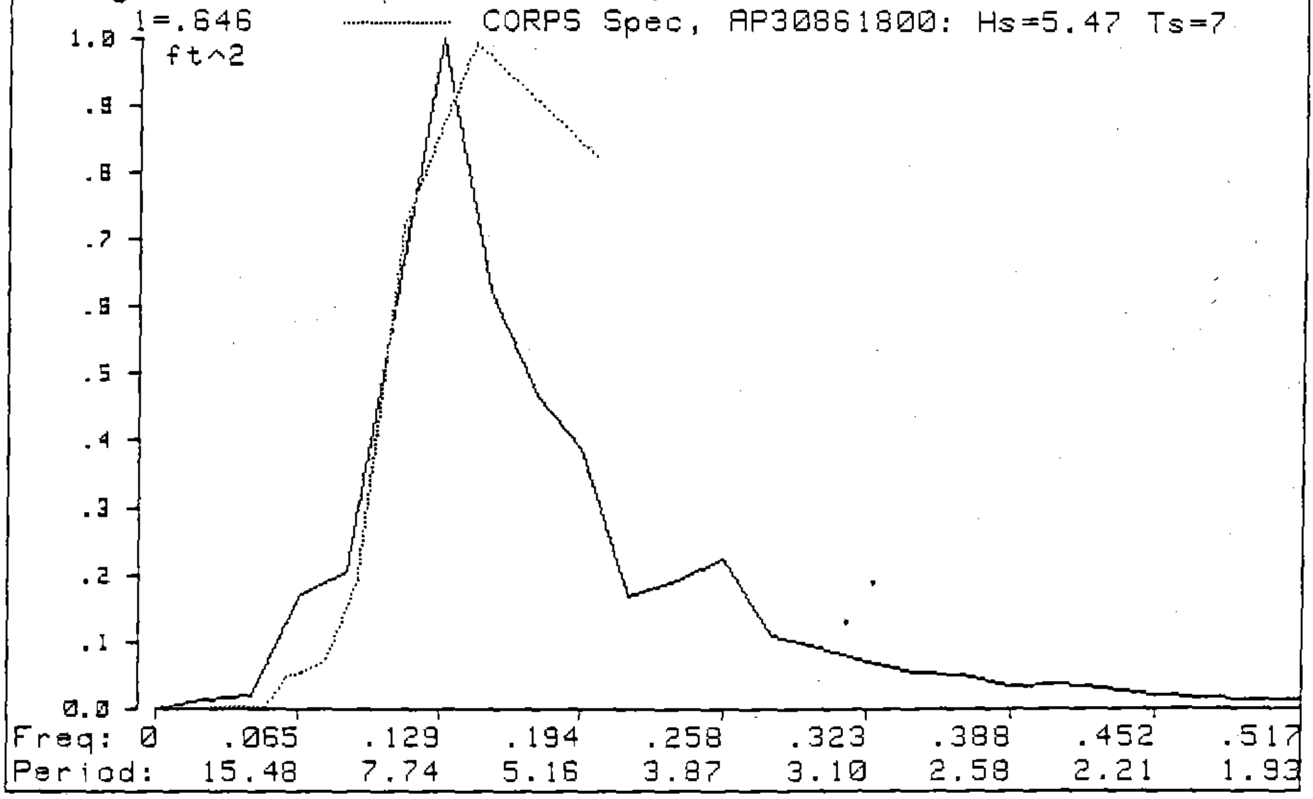


Fig. A-3. Makapuu Waverider, JL17861400: Hs=6.09 Ts=6.44

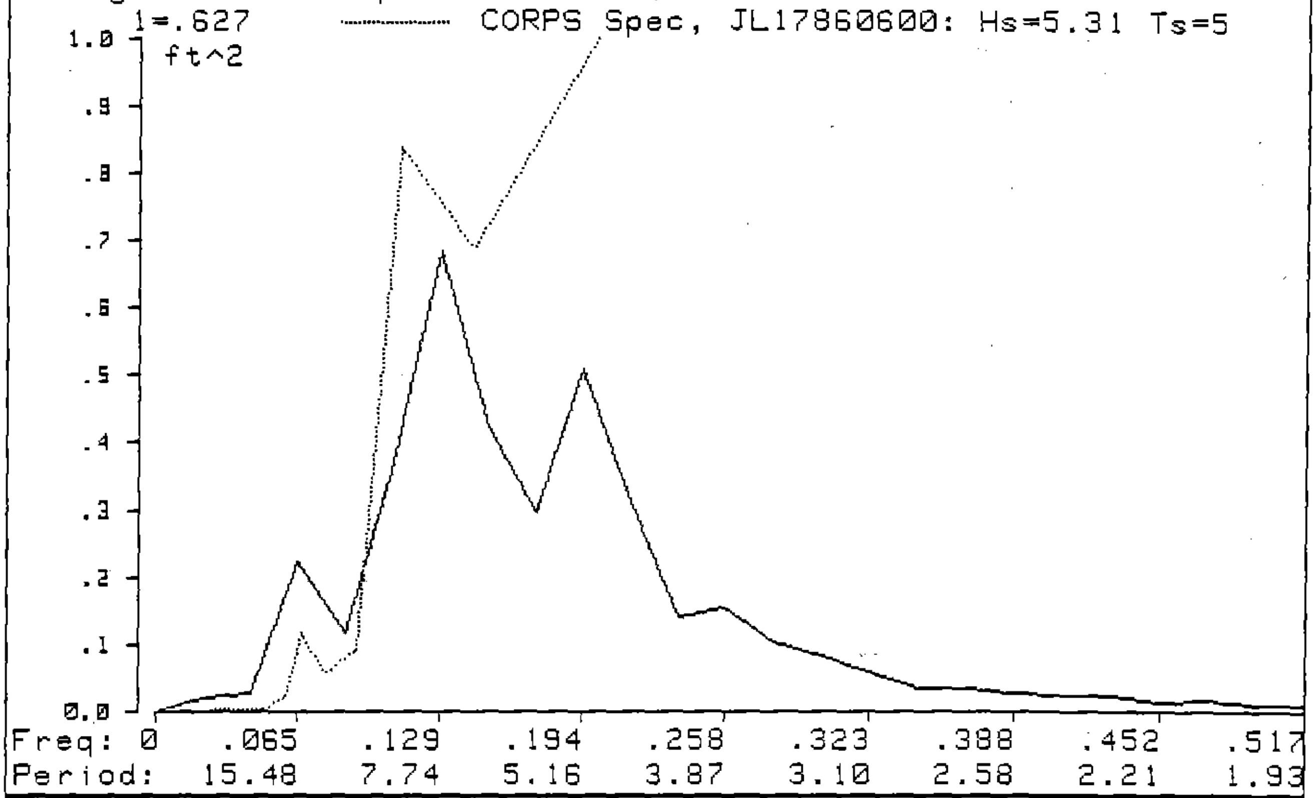
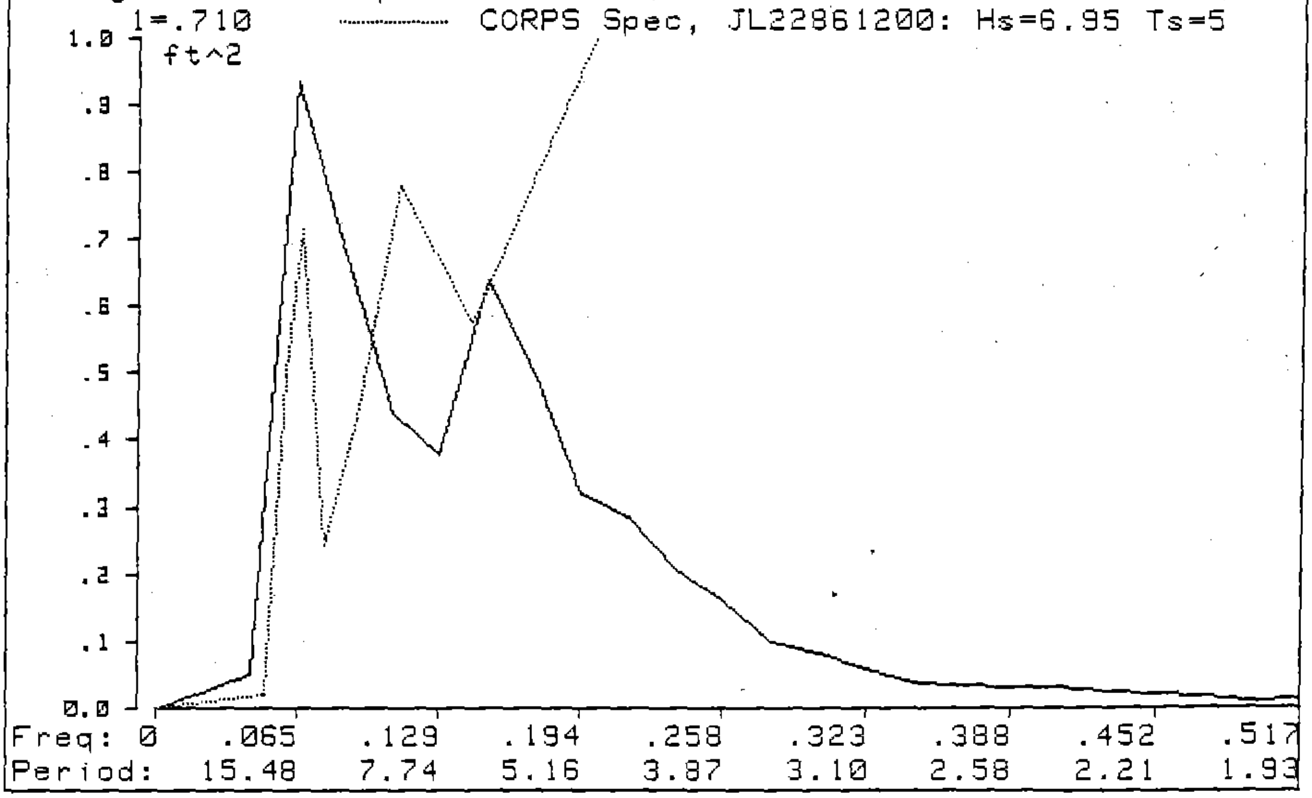


Fig. A-4. Makapuu Waverider, JL22861600: Hs=7.58 Ts=7.49



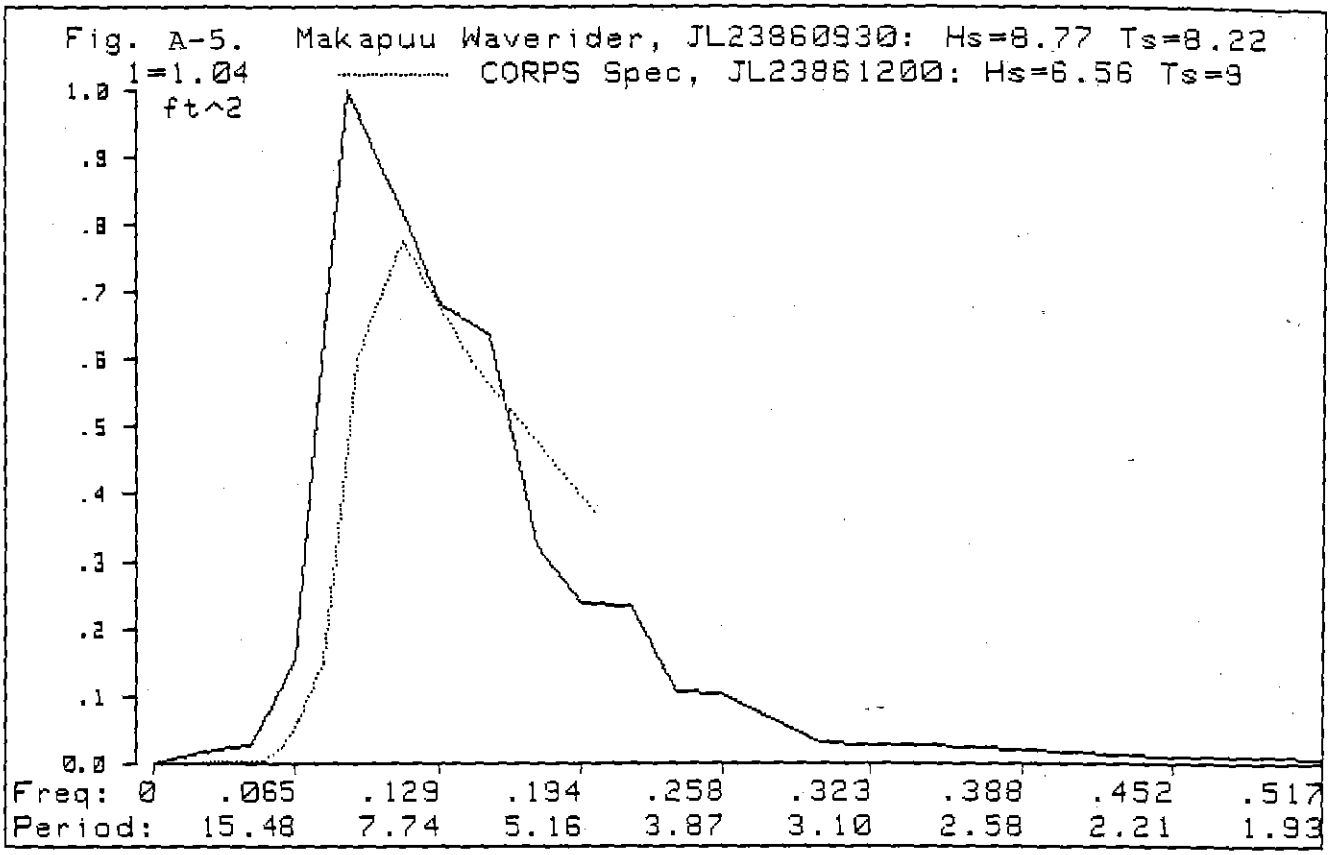


Fig. A-5. Makapuu Waverider, JL23860930: Hs=8.77 Ts=8.22