WAVE HEIGHT MEASUREMENTS AT THE RACCOON ISLAND BREAK WATERS DEMONSTRATION (TE-29) PROJECT: REPORT ON MARCH 1998 FIELD DEPLOYMENT

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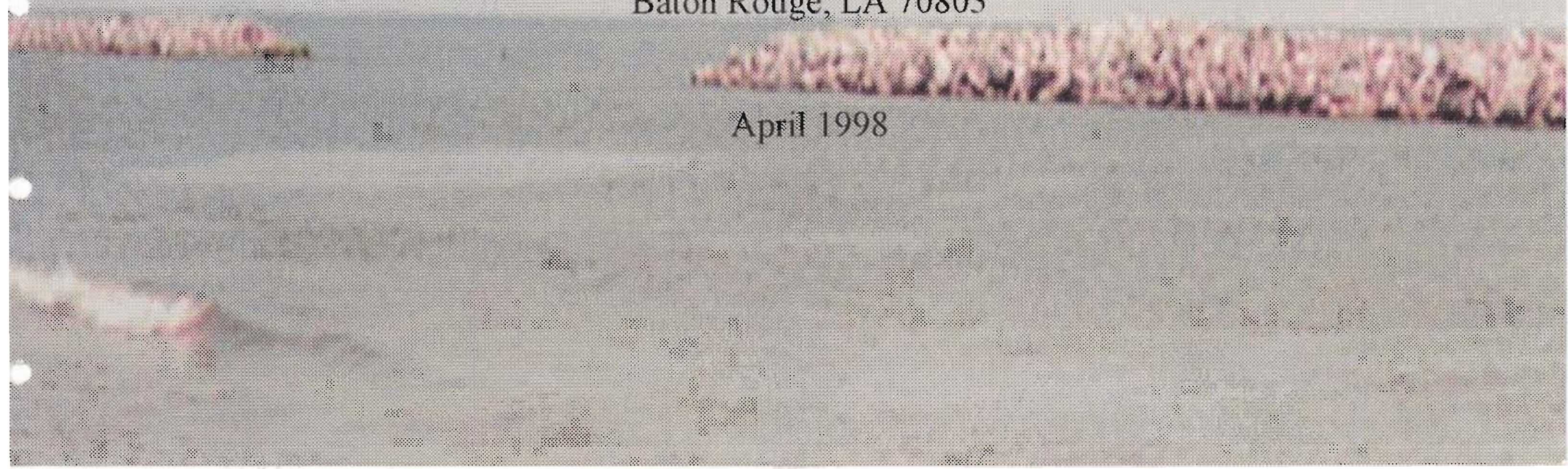

April 1998

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INTRODUCTION

In May 1997, scientists in the Coastal Studies Institute at Louisiana State University, were contracted by the Louisiana Department of Natural Resources/Coastal Restoration Division, to monitor wave conditions at the Raccoon Island Breakwaters Demonstration Project (TE-29) funded under the Coastal Wetlands Planning, Protection and Restoration Act (see Figure 1 for location). This is the second of a series of reports in which the experimental design, field deployment, and information in the form of wave statistics and spectra are presented and interpreted along with bathymetric and topographic surveys of the site. Comparisons with results obtained from the first deployment in October 1997 are also discussed.

The second wave measurement experiment at Raccoon Island was conducted on March 2nd, 1998. Beach profile surveys occupying the same transects established in October 1997 were conducted along with the wave measurements. An additional beach survey was conducted in November 1997 due to rapid morphological adjustment to the breakwaters. Results from the November 1997 survey are also summarized in this report.

The objective of the study is to monitor and quantify the impact of the segmented breakwaters on the nearshore wave field and morphology. This report includes an explanation of the instrumentation and sampling scheme, a description of the sampling locations based on field observations, and a discussion of the breakwaters' influence on the wave field and nearshore morphology. An initial assessment of the breakwaters' performance during the first six months after construction is provided based on two wave measurement experiments and three sets of beach surveys.

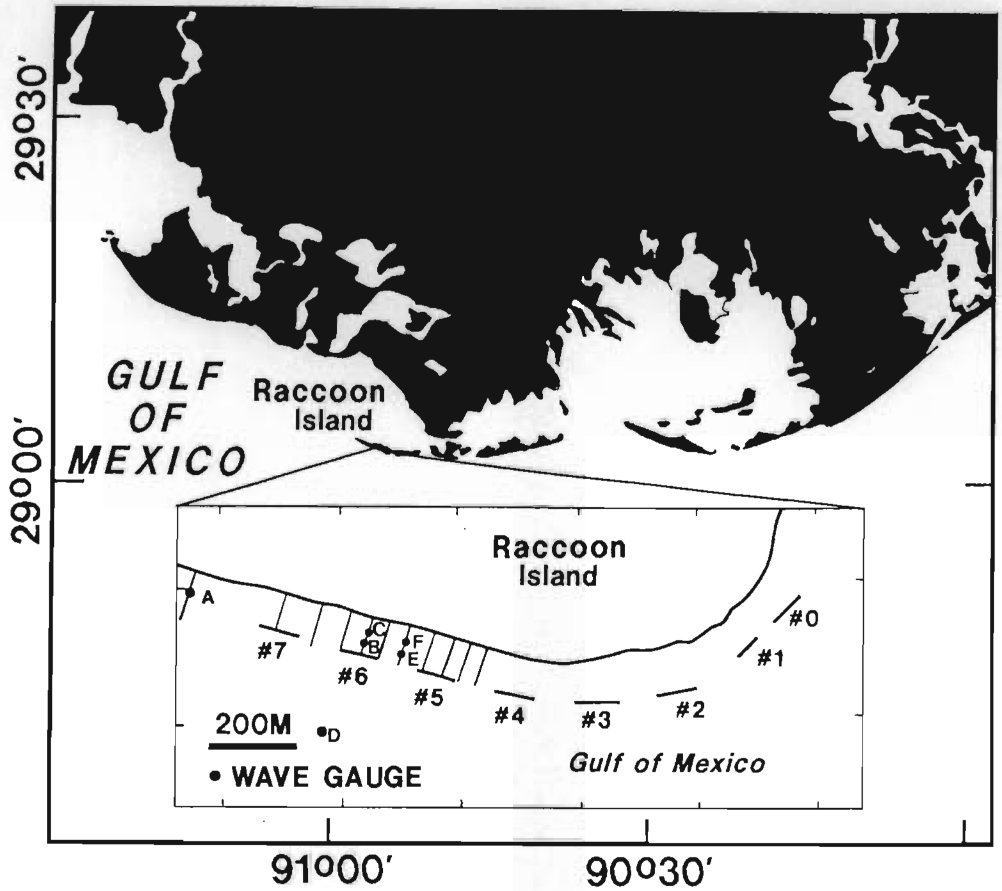

Figure 1. Study area, showing the locations of wave gages and survey lines.

INSTRUMENTATION AND SAMPLING SCHEMES

Wave height and period were measured with four precise, Paroscientific digital quartz pressure transducers. As compared to the October 1997 deployment, an extra wave gage was used in March 1998 to obtain more detailed wave information landward of the breakwaters. The pressure transducers, which record the instantaneous fluctuation of water level, are capable of 0.01% accuracy and 0.0001% resolution. For conditions at the Raccoon Island breakwaters site, the accuracy of the instrument is expected to be well within 5 mm (0.2 in). The pressure transducers were assembled by CSI personnel in a self-contained, solid-state recording package, suitable for underwater deployment. An example of the pressure sensor array is shown in Plate 1. The instrument packages are capable of sampling at a high frequency of 4 Hz.

Plate 1. The pressure transducer arrays used in the Raccoon Island breakwater study. The pressure sensors and solid-state recorders are housed in a water-tight casing and are being tested in the Coastal Studies Institute's Wave Simulation Facility.

After a series of on-site experiments, an optimal sampling scheme was determined which allowed maximum temporal coverage and efficient data processing. Two thousand and forty-eight (2048) readings (one bust of 8.5 minutes) were recorded every 20 min at 4 Hz. The 4-Hz sampling allows reliable measurement of high-frequency wave components with periods as low as 1 second. The 8.5-minute burst, which is sufficient in duration to include 100 to 150 waves of 3- to 5-second periods, yields reliable data for statistical analysis of wave spectra and was deemed appropriate for the objectives of this study. The locations of the deployments are shown in Figure 1, and include those sites landward and seaward of the breakwaters, and the control site to the west. The latter provides information on the unprotected location.

The nearshore morphology was surveyed using the standard level and transit procedure utilizing a Topcon electronic total station. For the surveying range at the breakwater project, the accuracy of the instrument is expected to be within 10 mm (0.4 in.) in the horizontal and 5 mm (0.2 in.) in the vertical. Ten survey lines spanning the three westernmost breakwaters were surveyed. Additional beach profiles covering the entire breakwater site were surveyed in November 1997. At the eastern portion of the project location, the exposure of vegetation at the shoreline and a muddy bottom between the shoreline and the breakwaters made it difficult to conduct accurate surveys. Thus, morphological analyses concentrates on the western, sand-dominated portion. The profile locations of the project are shown in Figure 1. Temporary benchmarks were established using 1.5-m (5-ft) long PVC pipes. Beach posts and pipes protruding from the crown of the breakwaters were used as elevation controls. A temporary elevation, measured relative to an estimated zero water level during the October 1997 survey, was used but will be tied to the NGVD datum at a later date. The density of survey points along profile lines is a direct function of the topographic/bathymetric complexity. Significant breaks in slope associated with morphological/bathymetric features were recorded during each survey. The profile surveys start landward at the edge of the vegetation, and end seaward at the crown of the breakwater, or at the same relative locations for the survey lines in the gaps of the breakwaters.

The bathymetric and topographic surveys were conducted to determine trends associated with sedimentation/erosion induced by the segmented breakwaters. The topographic survey and nearshore morphological analysis was not part of the contract with LADNR. However, this undertaking is viewed here as being critical to a more profound comprehension of the impacts of the breakwaters on coastal processes and sediment transport at the monitoring sites. The topographic surveys will be conducted during each wave monitoring event on a quarterly basis. Nearshore morphological changes will be analyzed by comparing pre- and post-construction surveys (provided by LADNR), and each of the quarterly surveys.

WAVE MEASUREMENTS

The wave measurements were conducted on March 2, 1998. A moderately strong WSW wind generated a highly oblique-incident wave field relative to the shoreline. The incident wave conditions were quite different during the March 1998 measurements as compared to the October 1997 measurements, with the former being highly oblique and the later being nearly shore-perpendicular. Field observations indicated a choppy sea state during the March 1998 deployment. Wave heights increased during the afternoon commensurate with wind speed.

Simultaneous wave measurements were conducted at 4 locations (Figure 1). Wave gage A served as a control, and was deployed approximately 150 m (500 ft) west of breakwater #7. The average water depth at the control site during the measurement was approximately 0.6 m (2.0 ft). The control site measurement provided wave conditions for an unprotected scenario. Comparisons between the protected and unprotected sites provide a direct assessment of the influence of the breakwaters on wave height. Wave gage B was deployed approximately 30 m (98 ft) landward of the center of breakwater #6 (Figure 1). Wave gages A and B were deployed at the same distance of approximately 60 m (200 ft) seaward of the shoreline. The average water depth at the inside location (B) was approximately 0.35 m (1.1 ft), slightly shallower than the control site. Wave gage C was deployed approximately 55 m (180 ft) landward of the center of breakwater #6, at a water depth of approximately 0.5 m (1.6 ft). Wave gages B and C lay on a transect perpendicular to the shoreline and the breakwater. The objective was to provide information on wave diffraction and propagation landward of the breakwater. More specifically, this permitted examination of the influence of the diffracted wave around the tips of the breakwater on the area landward of the center of the breakwaters near the shoreline. Wave gage D, measuring offshore wave conditions, was deployed approximately 150 m (500 ft) seaward of the center of breakwater #6. The average water depth at the offshore location was approximately 1.6 m (5.2 ft). Wave gages at sites B and C were moved to the gap (sites E and F, respectively) between breakwaters #6 and #5 (Figure 1). The measurements at sites B-C, and E-F, were conducted at slightly different times, so that waves could be measured at six sites with four gages. The water depths at sites E and F were similar to those at sites B and C.

The control wave gage (A) and the offshore gage (D) remained at the same location throughout the entire experiment. Measurements at sites B and C landward of the center of the breakwaters were conducted in the early afternoon. Measurements at sites E and F landward of the breakwater gap were conducted in late afternoon. Comparisons between wave conditions in the protected (landward of the center of the breakwater), unprotected, and offshore sites are based on simultaneous measurements. While comparisons between wave conditions in the protected sites and the gaps are influenced by the slight time difference, this influence is assessed by the continuous measurement at the control and offshore sites.

DATA ANALYSES

One of the major objectives of this monitoring project is to quantify the influence of the breakwaters on incident wave conditions. This was accomplished by comparing wave conditions measured behind the breakwaters with the conditions at the control site, the latter being devoid of the influence of the breakwaters. Comparisons between wave conditions landward of the breakwater and those in the gap also provide direct information on the breakwaters' influences on waves in the immediate vicinity of the tips of the structures. This information is critical in establishing or refining the optimal segment length and spacing width ratio.

The raw data record of water level fluctuations is a composite of waves of different frequency (Appendix 1). In order to examine the energy contributions of each frequency, a spectral analysis is necessary. The spectral analysis of the raw data was based on the "Field Wave Gaging Program, Wave Data Analysis Standard," recommended by the Coastal Engineering Research Center (see Earle et al., 1995 for a detailed review).

Significant wave height was calculated based on CERC's standard procedure

$$H_{mo} = 4.0\sqrt{m_o} \qquad \textbf{Eq. 1}$$

where the zero moment, m_o, is computed as

$$m_o = \sum_{n=1}^{N_b} C_{zz}(f_n)df_n \qquad \textbf{Eq. 2}$$

where $C_{zz}(f_n)$ is the power spectrum density of the *nth* frequency f_n, and df_n is the bandwidth. The peak period T_p is given by

$$T_p = \frac{1}{f_p} \qquad \textbf{Eq. 3}$$

where f_p, the peak frequency, is the frequency for which spectral wave energy density is a maximum. The power spectrum densities were calculated using the Welch method of the fast Fourier transformation (Welch, 1967).

Beach profile analyses, including shoreline-position comparisons and volume change calculations, were conducted using the software BMAP (Beach Morphology Analysis Package). BMAP was developed and verified in the Coastal Engineering Research Center for various beach profile analyses.

RESULTS

The high-frequency recordings allow a close examination of wave properties including significant wave height, peak wave period, and wave-energy distribution with respect to frequencies. Wave diffraction in the lee of the breakwaters was observed and had significant influence on the sand accumulation landward of the breakwaters and the development of the rhythmic shoreline features. A trend in the response of nearshore morphology to the presence of the breakwaters is examined through the time-series beach profile surveys.

Wave Diffraction and Breaking

As discussed in the previous report summarizing the October 1997 measurement (Stone et al., 1997), wave diffraction patterns were well established in the lee of the breakwaters during normally incident waves and had a significant influence on the patterns of wave breaking at the shoreline. Behind the center of the breakwaters, diffracted waves converged in the vicinity of the shoreline resulting in a converging wave-breaking pattern, while waves diverged at the shoreline landward of the gap.

As discussed in the previous section of this report, obliquely incident waves dominated during the March 1998 measurement, as opposed to the shore-perpendicular waves observed during the October 1997 experiments. The converging and diverging wave-breaking patterns at the shoreline observed under shore-perpendicular wave conditions (Stone et al. 1997) were not observed during the oblique-incident waves. The oblique waves propagated through the gaps and broke at a considerable angle at the shoreline (Plates 2 and 3). A significant portion of these oblique waves propagated through the gaps also broke at large angles at the upwind side of a sand body that had been accumulating to the point of emergence directly landward of the breakwaters (Plate 2). Little wave action was observed at the downwind side of the sand body (Plate 3B). The emerged sand bodies, which were observed landward of the western four breakwaters (Plate 3), will be discussed in detail in the following sections. The emerged sand bodies were not apparent landward of the eastern four breakwaters.

Considerable wave breaking was observed in the gap between the breakwaters (Plates 2 and 3), especially the higher waves. As will be discussed in the following sections, significant sand accumulation was measured in the gap, resulting in shallower water. The observed wave breaking in the gap, which contributed significantly to the measured lower wave height (discussed in the following sections), was caused by the shallow water.

Plate 2. Obliquely incident waves. Upper: oblique waves breaking at the shoreline, looking south from Raccoon Island. Lower: oblique waves propagating through the gap and breaking at the upwind side of the emerged sand body directly behind breakwater #6, looking west from the emerged sand body directly landward of the breakwaters.

Plate 3. Upper: location of the wave gages, which are approximately 5 m (15 ft) to the right of the floats, which drifted to the east driven by a westerly wind. Also note the oblique wave breaking at the shoreline, looking south from Raccoon Island. Lower: Reduced wave action at the downwind side of the emerged sand body. Also note the sand bodies behind other breakwaters, looking east from the emerged sand body directly landward of the breakwaters.

Significant Wave Heights

Significant decreases in wave heights were measured behind breakwater #6 when compared to those at the unprotected site (Figures 2 and 3). A greater percentage of wave-height reduction was measured during the normally incident waves encountered in October 1997 than the oblique waves encountered in March 1998 (Figure 2). A 90% reduction in wave height landward behind the center of the breakwater was calculated from measurements obtained during the October 1997 deployment for normally incident waves. The wave height reduction decreased to approximately 70%, from 0.33 m (1.1 ft) to 0.09 m (0.3 ft), during the March 1998 deployment during oblique waves. During normally incident waves, wave height in the gap between the breakwater segments was almost identical to that at the unprotected site, while a reduction of approximately 50%, form 0.33 m (1.1 ft) to 0.17 m (0.56 ft), was measured in the gap during oblique incident wave conditions (Figures 2 and 3).

During the March 1998 experiment, a considerably lower wave height, 0.25 m (0.8 ft) as compared to 0.33 m (1.1 ft) at control site, was measured at the offshore site. This was caused by wave-energy attenuation through the water column. Wave-energy attenuation is a strong function of frequency. Higher frequency waves, or wave components, attenuate much faster than lower frequency waves. The wave-energy attenuation was negligible during the October 1997 measurement owing to the relatively longer average peak period of 4.75 s. The depth attenuation was significant for March 1998 because of a much lower average peak period of 2.93 s. The offshore waves were measured in deeper water (1.6 m) than all the other sites (0.3 to 0.6 m). The lower wave height measured at the offshore site is attributed to the depth attenuation of the high-frequency wave.

Wave heights measured at the site near the breakwater (Site B, Figure 1) were similar to that measured near the shoreline (Site C, Figure 1) landward of the center of the breakwater. While in the gap, nearshore waves (Site F) were much lower than the waves near the breakwater (Figure 3), and this is attributed to wave refraction as the oblique wave entered through the gap, energy dissipation induced by bottom friction, and the breaking of higher waves as discussed in the previous section (Plates 2 and 3).

In summary, a considerable wave-height reduction, of more than 70%, was measured during both normally and obliquely incident wave conditions when compared to the unprotected site. A greater percentage of wave-height reduction landward of the center of the breakwaters was measured during normally incident waves. This is directly attributable to the influence of the breakwaters. In the gap between the breakwaters, during normally incident wave conditions, wave heights were virtually unchanged when compared to the unprotected site. A substantial reduction was measured, however, during obliquely incident waves.

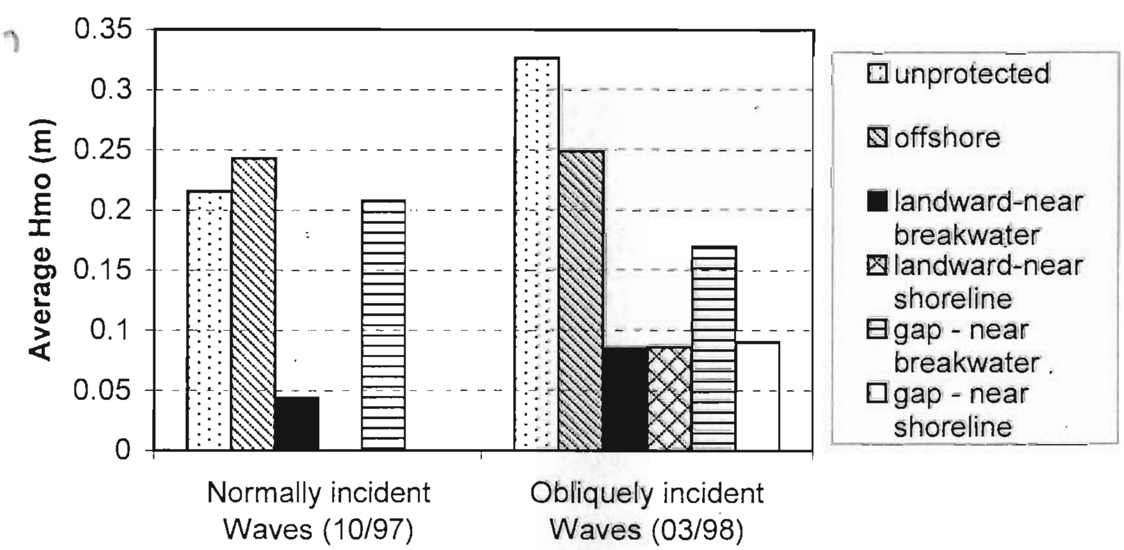

Figure 2. Comparison of significant wave heights at different locations. Note that two more locations were added for the March 1998 oblique wave measurements.

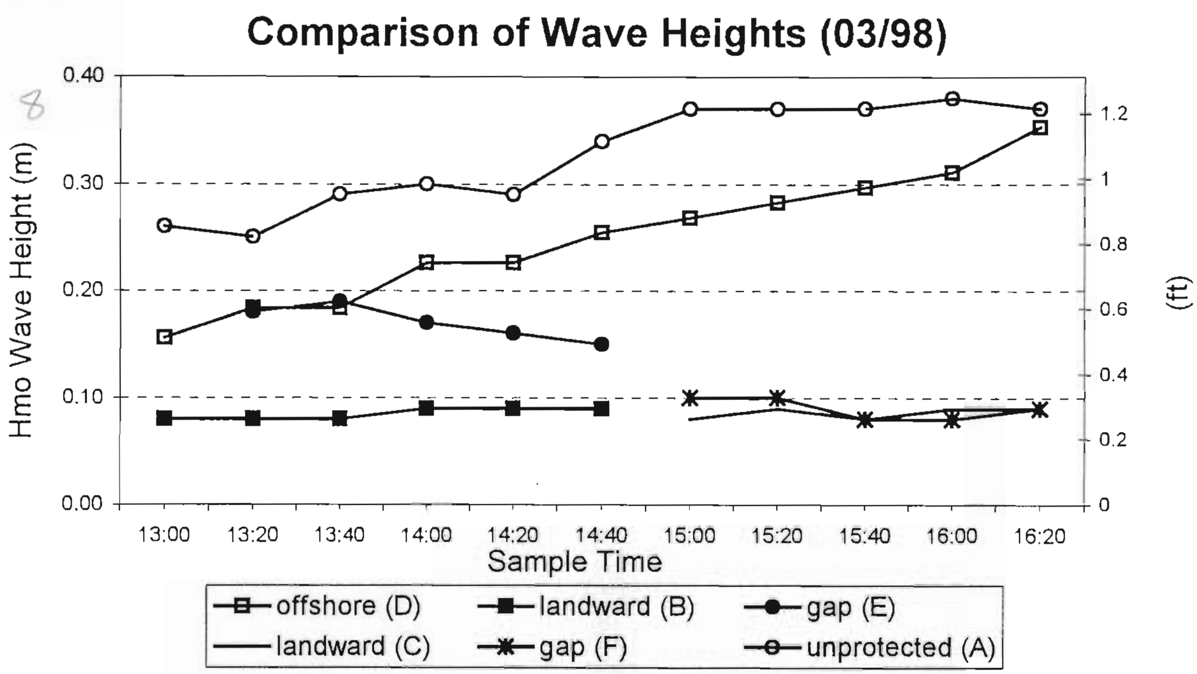

Figure 3. Time series of significant wave heights measured at the unprotected site (A), landward of the center (B), landward of the center (C), offshore (D), and in the gap (E and F) between the breakwaters (see Figure 1 for location map).

Peak Wave Period and Wave Spectra

Peak wave period, also referred to as dominant wave period or period of maximum wave energy, is defined as the wave period corresponding to the center frequency of the frequency band with the maximum non-directional spectral density. It is generally accepted that permeable rubble-mound breakwaters, such as those at the study site, function somewhat similar to a low-pass filter in that they reduce higher frequency waves more effectively than their lower frequency counterparts (CERC, 1984). This low-pass effect was apparent during the normally incident wave conditions encountered in October 1997 (Figure 4). The average peak wave period measured landward of the center of the breakwaters was longer than those at other sites, especially that at the unprotected site. Differences in peak wave period were minimal, however, under oblique incident waves (Figures 4 and 5).

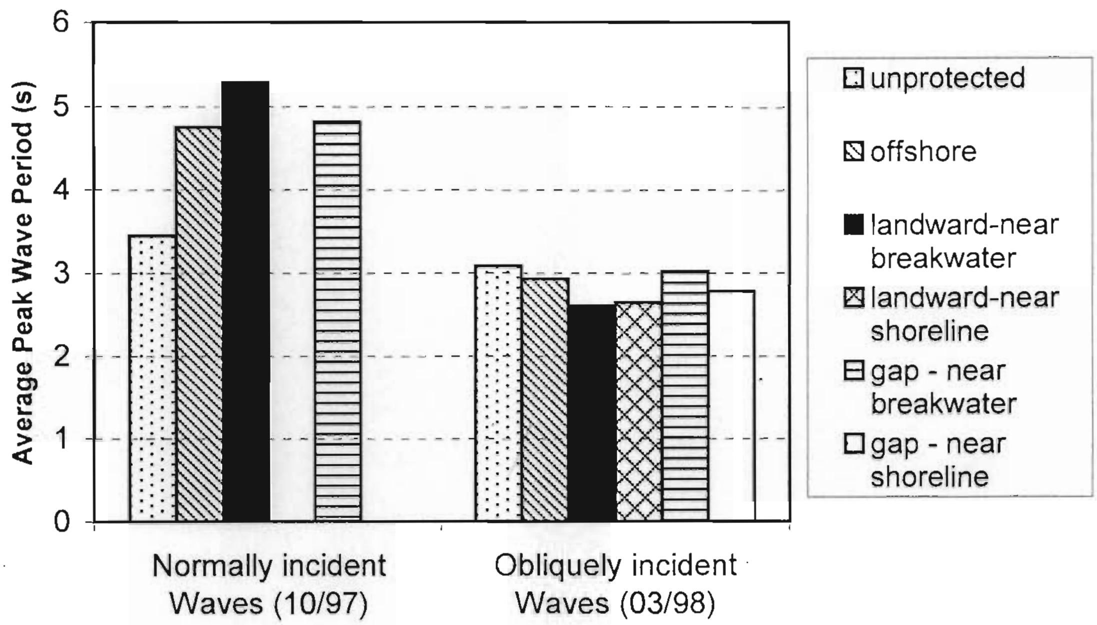

Figure 4. Comparison of peak wave periods at different locations. Note that two more locations were added for the March 1998 oblique wave measurements.

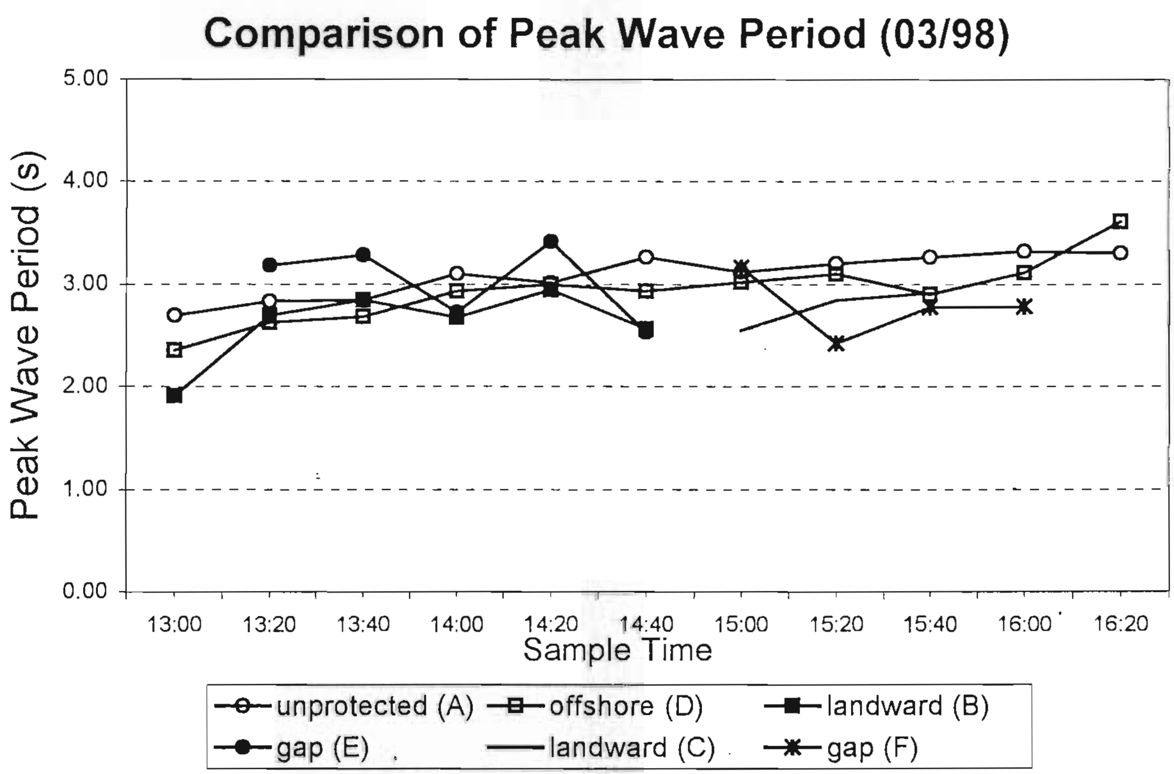

Figure 5. Measured peak wave period in March 1998, note the generally low period of approximately 3 s and little change between the different sites.

The results from the wave spectral analysis are summarized in Appendix 2. The wave spectra illustrate the distribution of wave energy with respect to each frequency component. The peaks in the wave spectra indicate that the waves of the specific frequencies carry more energy than other frequencies. Several distinct features were observed from the March 1998 measurements:

1. The magnitudes of the wave energy for the locations inside the breakwaters (sites B and C), as indicated by the power density, were much lower than that of the unprotected site (site A). These differences in the magnitudes of power density caused the large difference in significant wave heights.
2. Almost all the wave energy was distributed between 0.1 to 1.0 Hz, or 1.0 to 10 seconds. Contributions from wave components with period longer than 10 s or shorter than 1.0 s were not significant during the period of measurement.
3. As compared to the October 1997 measurement, more wave energy was distributed in higher frequency components and tended to have a broader distribution, indicating a young, locally-wind generated sea state, and also resulted in a generally lower peak period.
4. Toward late afternoon, as the wind-speed increased, the power density increased across all the frequency components, and resulted in higher significant wave heights.

Shoreline Morphology and Nearshore Bathymetry

As discussed in the previous report (Stone et al., 1997), the presence of the segmented breakwaters induced a significant change in nearshore morphology. The development of beach cusps was apparent. However, both field observations and quantitative data obtained from beach-profile surveys indicate that the shoreline adjustment in the form of beach-cusp development seemed to have reached a quasi-equilibrium condition (Figure 6) after November 1997. No significant further adjustment in the vicinity of the shoreline was observed or measured between October 1997 and March 1998. Slight shoreline retreat was measured in March 1998, as compared to October 1997. More retreat was measured between the gap of the breakwaters (2 to 3 m) than that landward of the center of the breakwaters (approximately 1m), although the overall change in the vicinity of the shoreline was small compared to changes directly landward of the breakwater and total volume change, as discussed in the following paragraph.

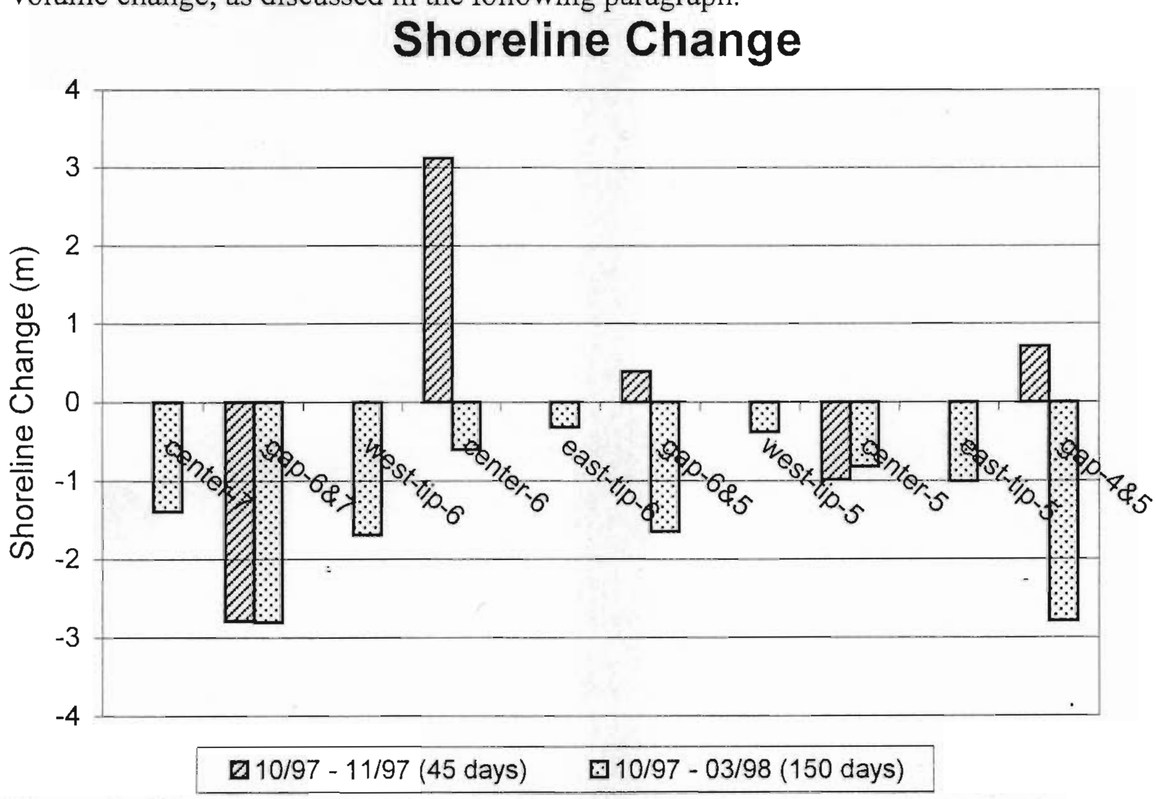

Figure 6. Shoreline changes during October 1997 to November 1997 and October 1997 to March 1998, respectively. Note the overall small magnitude, as compared to the amount of sand that had been accumulating in the area (Figure 7). Transects across the tips of the breakwaters were not surveyed in November 1997.

Substantial sand accumulation was measured directly landward of the breakwater surveyed with a large body of sand had aggraded and emerged to a height of approximately 0.3 m above an estimated zero water level during the March 1998 survey (Plates 2 and 3; Figure 7A). Considerable sand accumulation was also measured in the gap between the breakwater segments. As much as 40 m^3/m of sand accumulated on the beach profiles between the vegetation line and the breakwaters during the 5-month period between the beginning of October 1997 to the beginning of March 1998. The maximum accumulation occurred landward of the center of the breakwaters and decreased toward the gaps. The majority of the beach volume change occurred directly landward of the breakwaters (Figure 7B). Volume changes in the vicinity of the shoreline were small compared to the overall changes and changes adjacent to the breakwaters (Figure 7C). While a net increase in sediment was measured immediately landward of the breakwaters, a general volume decrease was measured in the vicinity of the shoreline indicating slight erosion. These sand accumulations resulted in considerably shallower water depths between the breakwaters and the shoreline six months after construction in comparison to two months post-construction (Figure 8). The shallower water had considerable influences on wave conditions as described in the previous sections.

The substantial sand accumulation was concentrated directly behind the breakwaters (Appendix 3). This sand accumulation pattern has not been documented by previous studies on detached, segmented breakwaters (e.g., Toyohira, 1974; Walker et al., 1980). The implications at this juncture are that sand accumulating directly landward of the breakwaters cannot be attributed to longshore transport only. Onshore sand transport through the gaps between the breakwaters, which was indicated by the accumulation landward of the gap, and longshore redistribution induced by diffracted and obliquely incident waves appear responsible for the significant volume of sand accumulating immediately landward of the structures.

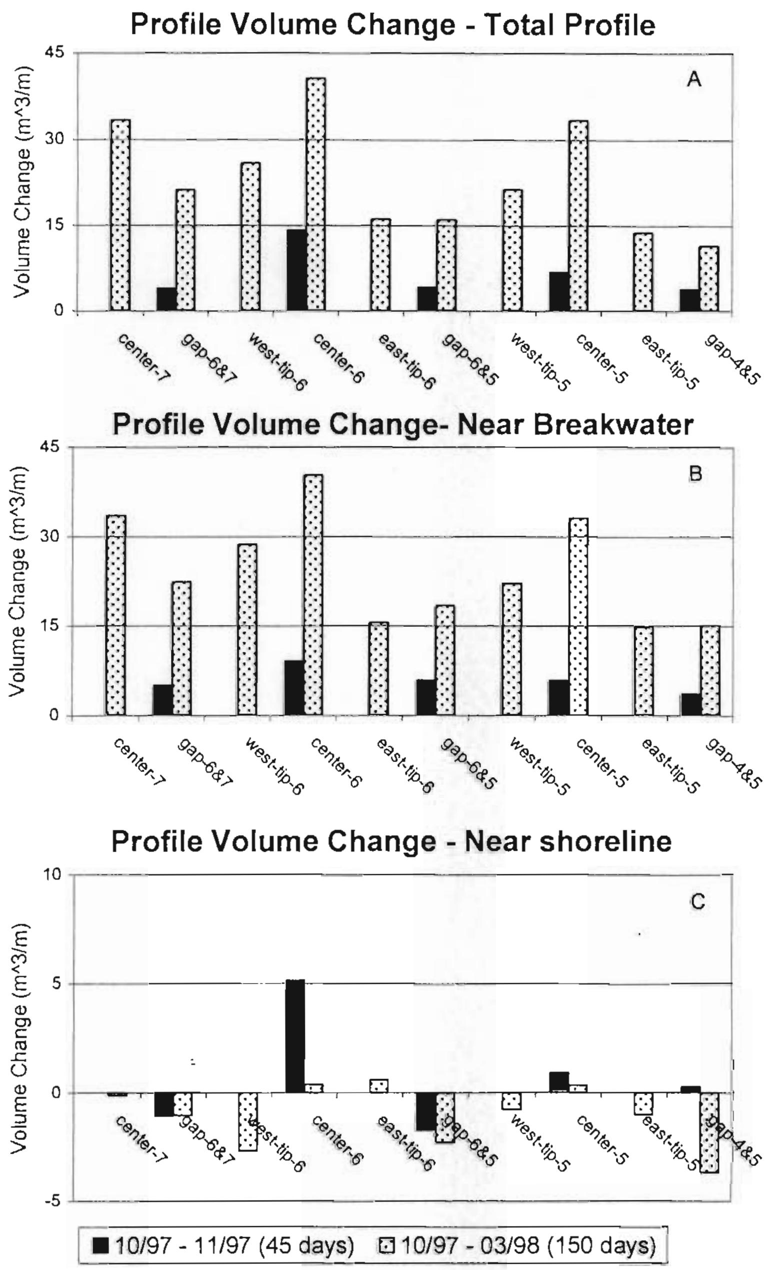

Figure 7. Overall beach-profile volume changes from the vegetation line to the breakwaters. (A). Changes landward adjacent to the breakwaters, from 30 m to the end of the profiles (B). Changes in the vicinity of the shoreline, from the vegetation line to 30 m seaward (C). Positive indicating volume gain and negative volume loss

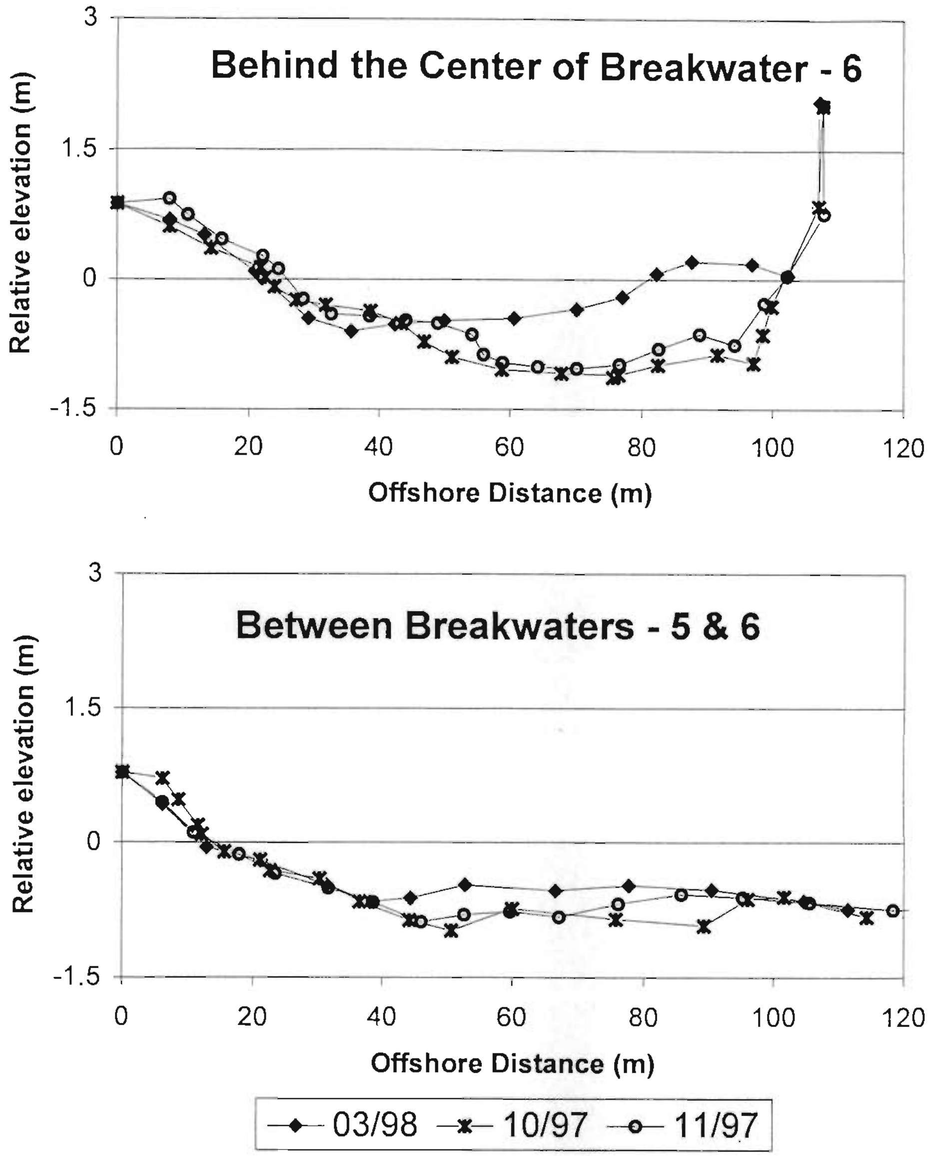

Figure 8. Examples of beach profiles across the center of the breakwaters and across the gap between segments.

SUMMARY

The results from both March 1998 and October 1997 deployments allow for the following summary, although it is important to note that this is an initial assessment of the performance of the breakwaters during the first six-months post-construction. A longer time series of data is necessary to allow a more comprehensive understanding of beach and nearshore response to the Raccoon breakwaters.

The results from the first two wave measurements indicate that the detached, segmented breakwaters functioned differently, in terms of wave-height reduction, during normally and obliquely incident wave approaches. During normally incident waves, wave height was 90% lower behind the center of the breakwater than at the unprotected site, while wave propagation through the gaps between the segments was largely unaffected. Wave diffraction around the tips of the breakwaters during the shore-perpendicular wave approaches created zones where longshore transport converged near the shoreline behind the center of the breakwaters (caused by the converging wave breaking) in addition to zones of divergence behind the gaps. During the oblique incident waves encountered in the March 1998 measurements, a reduction of wave height of approximately 70%, when compared to the unprotected site, was measured landward of the center of the breakwaters, in contrast to the 90% wave-height reduction under normally incident waves. Wave heights landward of the gap between the segments were 50% lower than at the unprotected site under obliquely incident waves, while wave conditions in the gap were almost the same under normally incident waves.

A rapid shoreline response, in the form of rhythmic beach cusps, was observed shortly after construction of the breakwaters. The initial shoreline adjustment reached quasi-equilibrium approximately three months after breakwater construction. No significant further planform shoreline adjustment was measured between months three and six. A substantial amount of sand accumulation was measured directly landward of the breakwater segments, as well as in the gaps between the breakwaters. A sand body has emerged landward of the center of the breakwaters and appears to be prograding onshore. Field observations indicate that the sand accumulation directly landward of the breakwaters probably resulted from an impoundment of onshore sand transport and a longshore redistribution by obliquely incident and diffracted waves.

The first six-months of post-construction data presented here are encouraging in that they suggest an initial morphodynamic response to breakwater structures not previously reported in the literature. Additional data which will be collected in the future deployments should add significantly to a model elucidating the response of the study site to an apparent abundance of sediment supplied from offshore, resulting in the development of tombolos prograding landward from the breakwaters.

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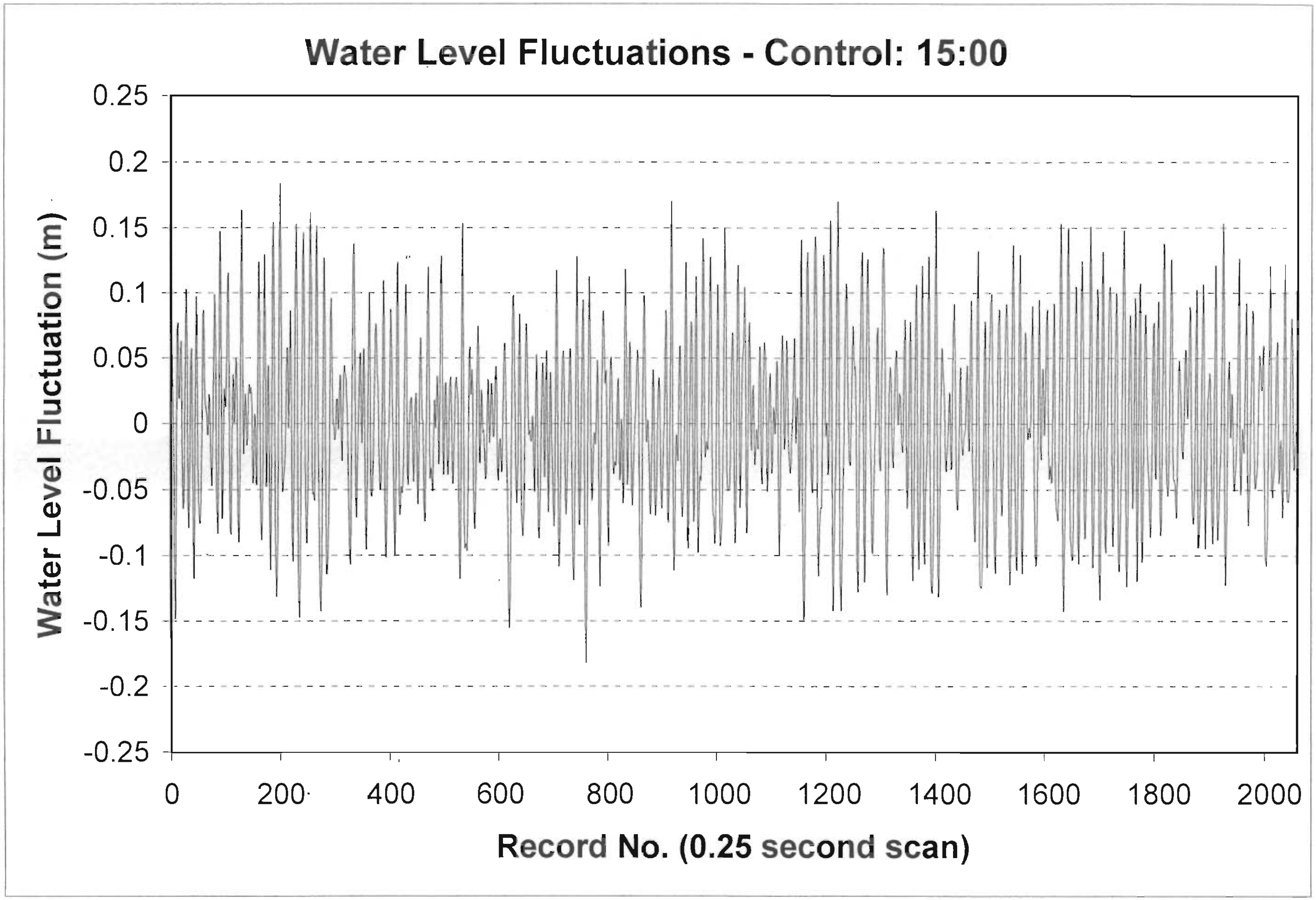
APPENDIX 1

Examples of raw water-level data at the study sites showing the complexity and presence of various waves at different frequencies.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-0.15
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0
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400
600
800
1000
1200
1400
1600
1800
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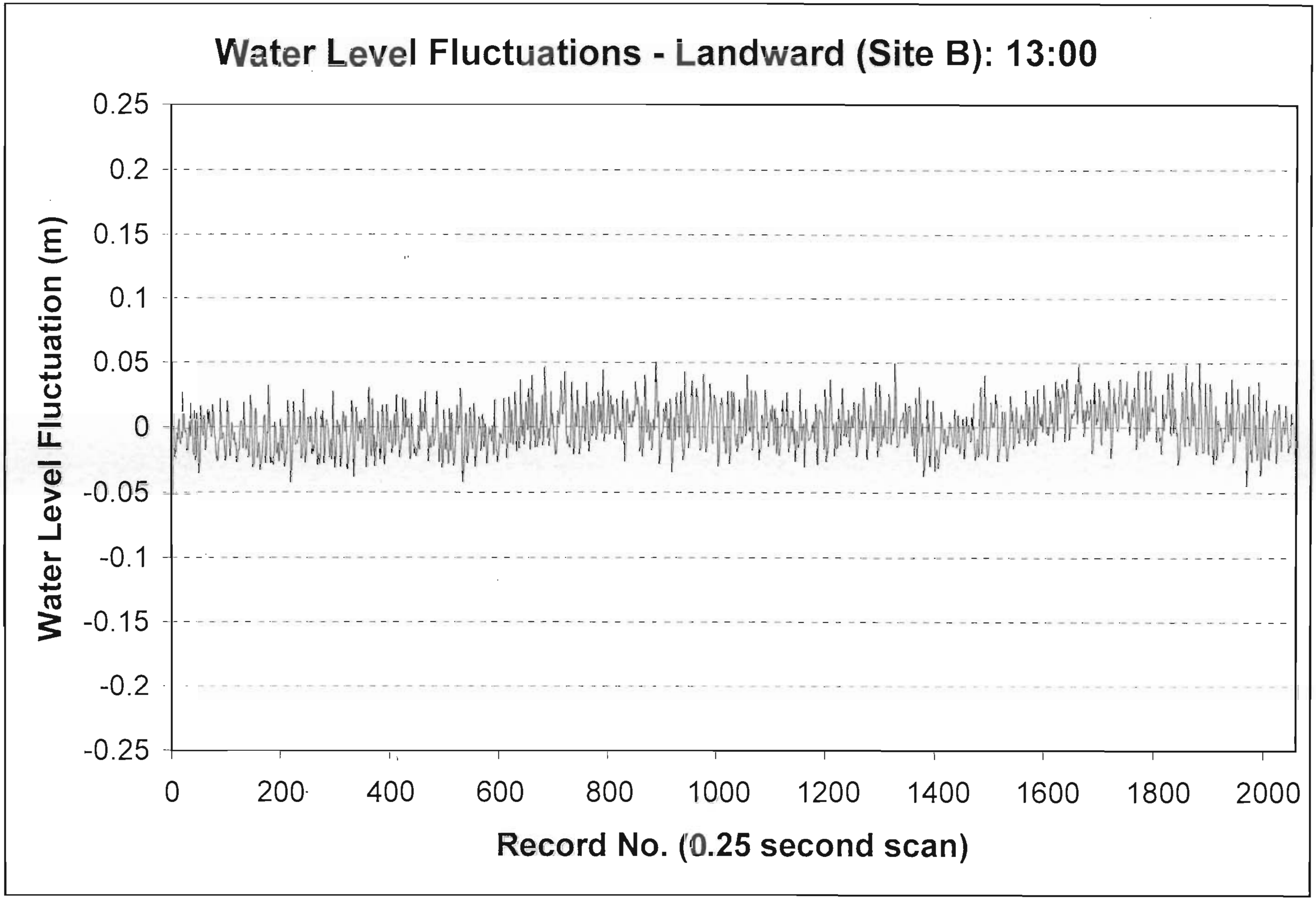
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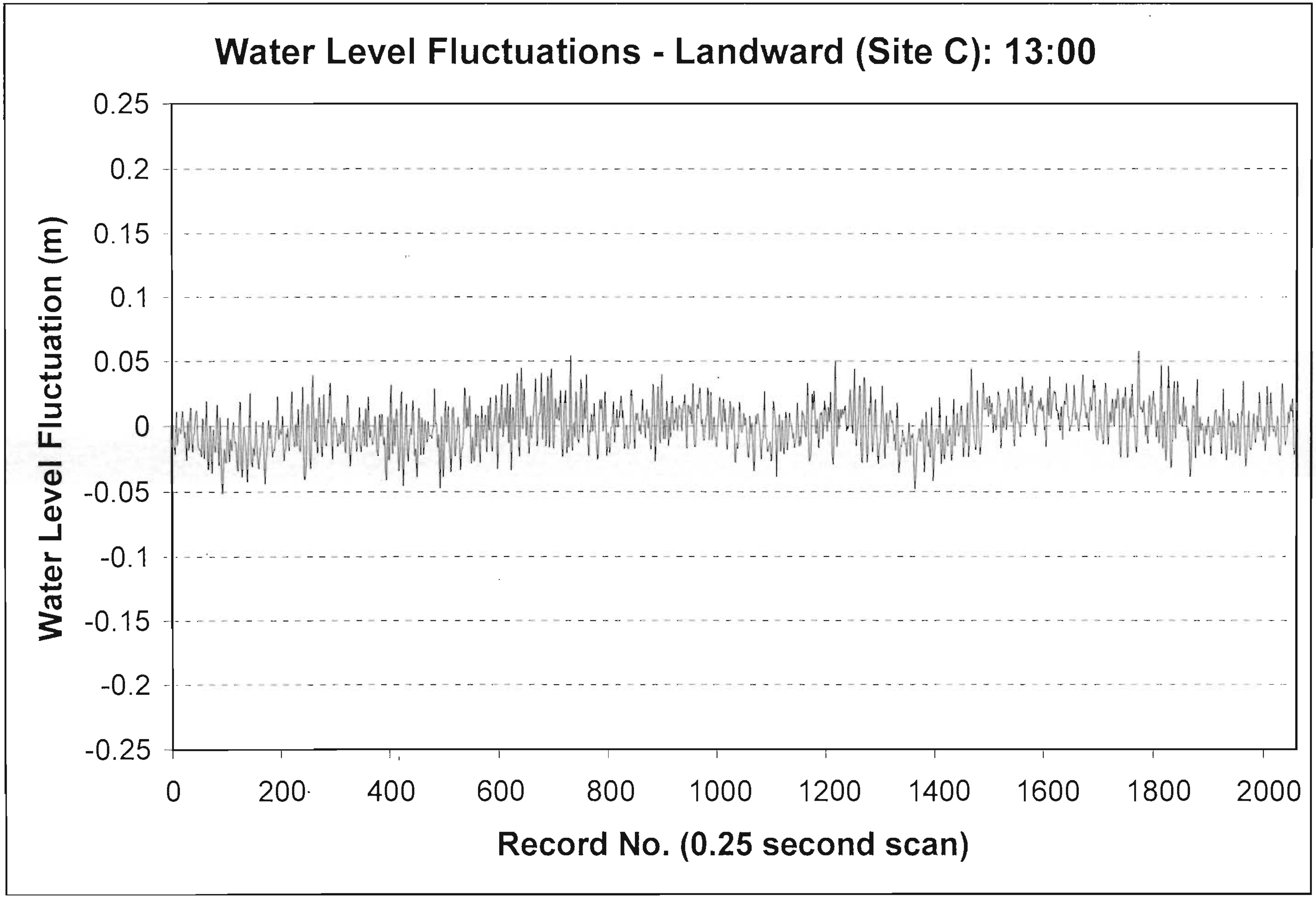
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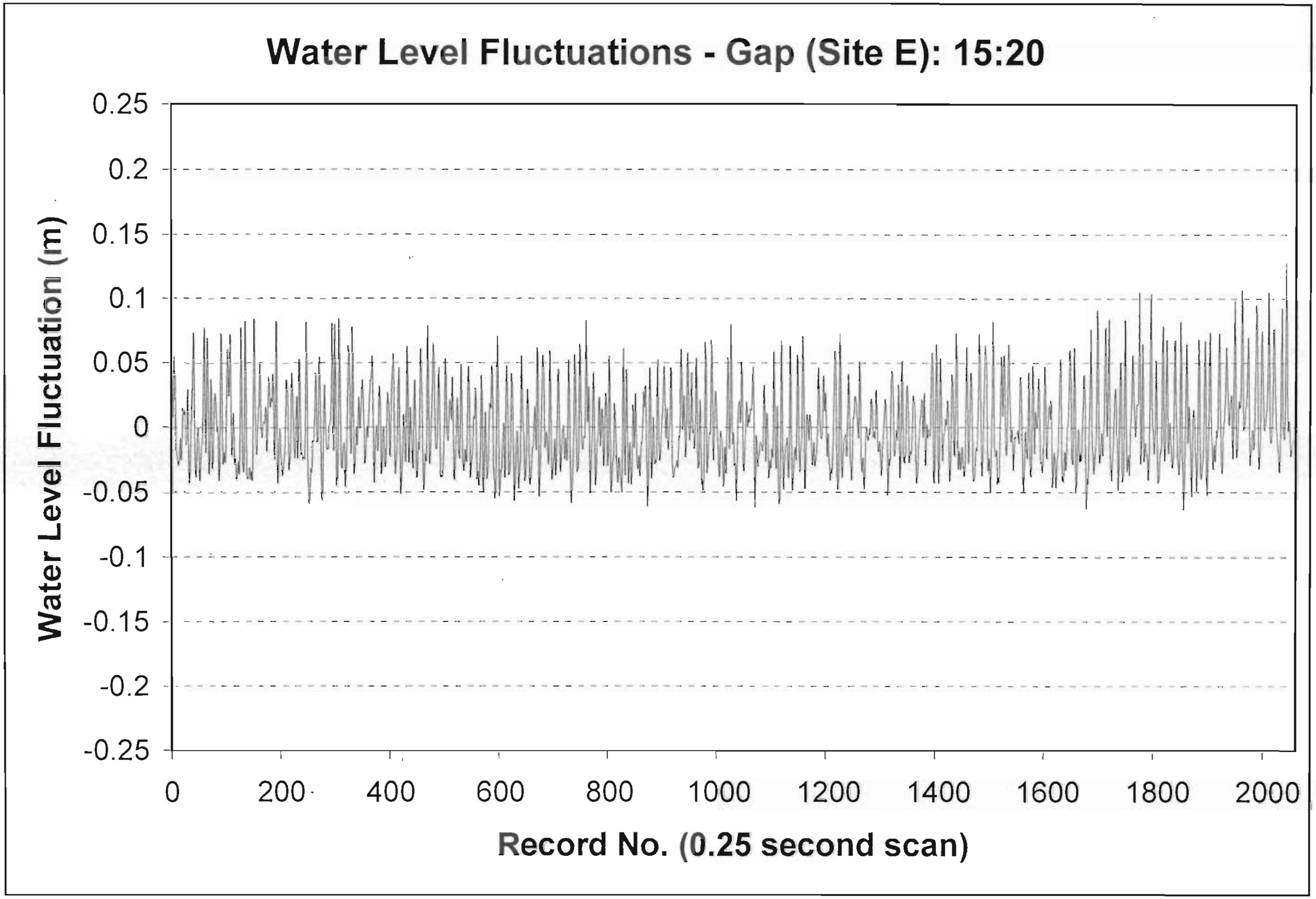
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0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
200
400
600
800
1000
1200
1400
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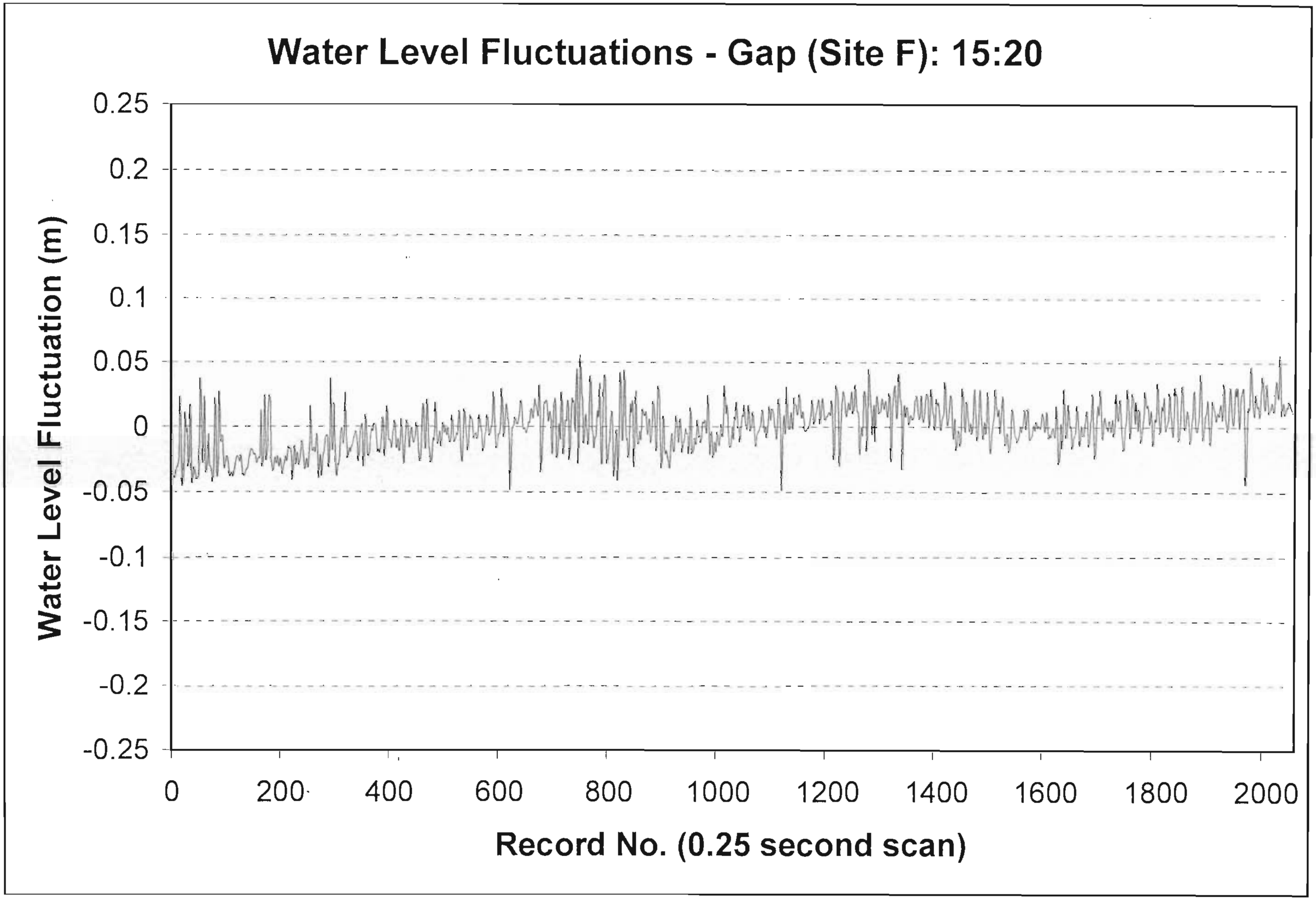
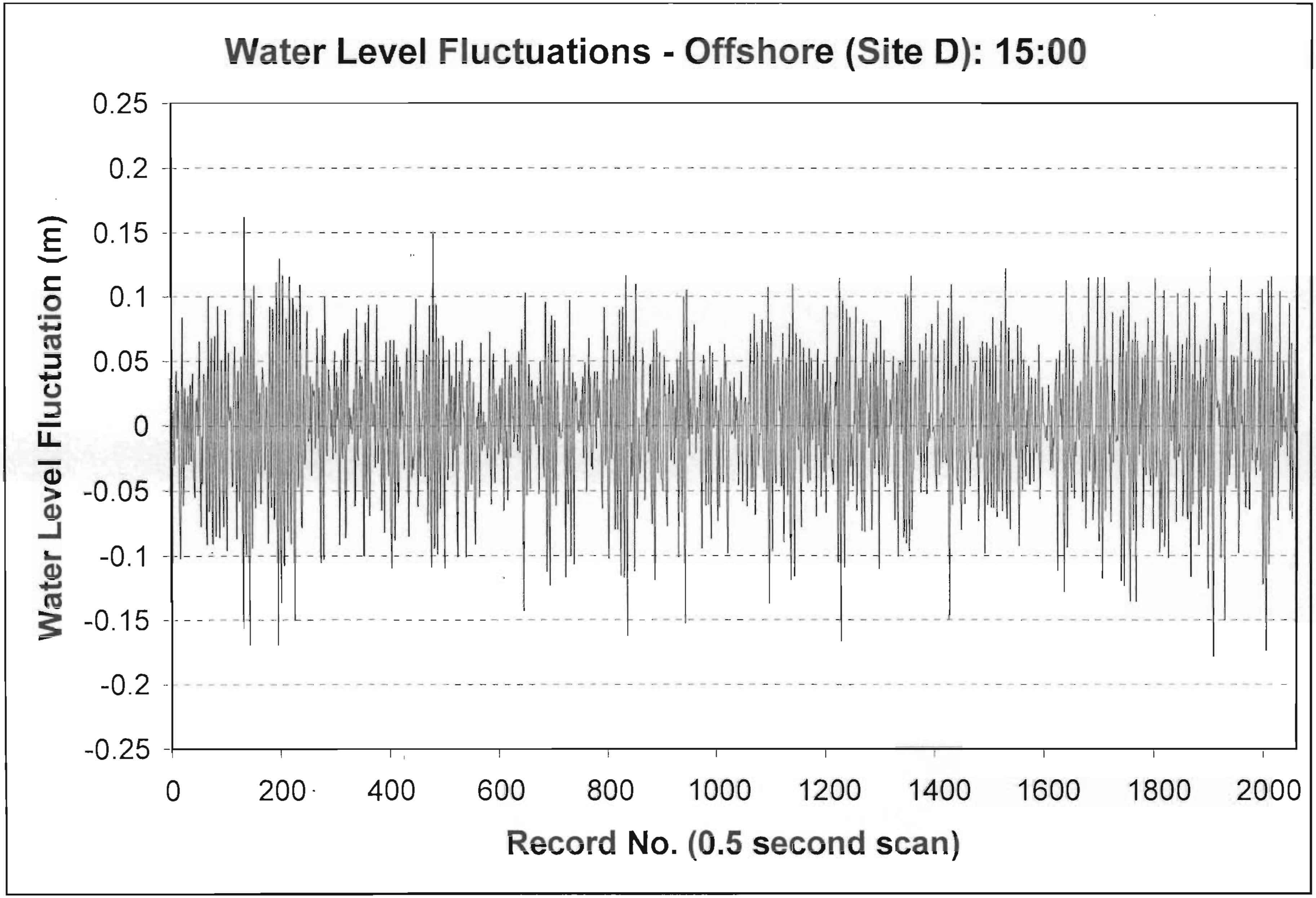
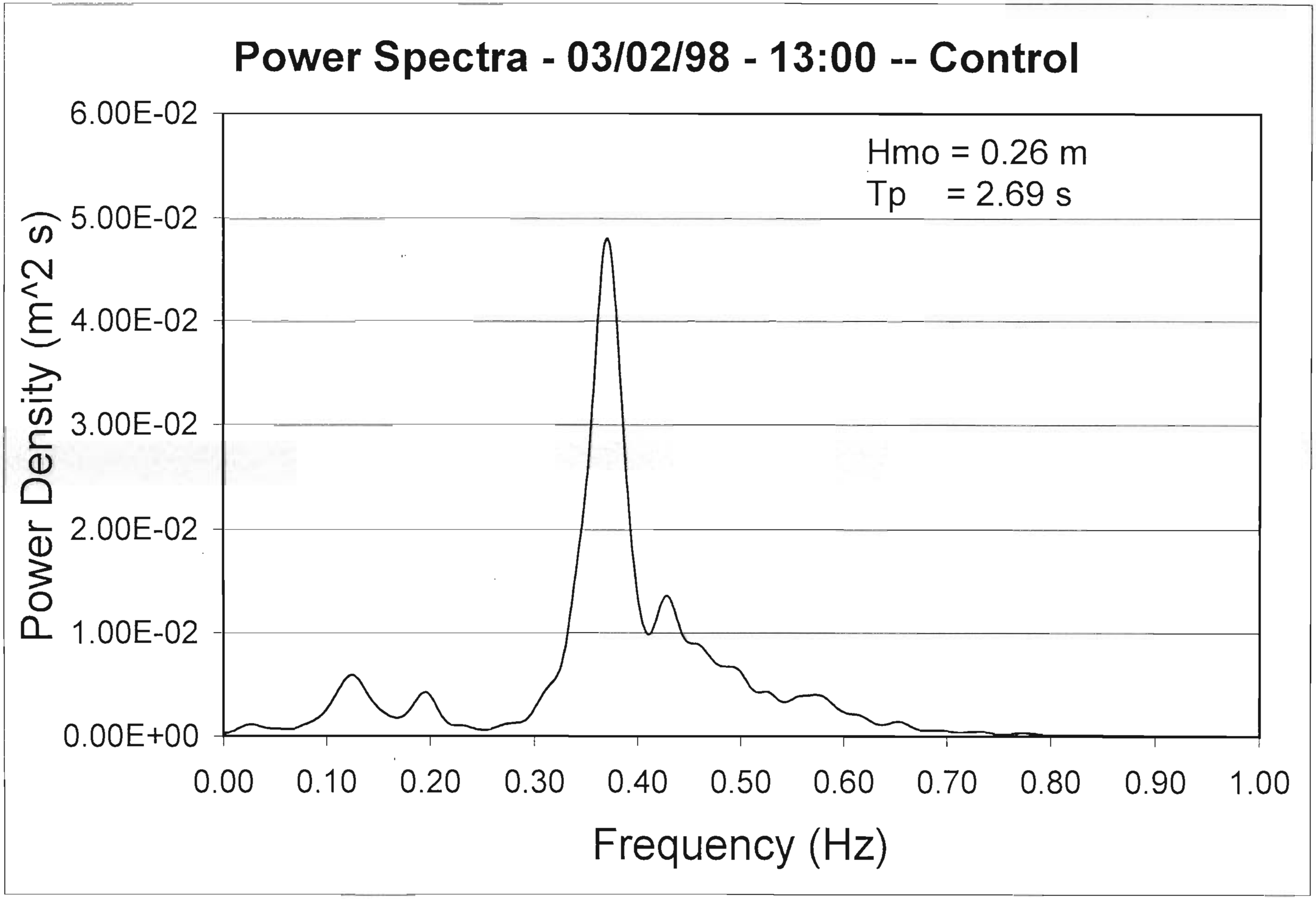
1800
2000
Record No. (0.25 second scan)

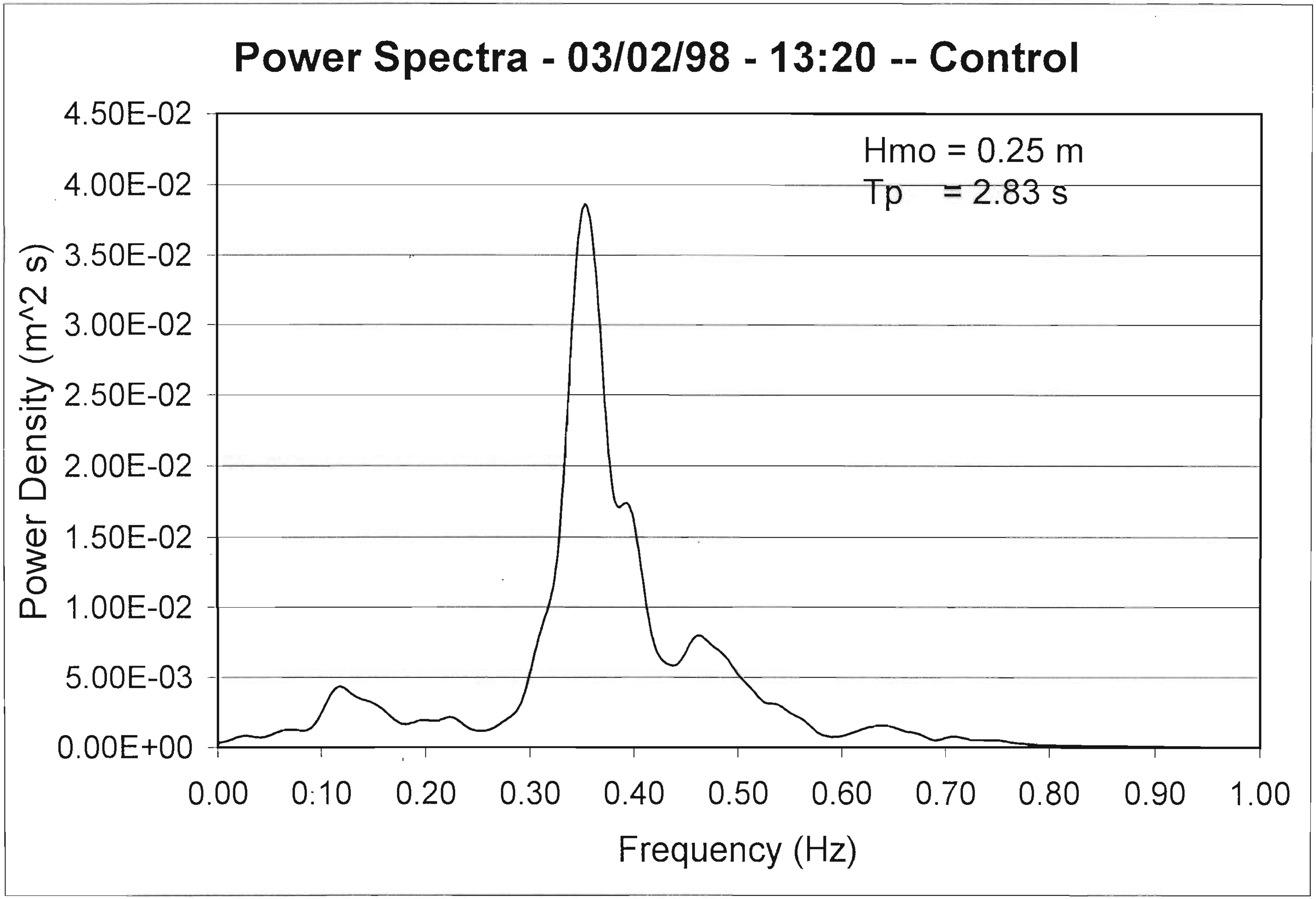

Water Level Fluctuations - Gap (Site F): 15:20
Water Level Fluctuation (m)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Record No. (0.25 second scan)


Water Level Fluctuations - Offshore (Site D): 15:00
Water Level Fluctuation (m)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Record No. (0.5 second scan)

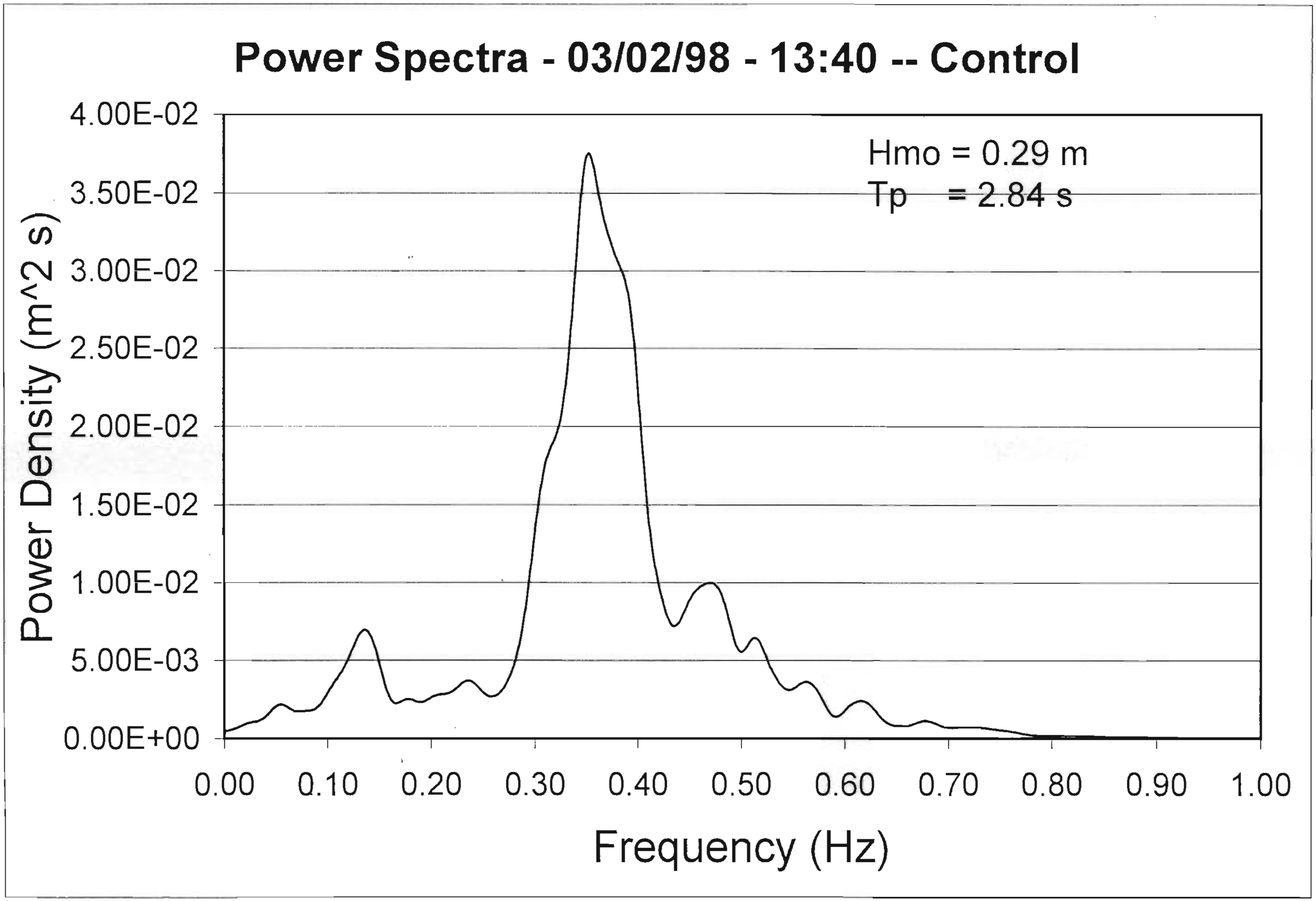
APPENDIX 2

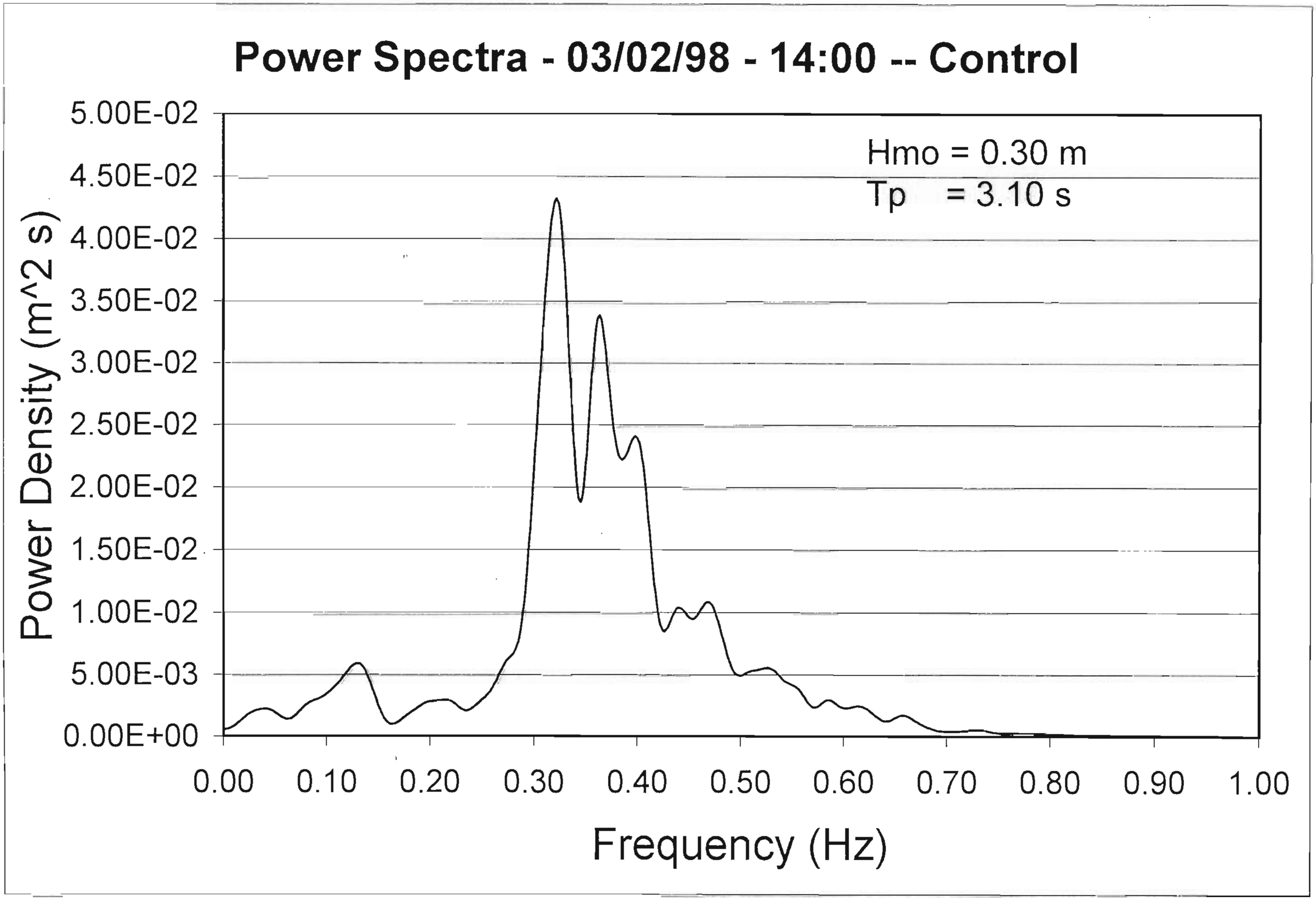
Wave spectra measured during March 1998 deployment.

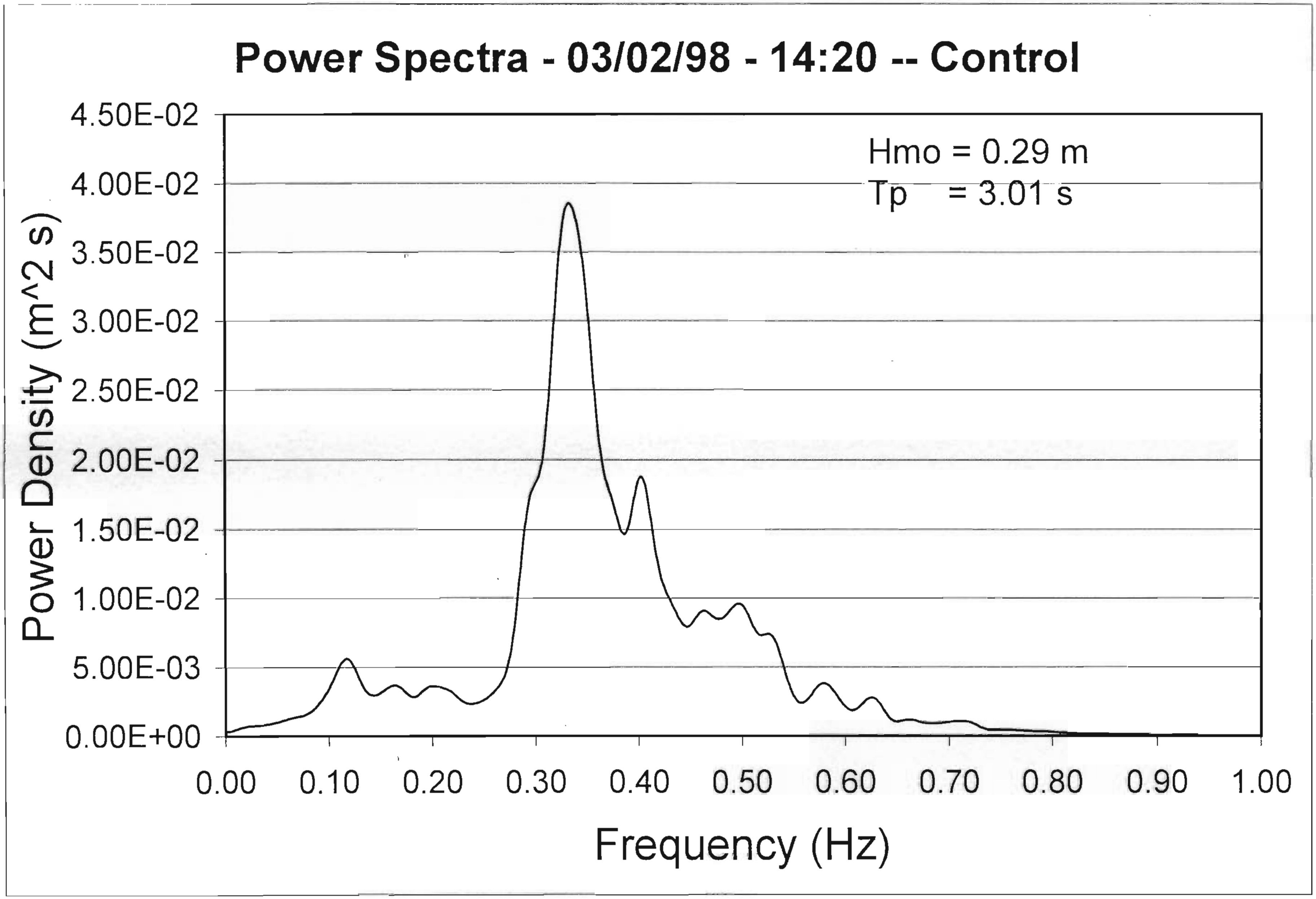

Power Spectra - 03/02/98 - 13:00 -- Control
Hmo = 0.26 m
Tp = 2.69 s
Power Density (m^2 s)
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

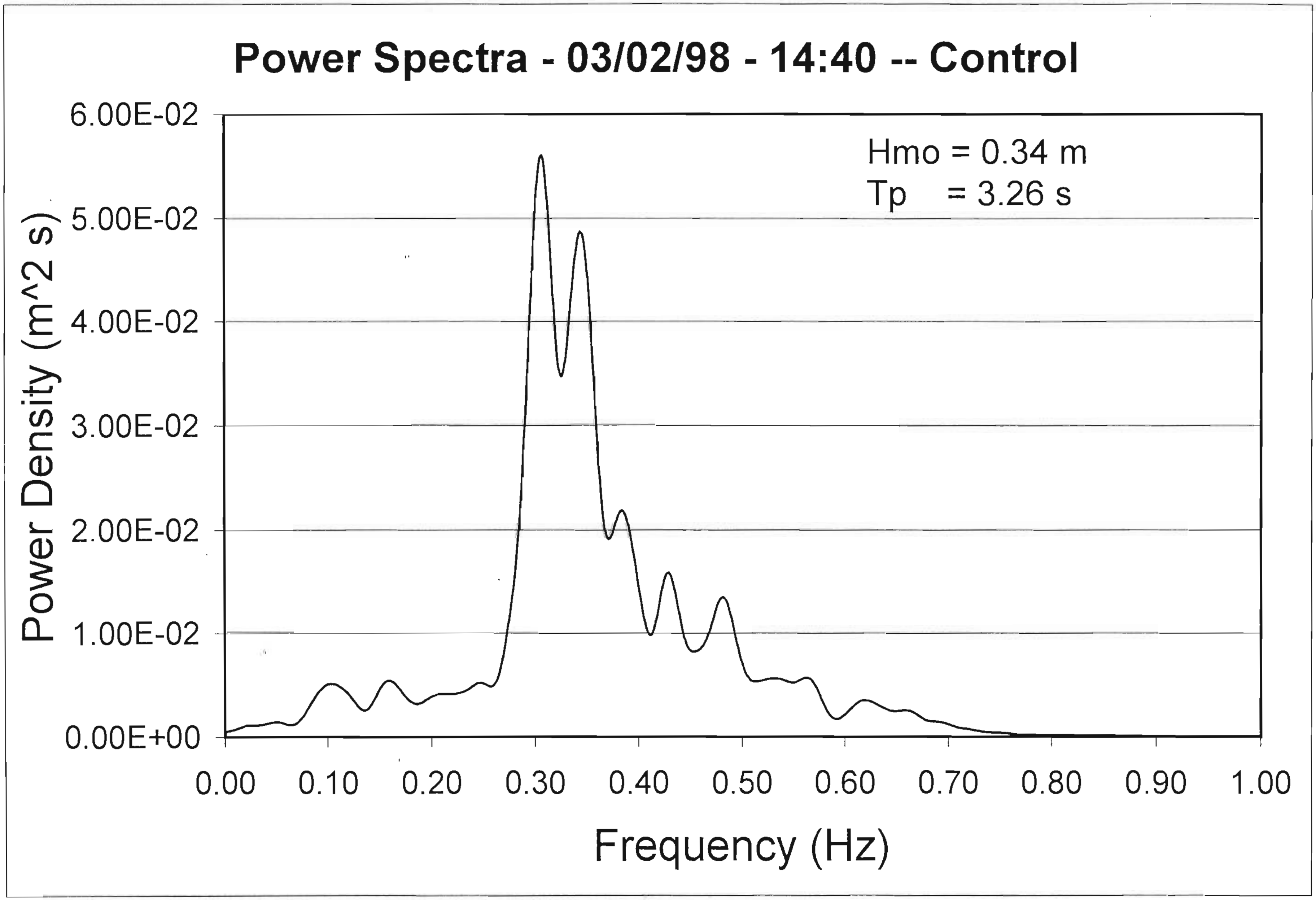


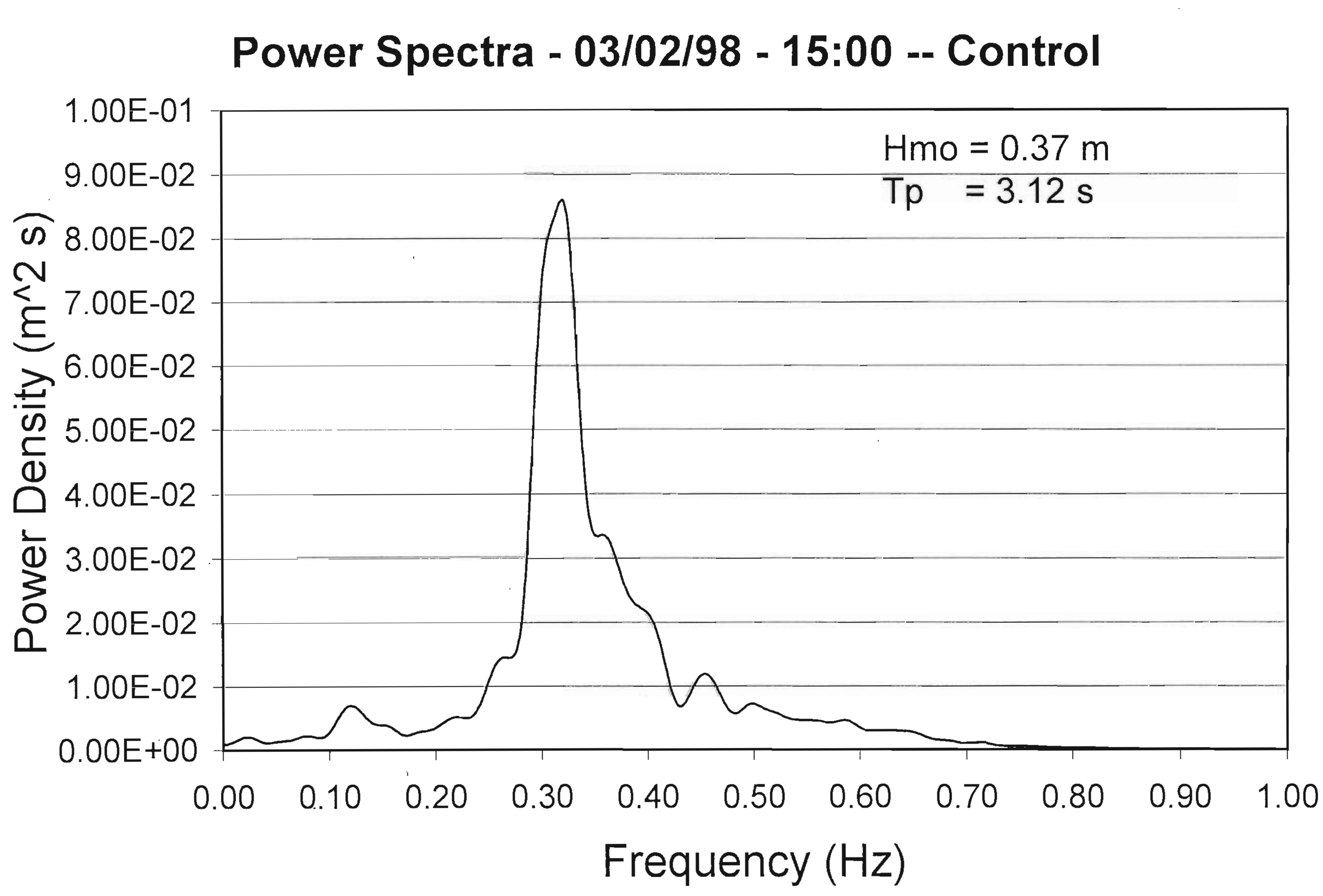
Power Spectra - 03/02/98 - 13:20 -- Control
Hmo = 0.25 m
Tp = 2.83 s
Power Density (m^2 s)
4.50E-02
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0:10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

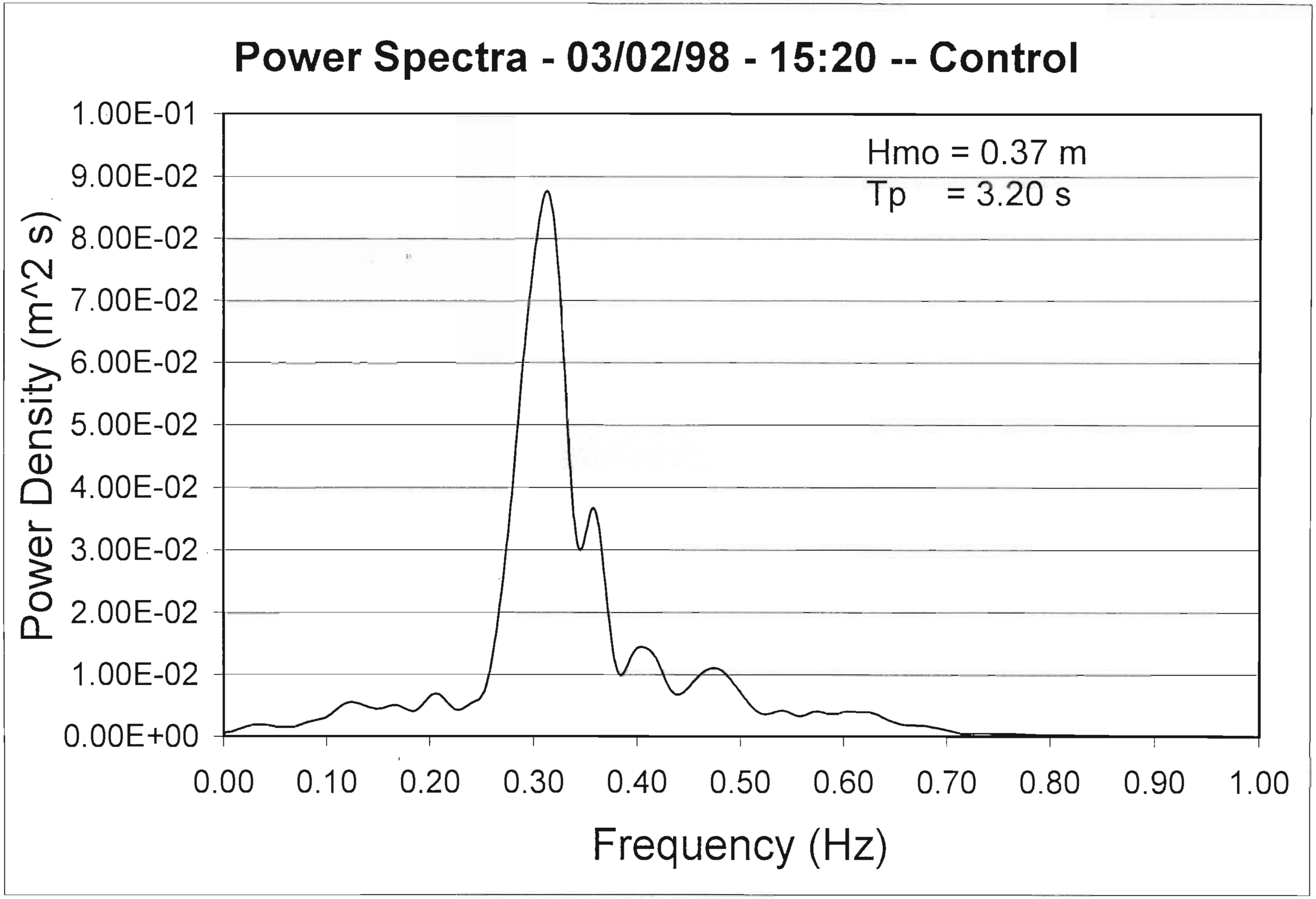

Power Spectra - 03/02/98 - 13:40 -- Control
Hmo = 0.29 m
Tp = 2.84 s
Power Density (m^2 s)
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

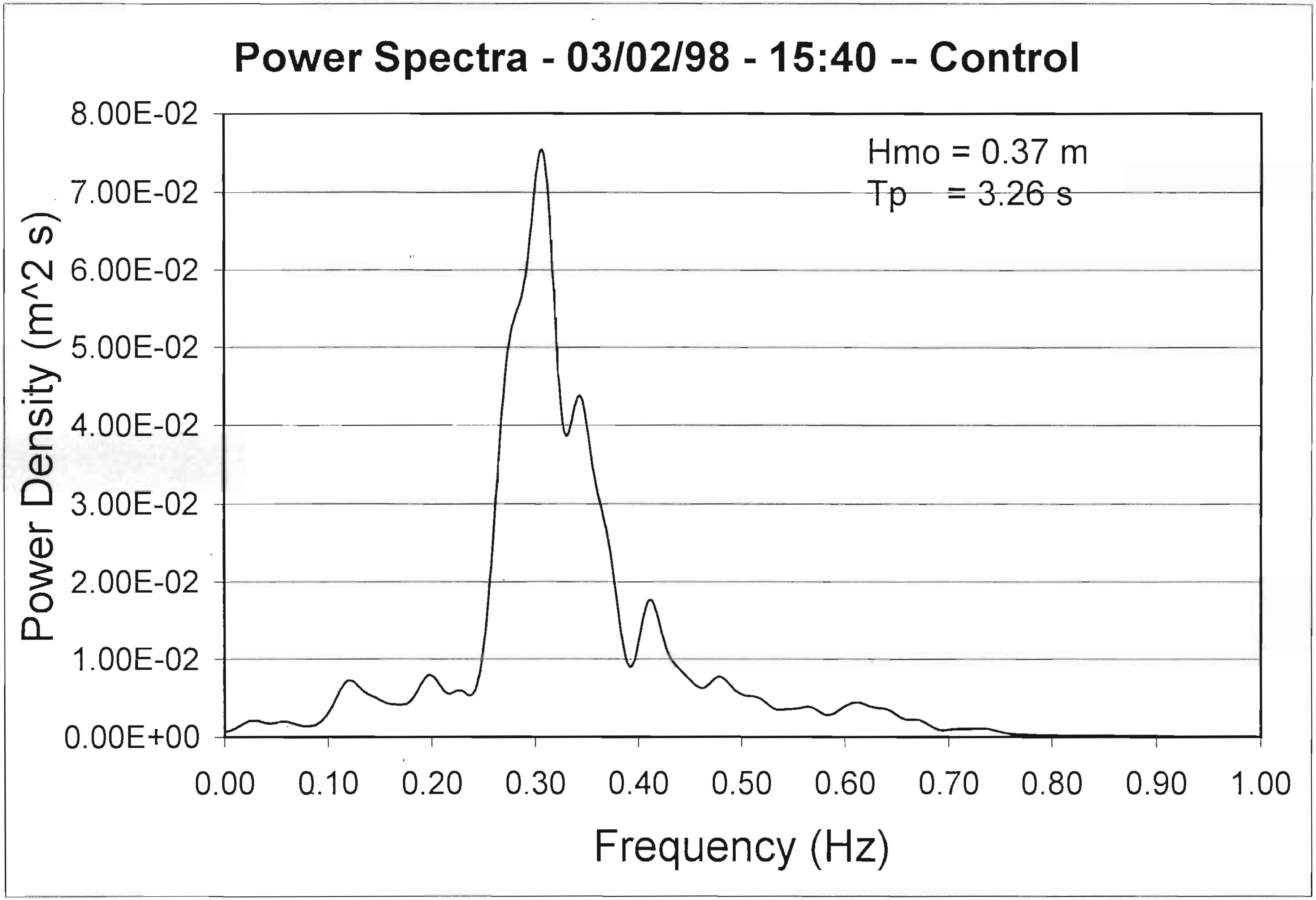

Power Spectra - 03/02/98 - 14:00 -- Control
Hmo = 0.30 m
Tp = 3.10 s
Power Density (m^2 s)
5.00E-02
4.50E-02
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

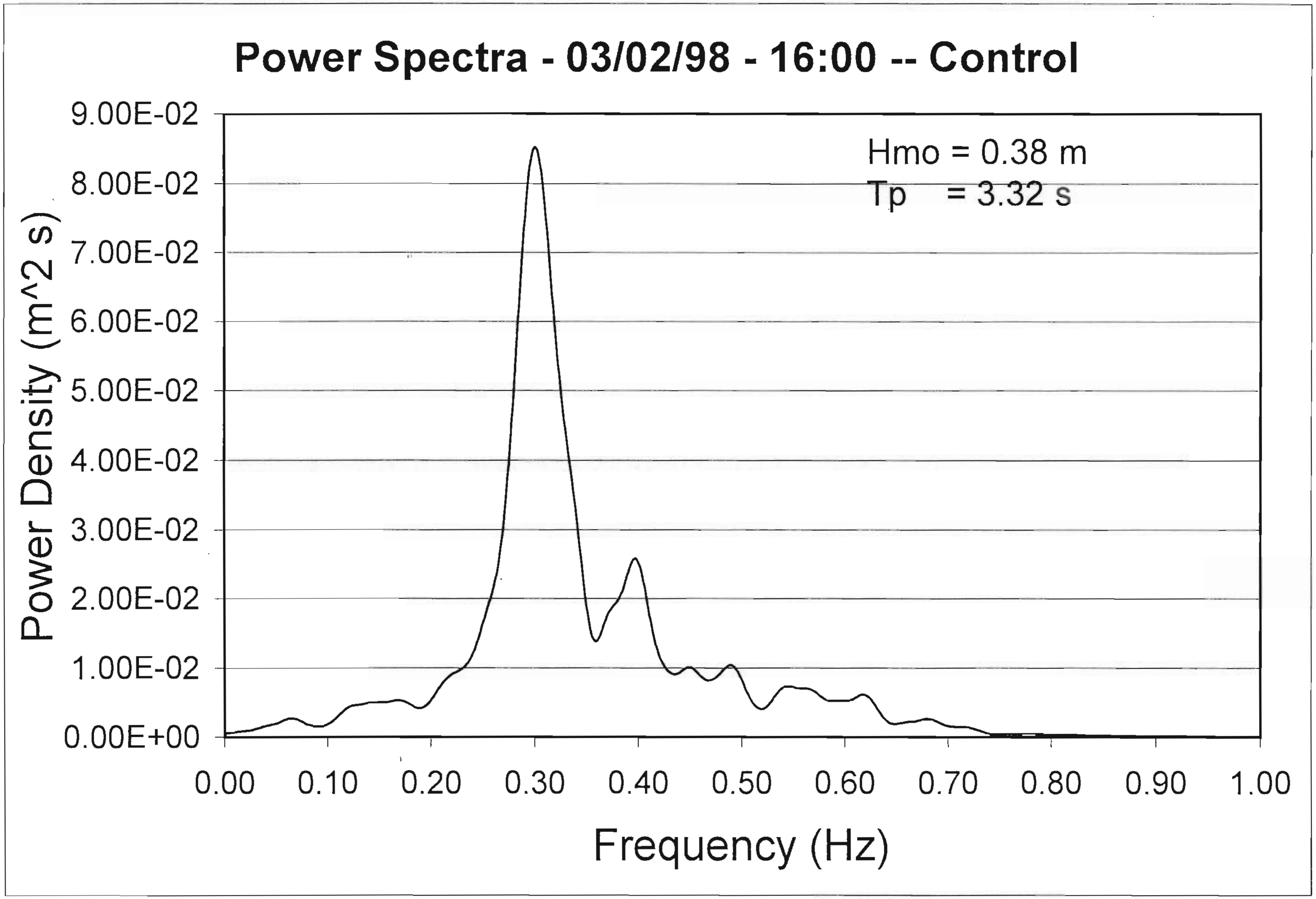

Power Spectra - 03/02/98 - 14:20 -- Control
Hmo = 0.29 m
Tp = 3.01 s
Power Density (m^2 s)
4.50E-02
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

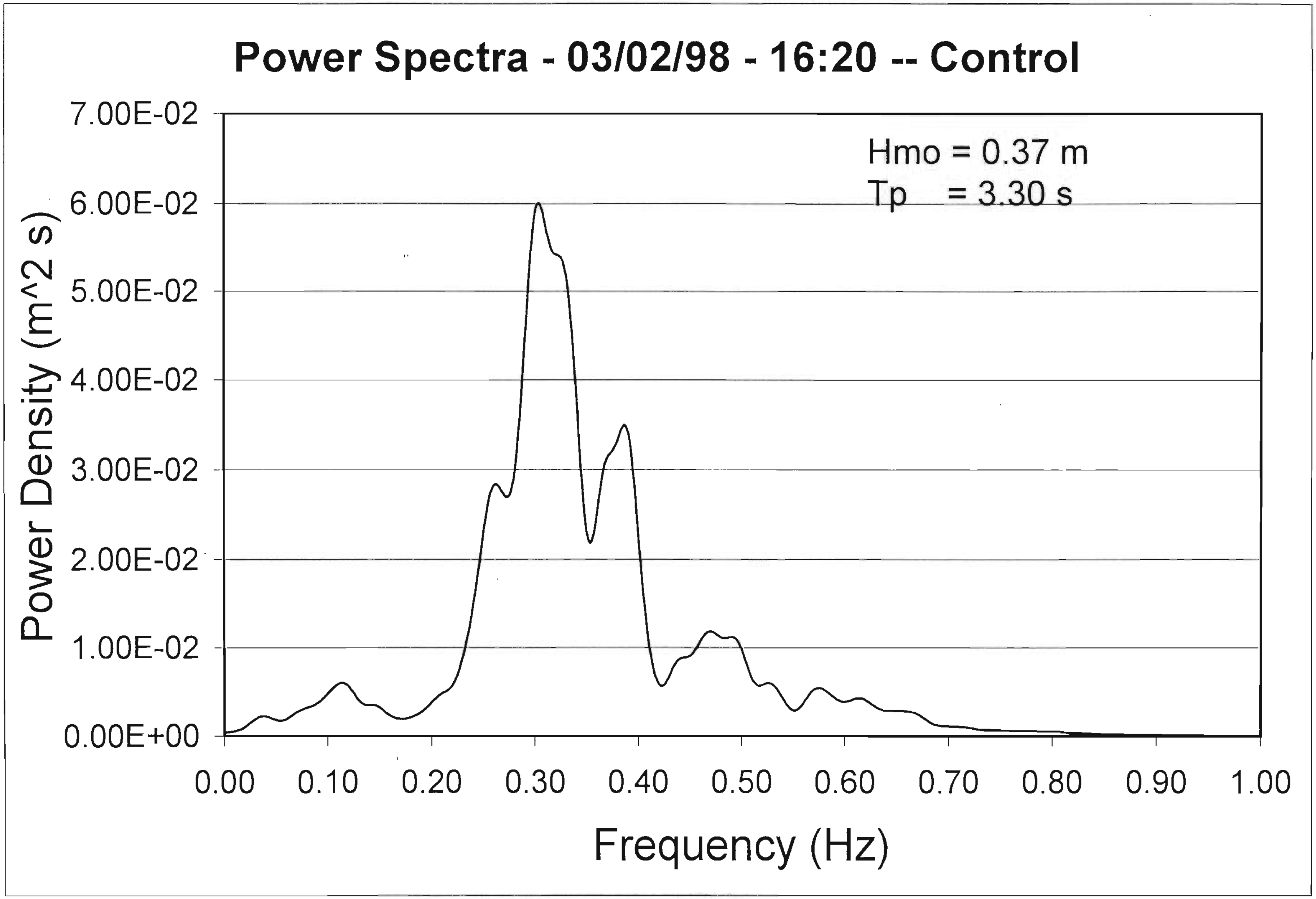

Power Spectra - 03/02/98 - 14:40 -- Control
Hmo = 0.34 m
Tp = 3.26 s
Power Density (m^2 s)
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

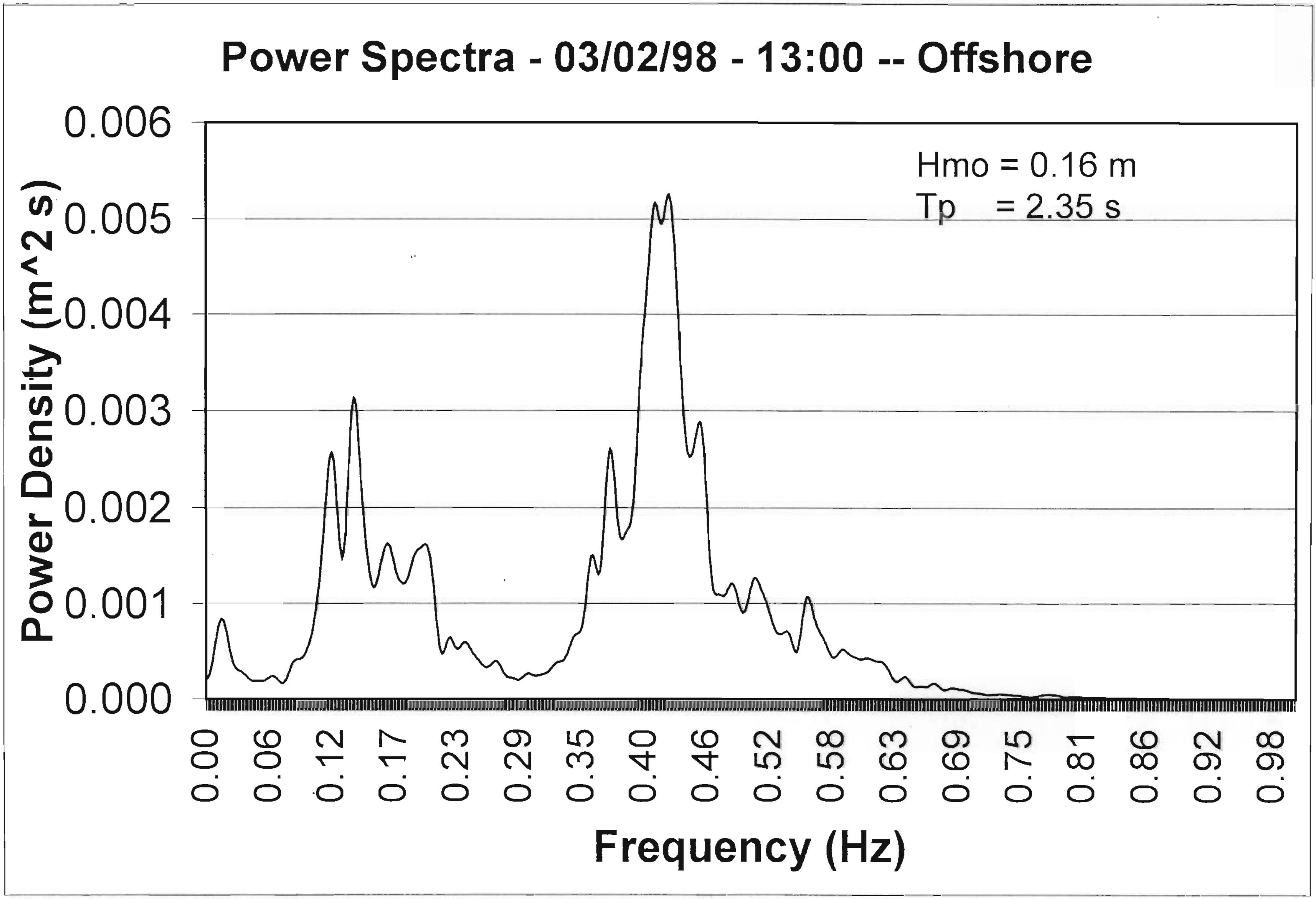

Power Spectra - 03/02/98 - 15:00 -- Control
Hmo = 0.37 m
Tp = 3.12 s
Power Density (m^2 s)
1.00E-01
9.00E-02
8.00E-02
7.00E-02
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

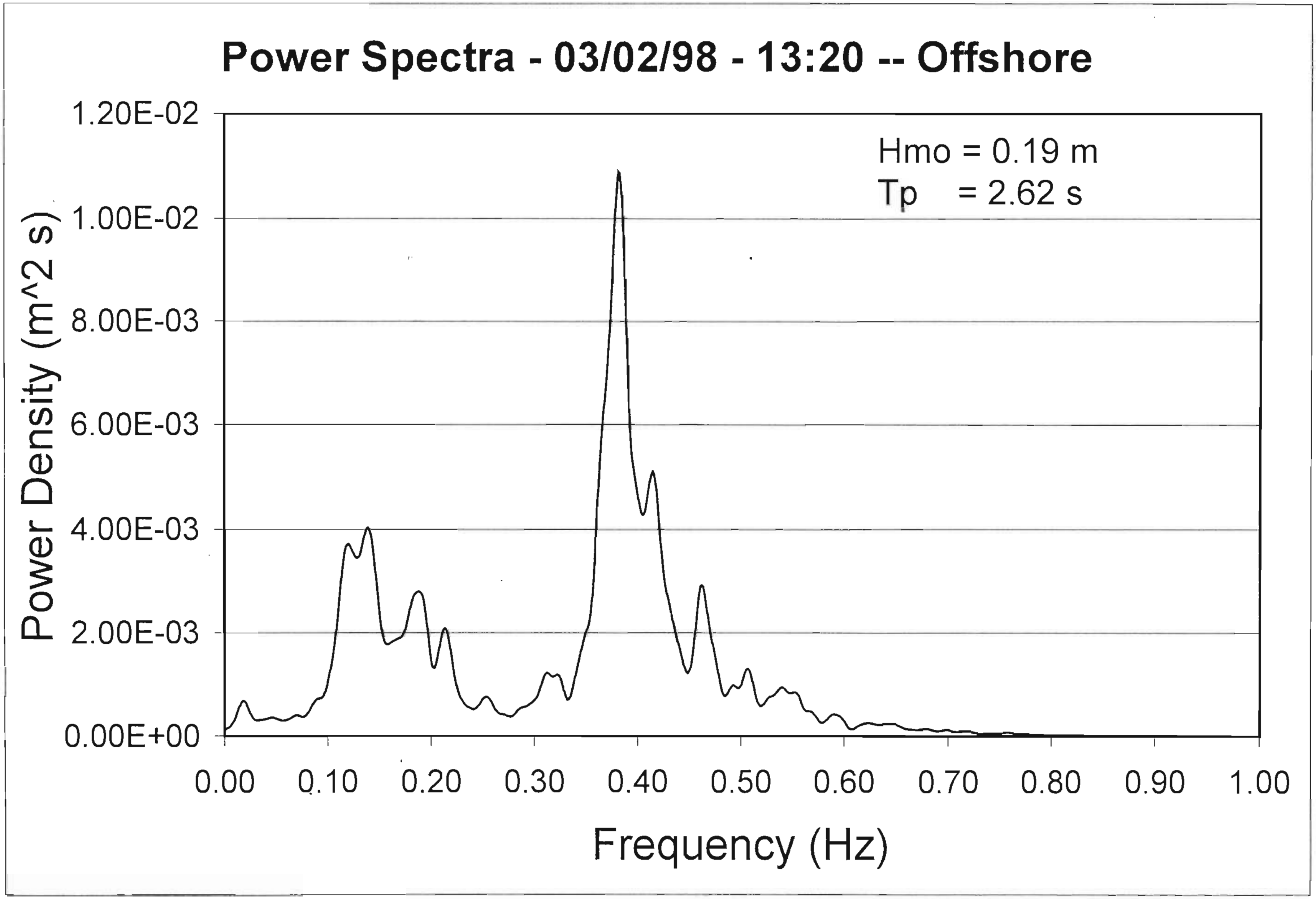

Power Spectra - 03/02/98 - 15:20 -- Control
Hmo = 0.37 m
Tp = 3.20 s
Power Density (m^2 s)
1.00E-01
9.00E-02
8.00E-02
7.00E-02
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)


Power Spectra - 03/02/98 - 15:40 -- Control
Hmo = 0.37 m
Tp = 3.26 s
Power Density (m^2 s)
8.00E-02
7.00E-02
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

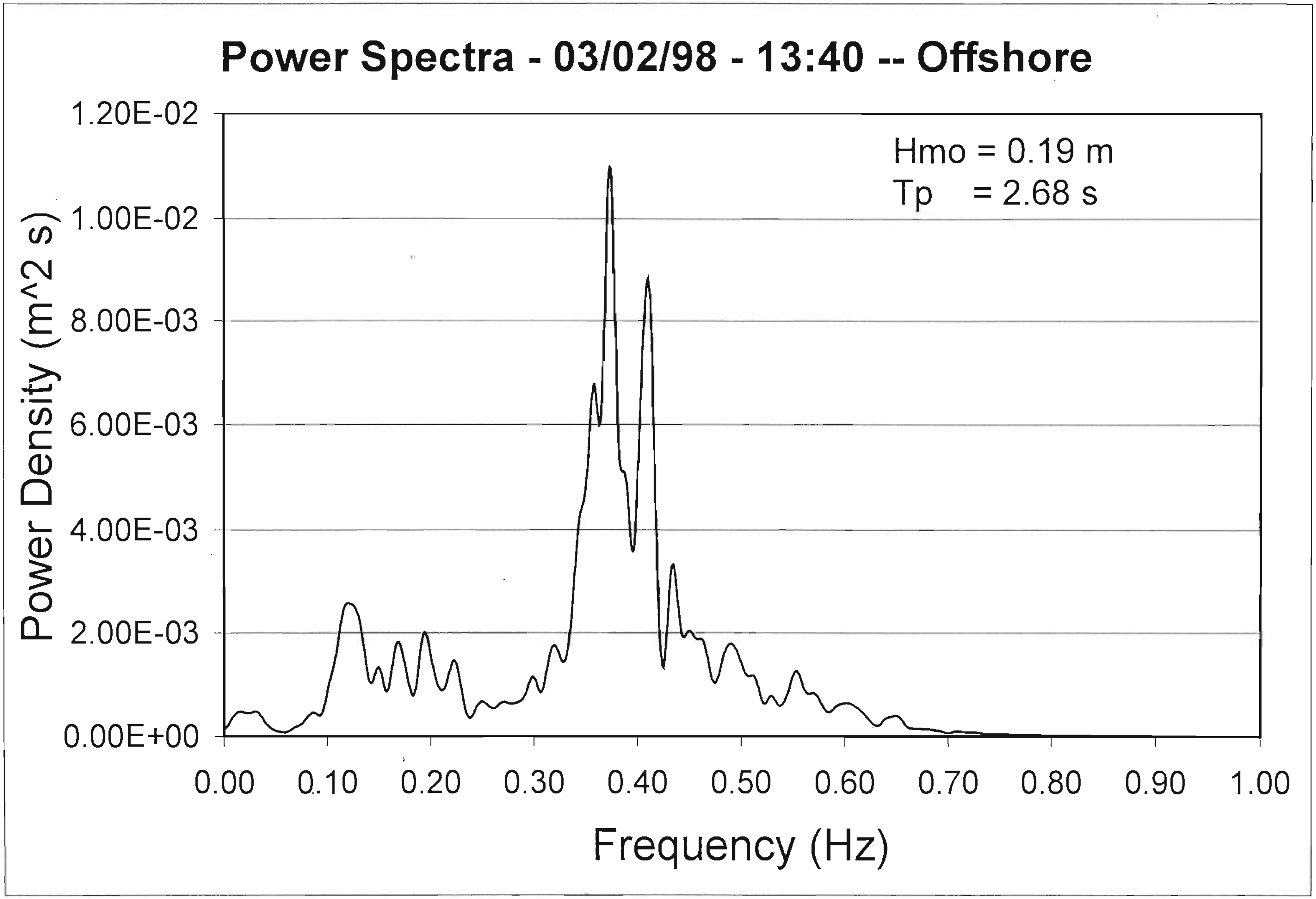

Power Spectra - 03/02/98 - 16:00 -- Control
Hmo = 0.38 m
Tp = 3.32 s
Power Density (m^2 s)
9.00E-02
8.00E-02
7.00E-02
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

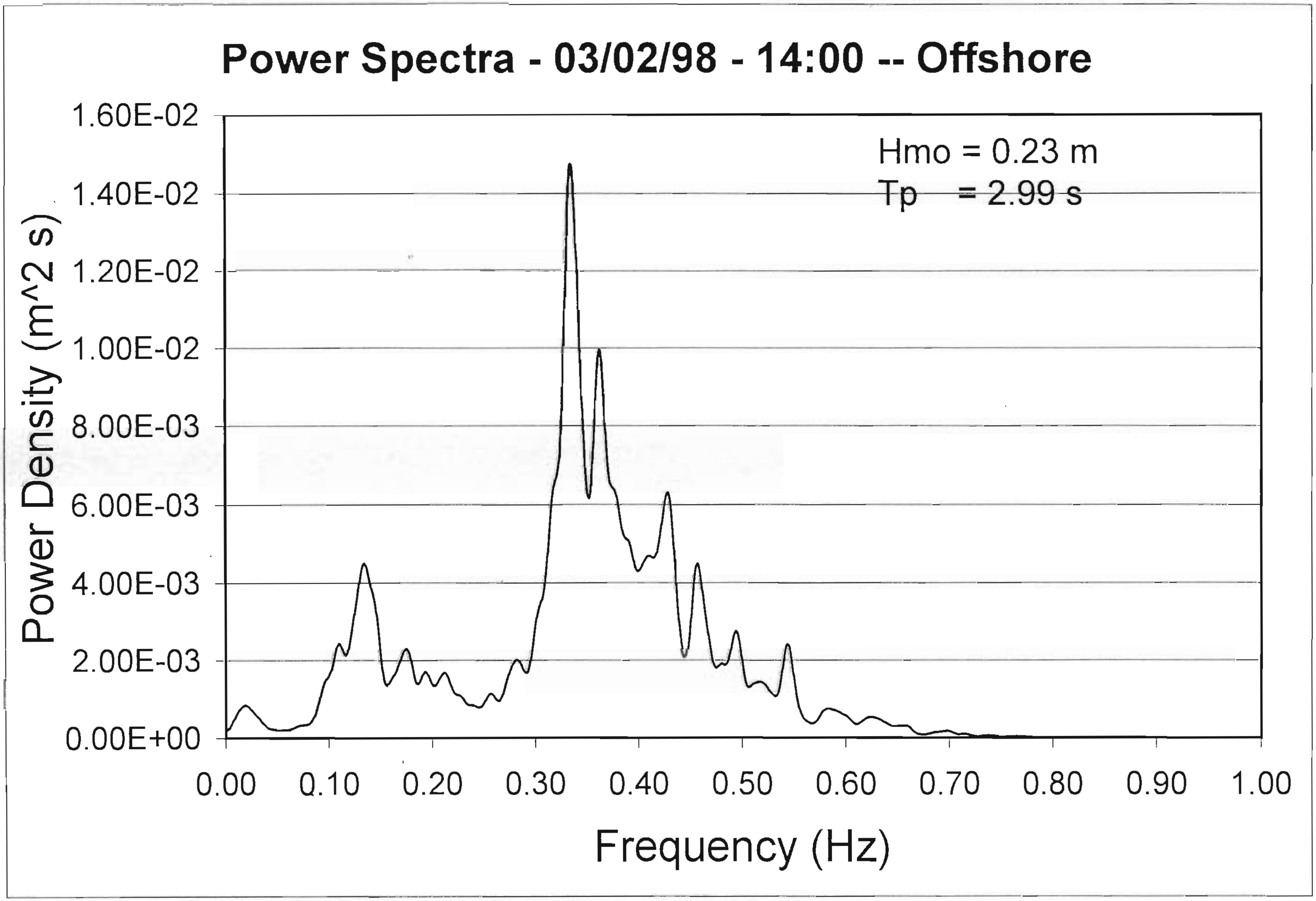

Power Spectra - 03/02/98 - 16:20 -- Control
Hmo = 0.37 m
Tp = 3.30 s
Power Density (m^2 s)
7.00E-02
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)


Power Spectra - 03/02/98 - 13:00 -- Offshore
Hmo = 0.16 m
Tp = 2.35 s
Power Density (m^2 s)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0.00
0.06
0.12
0.17
0.23
0.29
0.35
0.40
0.46
0.52
0.58
0.63
0.69
0.75
0.81
0.86
0.92
0.98
Frequency (Hz)

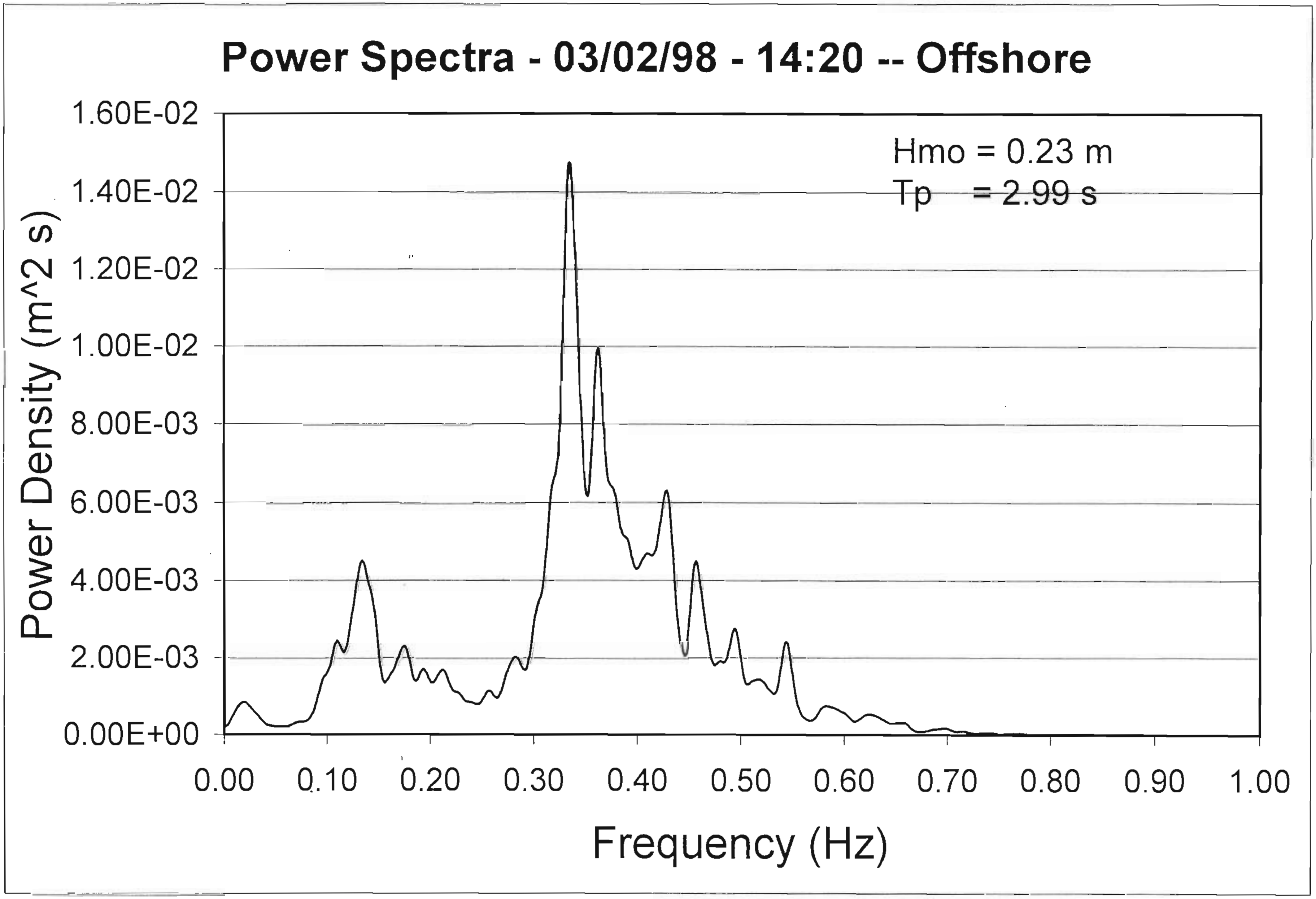


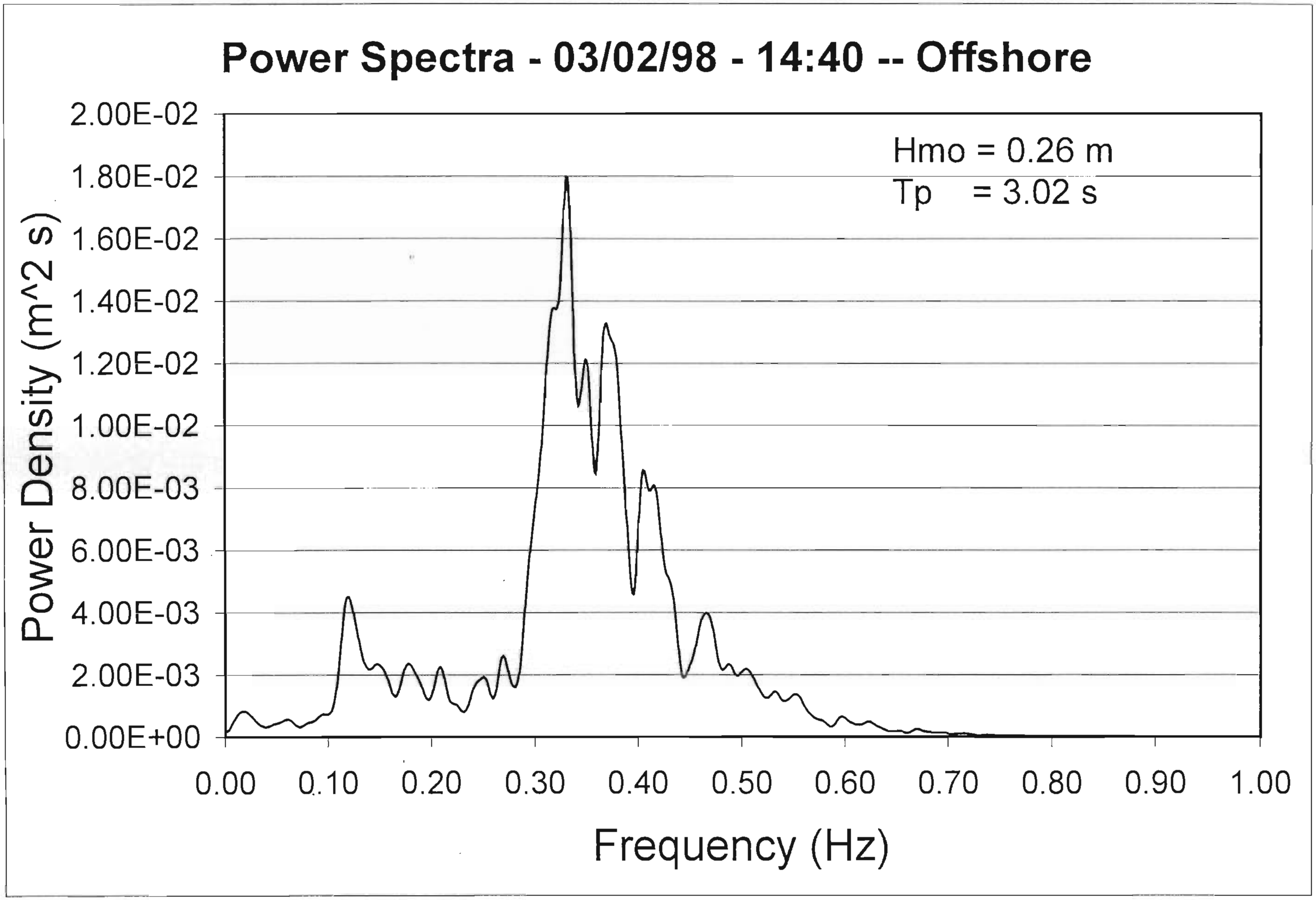
Power Spectra - 03/02/98 - 13:20 -- Offshore
Hmo = 0.19 m
Tp = 2.62 s
Power Density (m^2 s)
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

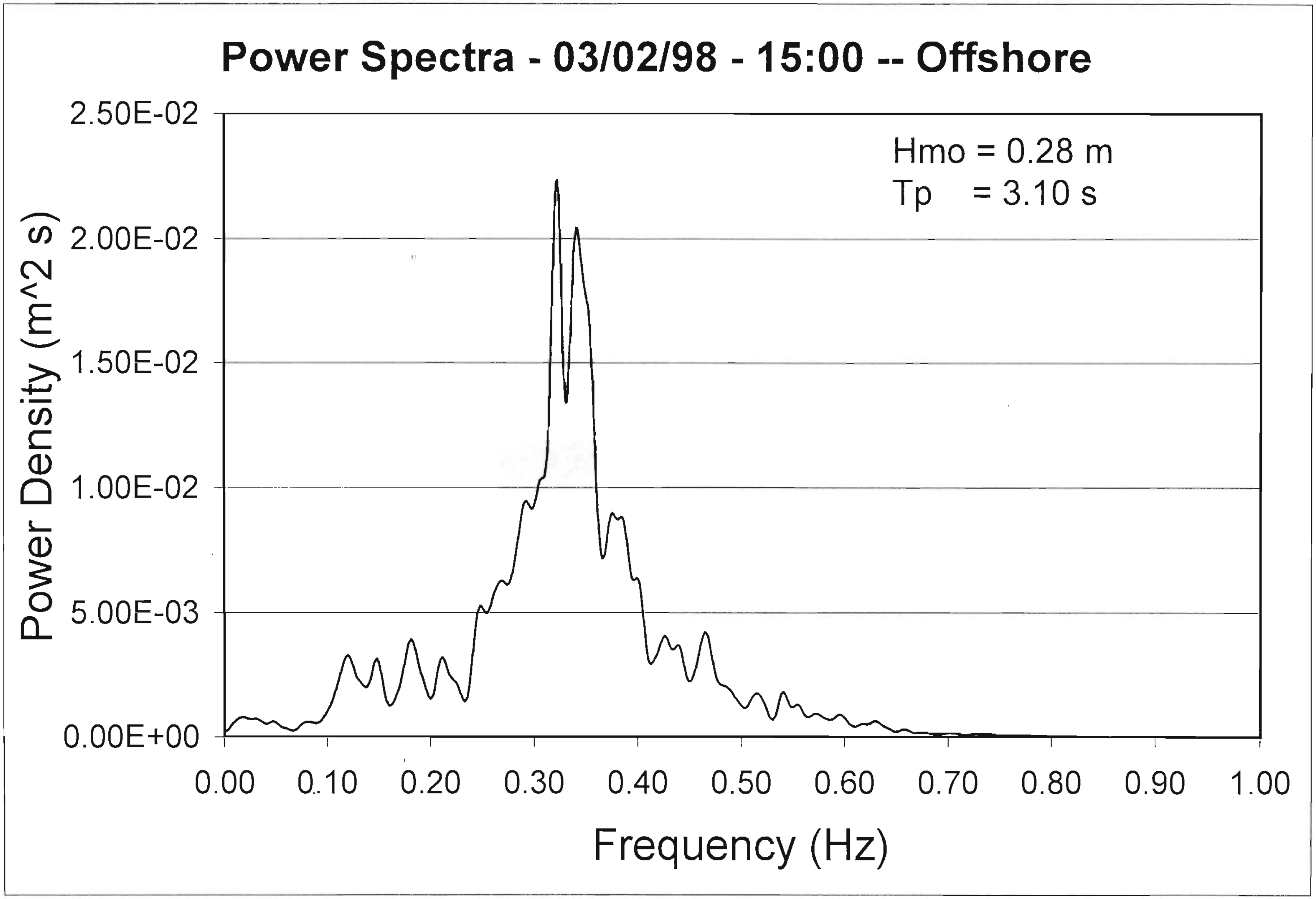

Power Spectra - 03/02/98 - 13:40 -- Offshore
Hmo = 0.19 m
Tp = 2.68 s
Power Density (m^2 s)
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)



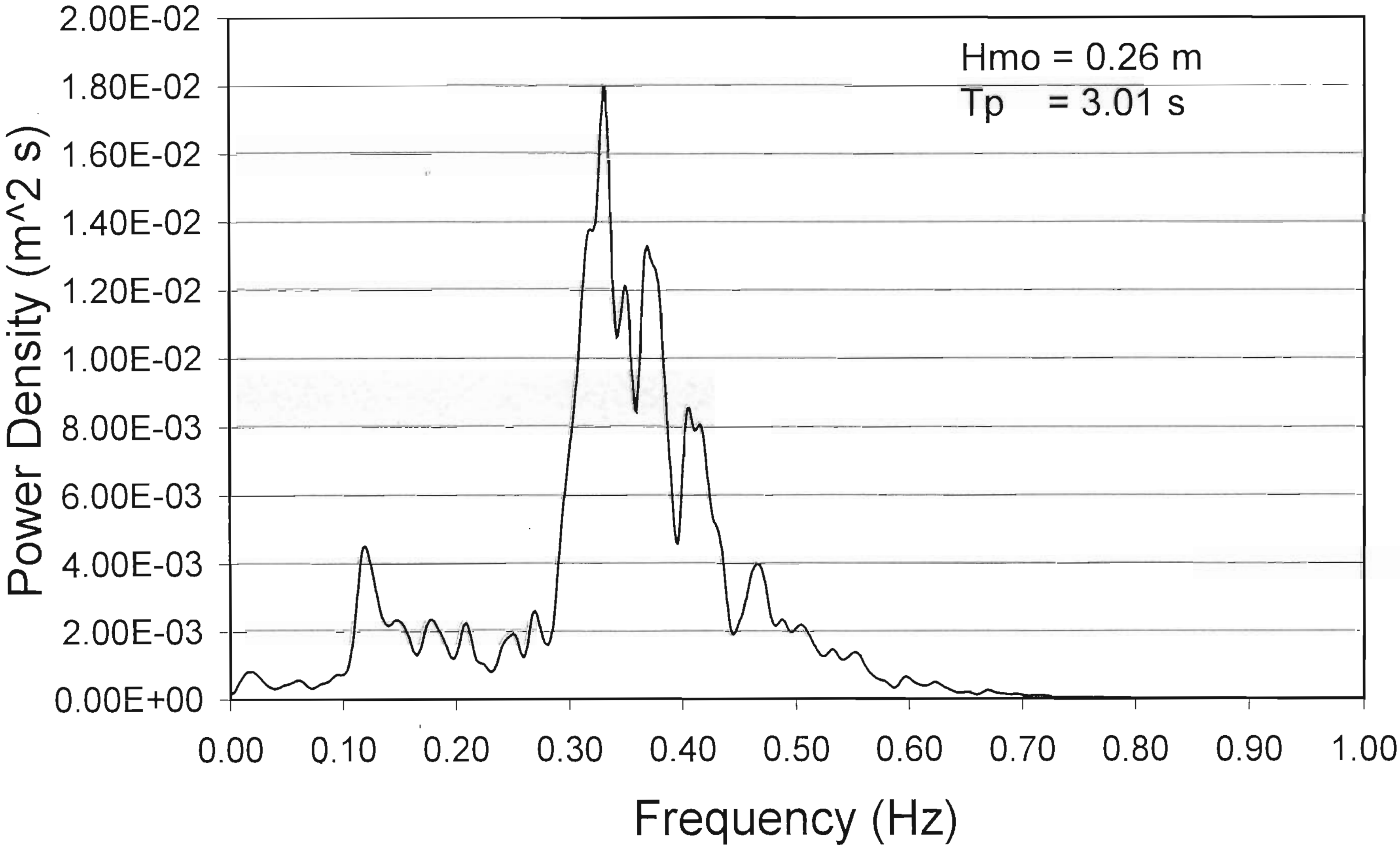
Power Spectra - 03/02/98 - 14:00 -- Offshore
Hmo = 0.23 m
Tp = 2.99 s
Power Density (m^2 s)
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

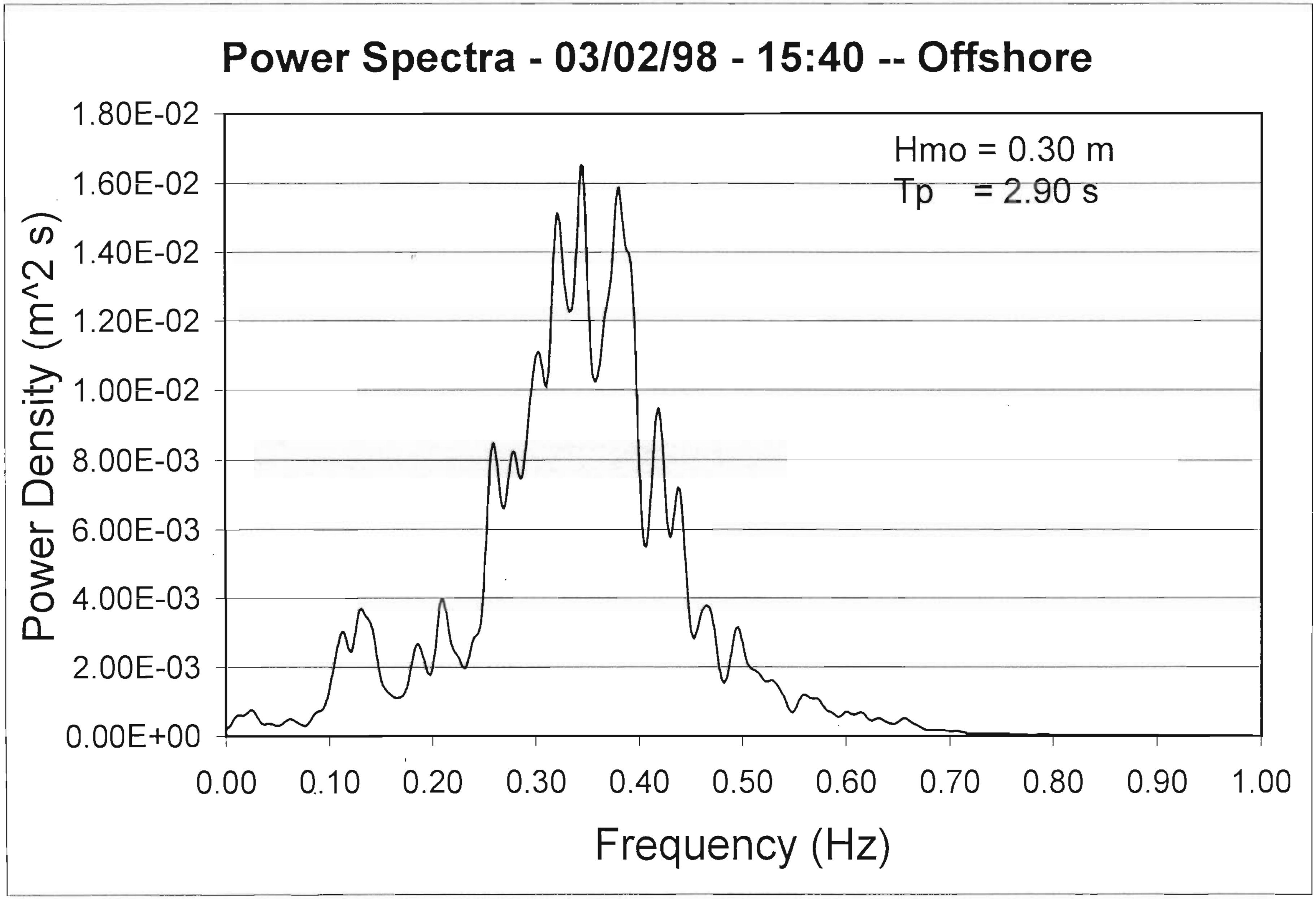

Power Spectra - 03/02/98 - 14:20 -- Offshore
Hmo = 0.23 m
Tp = 2.99 s
Power Density (m^2 s)
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)


Power Spectra - 03/02/98 - 14:40 -- Offshore
Hmo = 0.26 m
Tp = 3.02 s
Power Density (m^2 s)
2.00E-02
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

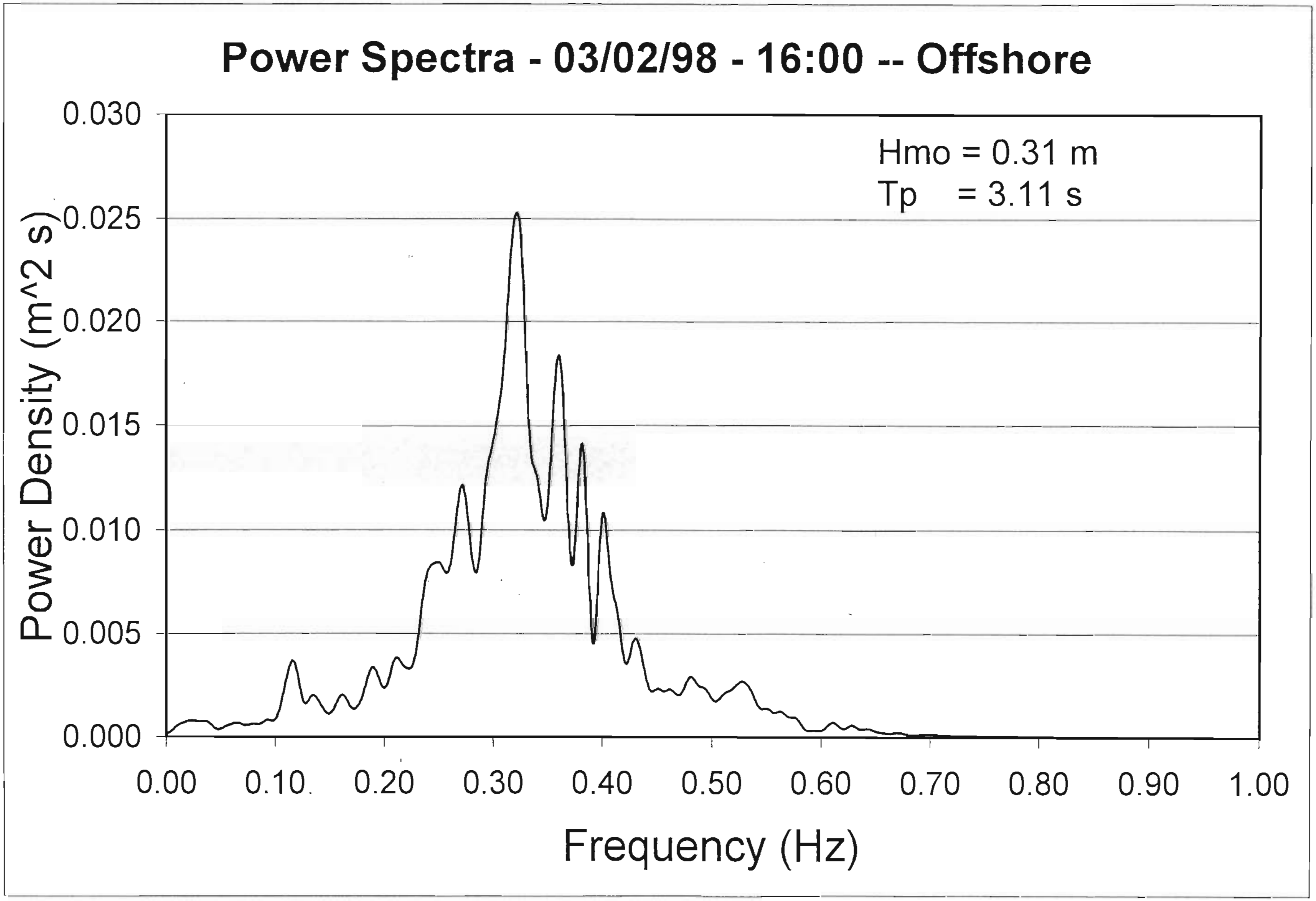

Power Spectra - 03/02/98 - 15:00 -- Offshore
Hmo = 0.28 m
Tp = 3.10 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

Power Spectra - 03/02/98 - 15:20 -- Offshore

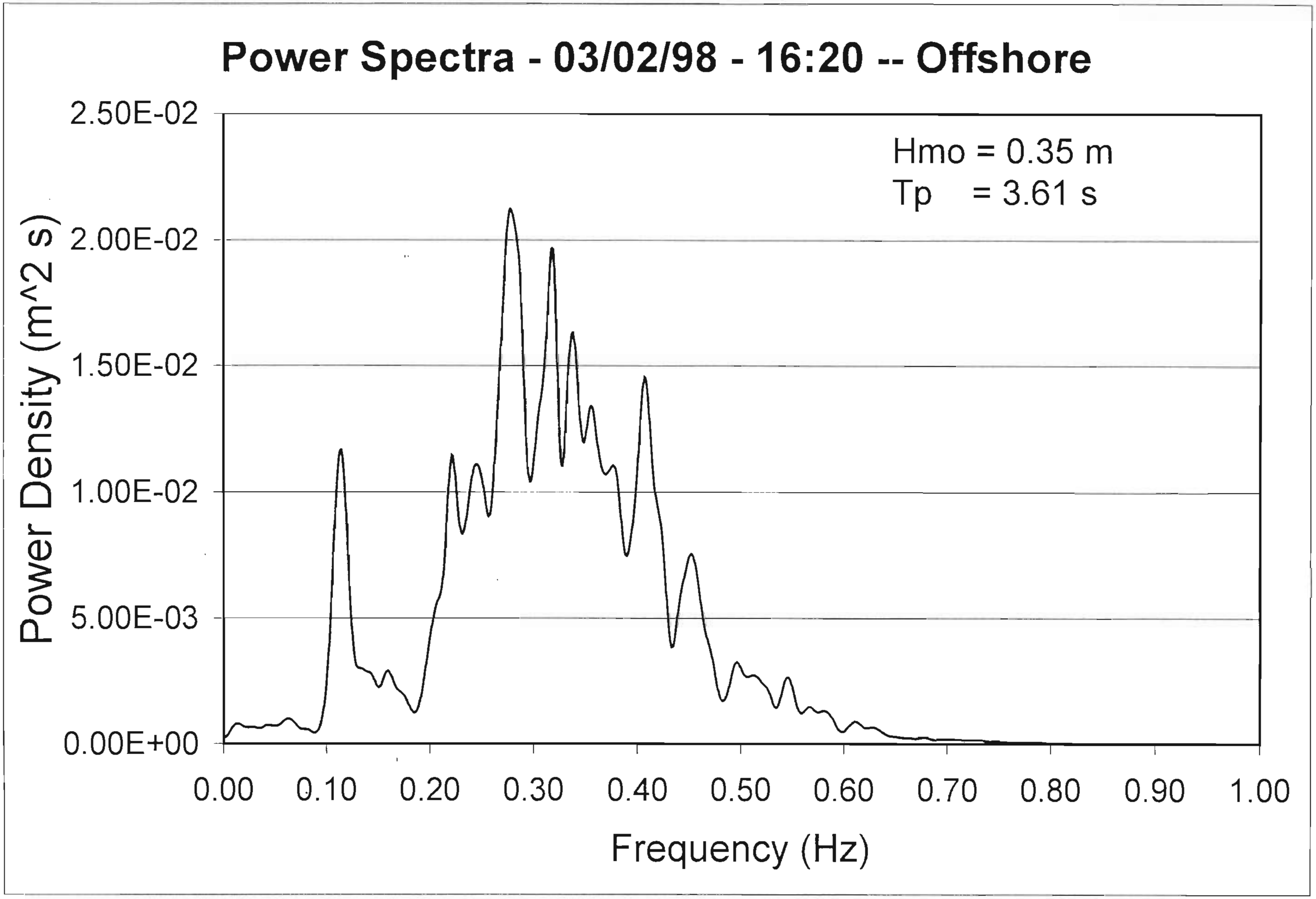




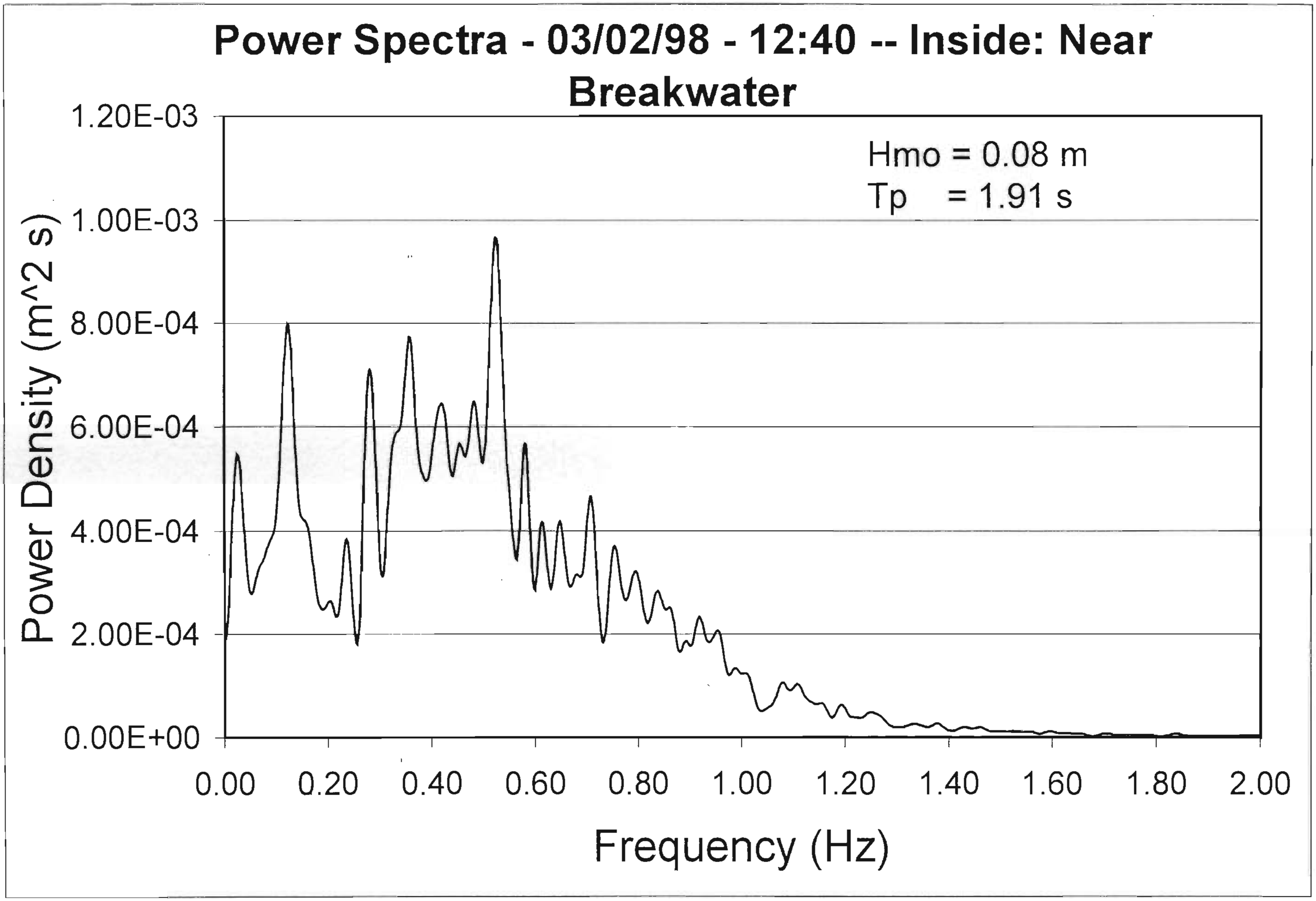
Power Spectra - 03/02/98 - 15:40 -- Offshore
Hmo = 0.30 m
Tp = 2.90 s
Power Density (m^2 s)
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)



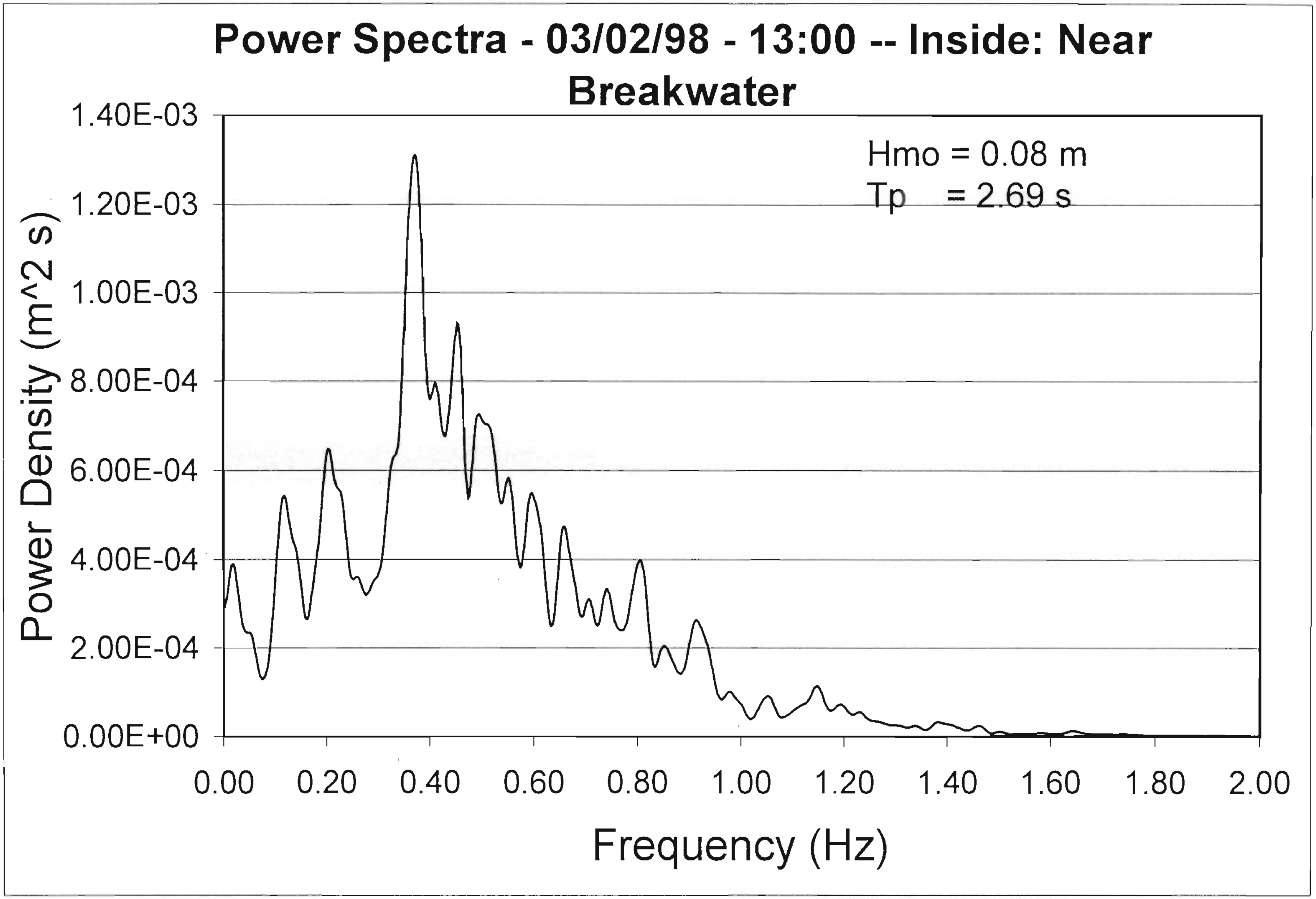
Power Spectra - 03/02/98 - 16:00 -- Offshore
Hmo = 0.31 m
Tp = 3.11 s
Power Density (m^2 s)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

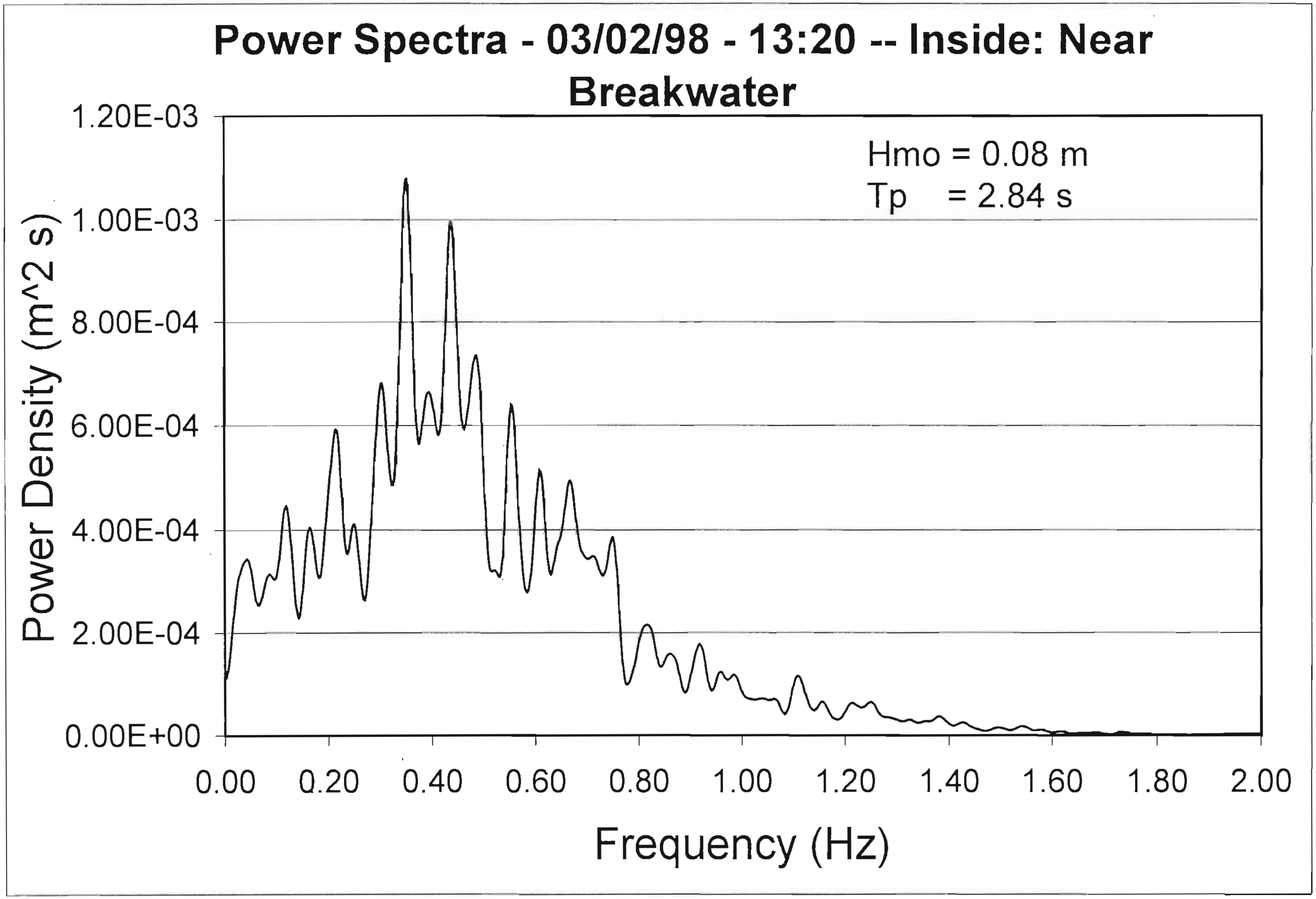


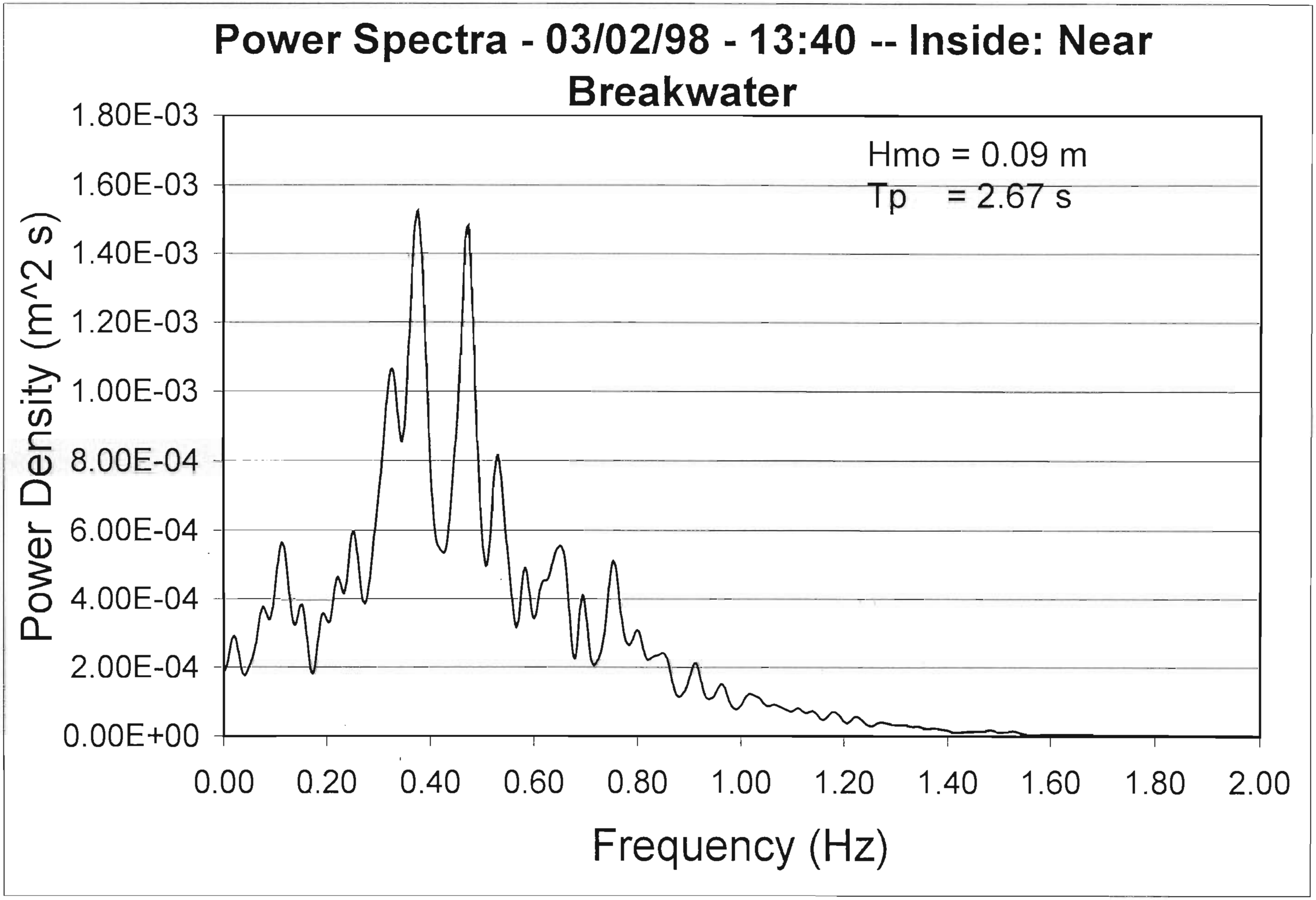
Power Spectra - 03/02/98 - 16:20 -- Offshore
Hmo = 0.35 m
Tp = 3.61 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

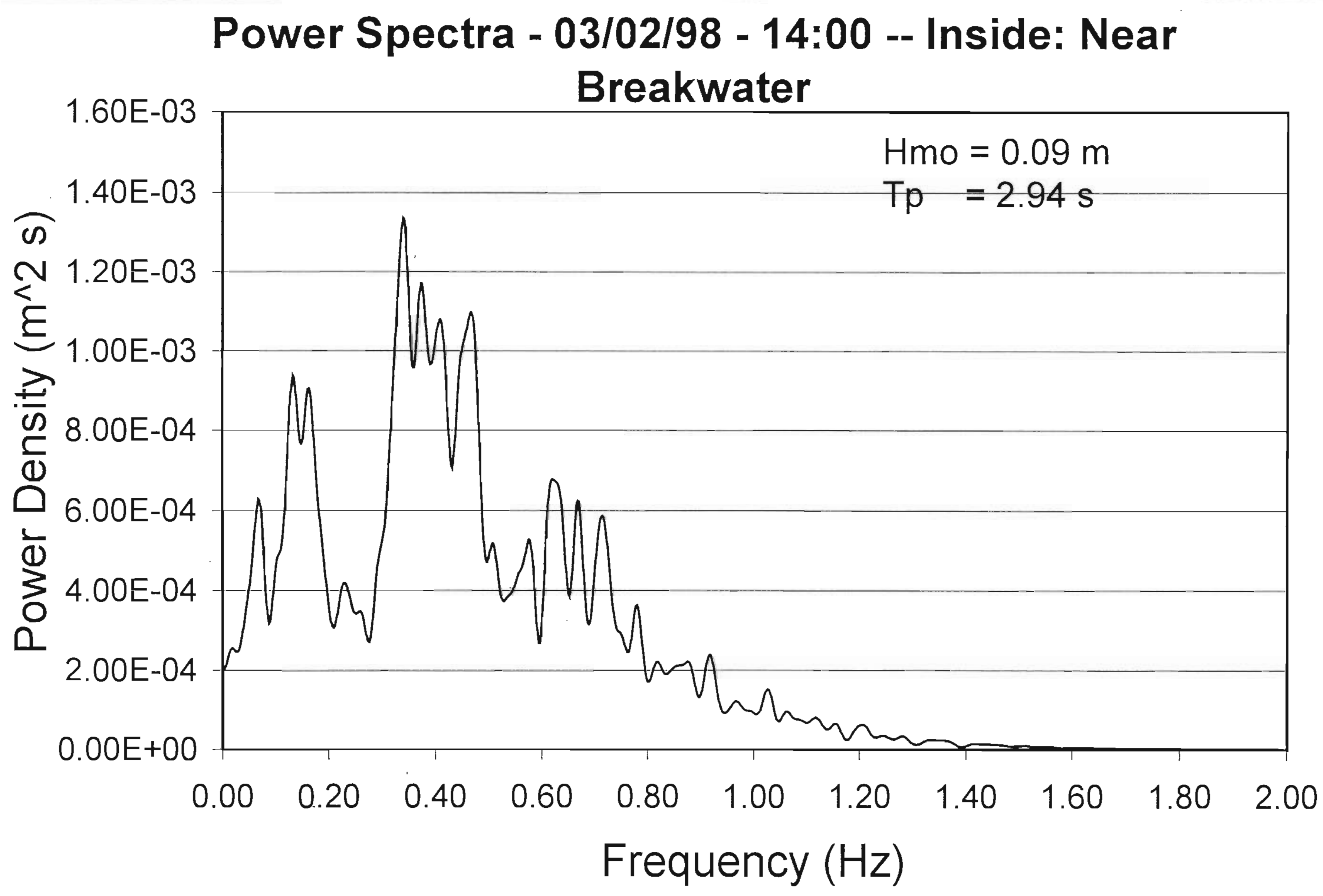


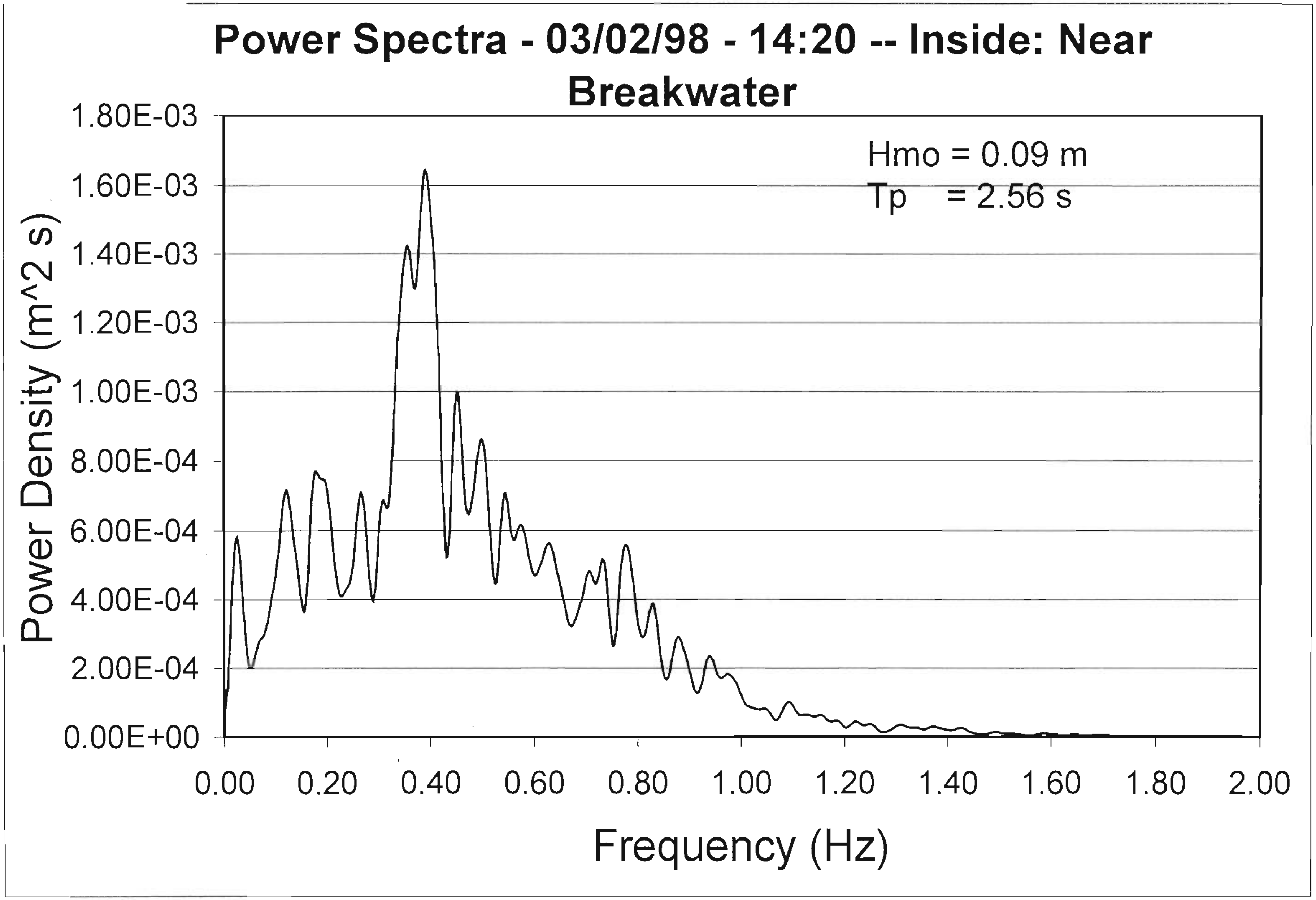
Power Spectra - 03/02/98 - 12:40 -- Inside: Near Breakwater
Hmo = 0.08 m
Tp = 1.91 s
Power Density (m^2 s)
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

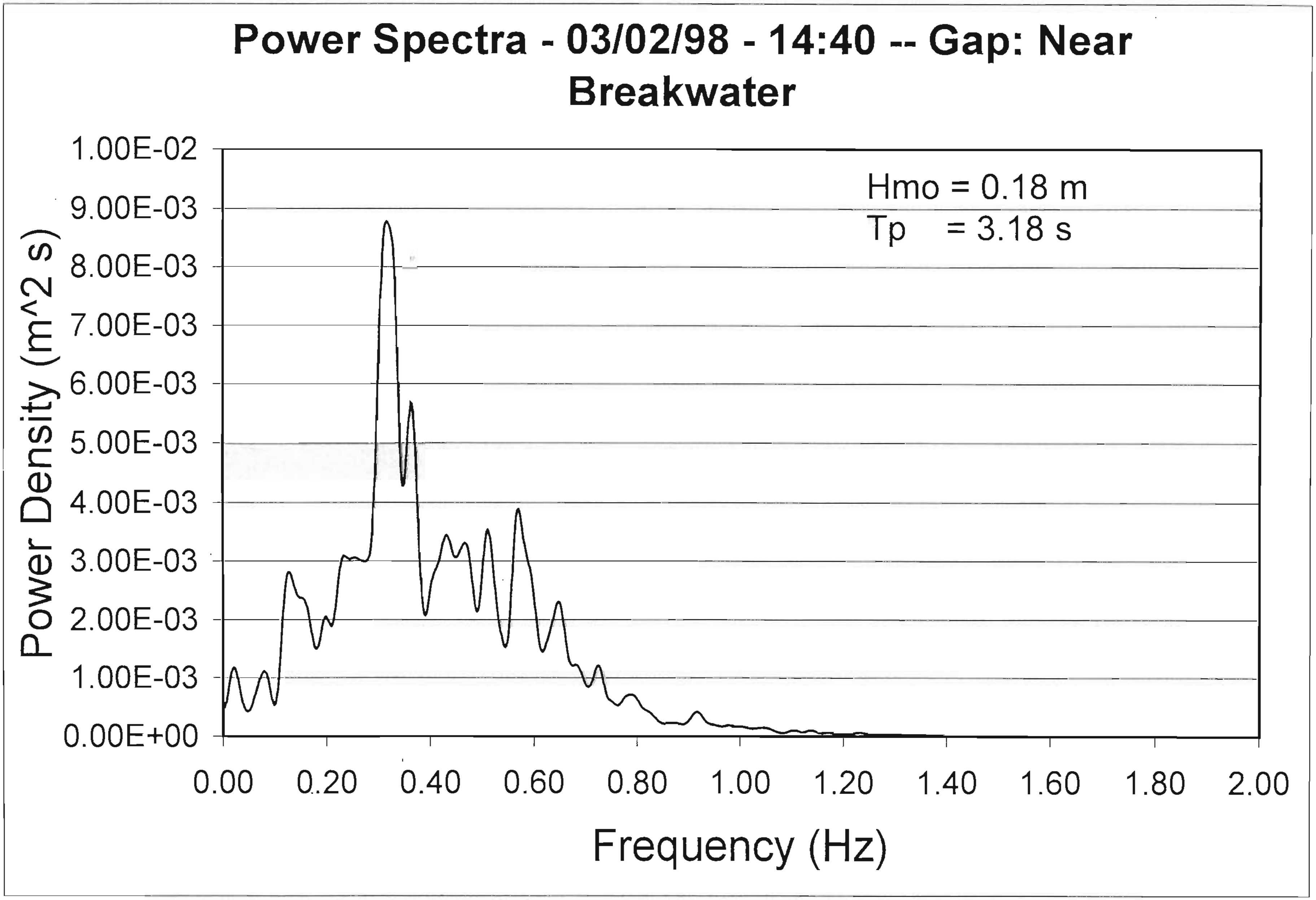

Power Spectra - 03/02/98 - 13:00 -- Inside: Near Breakwater
Hmo = 0.08 m
Tp = 2.69 s
Power Density (m^2 s)
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

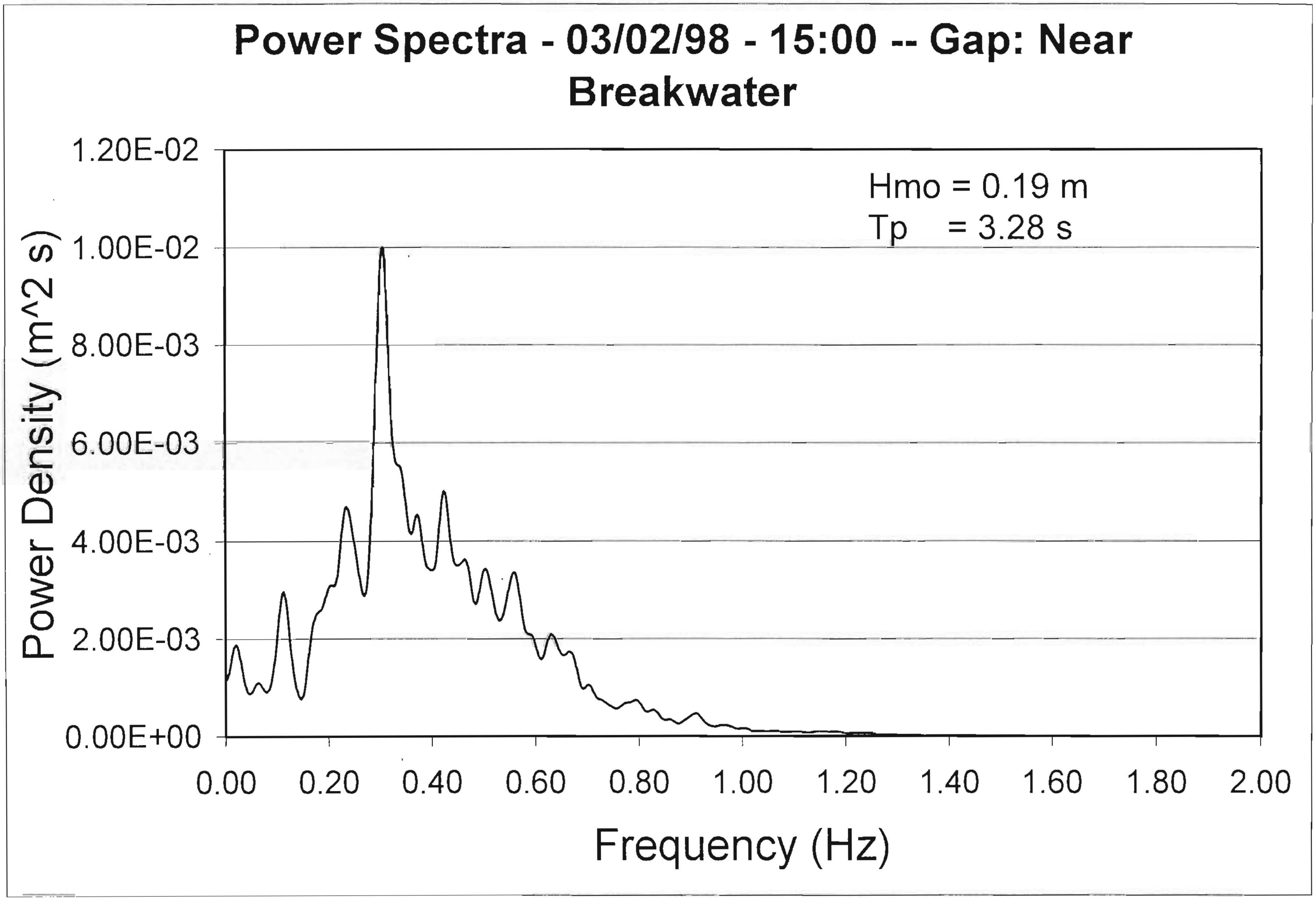

Power Spectra - 03/02/98 - 13:20 -- Inside: Near Breakwater
Hmo = 0.08 m
Tp = 2.84 s
Power Density (m^2 s)
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

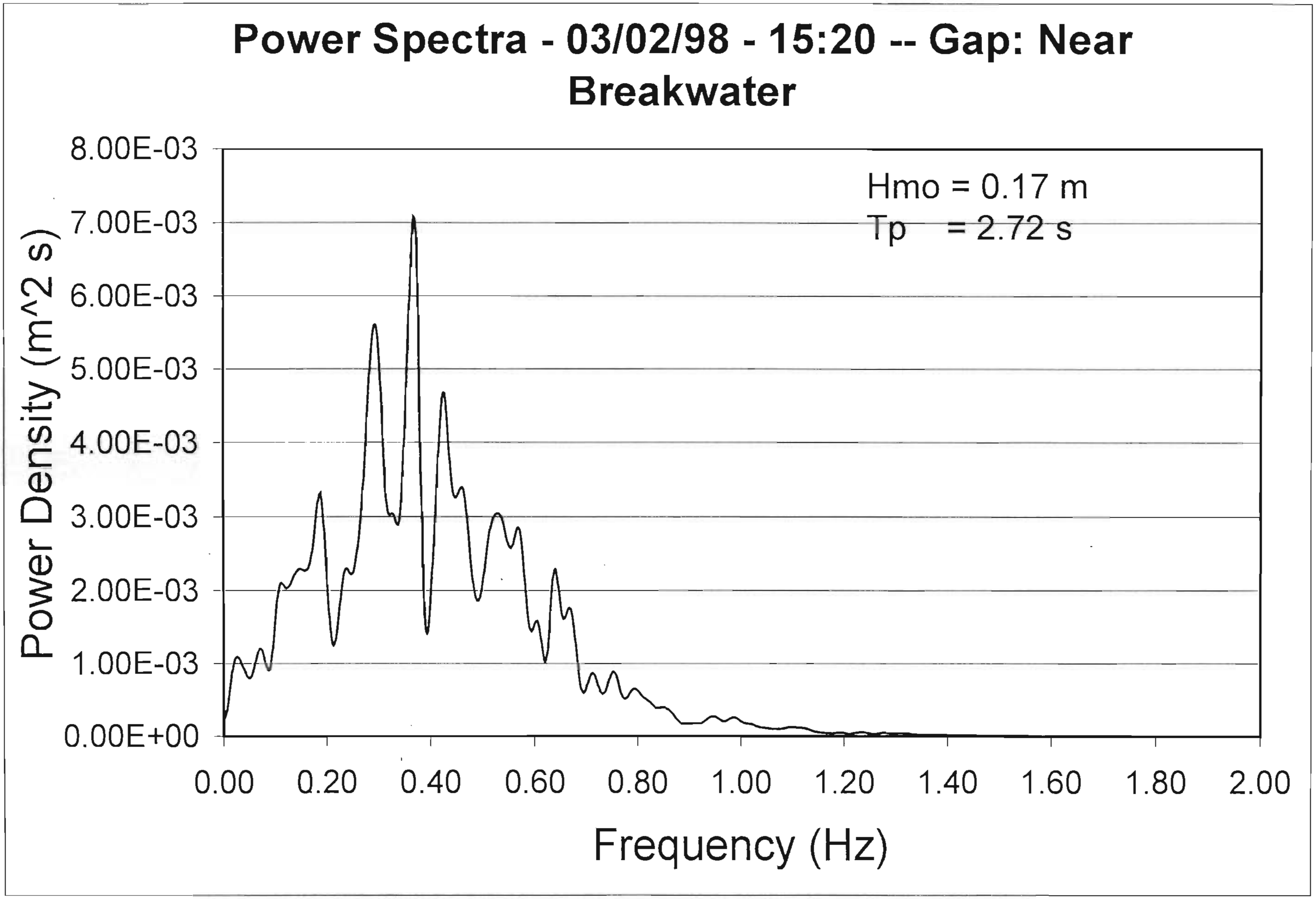

Power Spectra - 03/02/98 - 13:40 -- Inside: Near Breakwater
Hmo = 0.09 m
Tp = 2.67 s
Power Density (m^2 s)
1.80E-03
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

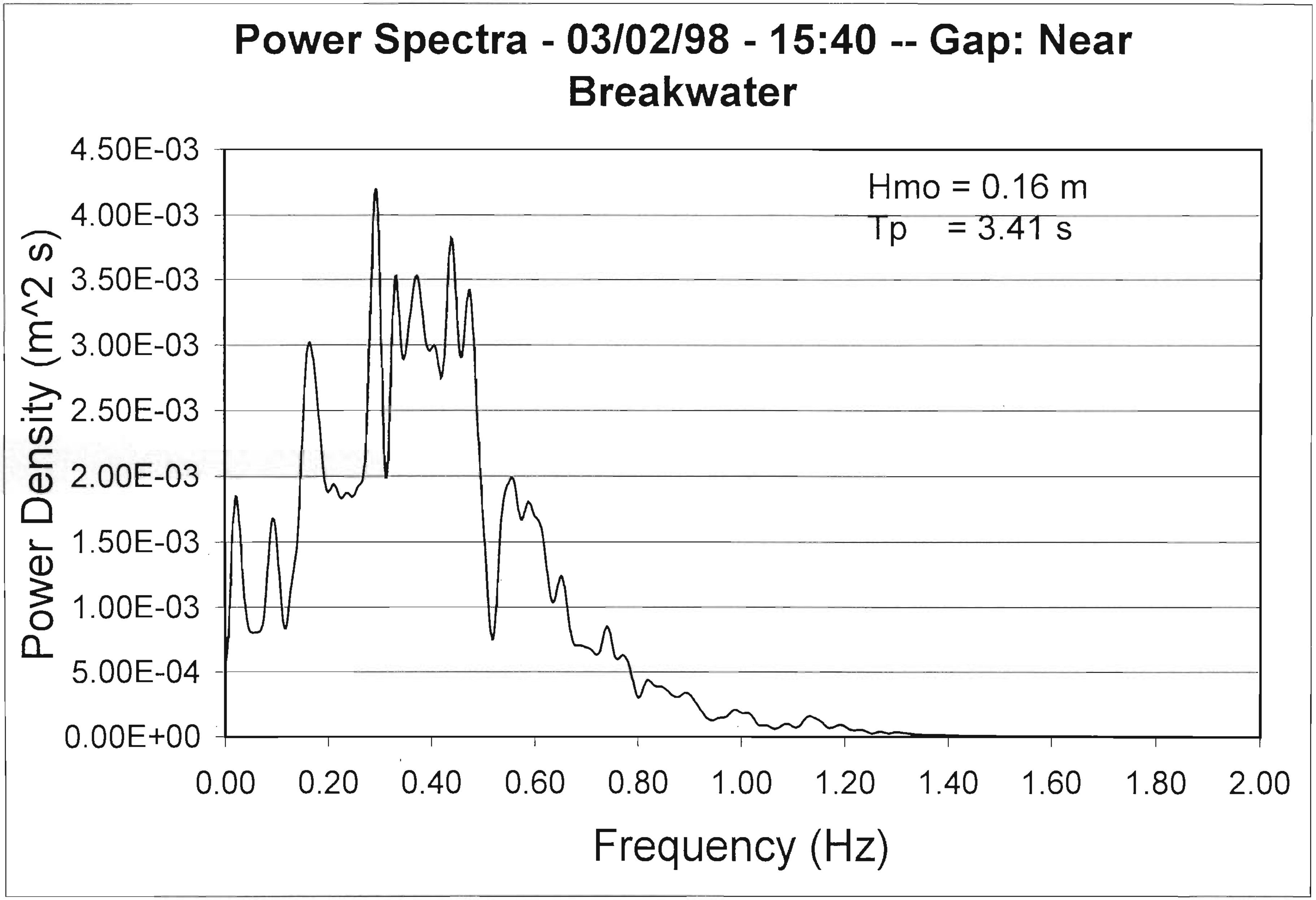

Power Spectra - 03/02/98 - 14:00 -- Inside: Near Breakwater
Hmo = 0.09 m
Tp = 2.94 s
Power Density (m^2 s)
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

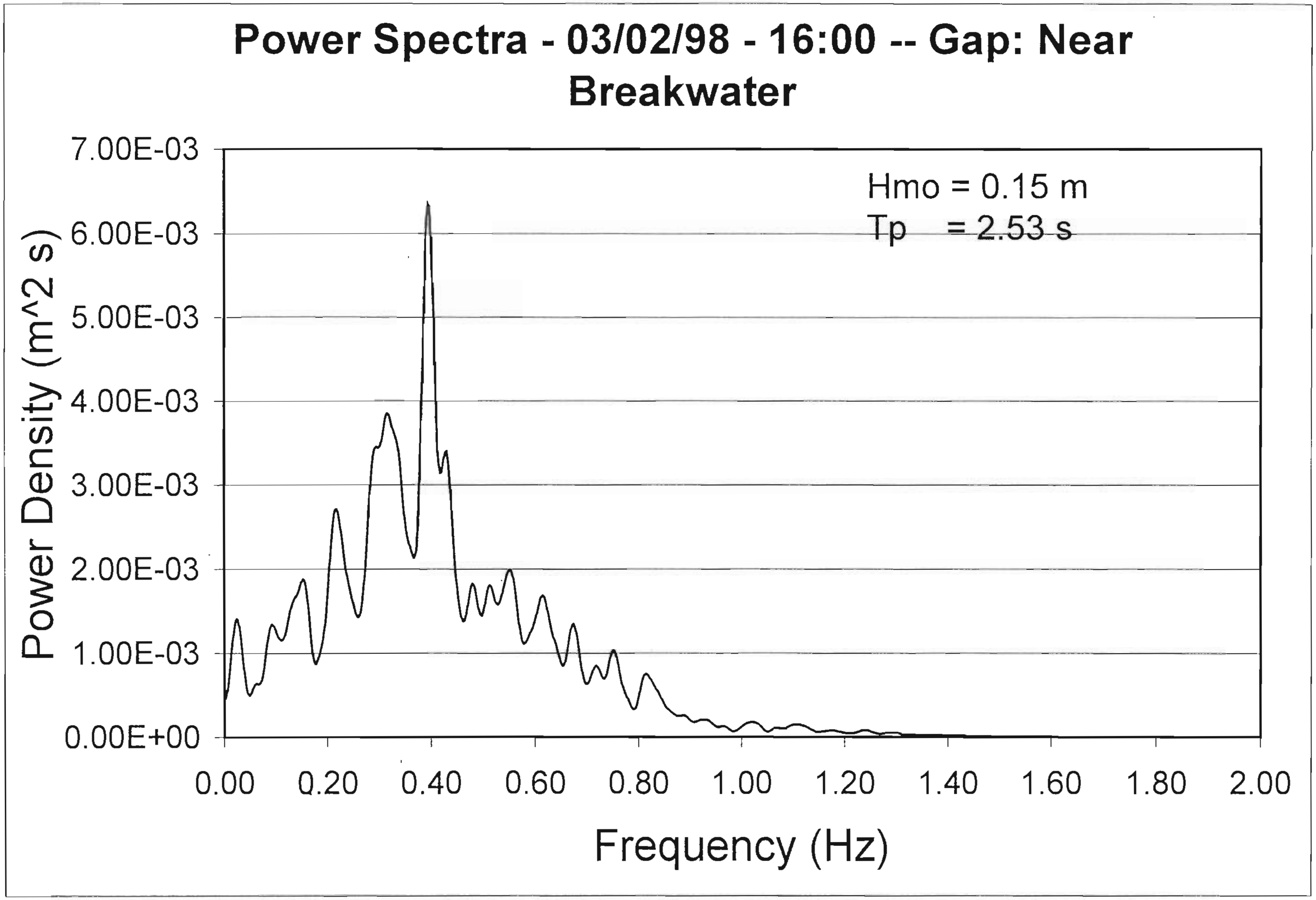

Power Spectra - 03/02/98 - 14:20 -- Inside: Near Breakwater
Hmo = 0.09 m
Tp = 2.56 s
Power Density (m^2 s)
1.80E-03
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

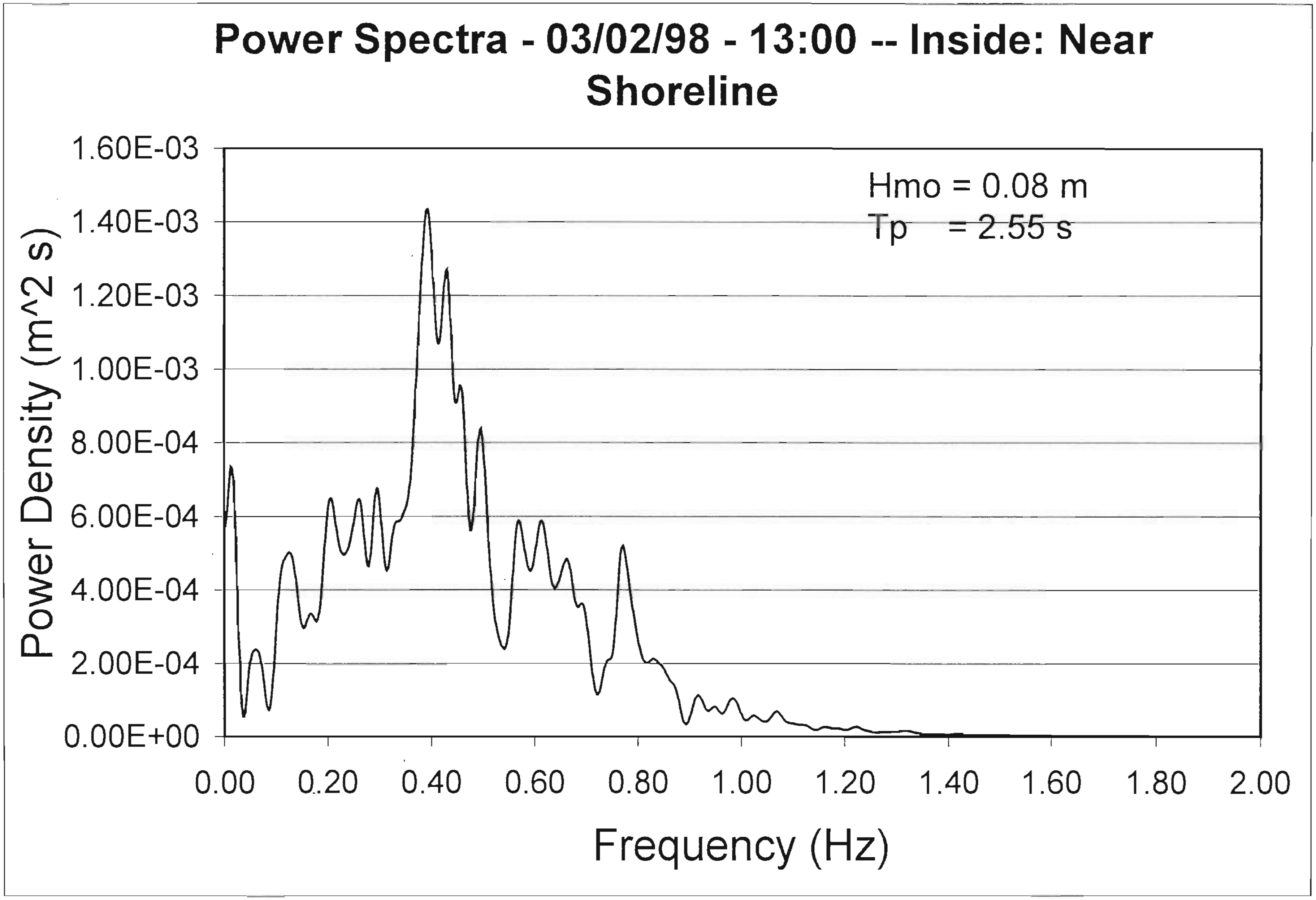

Power Spectra - 03/02/98 - 14:40 -- Gap: Near Breakwater
Hmo = 0.18 m
Tp = 3.18 s
Power Density (m^2 s)
1.00E-02
9.00E-03
8.00E-03
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

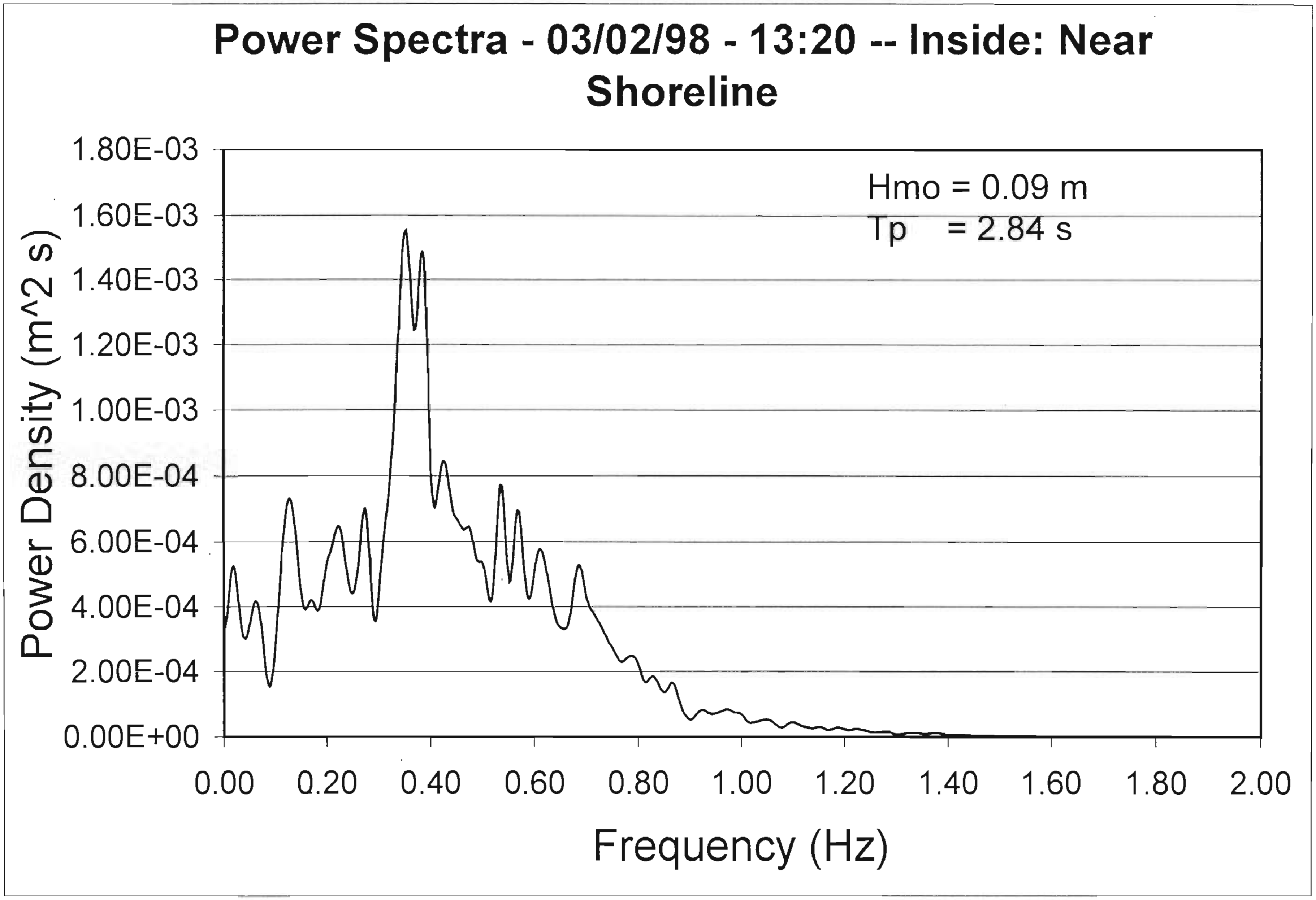

Power Spectra - 03/02/98 - 15:00 -- Gap: Near Breakwater
Hmo = 0.19 m
Tp = 3.28 s
Power Density (m^2 s)
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)


Power Spectra - 03/02/98 - 15:20 -- Gap: Near Breakwater
Hmo = 0.17 m
Tp = 2.72 s
Power Density (m^2 s)
8.00E-03
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

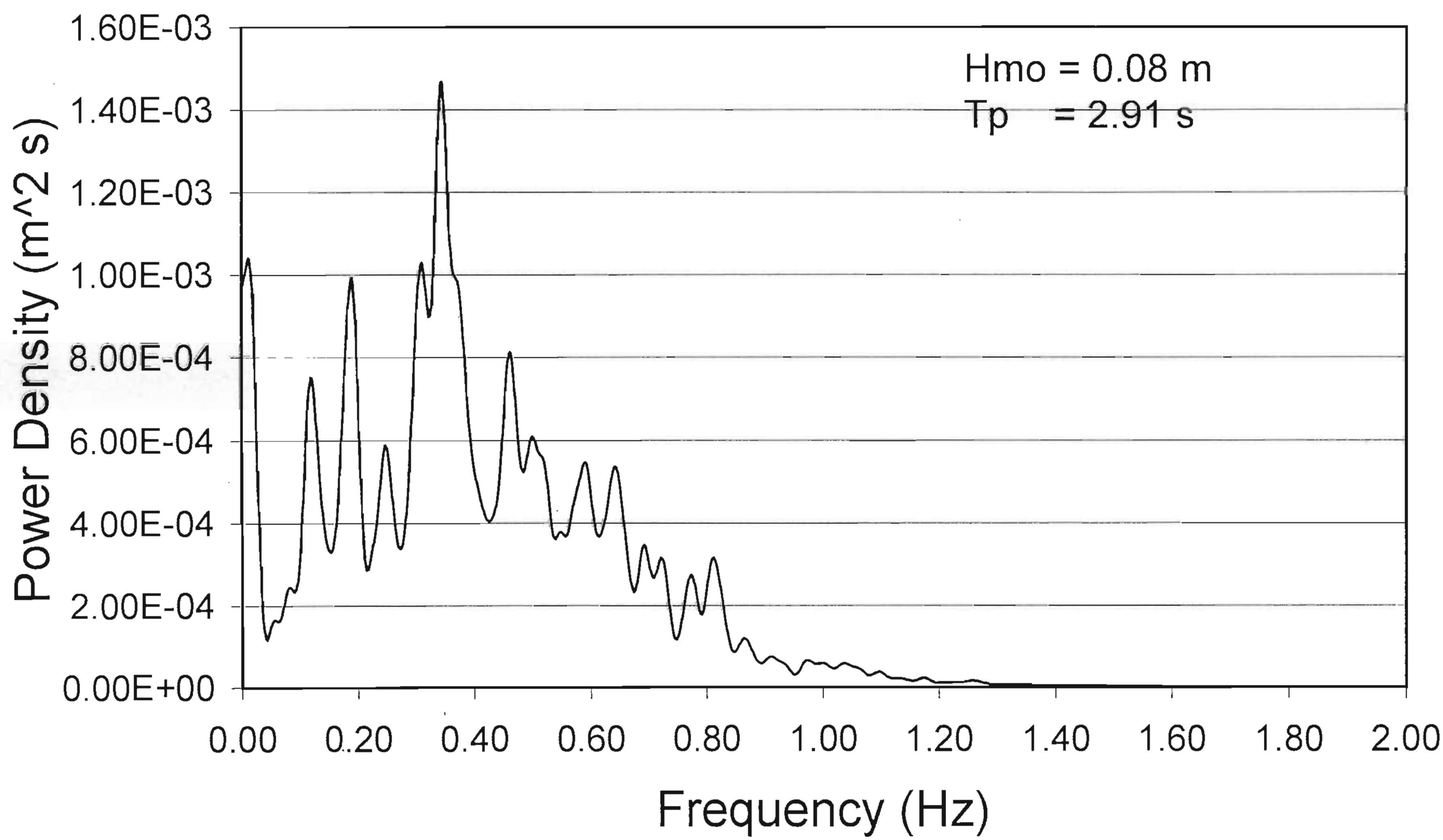

Power Spectra - 03/02/98 - 15:40 -- Gap: Near Breakwater
Hmo = 0.16 m
Tp = 3.41 s
Power Density (m^2 s)
4.50E-03
4.00E-03
3.50E-03
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

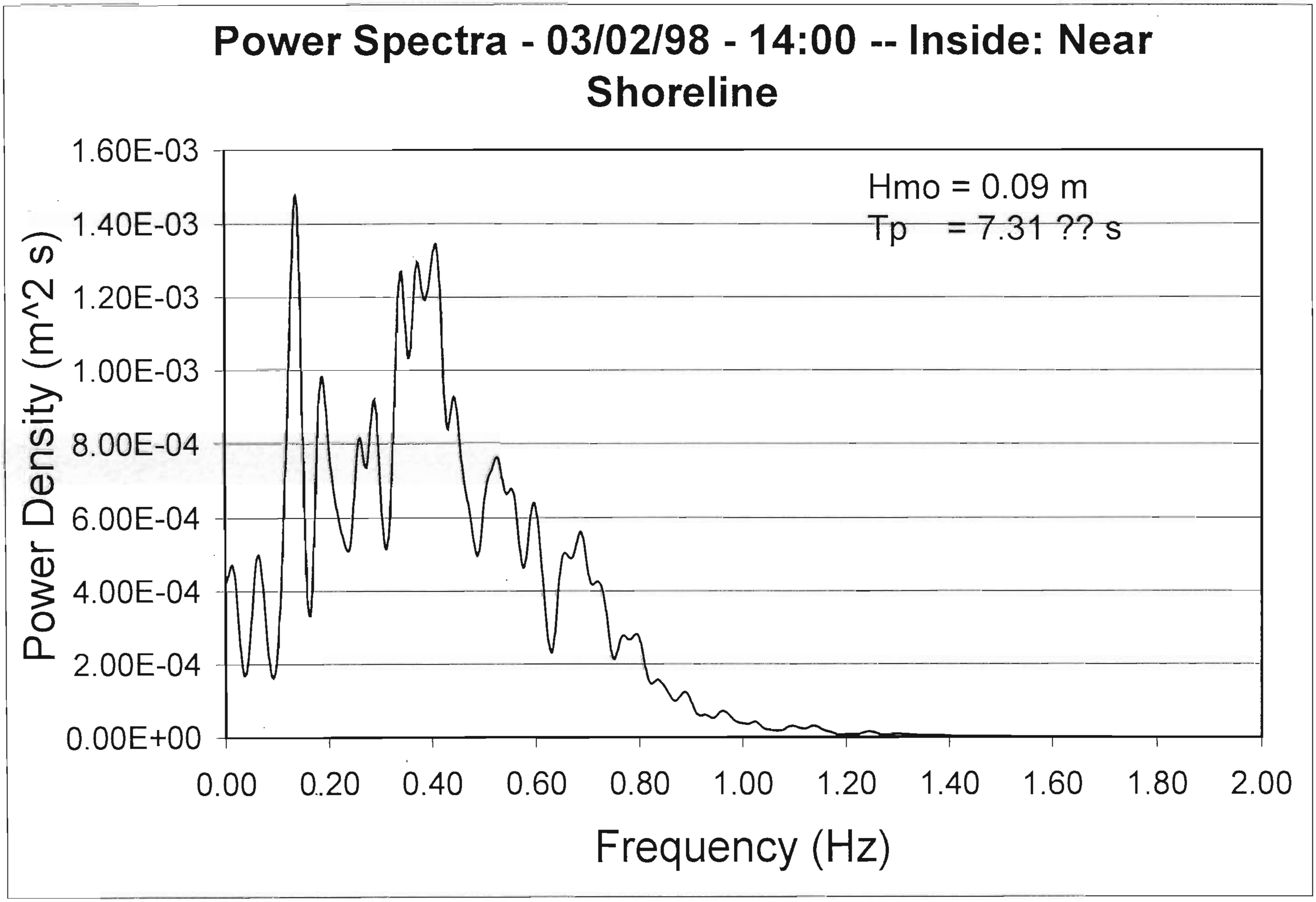

Power Spectra - 03/02/98 - 16:00 -- Gap: Near Breakwater
Hmo = 0.15 m
Tp = 2.53 s
Power Density (m^2 s)
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

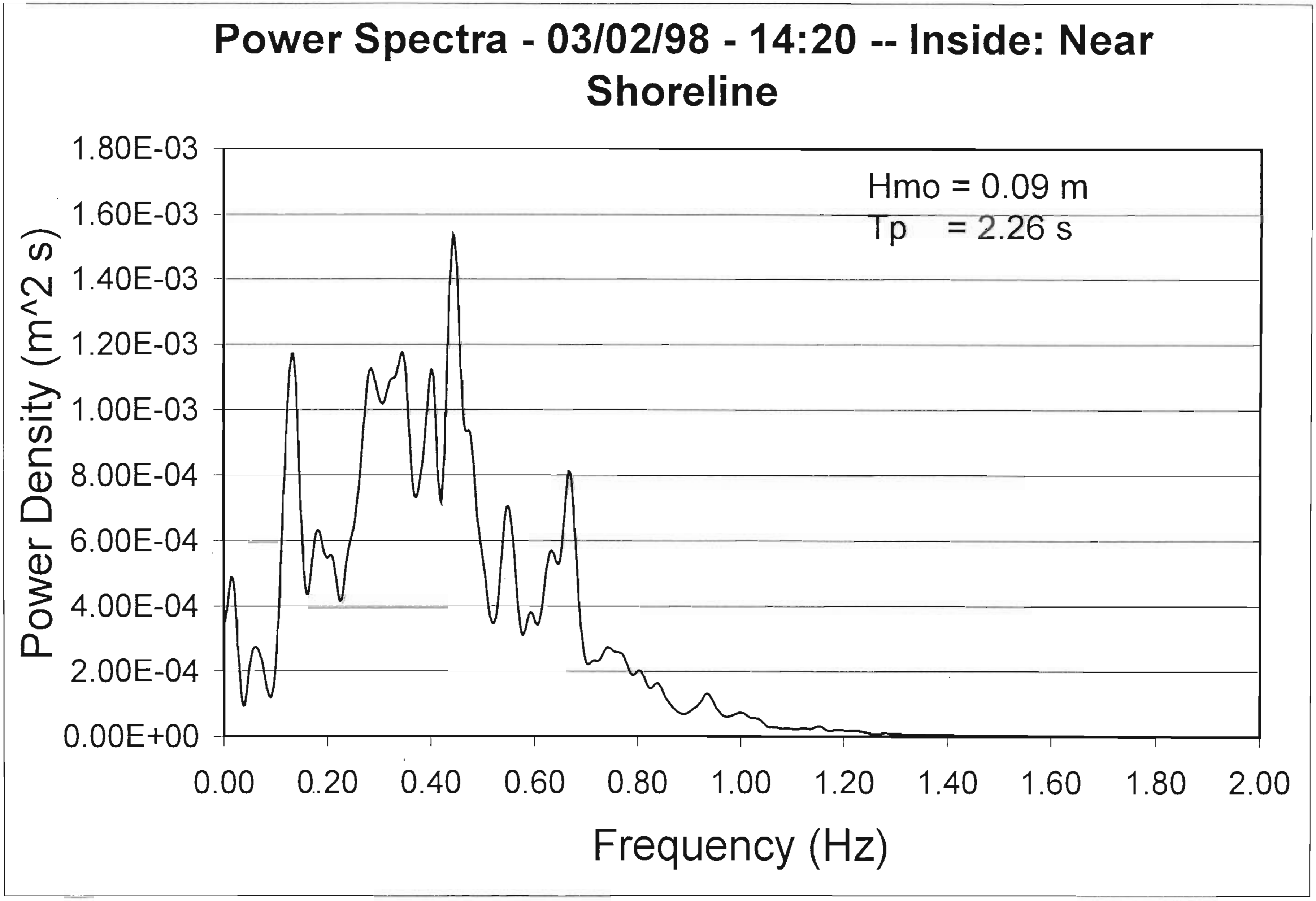

Power Spectra - 03/02/98 - 13:00 -- Inside: Near Shoreline
Hmo = 0.08 m
Tp = 2.55 s
Power Density (m^2 s)
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)


Power Spectra - 03/02/98 - 13:20 -- Inside: Near Shoreline
Hmo = 0.09 m
Tp = 2.84 s
Power Density (m^2 s)
1.80E-03
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

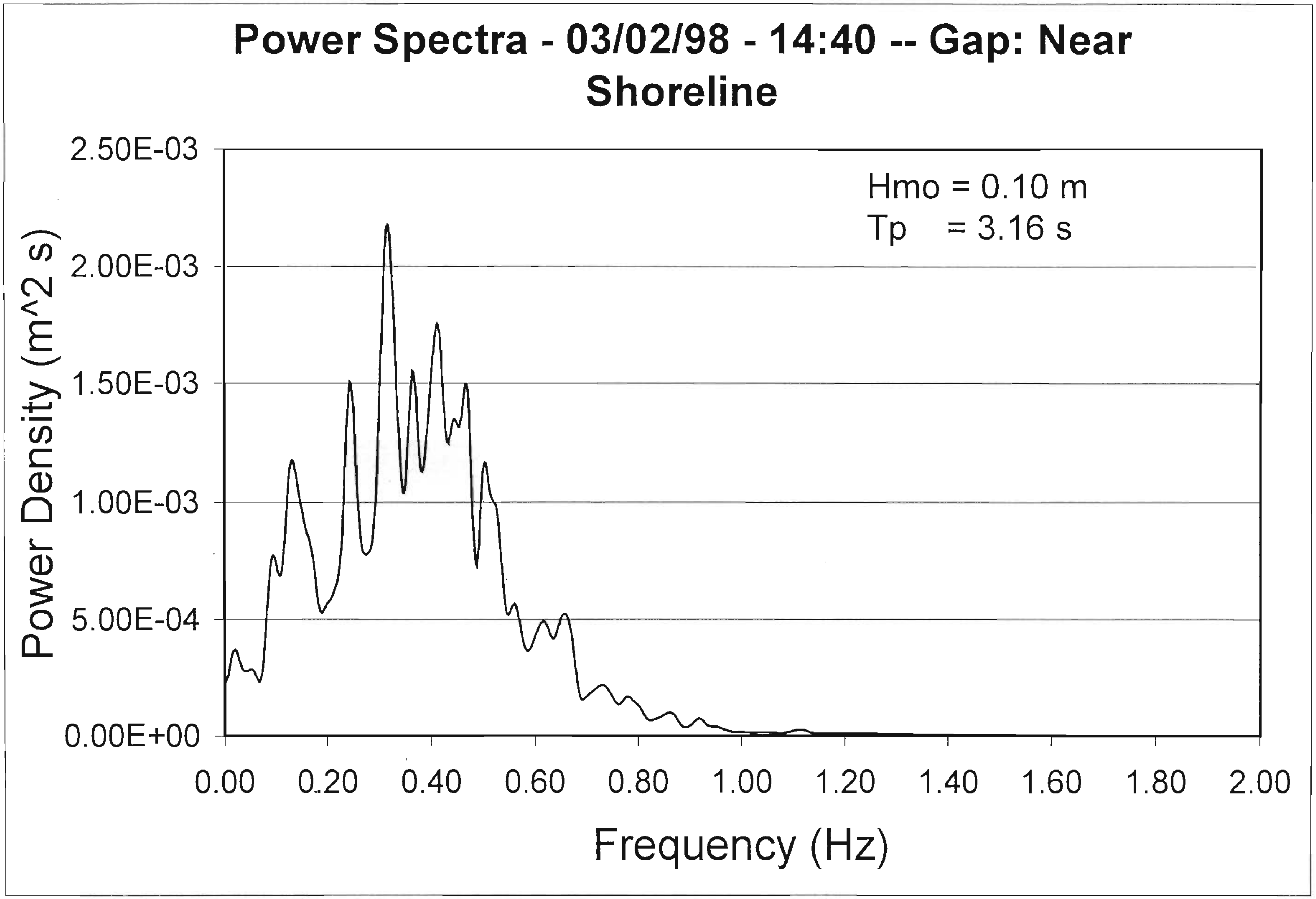
Power Spectra - 03/02/98 - 13:40 -- Inside: Near Shoreline

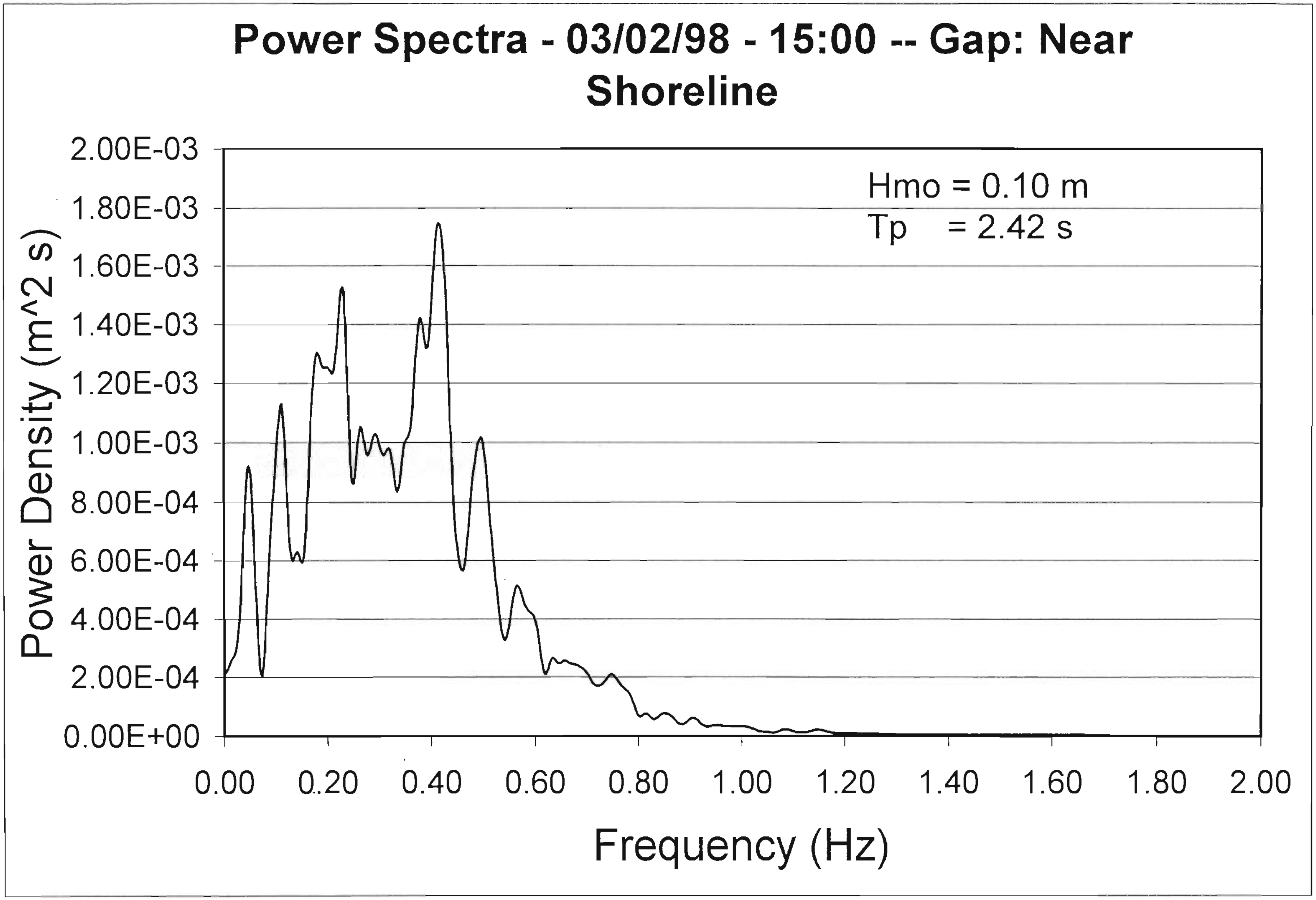


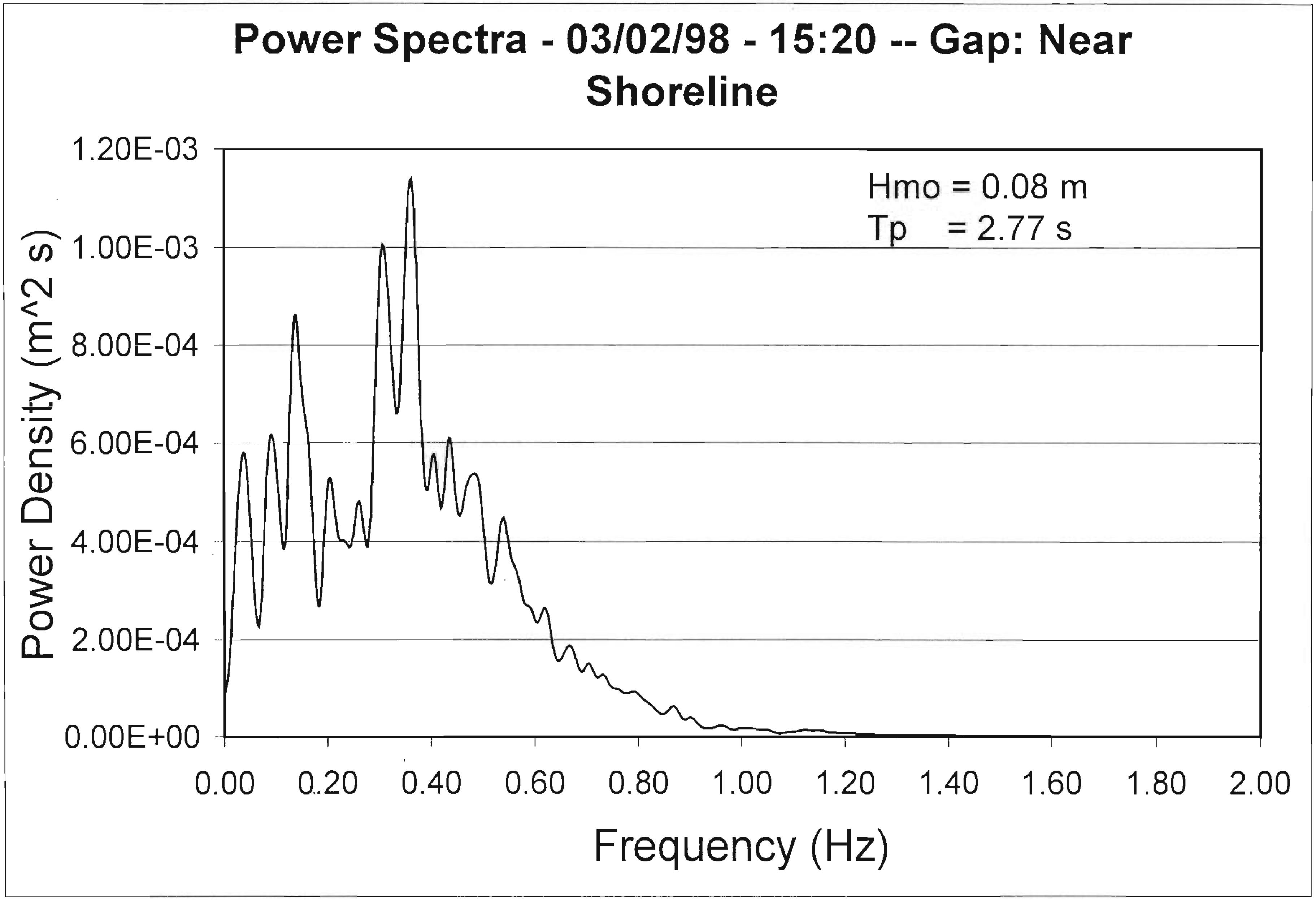

Power Spectra - 03/02/98 - 14:00 -- Inside: Near Shoreline
Hmo = 0.09 m
Tp = 7.31 ?? s
Power Density (m^2 s)
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

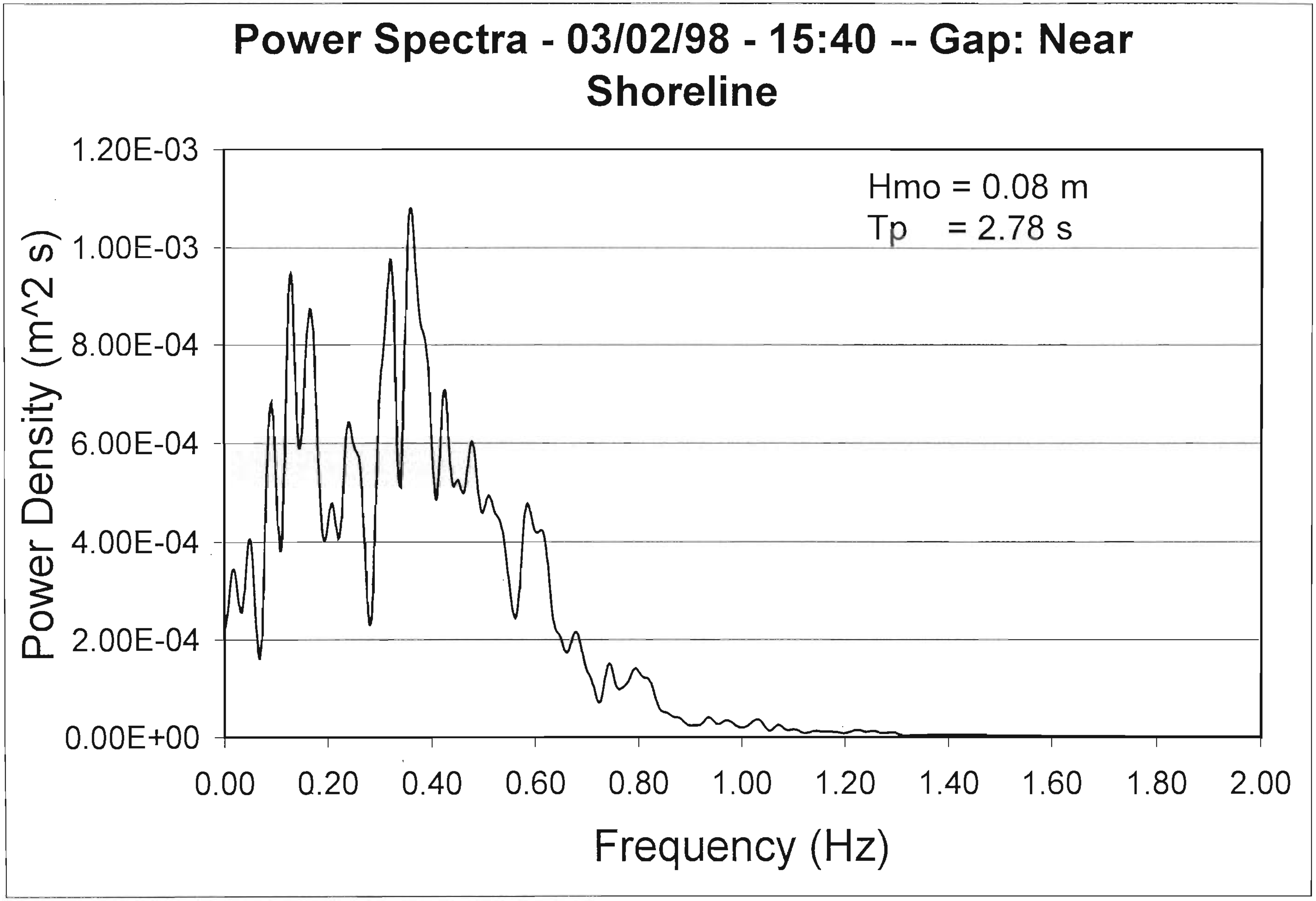


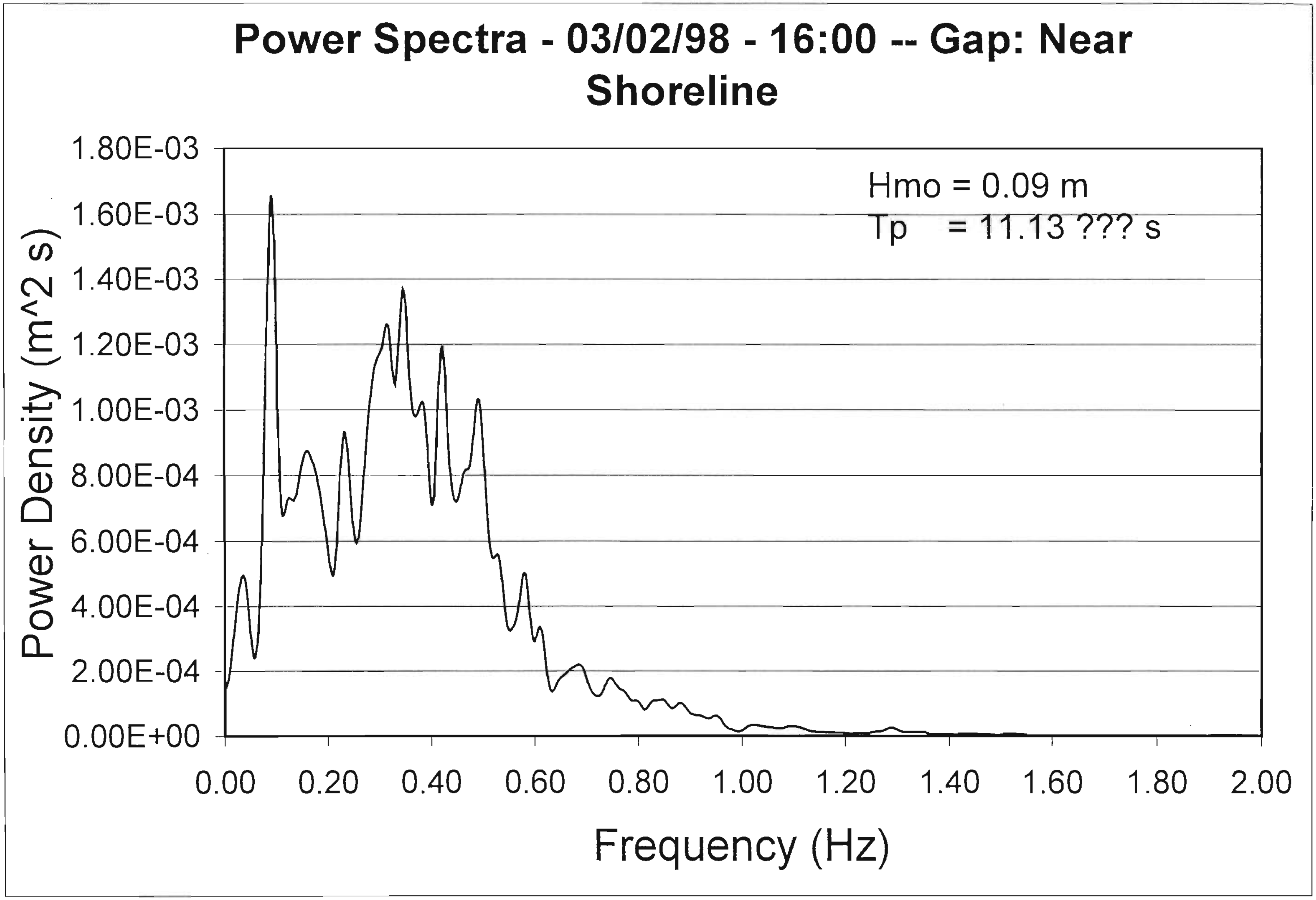
Power Spectra - 03/02/98 - 14:20 -- Inside: Near Shoreline
Hmo = 0.09 m
Tp = 2.26 s
Power Density (m^2 s)
1.80E-03
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)


Power Spectra - 03/02/98 - 14:40 -- Gap: Near Shoreline
Hmo = 0.10 m
Tp = 3.16 s
Power Density (m^2 s)
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)


Power Spectra - 03/02/98 - 15:00 -- Gap: Near Shoreline
Hmo = 0.10 m
Tp = 2.42 s
Power Density (m^2 s)
2.00E-03
1.80E-03
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

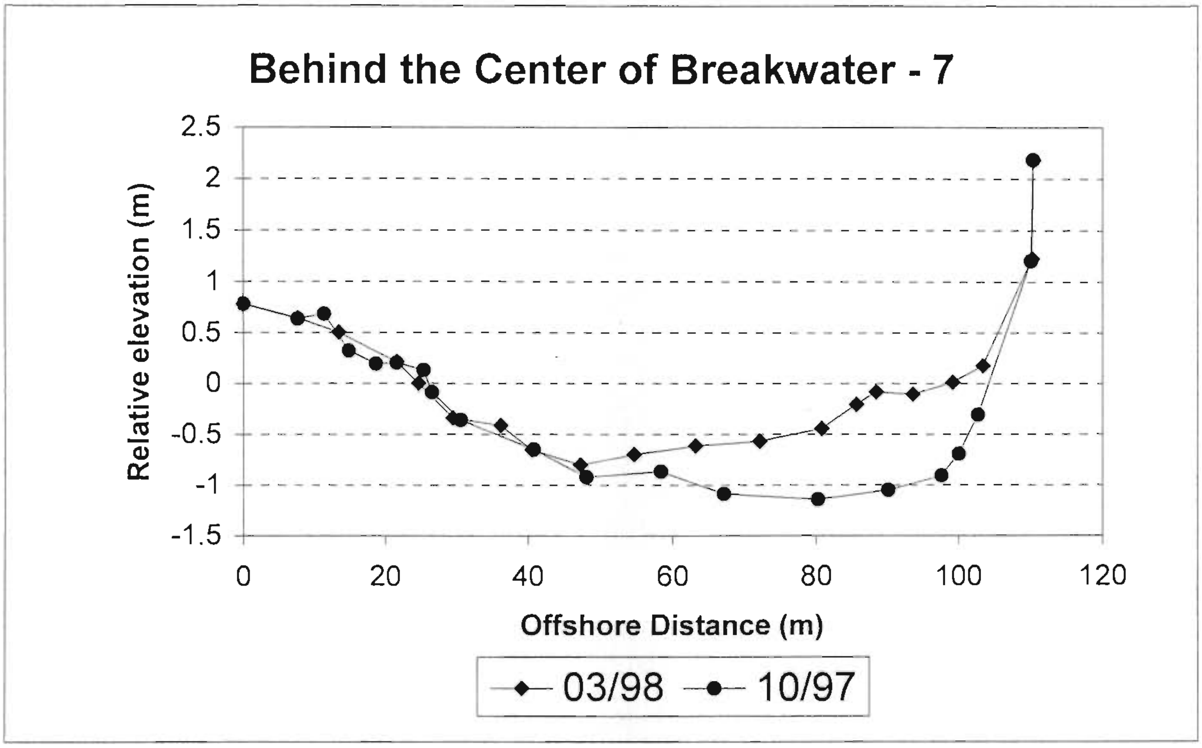

Power Spectra - 03/02/98 - 15:20 -- Gap: Near Shoreline
Hmo = 0.08 m
Tp = 2.77 s
Power Density (m^2 s)
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

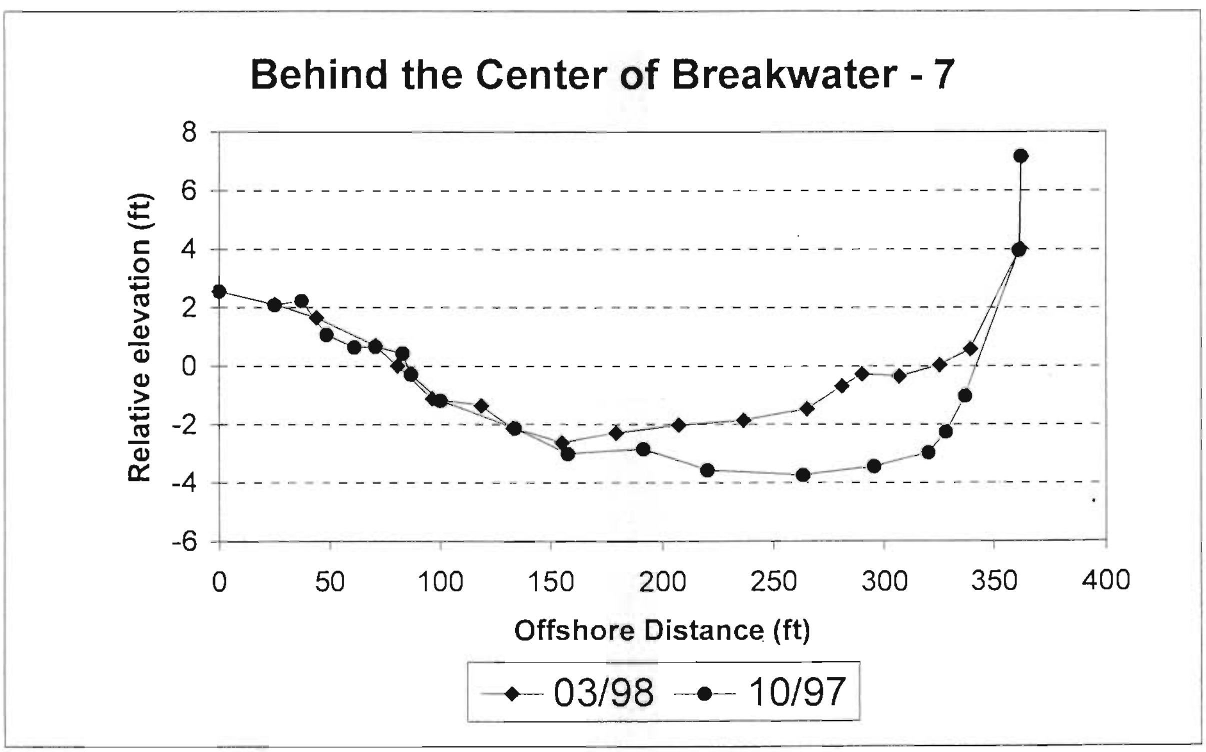

Power Spectra - 03/02/98 - 15:40 -- Gap: Near Shoreline
Hmo = 0.08 m
Tp = 2.78 s
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
Power Density (m^2 s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

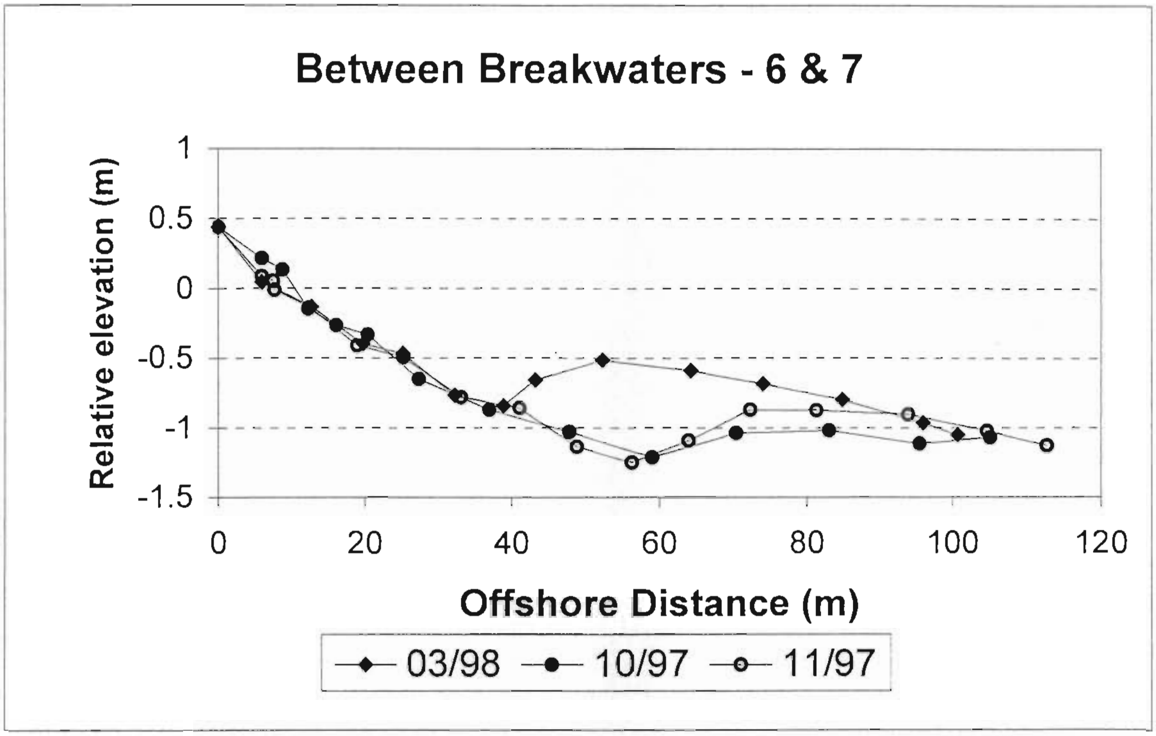

Power Spectra - 03/02/98 - 16:00 -- Gap: Near Shoreline
Hmo = 0.09 m
Tp = 11.13 ??? s
Power Density (m^2 s)
1.80E-03
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

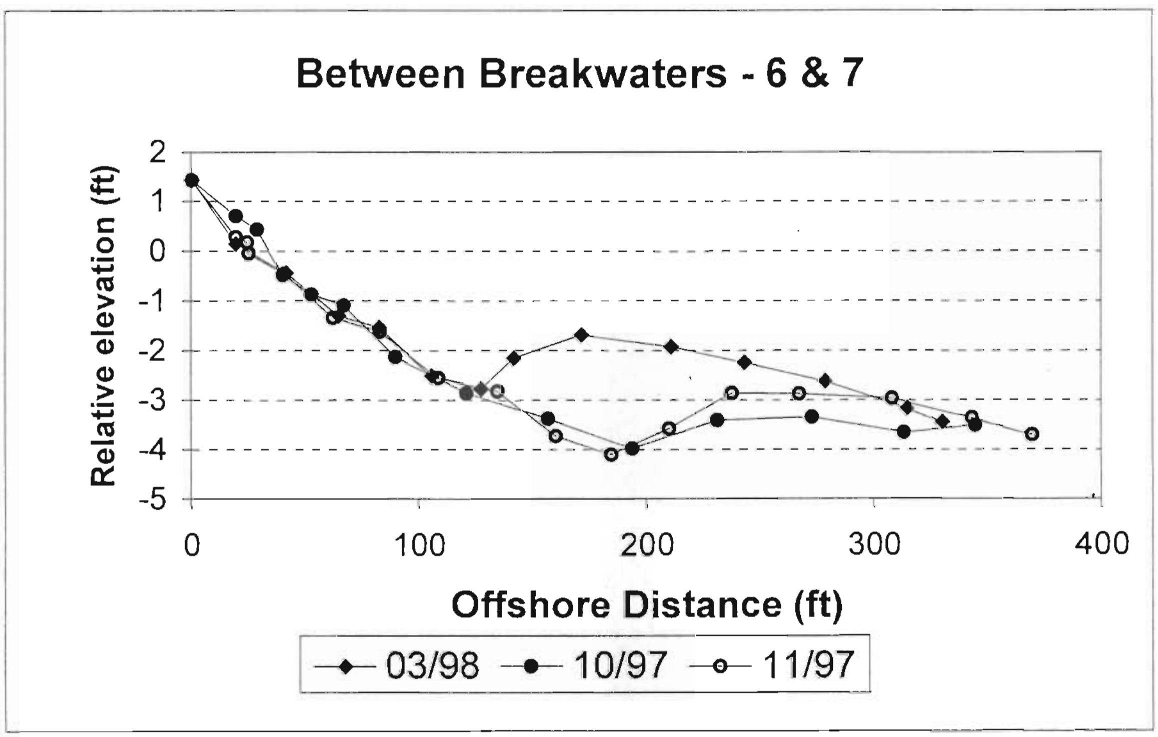
APPENDIX 3

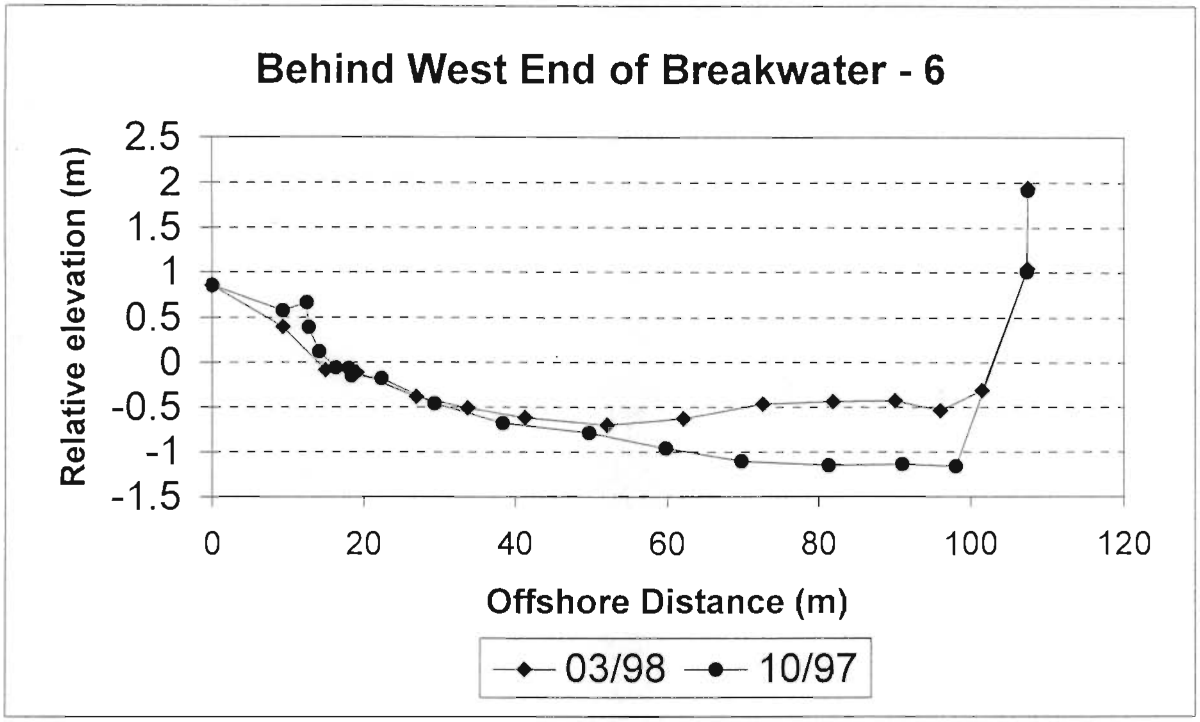
Time-series of beach profiles (profile locations are shown in Figure 1): Upper figures are in metric units; lower figures are in English units.

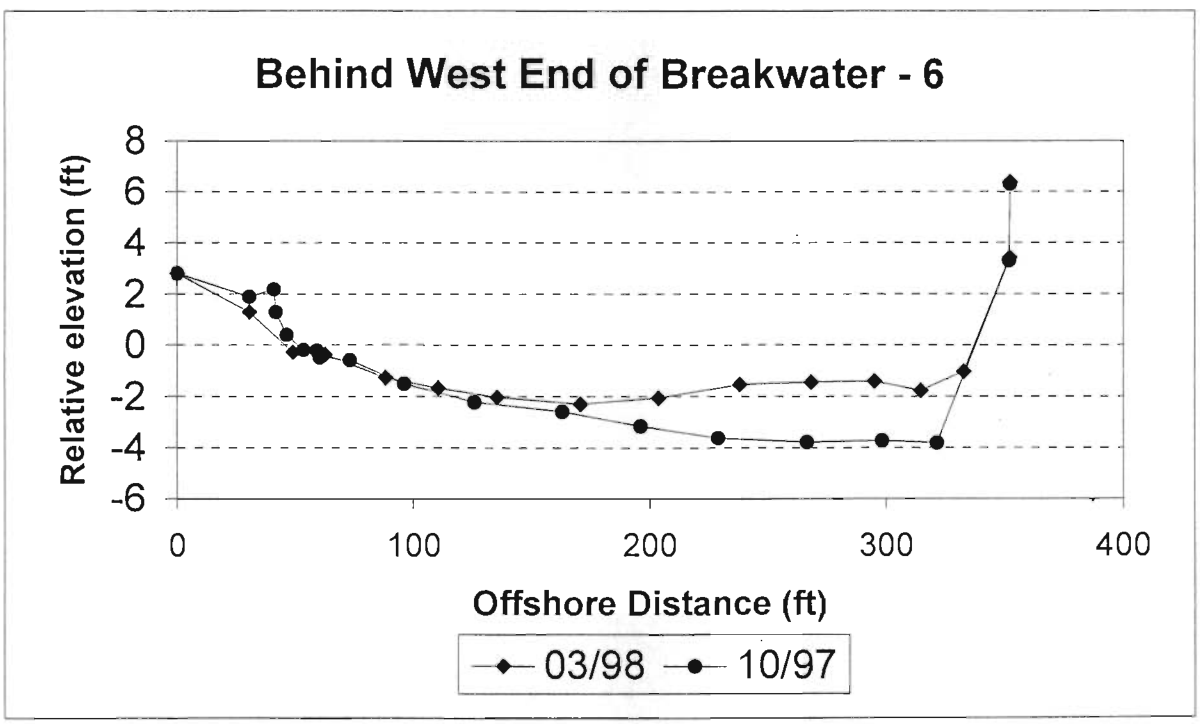

Behind the Center of Breakwater - 7
Relative elevation (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97

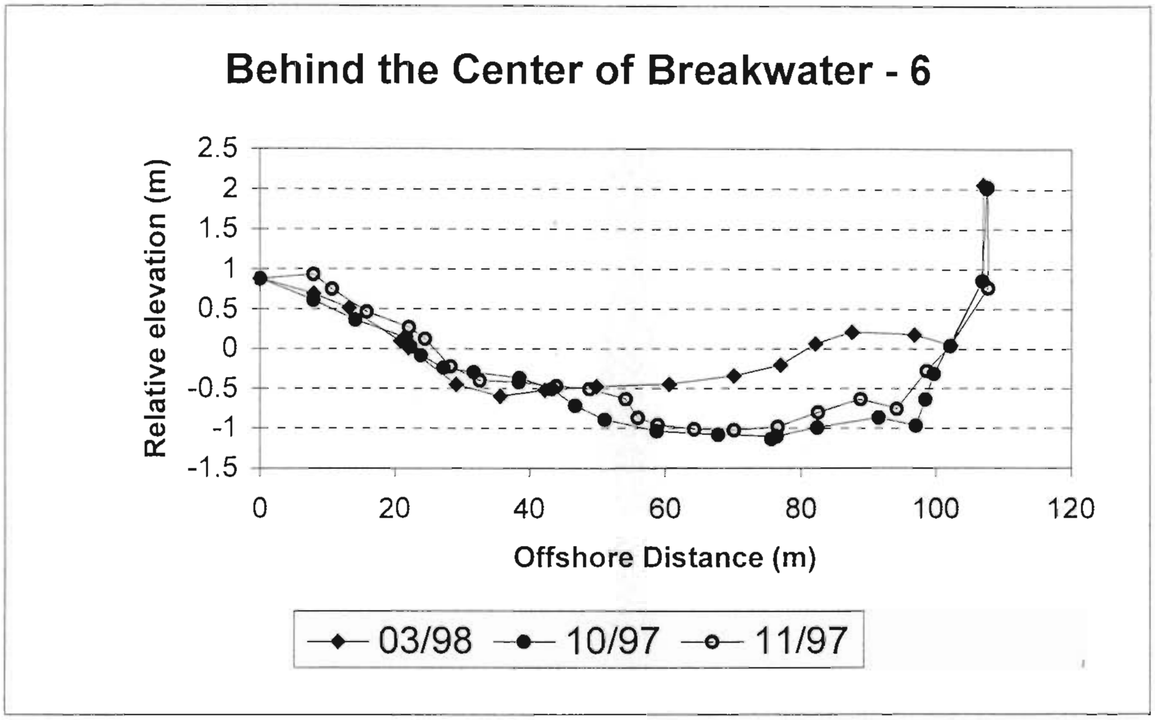

Behind the Center of Breakwater - 7
Relative elevation (ft)
8
6
4
2
0
-2
-4
-6
0
50
100
150
200
250
300
350
400
Offshore Distance (ft)
03/98
10/97


Between Breakwaters - 6 & 7
Relative elevation (m)
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97
11/97

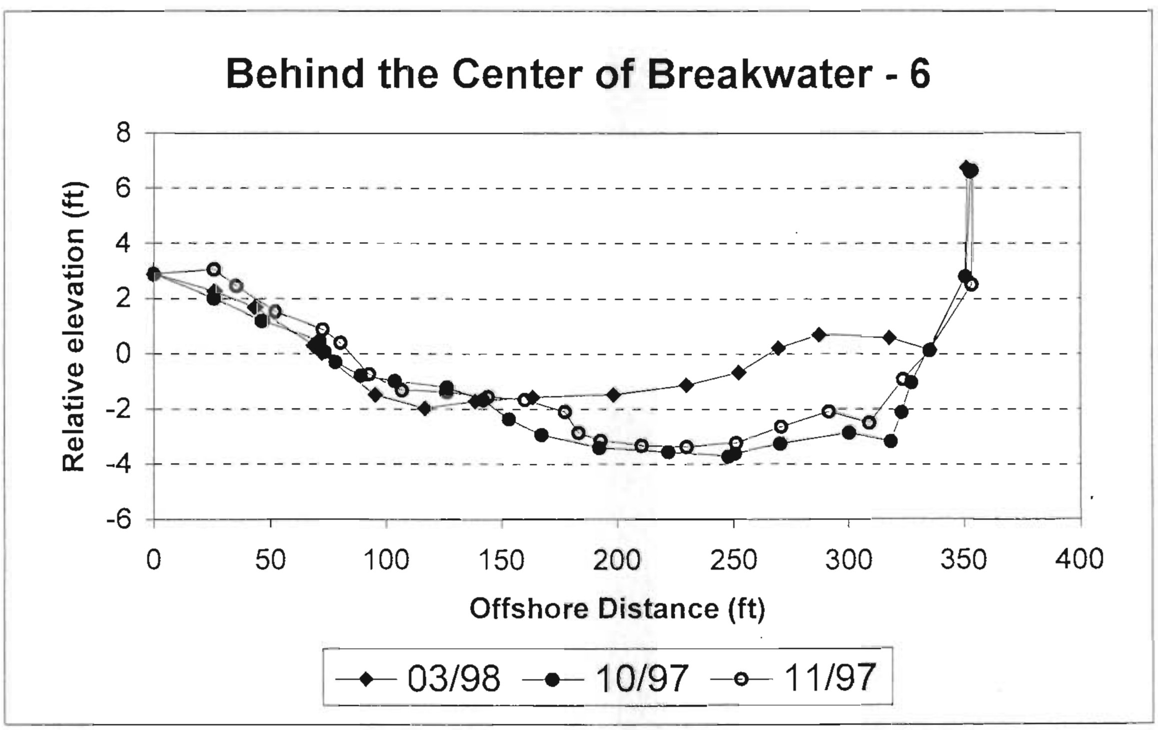

Between Breakwaters - 6 & 7
Relative elevation (ft)
2
1
0
-1
-2
-3
-4
-5
0
100
200
300
400
Offshore Distance (ft)
03/98
10/97
11/97


Behind West End of Breakwater - 6
Relative elevation (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97

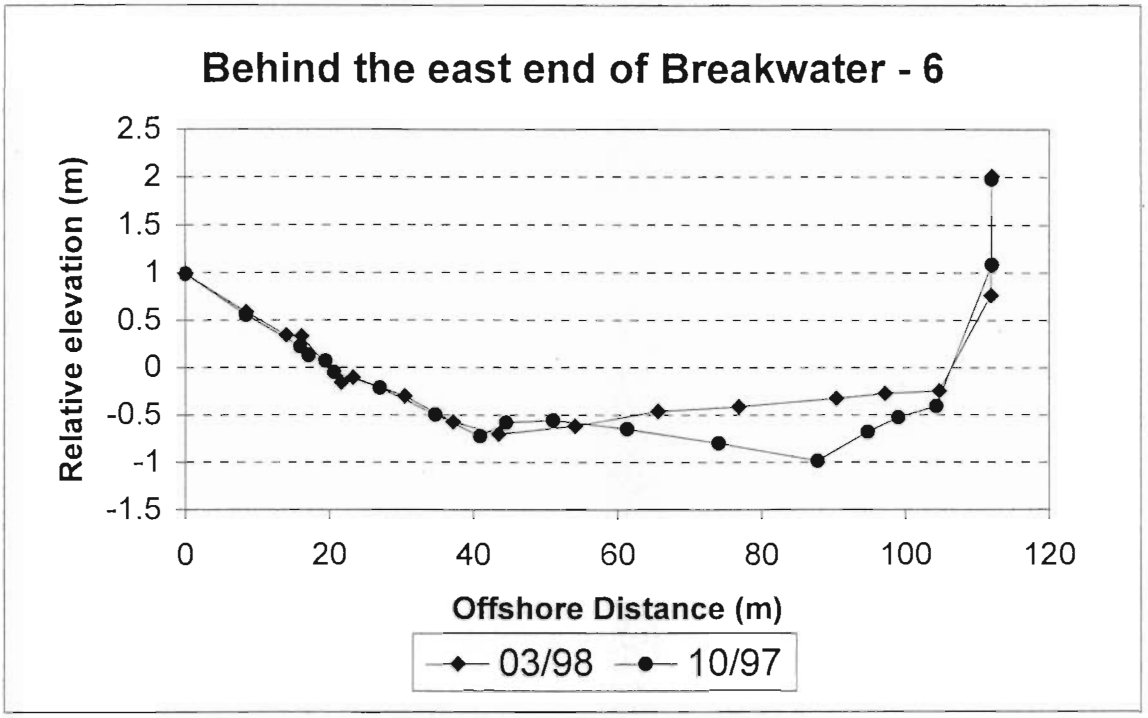

Behind West End of Breakwater - 6
Relative elevation (ft)
8
6
4
2
0
-2
-4
-6
0
100
200
300
400
Offshore Distance (ft)
03/98
10/97

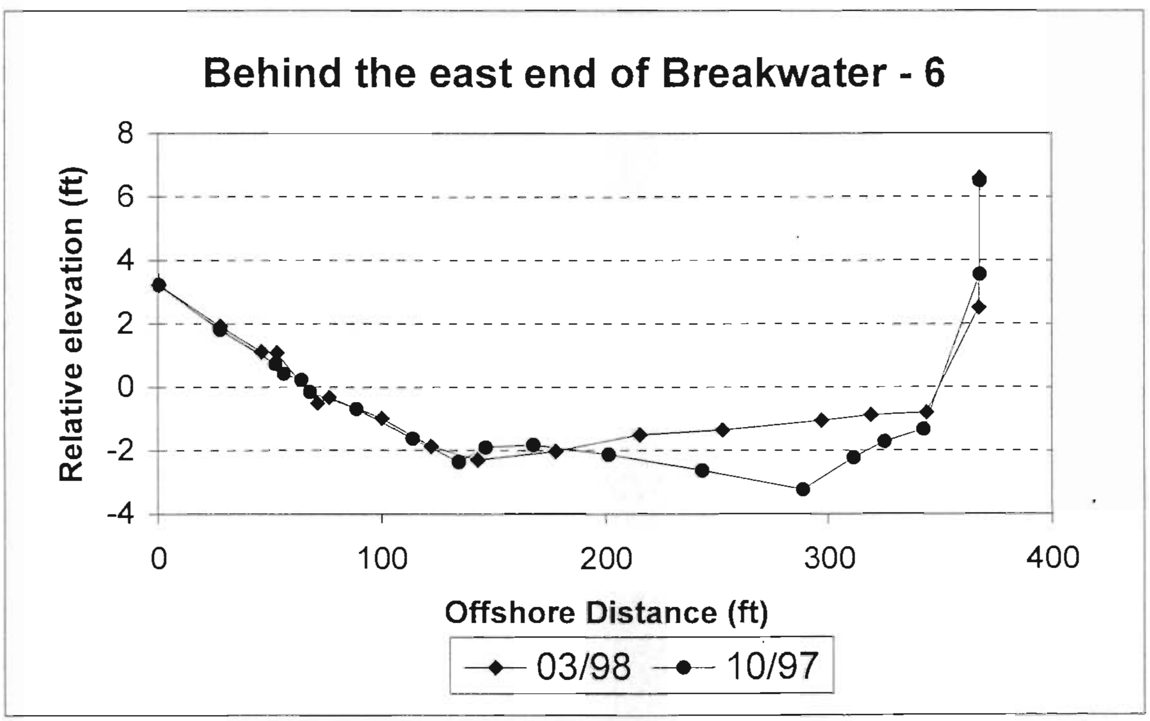


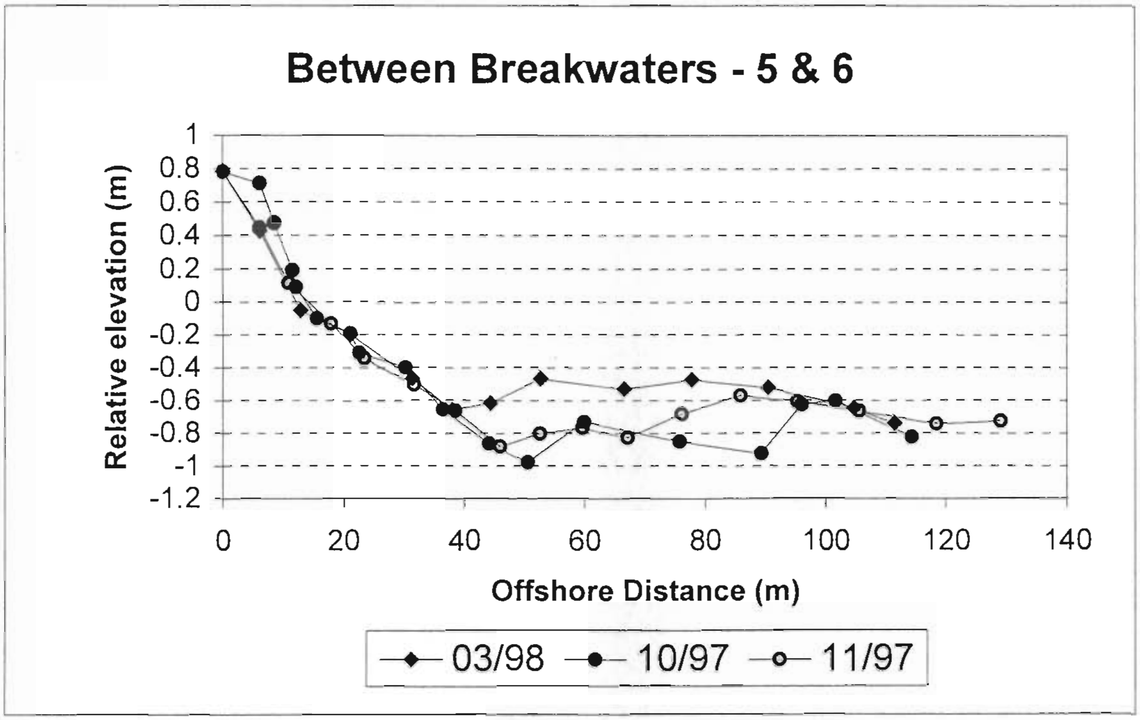
Behind the Center of Breakwater - 6
Relative elevation (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97
11/97

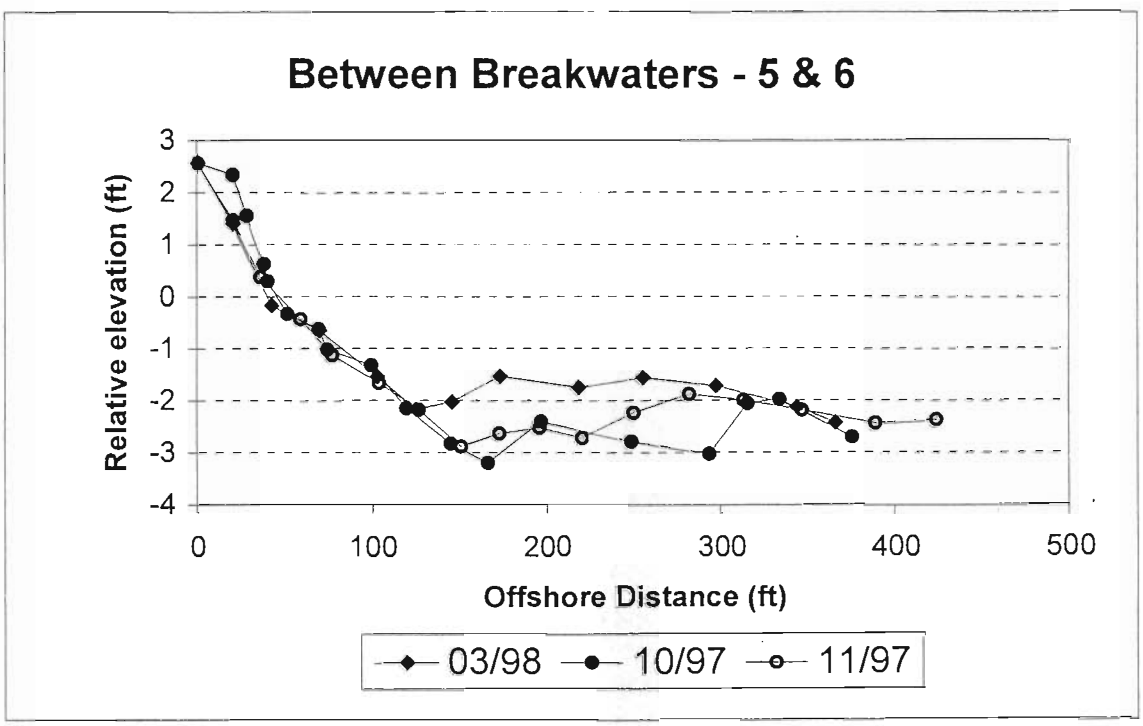


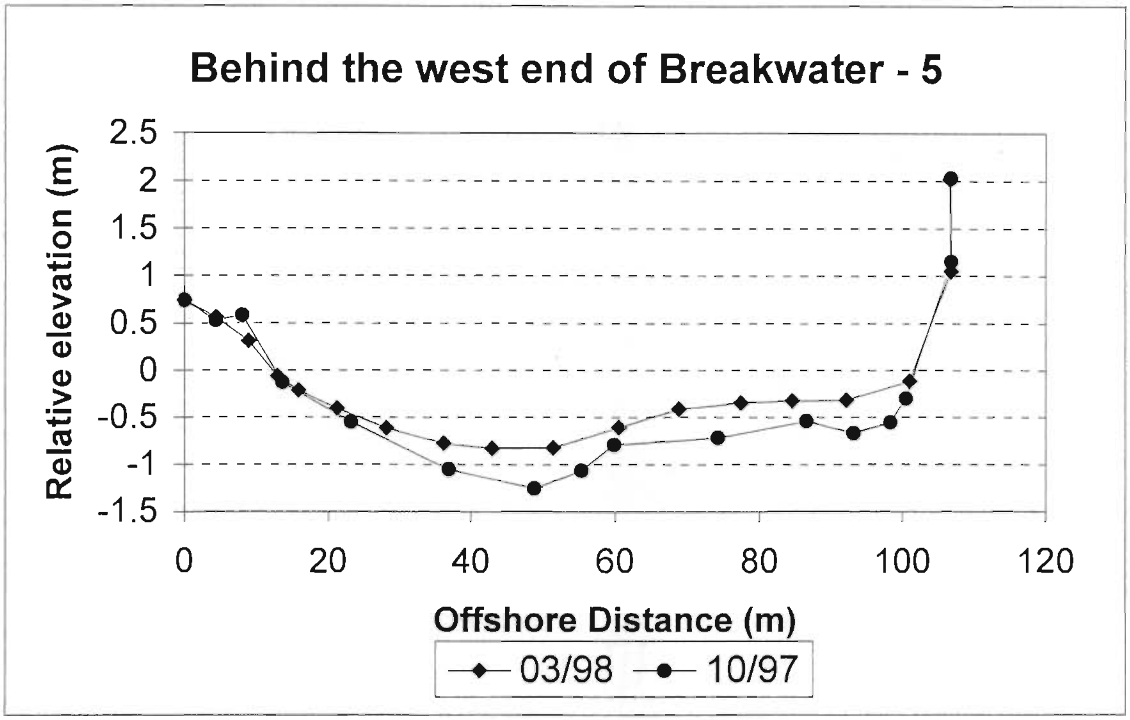
Behind the Center of Breakwater - 6
Relative elevation (ft)
8
6
4
2
0
-2
-4
-6
0
50
100
150
200
250
300
350
400
Offshore Distance (ft)
03/98
10/97
11/97

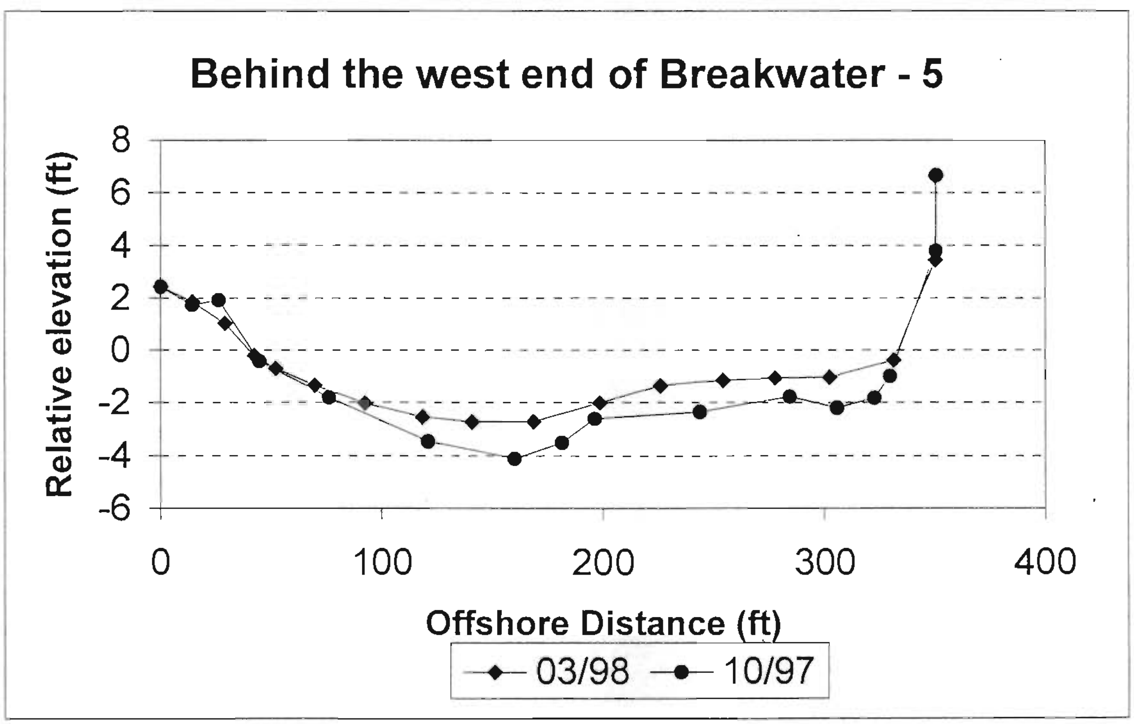

Behind the east end of Breakwater - 6
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
Relative elevation (m)
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97

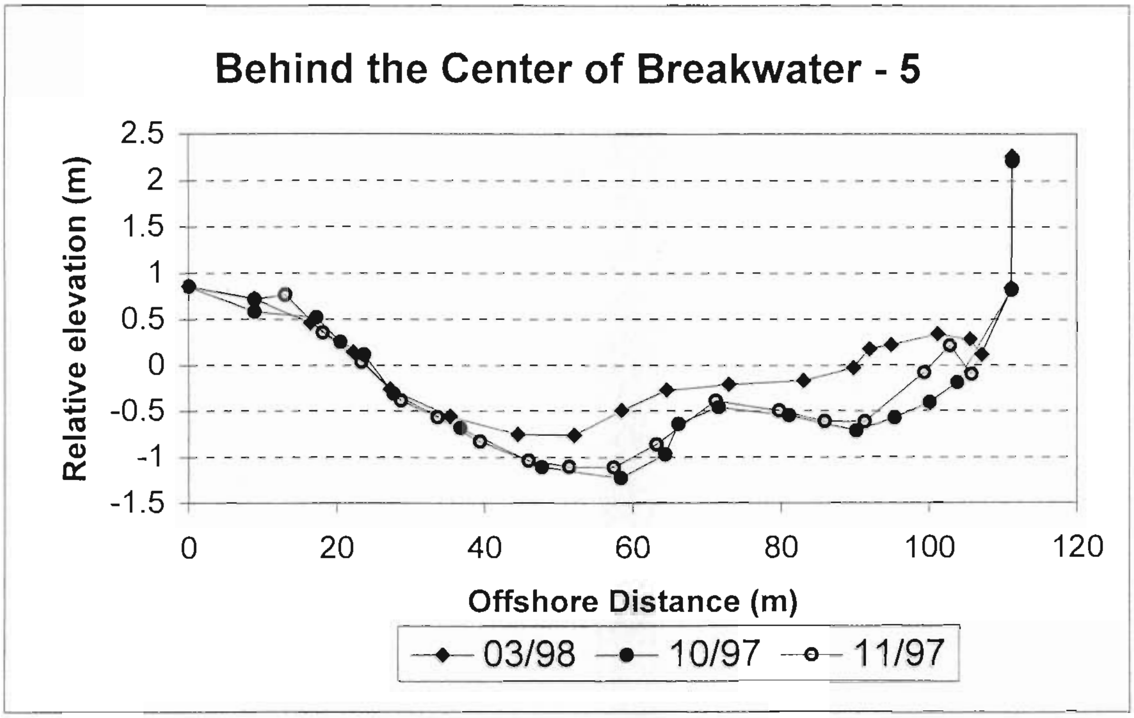

Behind the east end of Breakwater - 6
8
6
4
2
0
-2
-4
Relative elevation (ft)
0
100
200
300
400
Offshore Distance (ft)
03/98
10/97

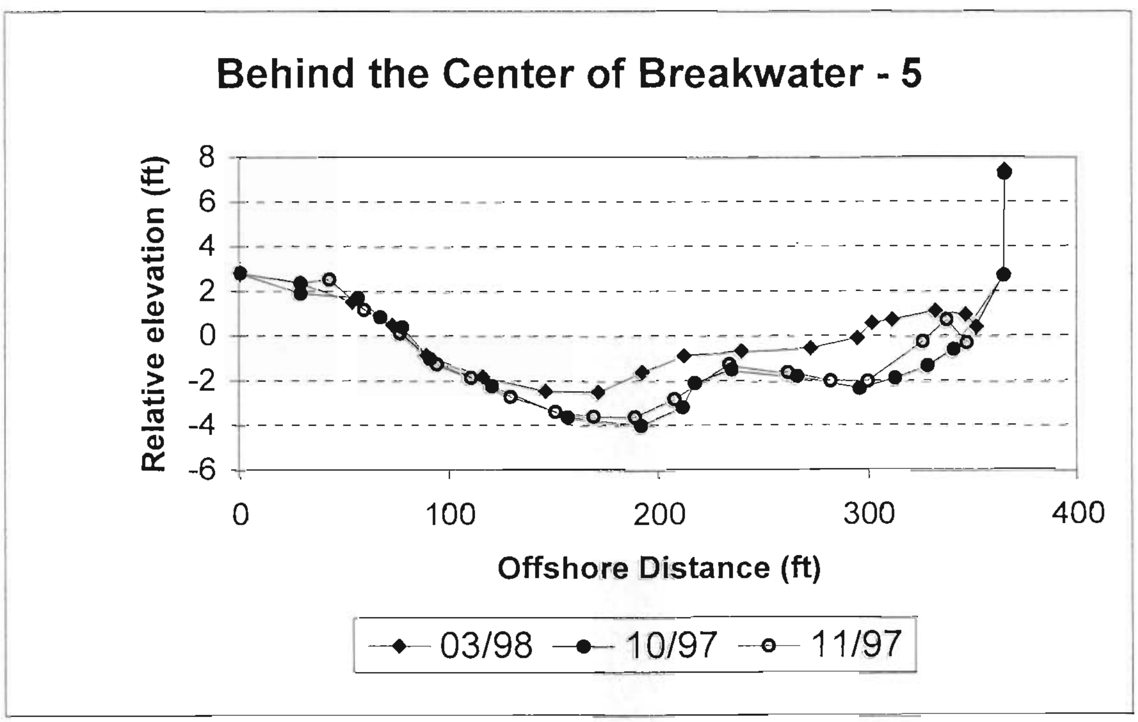

Between Breakwaters - 5 & 6
Relative elevation (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
20
40
60
80
100
120
140
Offshore Distance (m)
03/98
10/97
11/97

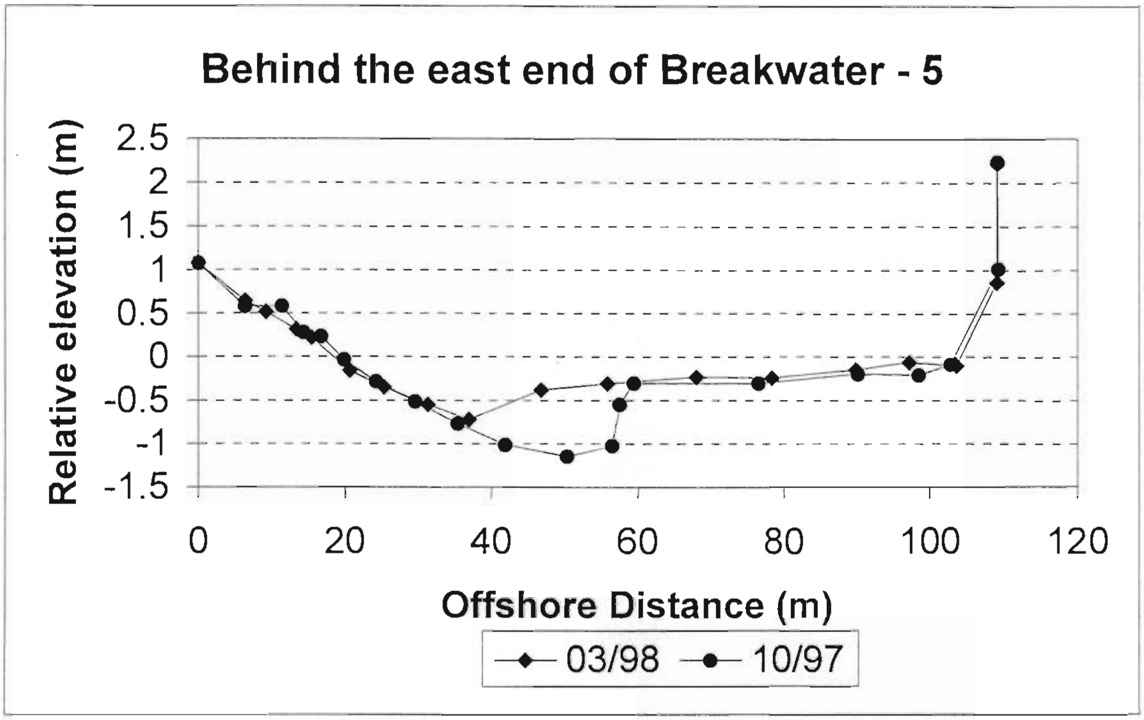

Between Breakwaters - 5 & 6
Relative elevation (ft)
3
2
1
0
-1
-2
-3
-4
0
100
200
300
400
500
Offshore Distance (ft)
03/98
10/97
11/97

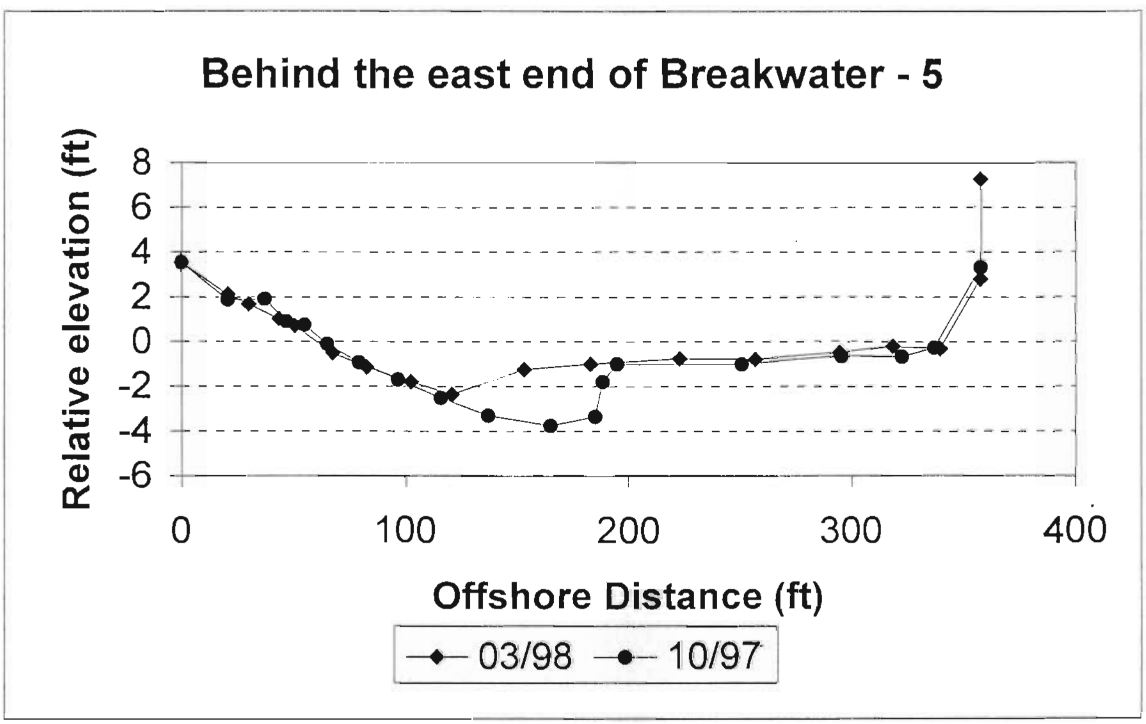

Behind the west end of Breakwater - 5
Relative elevation (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97

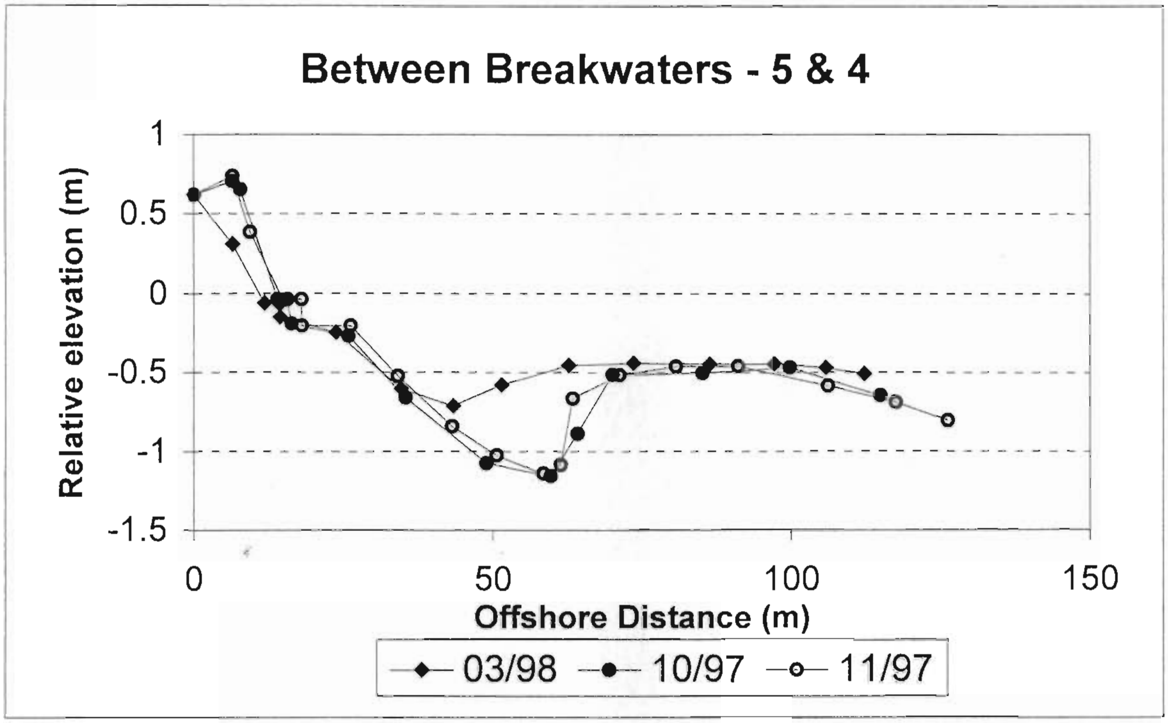

Behind the west end of Breakwater - 5
Relative elevation (ft)
8
6
4
2
0
-2
-4
-6
0
100
200
300
400
Offshore Distance (ft)
03/98
10/97

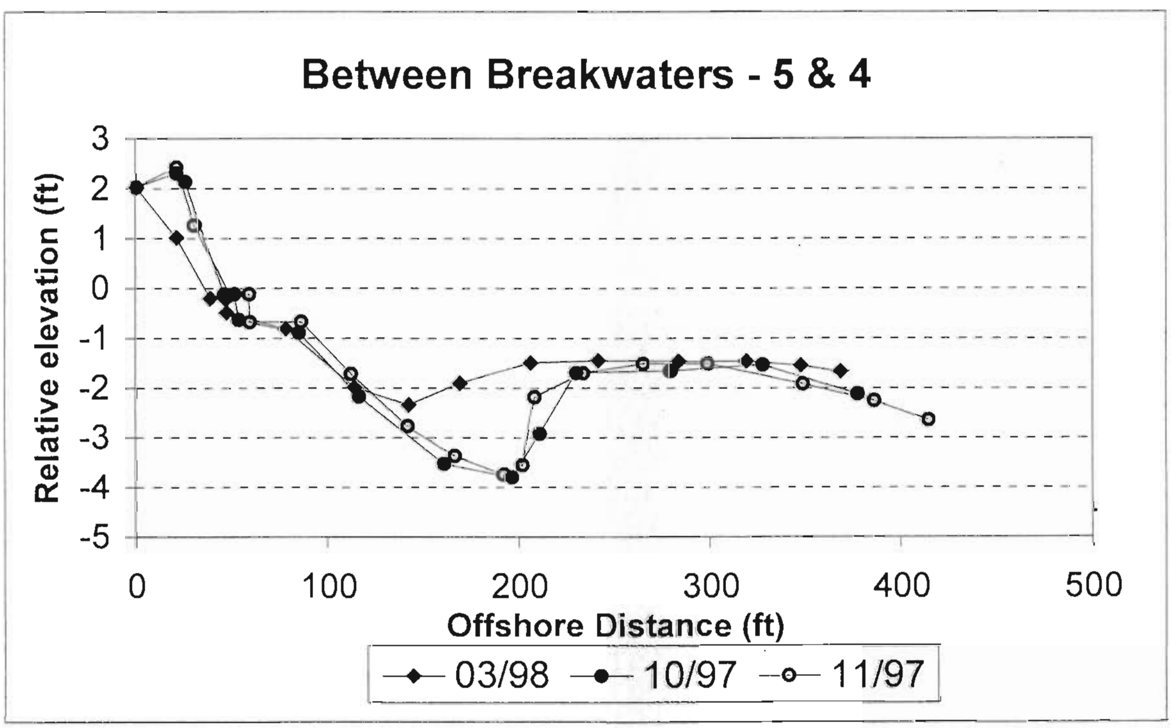

Behind the Center of Breakwater - 5
Relative elevation (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97
11/97


Behind the Center of Breakwater - 5
Relative elevation (ft)
8
6
4
2
0
-2
-4
-6
0
100
200
300
400
Offshore Distance (ft)
03/98
10/97
11/97


Behind the east end of Breakwater - 5
Relative elevation (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
Offshore Distance (m)
03/98
10/97


Behind the east end of Breakwater - 5
Relative elevation (ft)
8
6
4
2
0
-2
-4
-6
0
100
200
300
400
Offshore Distance (ft)
03/98
10/97


Between Breakwaters - 5 & 4
Relative elevation (m)
1
0.5
0
-0.5
-1
-1.5
0
50
100
150
Offshore Distance (m)
03/98
10/97
11/97


Between Breakwaters - 5 & 4
Relative elevation (ft)
3
2
1
0
-1
-2
-3
-4
-5
0
100
200
300
400
500
Offshore Distance (ft)
03/98
10/97
11/97