NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

ACOUSTIC PROPAGATION LOSS MODELING
FOR DABOB BAY, WA

by

John R. Mitchell

September, 1991

Thesis Advisor: O. B. Wilson, Jr.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a Report Security Classification UNCLASSIFIED	1b Restrictive Markings
2a Security Classification Authority	3 Distribution Availability of Report Approved for public release; distribution is unlimited
2b Declassification/Downgrading Schedule	
4 Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School / 6b Office Symbol *(If Applicable)* 3A	7a Name of Monitoring Organization Naval Postgraduate School
6c Address *(city, state, and ZIP code)* Monterey, CA 93943-5000	7b Address *(city, state, and ZIP code)* Monterey, CA 93943-5000
8a Name of Funding/Sponsoring Organization / 8b Office Symbol *(If Applicable)*	9 Procurement Instrument Identification Number
8c Address *(city, state, and ZIP code)*	10 Source of Funding Numbers Program Element Number / Project No / Task No / Work Unit Accession No

11 Title *(Include Security Classification)* Acoustic Propagation Loss Modeling For Dabob Bay, WA

12 Personal Author(s) Mitchell, John R.

13a Type of Report	13b Time Covered	14 Date of Report *(year, month, day)*	15 Page Count
Master's Thesis	From To	September 1991	65

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
Field	Group	Subgroup	Acoustic Propagation Loss Modeling, Dabob Bay, WA

19 Abstract *(continue on reverse if necessary and identify by block number)*

An analysis of the acoustic sound propagation in a multipath environment in an ocean at short ranges has been conducted using a Modified Time Delay Spectrometry (TDS) and an experimental continuous-wave technique. Data from the acoustic range at Dabob Bay, WA were analyzed to determine the relative amplitudes of the direct- and surface-reflected signals. The results show that, at moderate ranges and typical source and receiver depths, the surface-reflected sound is a significant contributor to the received sound level. The theory supporting both techniques is presented. Discussions and conclusions are drawn. Recommendations for future investigation are made.

20 Distribution/Availability of Abstract [X] unclassified/unlimited [ ] same as report [ ] DTIC users	21 Abstract Security Classification Unclassified
22a Name of Responsible Individual Prof. O. B. Wilson , Jr.	22b Telephone *(Include Area code)* (408) 646-2894 / 22c Office Symbol PH/Wl

DD FORM 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 Unclassified

Acoustic Propagation Loss Modeling For Dabob Bay, Wa.

by

John R. Mitchell
Lieutenant, United States Navy
B.S., Clemson University

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN APPLIED SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
September 1991

ABSTRACT

An analysis of the acoustic sound propagation in a multipath environment in an ocean at short ranges has been conducted using a Modified Time Delay Spectrometry (TDS) and an experimental continuous-wave technique. Data from the acoustic test range at Dabob Bay, WA were analyzed to determine the relative amplitudes of the direct- and surface-reflected signals. The results show that, at moderate ranges and typical source and receiver depths, the surface-reflected sound is a significant contributor to the received sound level. The theory supporting both techniques is presented. Discussions and conclusions are drawn. Recommendations for future investigation are made.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

The successful completion of this thesis is due to the support received from the Acoustics Division at NUWES, Keyport. Specifically, the time and effort in sponsoring my experience tour and subsequent use of their facilities for data collection and analysis is greatly appreciated. I want to thank Mrs. Shaari Unger, whose time and patience were critical to the completion of this project. Also, a special thanks to my thesis advisor, Prof. O. B. Wilson, Jr., for his guidance and encouragement.

Finally, I want to thank my wife, Lisa, for her love and support.

I. INTRODUCTION

A. Background

The Naval Undersea Warfare Engineering Station (NUWES) in Keyport, Washington performs underwater noise measurements for a wide variety of purposes. These measurements are conducted using a system known as the Noise Recording System (NRS). The exact determination of the source level of the radiated noise from an underwater vehicle requires an accurate sound transmission loss model.

The main thrust of this thesis is to study the propagation loss in a multipath environment for Dabob Bay, Washington, one of two test ranges operated by NUWES. Dabob Bay is the site where the majority of the radiated acoustical noise measurements are made.

Dabob Bay is an isolated inlet approximately six miles long, one mile wide and 600 feet deep. Its isolation from typical seaborne noise sources makes it an ideal location in which to measure and evaluate the radiated noise from underwater vehicles. However, this unique bathtub shape leads to several acoustical difficulties not common to traditional open-ocean test ranges. The shallow depth, along with a typically low sea state and corresponding smooth surface conditions, produce a strong multipath environment. At low frequencies, reverberation from the sides of the bay may also be important.

The initial step toward developing an improved transmission loss model for Dabob Bay is the development of a method to measure the relative contributions of each path of this multipath environment. The next step is to use this method to analyze data collected using different source and receiver depths and ranges. The results of this analysis may be useful in improving the existing transmission loss models.

Brekke [Ref. 1] developed a computer-controlled, Fast Fourier Transform (FFT) based variation of a technique known as Time Delay Spectrometry (TDS) to measure the individual contributions of multipath propagation in an ocean environment. Originally developed in 1967 by Richard C. Heyser [Ref. 2], TDS utilizes a Linear Frequency Modulated (LFM) pulse of constant amplitude. This allows a frequency-tracking spectrum analyzer to distinguish between individual multipath components by the differences in the frequencies of the signals at different arrival times caused by the differences in their path lengths.

B. Objective

The objective of this thesis is to further advance Brekke's technique by accounting more accurately for the individual multipath components. A slightly modified version of Brekke's TDS software will be used for data analysis. In addition, an experimental continuous wave method was employed to determine the relative contribution of each multipath component to the overall received signal.

A description of the multipath problem will be presented first. This will be followed by a description of the TDS system both in theory and in practice. Next, the continuous wave method will be described in detail. Then an analysis of data taken will be presented. Finally, the results will be discussed and conclusions drawn.

It is appropriate to point out that this research was limited in scope due to the constraint to use existing sources and receivers, which imposed a testing geometry that was less than optimum for the experimental techniques employed.

II. MULTIPATH PROBLEM DESCRIPTION

A. The Multipath Problem

An important test conducted on the Dabob Bay range is the measurement of the radiated noise level of a torpedo or other underwater vehicle as it moves through the water. The portion of interest during a test run is when the underwater vehicle passes a vertical array of three calibrated omni-directional hydrophones. The maximum horizontal range between the vehicle and the array is typically less than 1,000 yards. In general, both the test vehicle and hydrophone array are located at mid-depth, about 300 feet. The water depth in Dabob Bay is approximately 600 feet.

Since the tests are conducted in relatively shallow water, sound which is reflected from the boundaries could make a significant contribution to the sound level at the receiver, depending on range and frequency. In order to model the propagation accurately, the contributions of these multipaths must be considered.

B. Assumptions

For all the acoustic measurements and analyses reported herein, it is assumed that the acoustic signal is of small amplitude and that the sound propagation can be described by the linear acoustic wave equation. It is also assumed the water column containing the source and receiver is homogenous, and that no relative motion exists between the source and receiver during measurements. Lastly, the bottom is considered to be flat with a constant depth of 600 feet.

C. Multipath Geometry

The simple multipath geometry is shown in Figure 1 [Ref. 1:p. 26]. Following the approach developed in Albers [Ref. 3:pp. 49-51], and utilized by Brekke [Ref. 1], it is seen that the reflected signals travel an extra distance from a virtual or image source and reach the receiver at a time later than does the direct-path sound. Therefore, the acoustic signal at the receiver is the sum of the signal from the direct path and the image sources.

Utilizing Brekke's notation [Ref. 1:pp. 25-27], the source depth is ZS, the receiver depth is ZR, the water depth is H, and the horizontal separation between source and receiver is R. From the geometry it can be seen that the expression for the direct path (XR), the surface-reflected path (XSR), and the bottom-reflected path (XBR) are given by:

$$XR = [R^2 + (ZR - ZS)^2]^{1/2} \quad , \qquad 2.1$$

$$XSR = [R^2 + (ZR + ZS)^2]^{1/2} \quad , \qquad 2.2$$

and

$$XBR = [R^2 + (2H - ZR - ZS)^2]^{1/2} \quad . \qquad 2.3$$

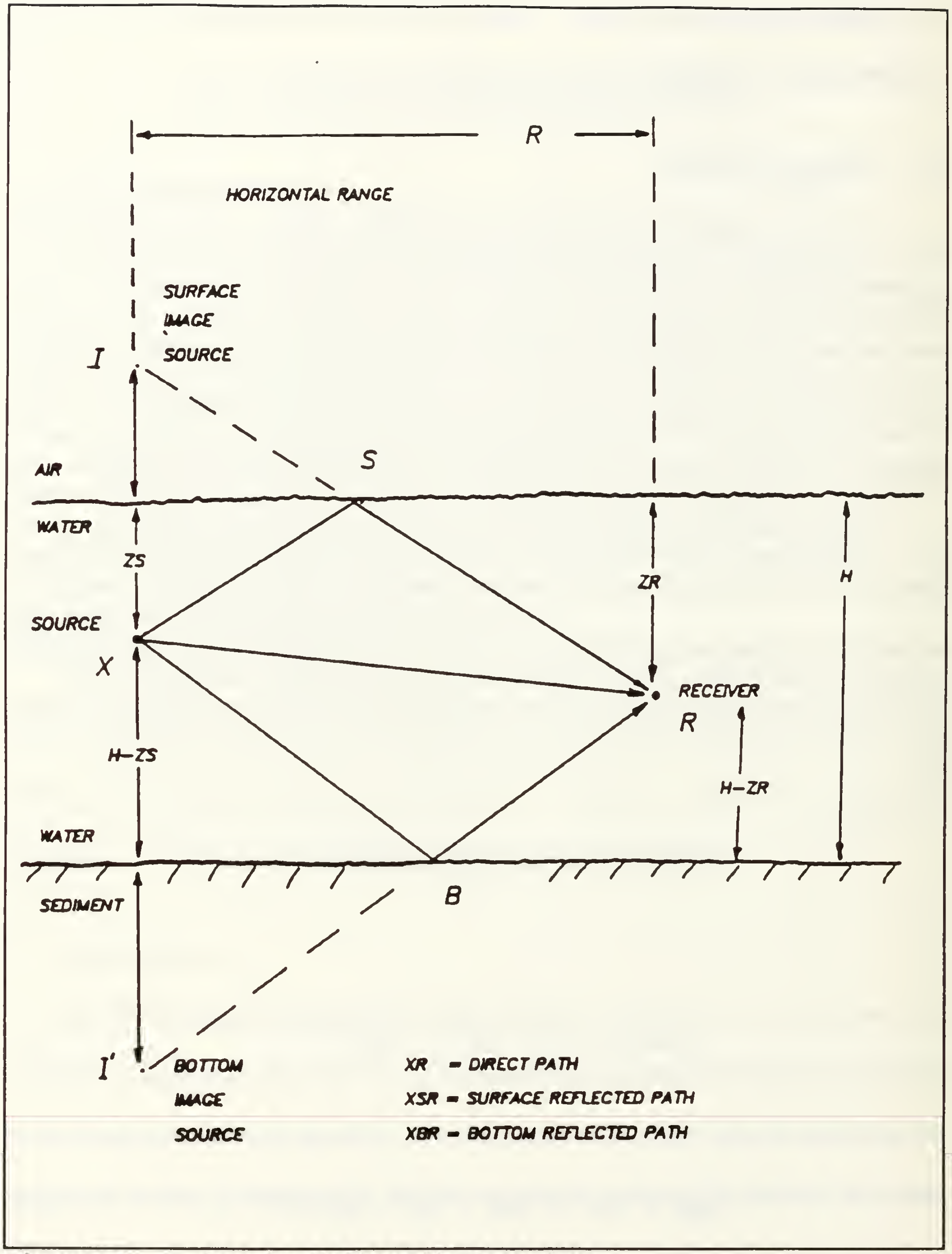

Figure 1 Simple Multipath Geometry

The travel time along each path can be determined simply by dividing the path length by the speed of sound c. Assuming that the variation in sound speed along the ray path is small, the time delays between the direct and reflected paths are given by:

$$t_s = \frac{XSR - XR}{c} , \qquad 2.4$$

and

$$t_b = \frac{XBR - XR}{c} , \qquad 2.5$$

where t_s is the time delay for the surface-reflected path and t_b is the time delay for the bottom-reflected path. The time delay between the two reflected paths, t_r is:

$$t_r = \frac{| XSR - XBR |}{c} . \qquad 2.6$$

The acoustic signal at the receiver is the sum of the signals travelling along the direct and various reflected paths. For periodic signals, these contributions must be considered both in terms of amplitude and phase. Each reflected signal may have a different amplitude and may undergo a different phase shift relative to the direct path signal.

III. MEASUREMENT TECHNIQUES

To study the effects of the individual multipath components, two techniques were utilized. These are the modified TDS technique and the experimental continuous-wave method.

A. TDS Technique

The classical TDS technique was developed and described by Heyser [Ref. 2]. This technique was modified by Brekke [Ref. 1] for underwater acoustical measurements. Brekke presents a thorough development of the theory supporting TDS and explains why this technique is well suited for use in multipath signal identification and amplitude measurements.

1. The Excitation Signal

The excitation signal used in the modified TDS technique has the characteristics shown in Figure 2. It is a periodic linear frequency sweep at constant amplitude over a period of T seconds. Let $F = f_2 - f_1$ be the frequency range, where f_1 is the starting frequency and f_2 the ending frequency. The carrier frequency is defined as $f_c = (f_1+f_2)/2$. The excitation signal may be written as:

$$X(t) = \cos\left[\phi(t)\right] = \cos\left[\frac{\pi F}{T}t^2 + 2\pi f_c t\right] \quad . \qquad 3.1$$

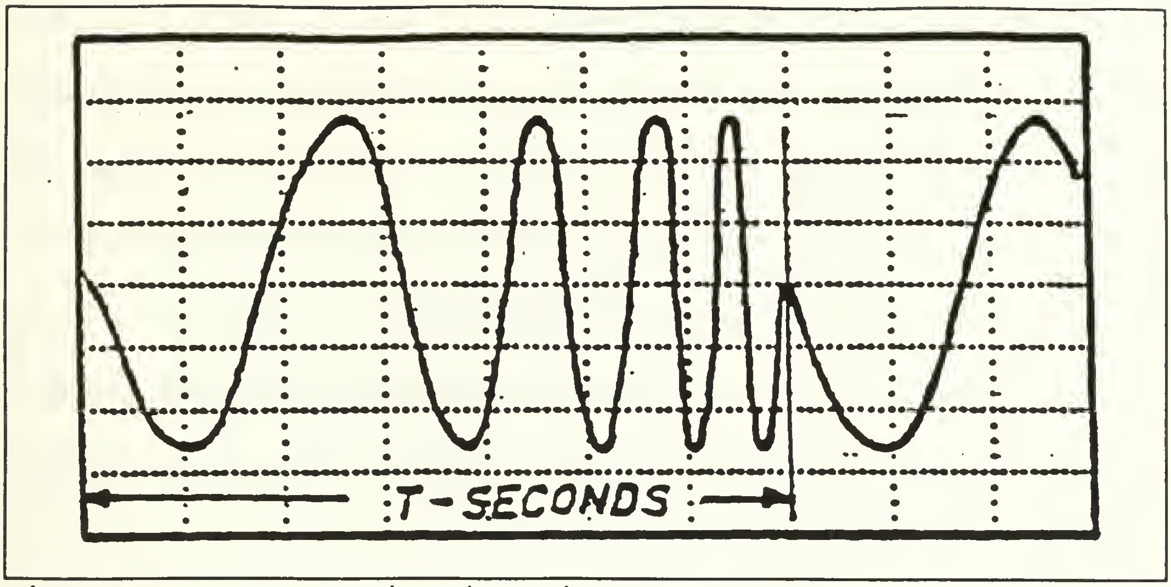

Figure 2 TDS Excitation Signal

The instantaneous frequency, f_i, is $1/(2\pi)$ times the derivative of the phase $\phi(t)$ with respect to time:

$$f_i = \frac{1}{2\pi}\frac{d\phi}{dt} = \frac{F}{T}t + f_c \ . \qquad 3.2$$

The sweep rate, S, is the derivative of the instantaneous frequency, f_i, with respect to time:

$$S = \frac{F}{T} \ . \qquad 3.3$$

The sweep rate, which is a constant, will be an important parameter to consider when an appropriate signal is designed for particular range conditions.

2. Dynamic Signal Analyzer Operation

The signal received by the hydrophone consists of multiple, time-delayed and attenuated replicas of the transmitted signal. For the modified TDS technique, the received signal was recorded on a magnetic tape as an analog signal. The signal was later analyzed using an HP 3561A dynamic signal analyzer.

The dynamic signal analyzer measurements are based on a 1024-point FFT algorithm. The displayed spectrum is contained in 400 bins. Therefore, the frequency resolution of the analyzer in terms of bin separation, b is:

$$b = F/400 \quad Hz \ , \tag{3.4}$$

where F is the frequency span of the analyzer. It follows that the time record length, or the observation time, t_{obs}, during which the analyzer receives data is:

$$t_{obs} = 1/b \quad \text{sec} \ . \tag{3.5}$$

A measurement window is applied to the input data to reduce errors caused by "leakage" into adjacent frequency bins. The result of using a window function is a minimum bandwidth separation, f_{band}, given by:

$$f_{band} = C \times F \ , \tag{3.6}$$

where C is a constant given as a percentage of the frequency span. For the Hanning window used in this research C = .00375. Thus, for a frequency span of 20 kHz, the resulting f_{band} is 75 Hz.

To resolve the multipath signals, it is necessary to ensure the delayed arrival times are sufficient to maintain the minimum bandwidth separation. This is accomplished by setting a lower bound on the sweep rate, S_m, given by:

$$S_m > \frac{f_{band}}{t_{delay}} , \qquad 3.7$$

where t_{delay} is the time delay between the direct and reflected paths. The t_{delay} can be determined using Equations 2.4 through 2.6. As an example, for surface-reflections, $t_{delay} = t_s$.

The choice of the optimum observation time and the relationship between it and the selected frequency span of the analyzer is straightforward. The time delay between arrivals from different signal paths must be greater than the observation time in order for resolution of these signals to occur. For time delays less than the observation time, the difference between the frequencies of the signals arriving by the direct and reflected paths will be less than the frequency resolution of the analyzer. Selection of a sweep rate, S greater than the minimum sweep rate, S_m ensures that the minimum bandwidth separation is maintained. The concept of the minimum sweep rate is shown graphically in Figure 3. Knowing the required time delay, the minimum sweep rate necessary to resolve the multipath signals can be determined for each analyzer frequency span.

B. Continuous-Wave Method

The second technique employed to determine the relative contributions of the individual multipath signals was a method using a stationary source of continuous single-frequency waves and making measurements at different receiver positions.

Due to differences in propagation path lengths between the direct- and surface-reflected waves, as well as a phase reversal of the surface-reflected waves upon reflection, the reflected signals can combine with the direct-path signal either destructively or constructively, depending on the difference in relative phase. Varying the receiver depth while maintaining source depth constant should make it possible to observe the changes in interference over the entire range of in-phase and out-of-phase conditions, which should allow determination of the relative contributions of the reflected signals to the observed level.

The advantages and disadvantages of this approach compared to the modified TDS technique, will be discussed later in this thesis.

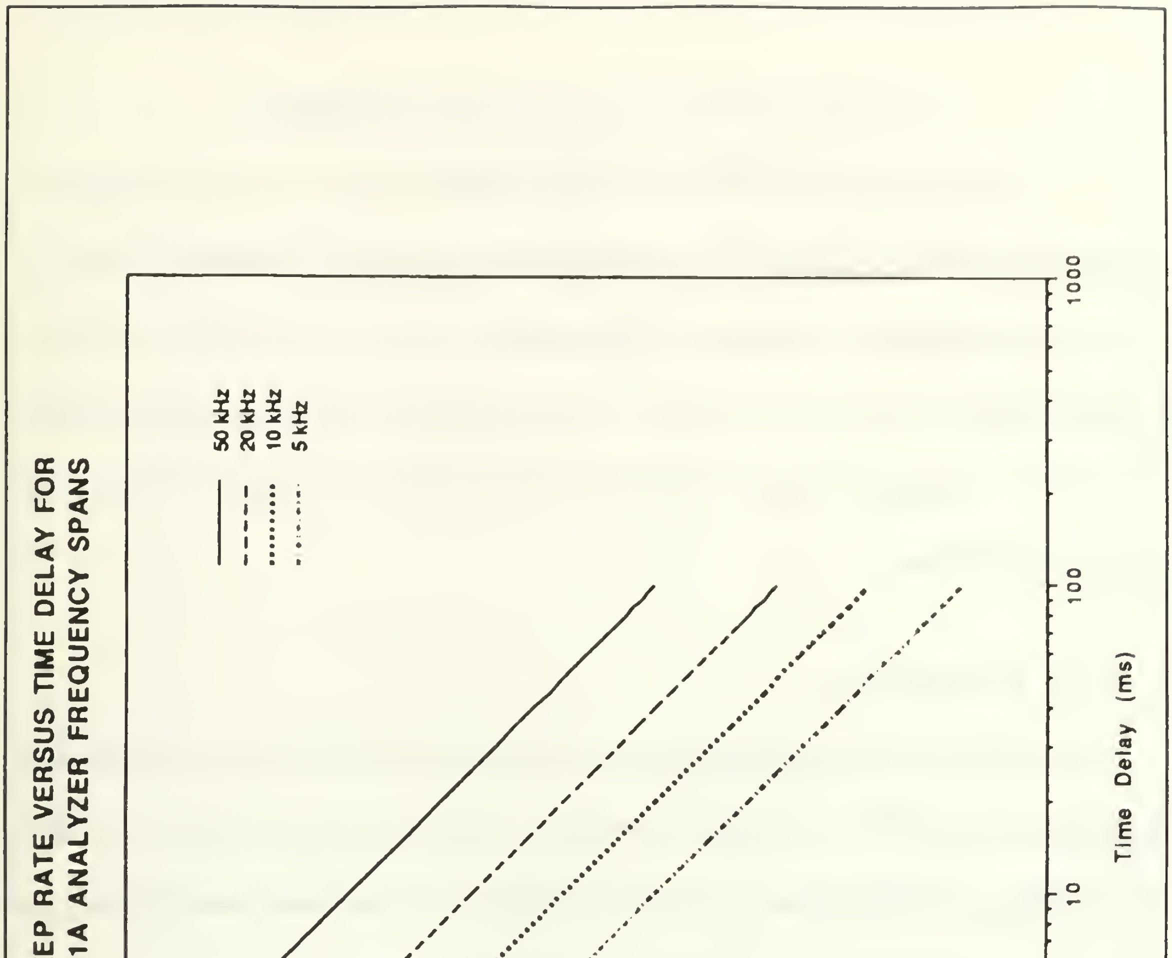

Figure 3 Plot of Minimum Sweep Rate Versus Time Delay

IV. MULTIPATH MEASUREMENT SYSTEM

The test configurations used for measurements in Dabob Bay were based on configurations used for previous TDS measurements and on the constraints imposed by existing range equipment. Existing range equipment was utilized in an effort to minimize the funds needed to conduct this research. The configuration ultimately used is described below. Also, a slightly modified version of the TDS software developed by Brekke was used and is described.

A. Test Configuration

The data used in this research were obtained at the NUWES range at Dabob Bay, Washington in May 1991. The acoustic projector used was the Mark 69 target simulator. The receiver was the Noise Recording System (NRS). The horizontal range between the Mark 69 and the NRS was approximately 650 yards.

The sound velocity profile measured during testing is shown in Figure 4. Wave heights were visually estimated to be one foot or less, with southerly winds at less than 10 knots prevailing during all portions of the test.

The Mark 69 source is a target simulator permanently located on the Dabob Bay range. It is suspended from the floor of Dabob Bay and its depth can be remotely controlled. The designed operating frequency range of the Mark 69 is less than was desired for these tests. Although the beam pattern is not omni-directional, the major lobe is broad enough that ensonification of the surface was assured.

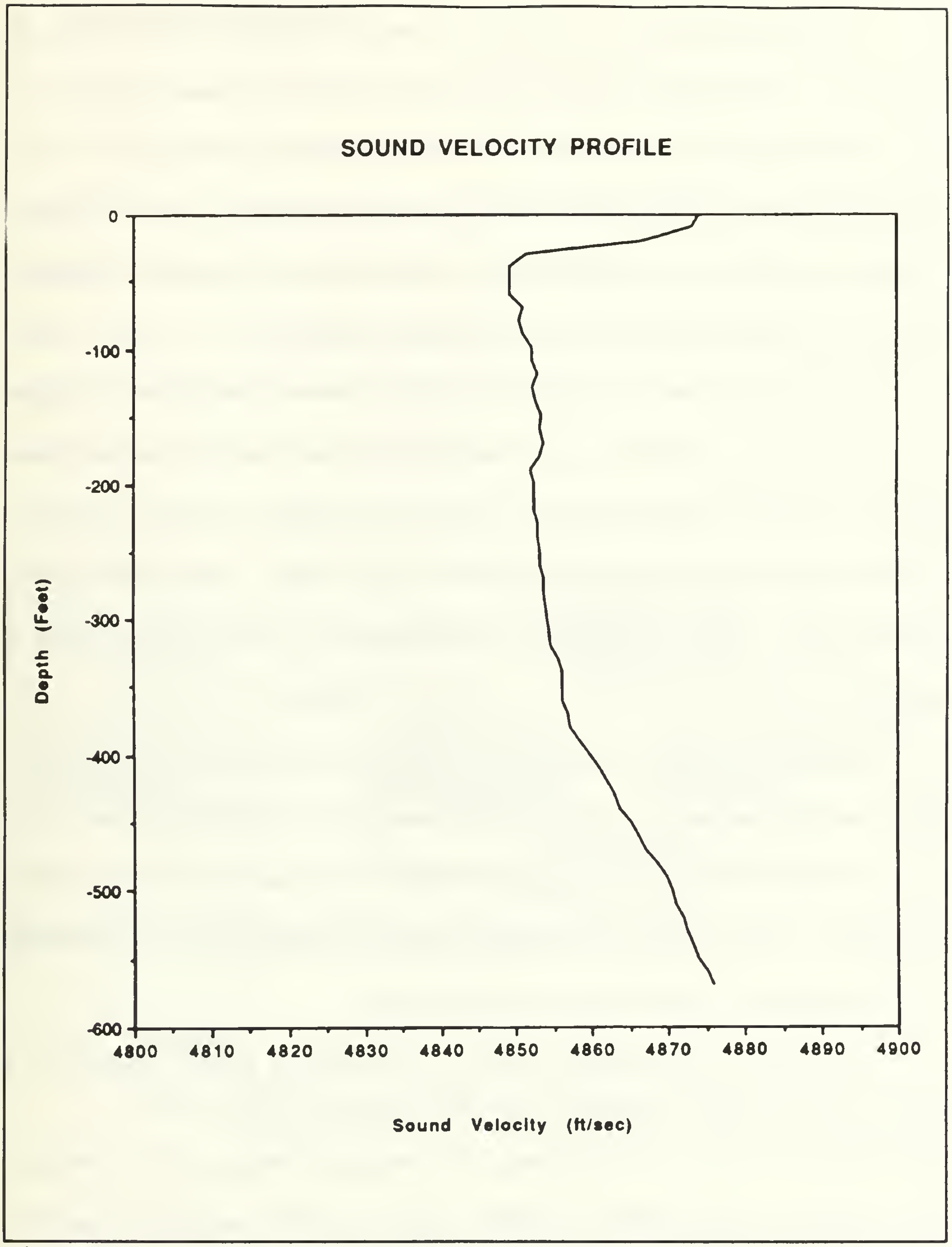

Figure 4 Sound Velocity Profile Taken At Mark 69 Location For Dabob Bay, WA 17 May 1991

The acoustic receiver for the NRS is a vertical line array of three calibrated hydrophones. The separation between the upper and center hydrophones, and the center and lower hydrophones is 60 and 40 feet, respectively. The array is suspended from the floor of Dabob Bay, and it's depth can also be remotely controlled. After conditioning by amplifying electronics, the signal from the NRS array can be analyzed immediately or can be recorded on magnetic tapes for subsequent analysis.

During the TDS portions of the test, the three calibrated hydrophones of the NRS array were located at depths of 240, 300, and 340 feet. The source was operated at three depths, namely 200, 300, and 400 feet. The two test signals used were frequency-modulated sweeps from 8 to 20 kHz, and from 20 to 40 kHz. A sweep period of one second was used. Data was collected for approximately 15 minutes for each signal at each source depth.

During the continuous-wave test, the Mark 69 source was located at a depth of 300 feet. The NRS array center hydrophone depth was varied from 300 to 400 feet in 25 foot increments. The other hydrophones in the NRS array also moved with the center hydrophone. The test signal was an 8 kHz continuous-wave tone. Data was collected for approximately 15 minutes for each receiver depth.

For both tests the received signals were recorded on separate channels of a magnetic tape recorder. These tapes were subsequently analyzed.

B. Data Processing System

1. Hardware

The equipment configuration used was essentially the same as that used by both Brekke [Ref. 1] and Prudhomme [Ref. 4]. An HP 9836 computer running the applicable TDS software was used to control the functions of a HP 3561A Dynamic Signal Analyzer. An HP Thinkjet printer was used to produce tabular output. The equipment configuration is shown in Figure 5. Plots were produced using the Cricket Graph program run on a Macintosh computer.

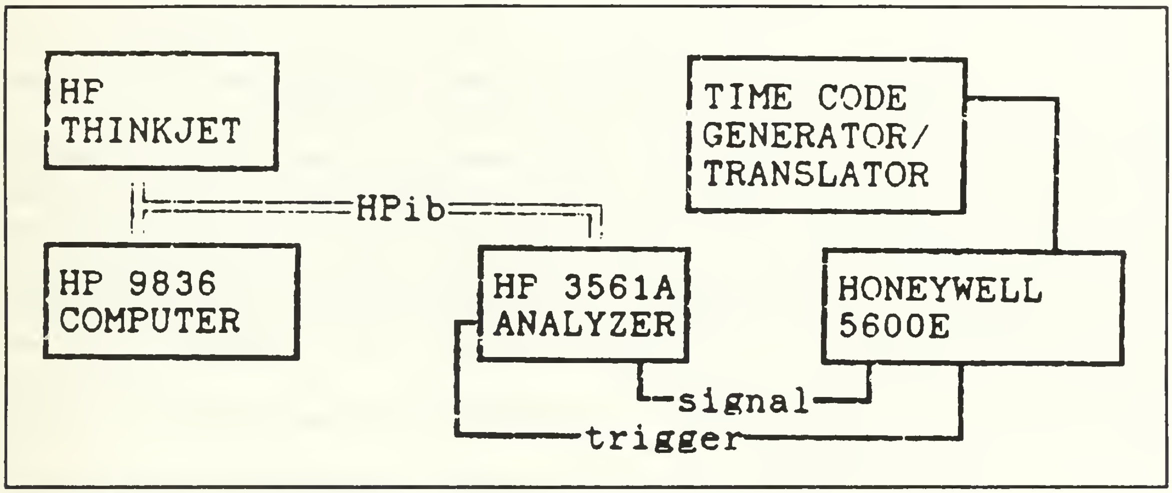

Figure 5 TDS Hardware Configuration

2. Software

Brekke [Ref. 1] provides a detailed and complete documentation of the TDS program. Here, a general discussion of the capabilities of the three subroutines of the TDS analysis program will be presented. This will be followed by a discussion of the modifications made to the TDS program.

a. Quick_Analysis

Using this subroutine, the HP 3561A is operated in the Time-Capture Mode. The analysis is based on data from 40 time records stored in the analyzer. Each time record consist of data processed during one observation time, t_{obs}.

The intention of the Quick_Analysis subroutine is to provide a general overview of the received signal as a function of frequency and time. This also allows the arrival time of the direct and reflected paths to be determined. The Quick_Analysis subroutine was not used in this research.

b. Normal_Analysis

This is an interactive analysis subroutine. Signal identification is done by the operator. Using this subroutine, eight consecutive sweeps are RMS averaged to increase the signal to noise ratio. This averaging is required to reduce the effect of minor fluctuations in the received signal. The Normal_Analysis subroutine was the only one used in this research.

c. Auto_Analysis

This subroutine automates the measurements performed in the Normal_Analysis program. Since operator interaction is necessary to discriminate between direct and reflected signals, the Auto_Analysis subroutine was not used in this research.

d. Program Modifications

All three subroutines of the original TDS program were designed to measure a special case of the multipath possibilities, specifically, when there is a direct-path and only one reflected-path signal. In this experiment, there could be either surface- or bottom-reflected paths. This limited the applicability of the program in the general multipath environment because it could not handle the situation in which both a surface- and bottom-reflected signal were present. To move beyond this limitation, the TDS program was modified, as recommended by Brekke [Ref. 1:p. 71], to incorporate all possible received signal combinations. These program improvements allow the program to record surface and bottom reflections independently.

The program modifications to allow analysis of the general case were made only to the Quick_Analysis and Normal_Analysis routines. To modify the Auto_Analysis routine would require a complete reworking of this portion of the software. In addition, since substantial operator interface is required to distinguish between the surface and bottom reflections, the final product of the Auto_Analysis routine, upon implementation of the changes, would closely resemble that of the Normal_Analysis routine.

V. EXPERIMENTAL DATA AND ANALYSIS

The results of the TDS portion of the tests are presented first. This includes a detailed discussion of the particular geometry and analyzer conditions used, and the suitability of these choices. This is followed by a discussion of the results of the continuous-wave measurements.

A. TDS Geometry and Analyzer Settings

As described earlier, the range between source and receiver was approximately 650 yards. Table I gives the expected time delays relative to the arrival of the direct- path signal for the surface- and bottom-reflected paths for the source and receiver depths utilized. These calculations are for a water depth of 600 feet, with an isovelocity sound speed profile of 4850 ft/sec. The assumption of an isovelocity sound speed profile is in general not an accurate assumption for Dabob Bay. However, for the purpose of obtaining approximate propagation times, and further comparing the delay times between paths, this assumption is adequate.

When examining Table I, two points must be considered. First, the time delay for the surface- and/or bottom-reflected path must be greater than the analyzer observation time. Second, the observation time of the analyzer must be set to ensure that the energy contained in each signal is received in a separate frequency bin.

Table I TIME DELAYS RELATIVE TO THE DIRECT PATH SIGNAL FOR SURFACE AND BOTTOM-REFLECTED PATHS

Receiver Depth (ft)	Source Depth (ft)	t_a (ms)	t_b (ms)	t_a-t_b (ms)
240	200	10.0	29.4	19.4
	300	14.9	22.2	7.3
	400	19.8	14.9	4.9
300	200	12.5	24.6	12.1
	300	18.6	18.6	0.0
	400	24.6	12.5	12.1
340	200	14.1	21.4	7.3
	300	21.0	16.2	4.9
	400	27.8	10.9	16.9

Sound Speed: 4850 ft/sec
Water Depth: 600 ft
Range: 650 yards

As a first try, the decision was made to use a 50 kHz frequency span. However, the resolution of the analyzer with this frequency span was not sufficient to resolve the reflected signals. Consequently, a frequency span of 20 kHz, with a corresponding 20 ms observation time, had to be used. This limited the usable data to certain specific cases. Table II shows the source and receiver depth combinations for these cases. Only these data were used for further analysis.

Table II SOURCE/RECEIVER DEPTHS USED FOR TDS DATA ANALYSIS

Receiver Depth (ft)	Source Depth (ft)	t_a (ms)
240	400	19.8
300	300	18.6
	400	24.6
340	300	21.0
	400	27.8

Sound Speed: 4850 ft/sec
Water Depth: 600 ft
Range: 650 yds

B. TDS Results

The results for the TDS measurements are shown in Figure 6 through Figure 17.

1. 8 to 20 kHz Data

Each plot for the 8 to 20 kHz signal shows a drop-off in level at low frequencies, due to the transmitting characteristics of the Mark 69 source. Because the level between 8 and 10 kHz was low, acquisition of data at below 10 kHz was not possible, and thus, these plots represent data only from 10 to 20 kHz. Two plots are presented for each test run. This is due to the use of two different time steps in the TDS analysis. The time step is a user input which is used by the TDS program to increment the analyzer trigger during measurements. The trigger is delayed by a multiple of the time step prior to each measurement. One plot was analyzed using a time step of 50 ms. The other plot, with half as many data points, was analyzed using a time step of 100 ms.

Figure 6 and Figure 7 show the results for the 8 to 20 kHz signal, with source and receiver both located at 300 feet. In each plot the direct- and surface-reflected path curves possess a similar shape. At each frequency from 11 to 17 kHz, Figure 6 shows a difference in measured level of 6 to 10 dB.

For the same frequency range, Figure 7 shows a difference in measured level of 4 to 6 dB. The reason for the discrepancy in level between Figure 6 and Figure 7 is unclear, but is most likely due to a variation in propagation conditions.

Figure 8 and Figure 9 are for a source depth of 300 feet and a receiver depth of 340 feet. From 10 to 13 kHz the measured level difference is small, about 2 to 4 dB. From 14 to 18 kHz the difference in level becomes significantly larger and is on the order of 14 dB. From 18 to 19 kHz the difference in level returns to approximately 2 to 4 dB. The large change in level at the intermediate frequencies is unexpected, but is probably related to a change in the propagation conditions for the surface-reflected path.

Figure 10 and Figure 11 are for a source depth of 400 feet and a receiver depth of 240 feet. They resemble each other, and also the previous plots in the 10 to 20 kHz range. Here, however, the difference in level between direct- and surface-reflected paths is small. From 10 to 14 kHz the level difference is less than 1 dB. From 14 to 20 kHz the difference is approximately 2 dB.

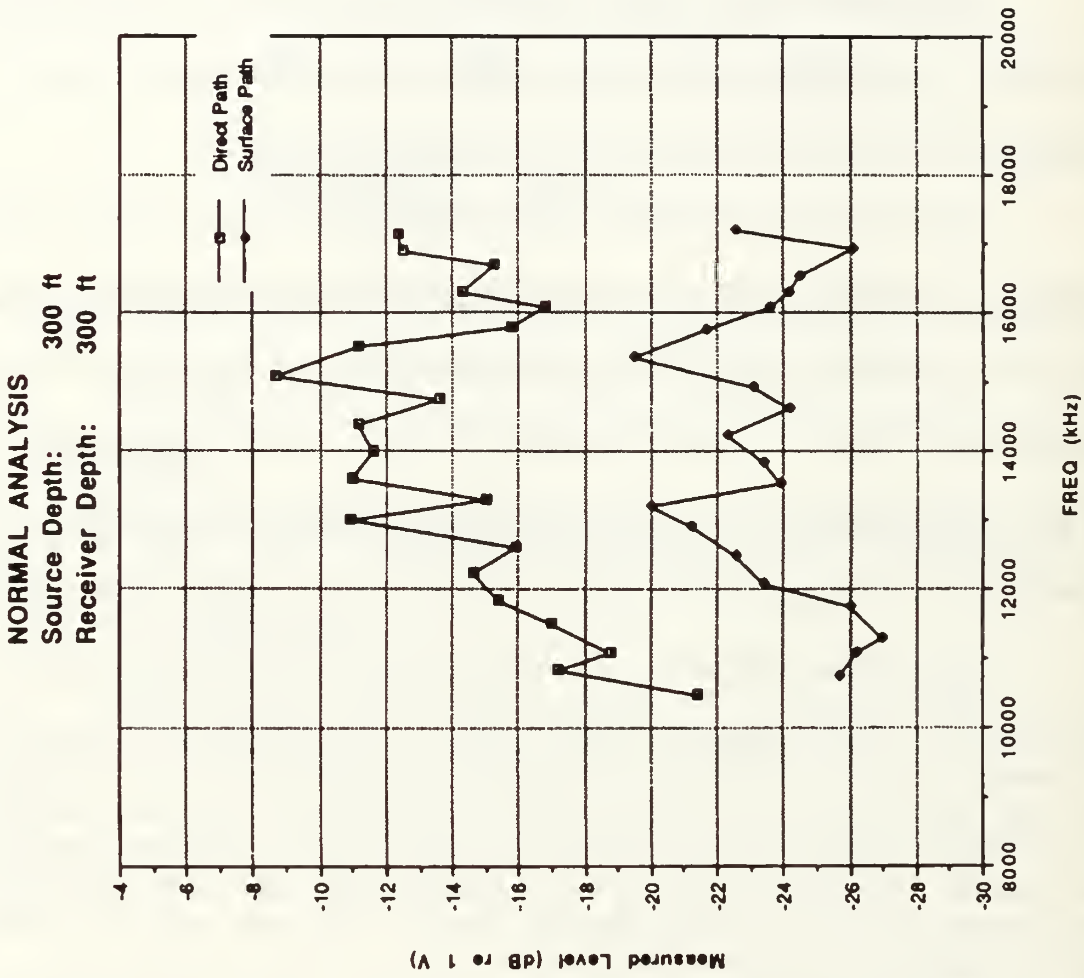

Figure 6 TDS Measured Level for 8 to 20 kHz
Source: 300 ft Receiver: 400 ft

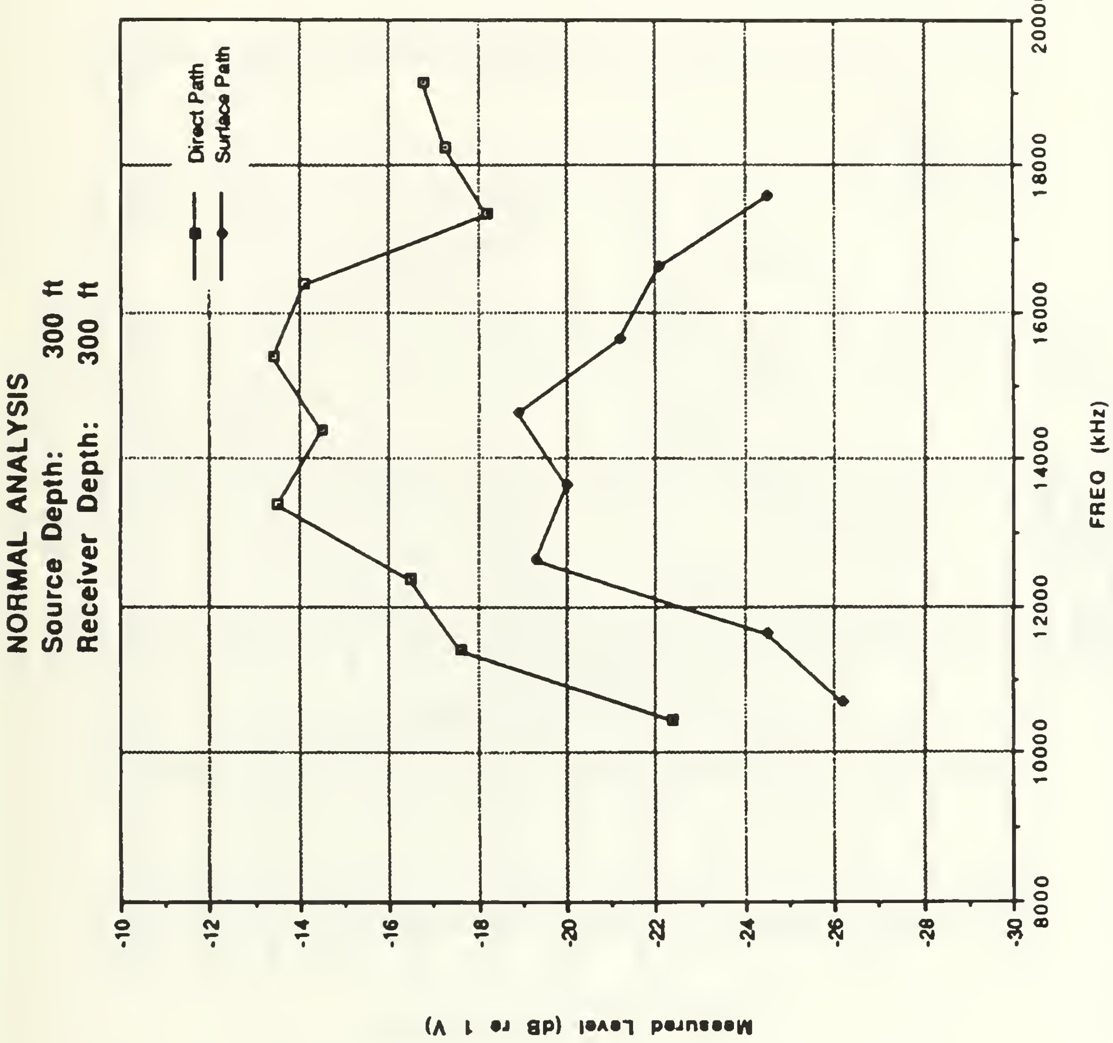

Figure 7 TDS Measured Level for 8 to 20 kHz
Source: 300 ft Receiver: 300 ft

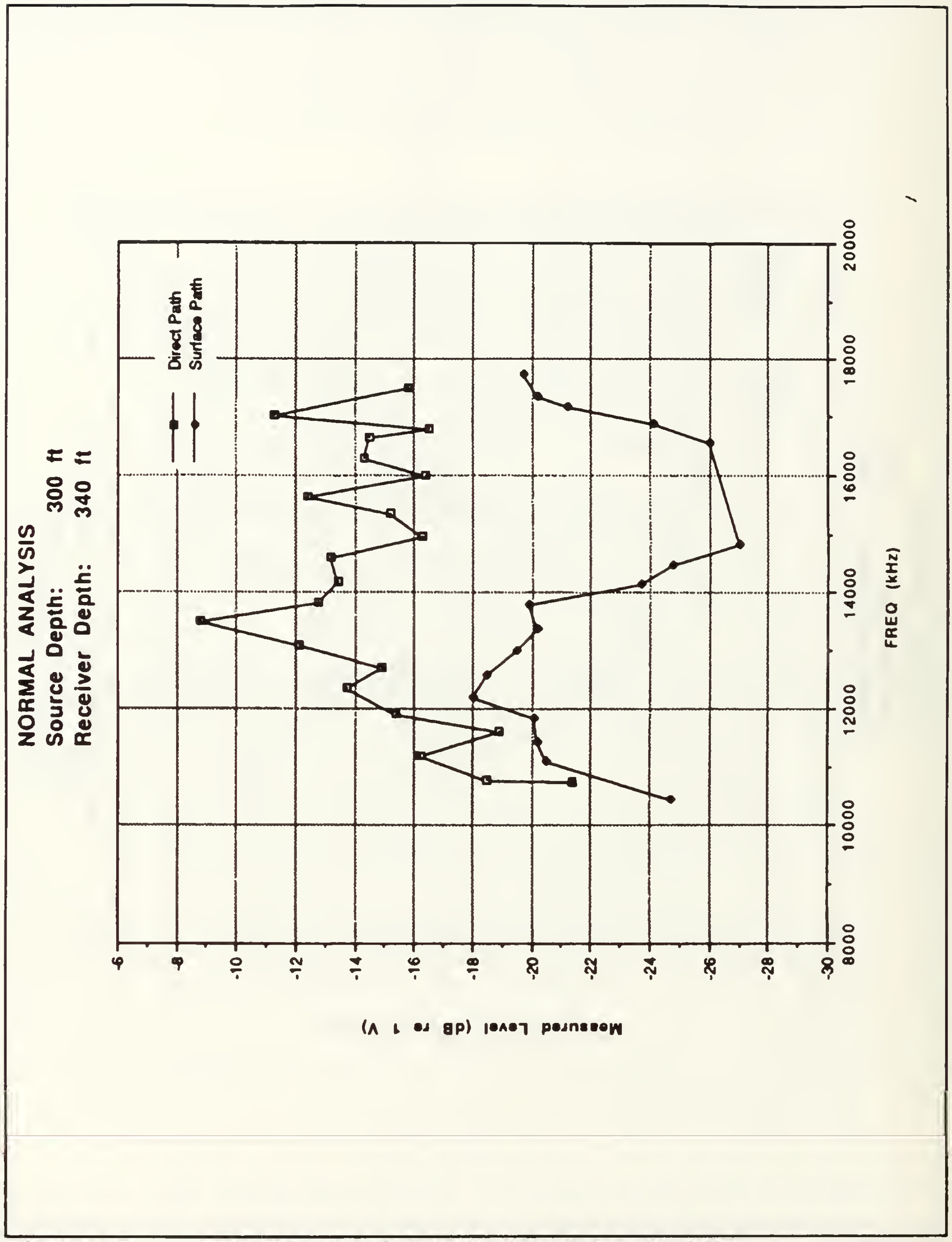

Figure 8 TDS Measured Level for 8 to 20 kHz
Source: 300 ft Receiver: 340 ft

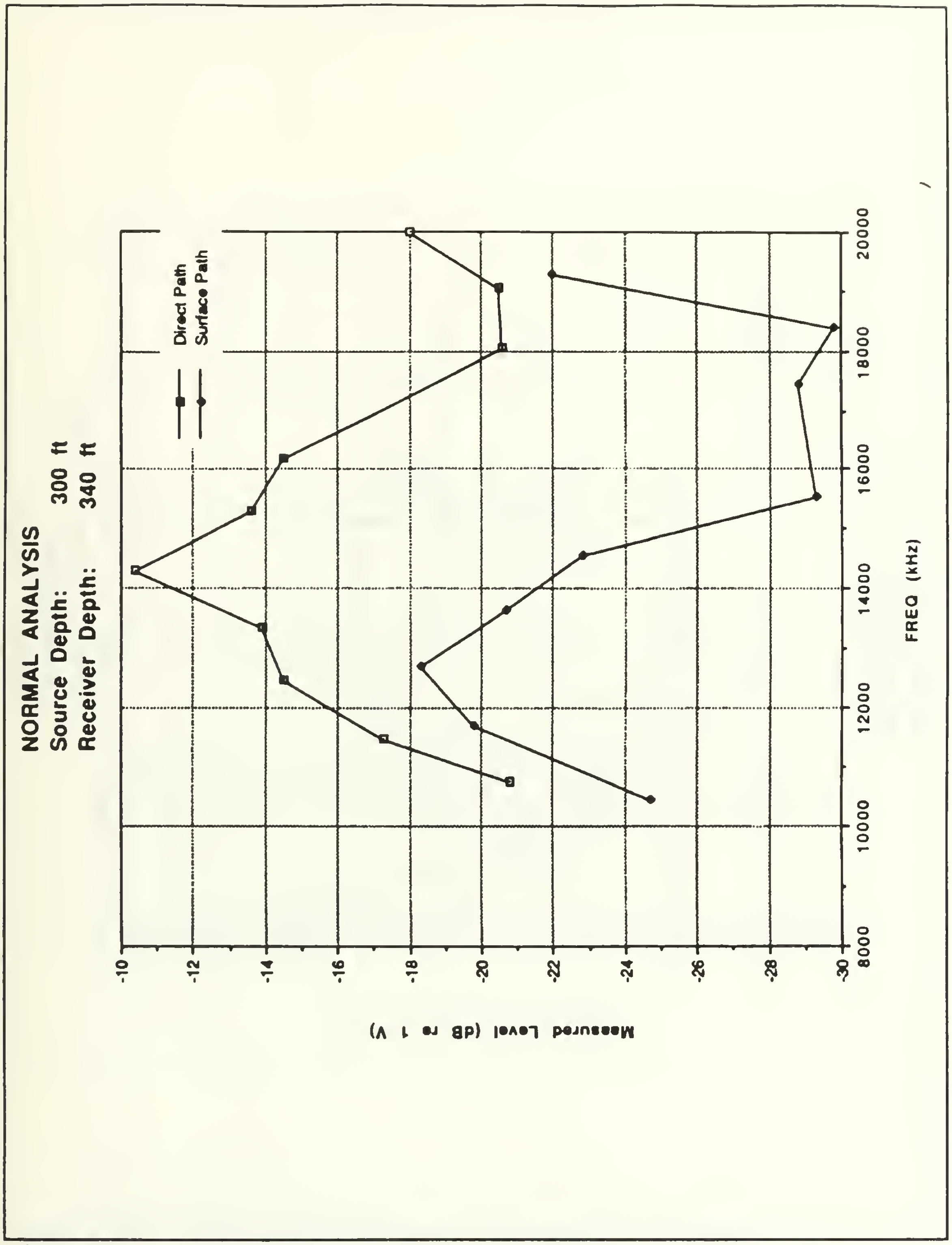

Figure 9 TDS Measured Level for 8 to 20 kHz
Source: 300 ft Receiver: 340 ft

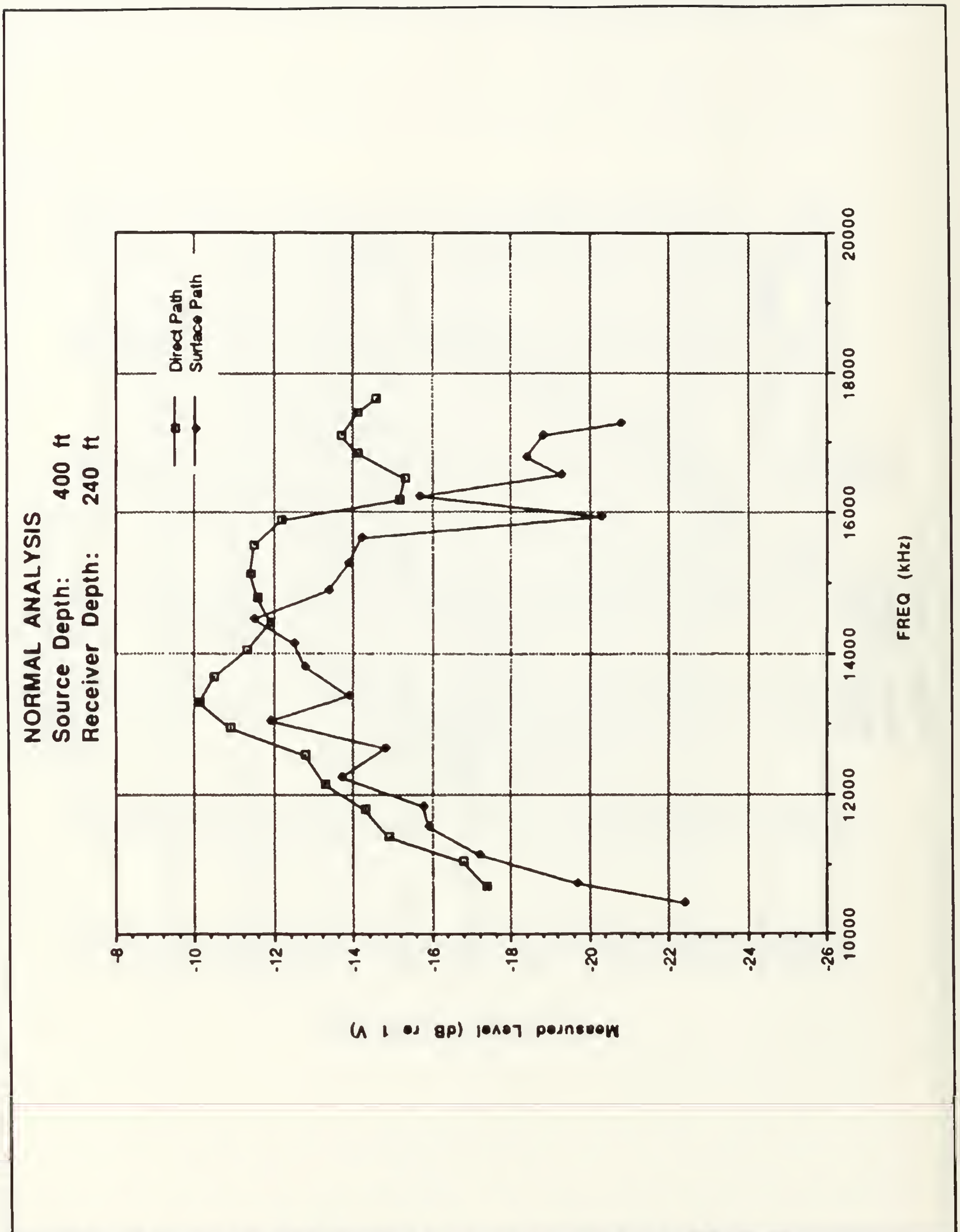

Figure 10 TDS Measured Level for 8 to 20 kHz
Source: 400 ft Receiver: 240 ft

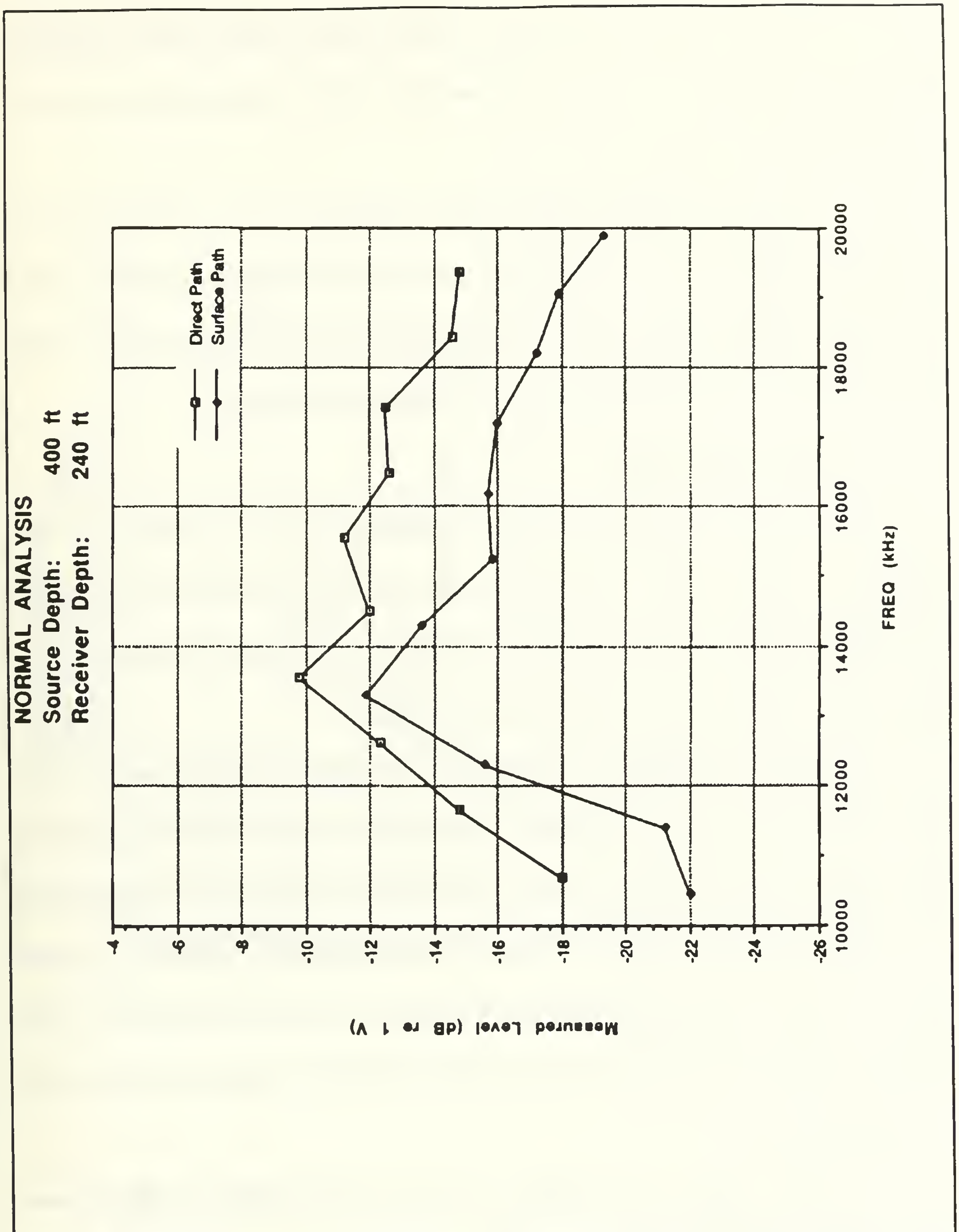

Figure 11 TDS Measured Level for 8 to 20 kHz
Source: 400 ft Receiver: 240 ft

Figure 12 is for a source depth of 400 feet and a receiver depth of 300 feet. Here the levels for the direct- and surface-reflected paths are essentially the same over the entire frequency range of 10 to 20 kHz.

Lastly, for the lower frequency data, is Figure 13 for a source depth of 400 feet and a receiver depth of 340 feet. Here the difference in measured level is consistently 5 dB between the direct- and surface-reflected paths. The exception is from 12 to 13 kHz, where the data points have the same measured level.

2. 20 to 40 kHz Data

In general, data taken at higher frequencies (20 to 40 kHz) did not produce meaningful, usable results. The data and subsequent plots produced were extremely noisy and appeared to be almost random. Presented here are those few high frequency data points that appear to have plausible interpretations.

Figure 14 and Figure 15 are for a source depth of 300 feet and a receiver depth of 340 feet. Here the difference in measured level between direct- and surface-reflected paths is 4 dB from 20 to 24 kHz. The difference then reduces to approximately 2 dB from 30 to 40 kHz. Figure 14 shows a lack of data from 23 to 30 kHz. A similar situation is seen in Figure 15, from 26 to 30 kHz. No data were acquired in these frequency ranges due to a synchronization problem between the tape recorded data and the TDS program.

Lastly, Figure 16 and Figure 17 are for a source depth of 400 feet and a receiver depth of 340 feet. These curves are the only ones presented in this thesis that bear little resemblance to one another. For the same reason as explained in the

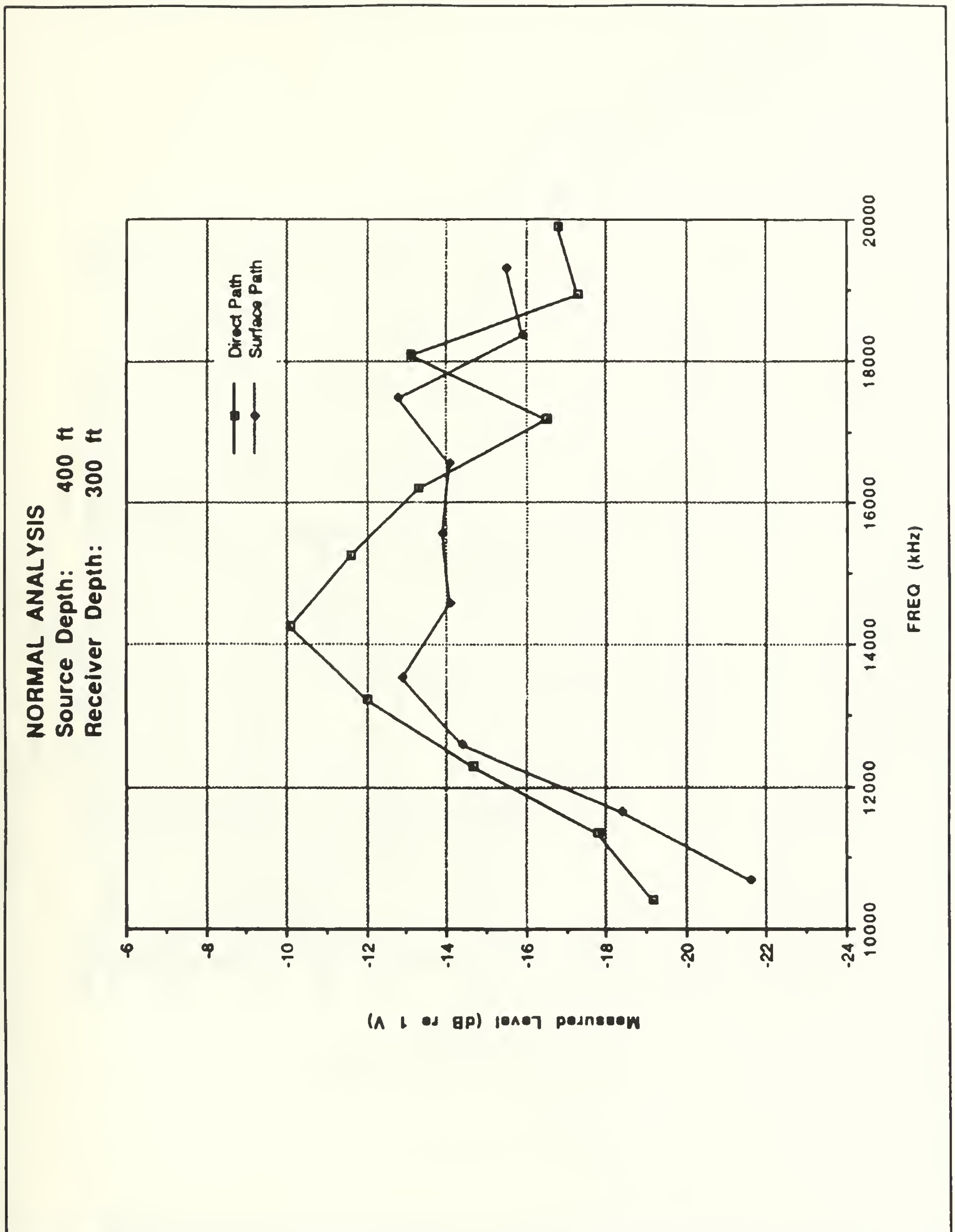

Figure 12 TDS Measured Level for 8 to 20 kHz
Source: 400 ft Receiver: 300 ft

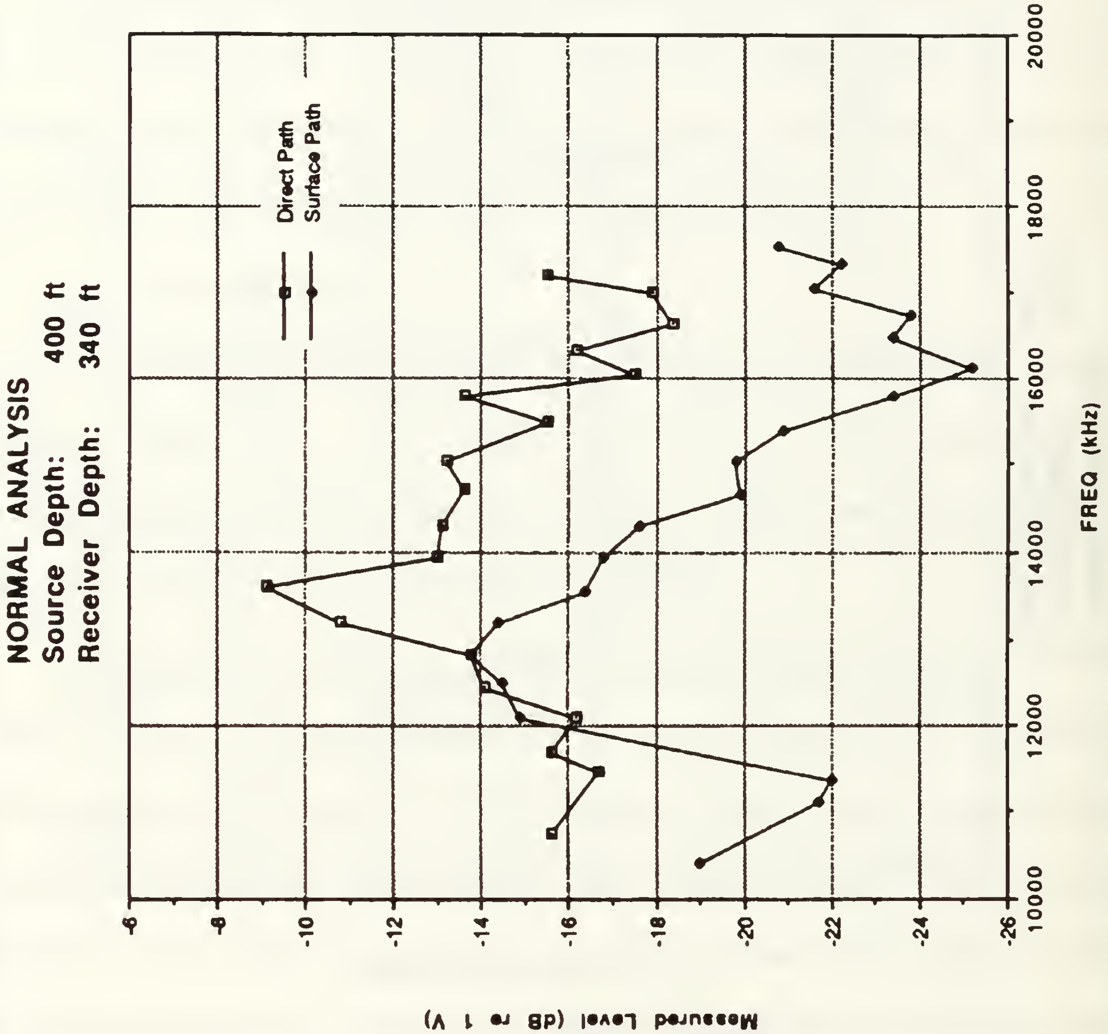

Figure 13 TDS Measured Level for 8 to 20 kHz
Source: 400 ft Receiver: 340 ft

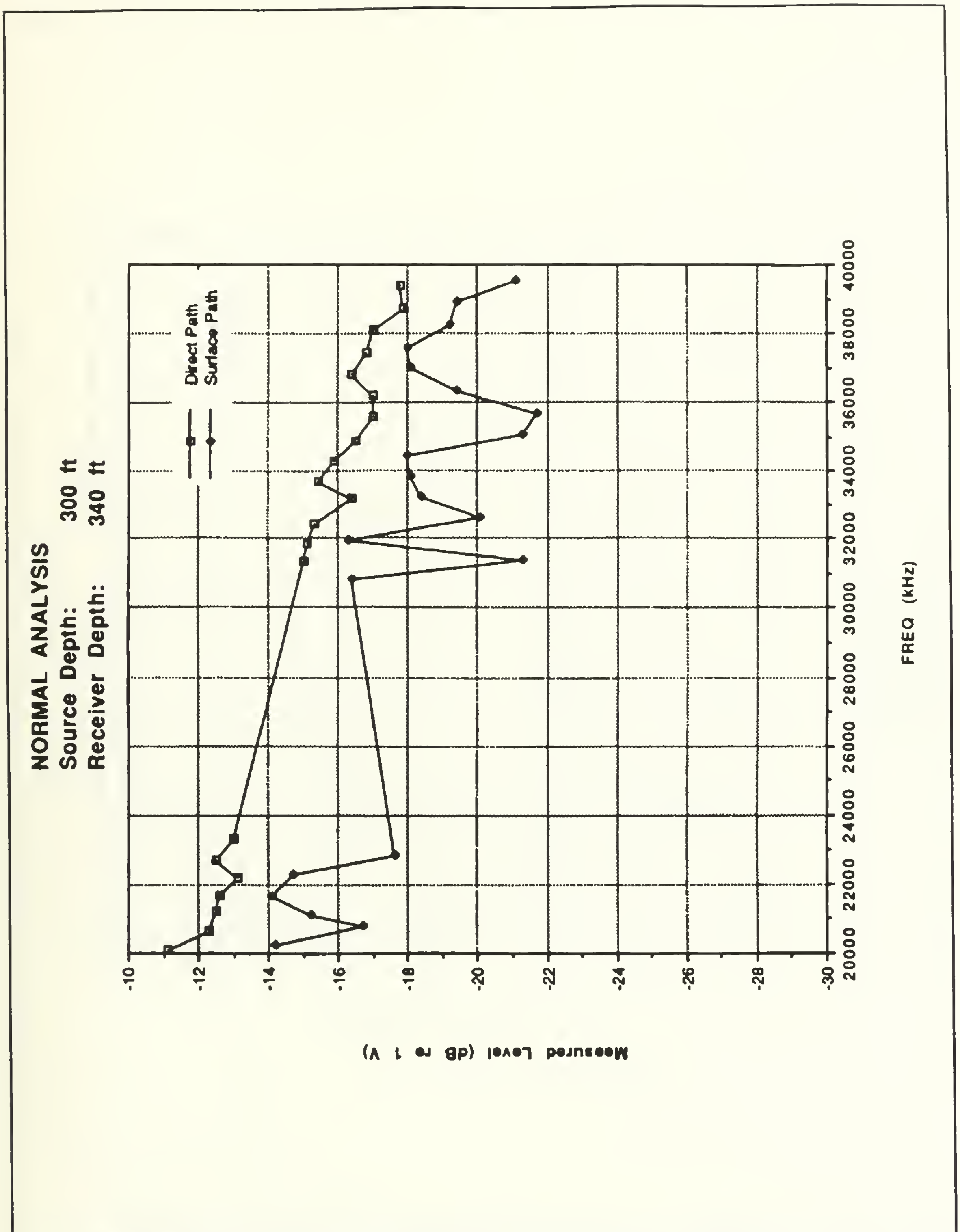

Figure 14 TDS Measured Level for 20 to 40 kHz
Source: 300 ft Receiver: 340 ft

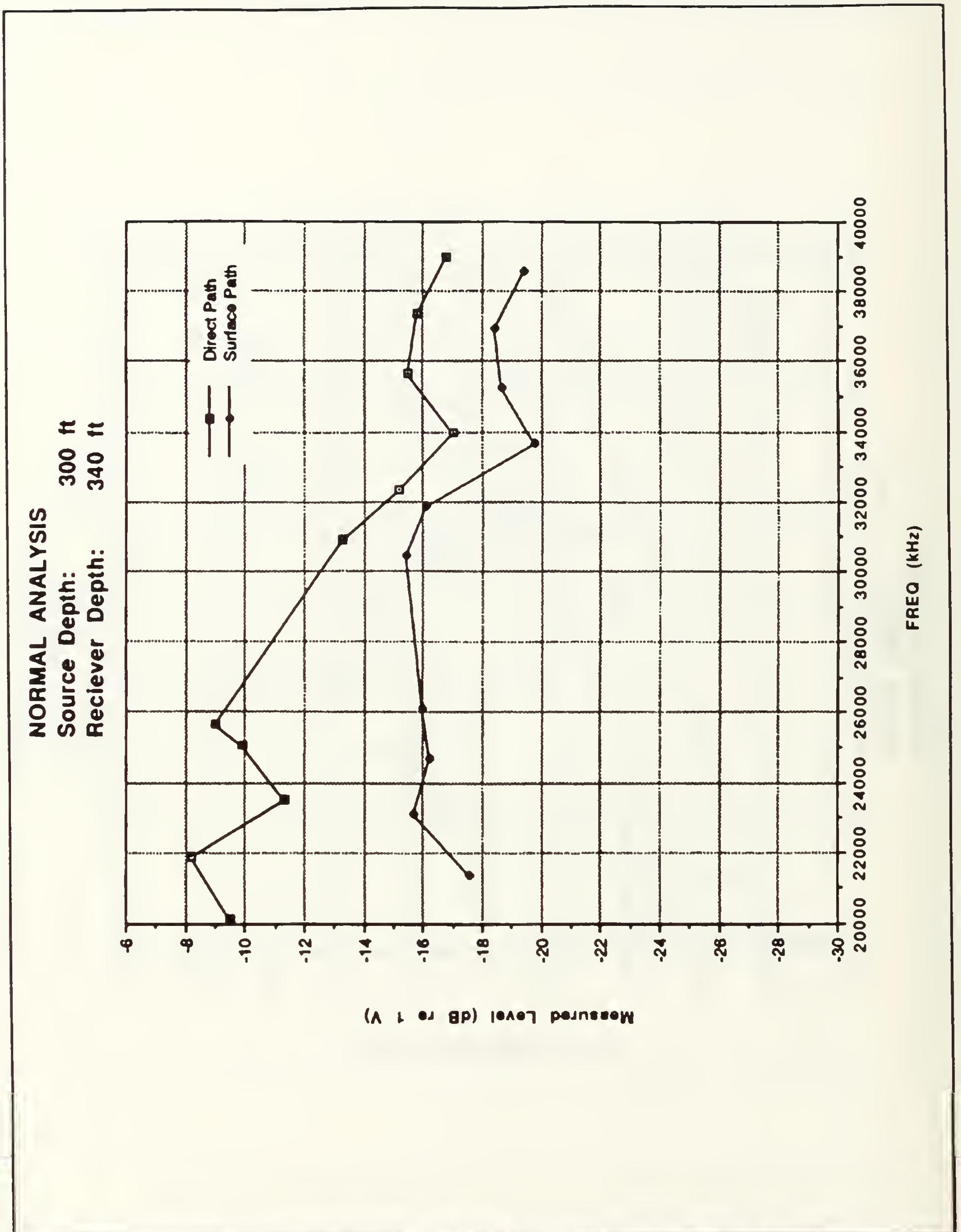

Figure 15 TDS Measured Level for 20 to 40 kHz
Source: 300 ft Receiver: 340 ft

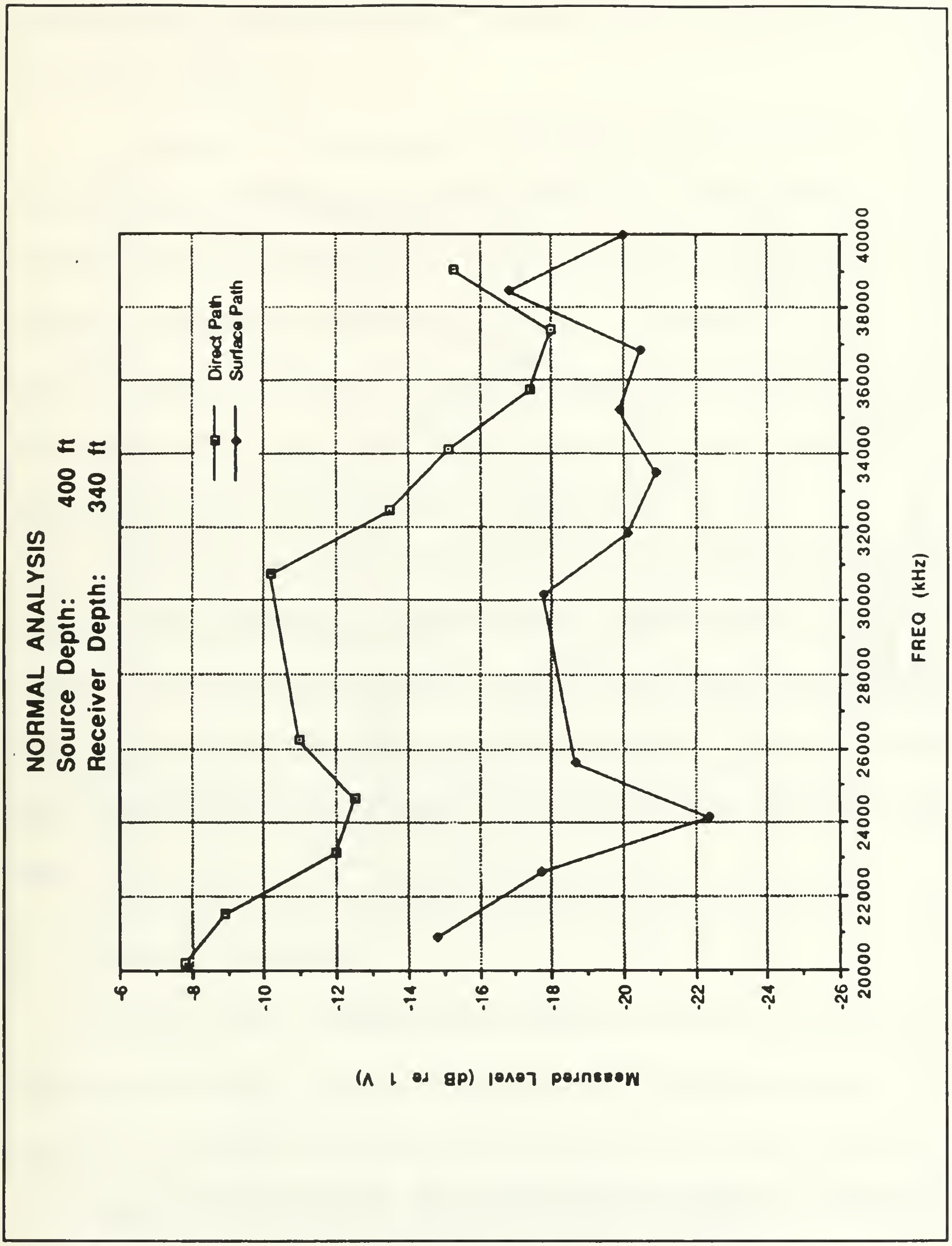

Figure 16 TDS Measured Level for 20 to 40 kHz
Source: 400 ft Receiver: 340 ft

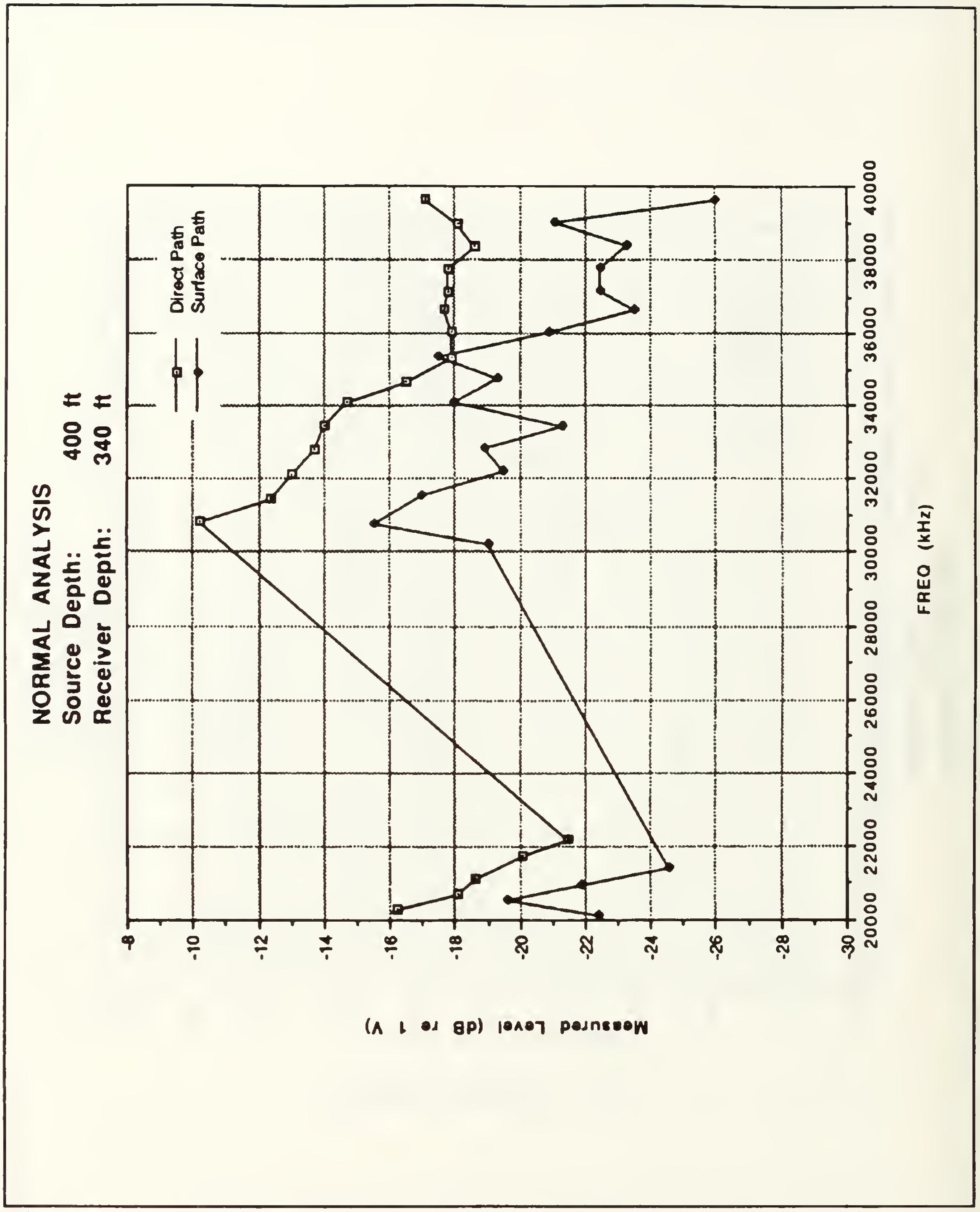

Figure 17 TDS Measured Level for 20 to 40 kHz
Source: 400 ft Receiver: 340 ft

previous paragraph, no data were acquired from 26 to 30 kHz for Figure 16, and from 22 to 30 kHz for Figure 17.

In Figure 16, the direct-path curve has a shape as expected, based on previous plots. In this curve, the difference in measured level is 6 to 7 dB from 20 to 34 kHz. From 34 to 40 kHz, the difference reduces to 1 to 2 dB. Figure 17, however, shows an unexpectedly low measured level at low frequencies, then changes to a more typical level. Regardless of this change, the difference between the levels of the direct- and surface-reflected paths is on the order of 4 dB throughout the entire frequency range. This is several dB less than the difference observed in Figure 16.

Although it cannot be seen from the plots presented, data analysis indicated the lack of a bottom-reflected path. If bottom reflections had been present, these should have been observed on the analyzer display during the shallow source and receiver data points. Such reflections were not observed during data analysis. It is believed that this is due to the low reflection coefficient from the soft clay sediments of the Dabob Bay range.

C. Continuous- Wave Results

As discussed earlier, a continuous wave method was employed as an alternative experimental technique to determine the magnitude of the reflections present in the reception of a range signal. The limitation of this method is that it does not provide a way to distinguish between surface- and bottom-reflections. However, as noted in the previous section, the collected data yielded no evidence of a bottom-reflected signal. For this reason, the variations in the magnitude of the received signal are believed to be solely the result of variations in the strength of the surface reflection.

It is important at this point to make a clarifying remark concerning the processing and plotting of this data. Processing was achieved using the TDS program. Since these data are simply the acoustic levels at a single frequency, namely 8 kHz, use of the TDS program was not necessary. It would have been simpler to manually operate the analyzer, and record the signal levels. However, the TDS program provides printed and graphical output, which eases data analysis and presentation. It also provides a means for presenting the variations in level with time during the test. The analysis of these data was done using the Normal_Analysis routine. Each output data point is the result of eight RMS averages. The separation in time between successive data points is approximately one minute.

The results are presented in two slightly different formats. The first format is to plot each test event independently. This produces a plot of the received signal for each of the three individual hydrophones of the NRS array. These plots, shown in Figure 18 to Figure 22, are for increasing depths of the center hydrophone from 300 to 400 feet in 25 foot increments. The second format is to plot the received signal from each hydrophone versus time for each of the five depths of the upper, center, and lower hydrophones. These plots are shown in Figure 23 through Figure 25.

The first four plots, Figure 18 to Figure 21, all show similar results. In all four, the difference between the maximum and minimum curve is approximately 4 dB. For each plot this 4 dB difference corresponds to a depth change of 100 feet.

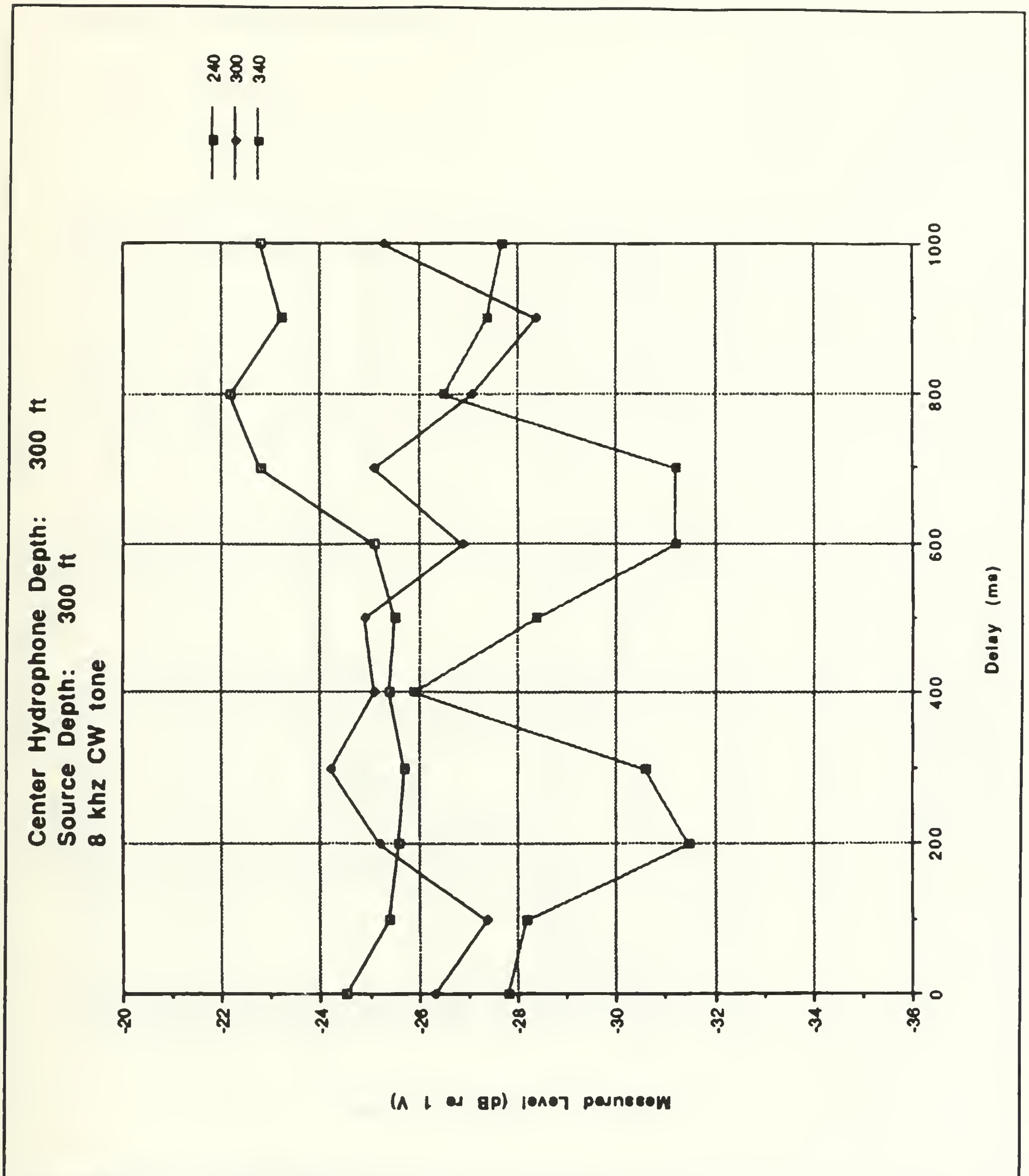

Figure 18 8 kHz CW tone All NRS Hydrophones
Center Hydrophone Depth: 300 ft

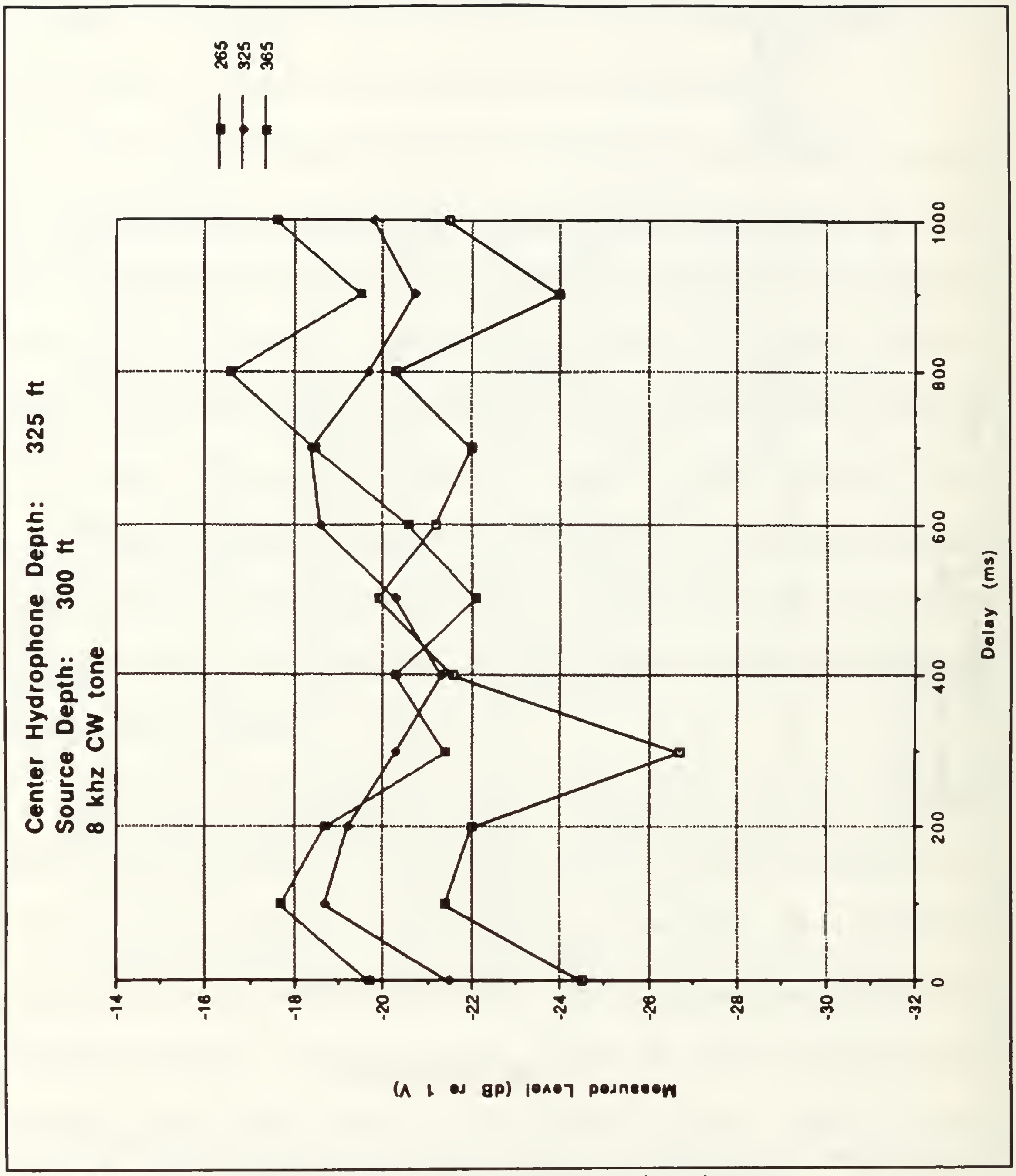

Figure 19 8 kHz CW Tone All NRS Hydrophones
Center Hydrophone Depth: 325 ft

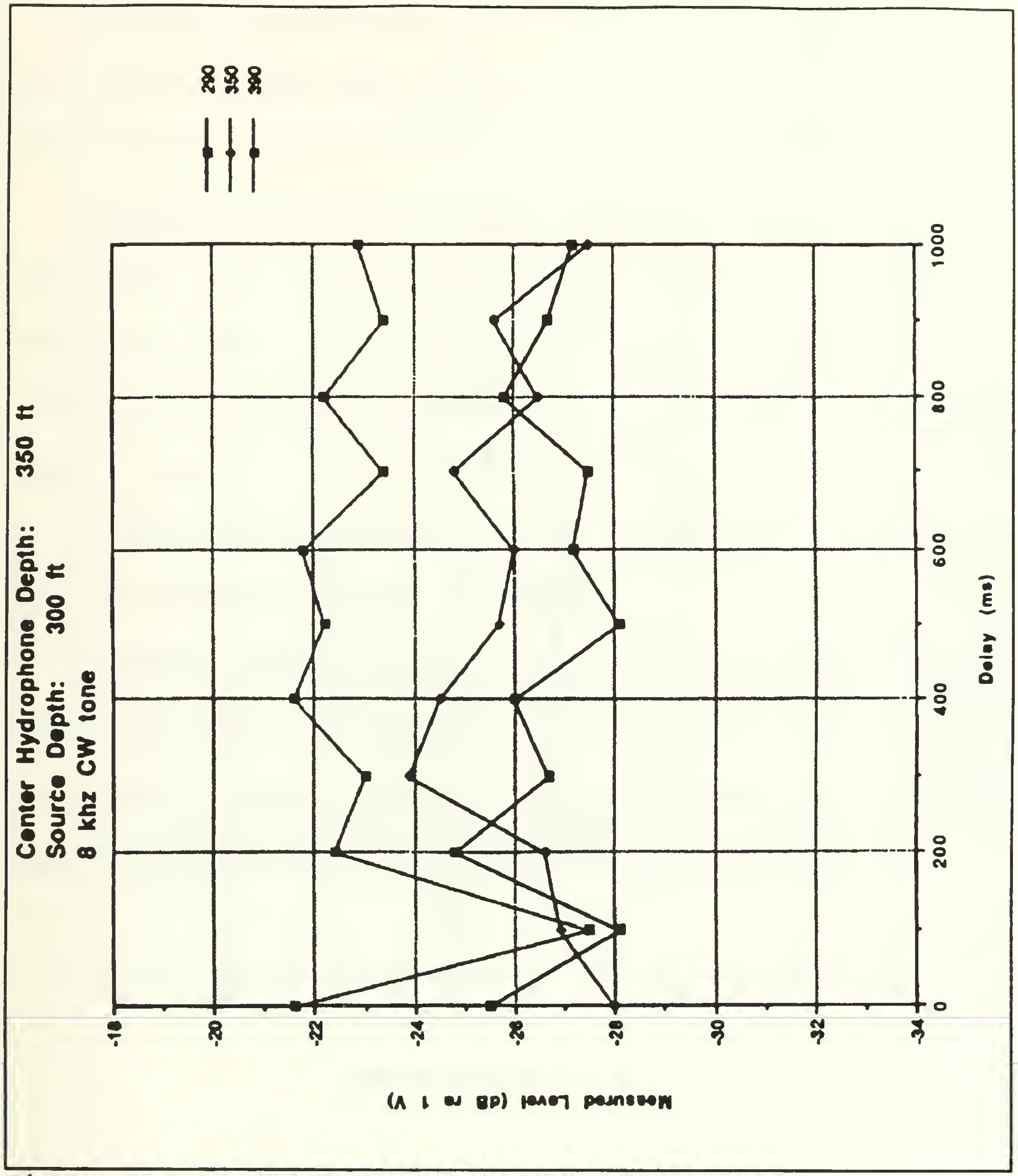

Figure 20 8 kHz CW Tone All NRS Hydrophones
Center Hydrophone Depth: 350 ft

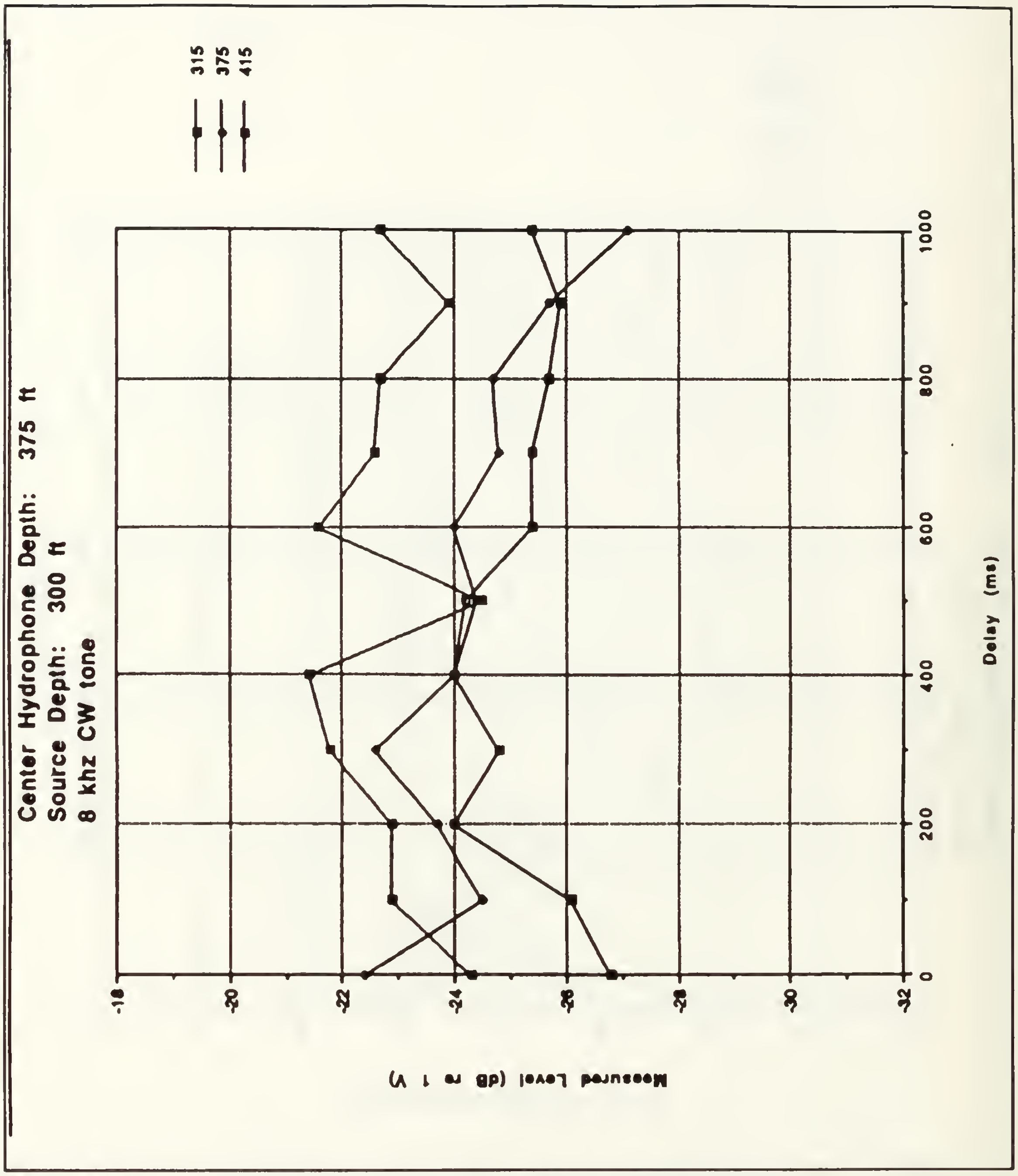

Figure 21 8 kHz CW Tone All NRS Hydrophones
Center Hydrophone Depth: 375 ft

The last plot, Figure 22, shows results which are dissimilar. Here the maximum change observed is approximately 8 dB, almost twice that seen in the previous plots. This 8 dB change is essentially the same for both the 60 and 100 feet depth differences.

Table III shows the calculated average level and standard deviation for each of the above figures. Table III also indicates a variation in the received levels for the upper hydrophone of between -21.9 to -30.7 dB, or a difference of 8.8 dB. The range in received levels for the center hydrophone is -19.7 to -29.7 dB, or a difference of 10 dB. Similarly, the range for the lower hydrophone is -19.0 to -28.4 dB, or a difference of 9.4 dB. As can be seen both in Figure 23 to Figure 25 and in Table III, the intermediate curves of each hydrophone have the same approximate value.

In summary, analysis of all the continuous-wave plots presented allows one major conclusion to be drawn. There appears to be a variation of up to 10 dB in the received level, believed to be due to the constructive and destructive interference patterns between sound travelling by a direct path and sound involving one surface reflection.

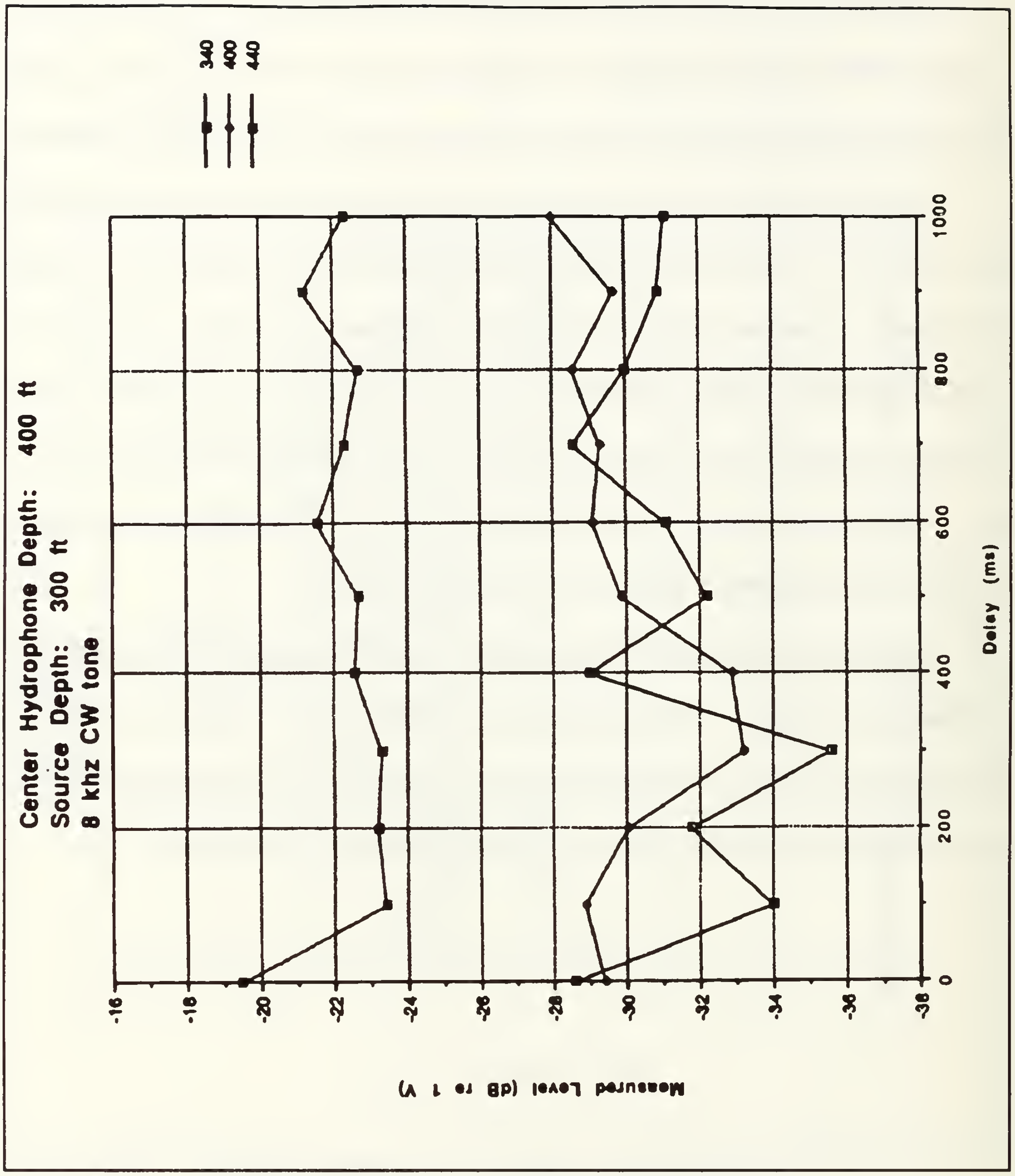

Figure 22   8 kHz CW Tone All NRS Hydrophones
Center Hydrophone Depth: 400 ft

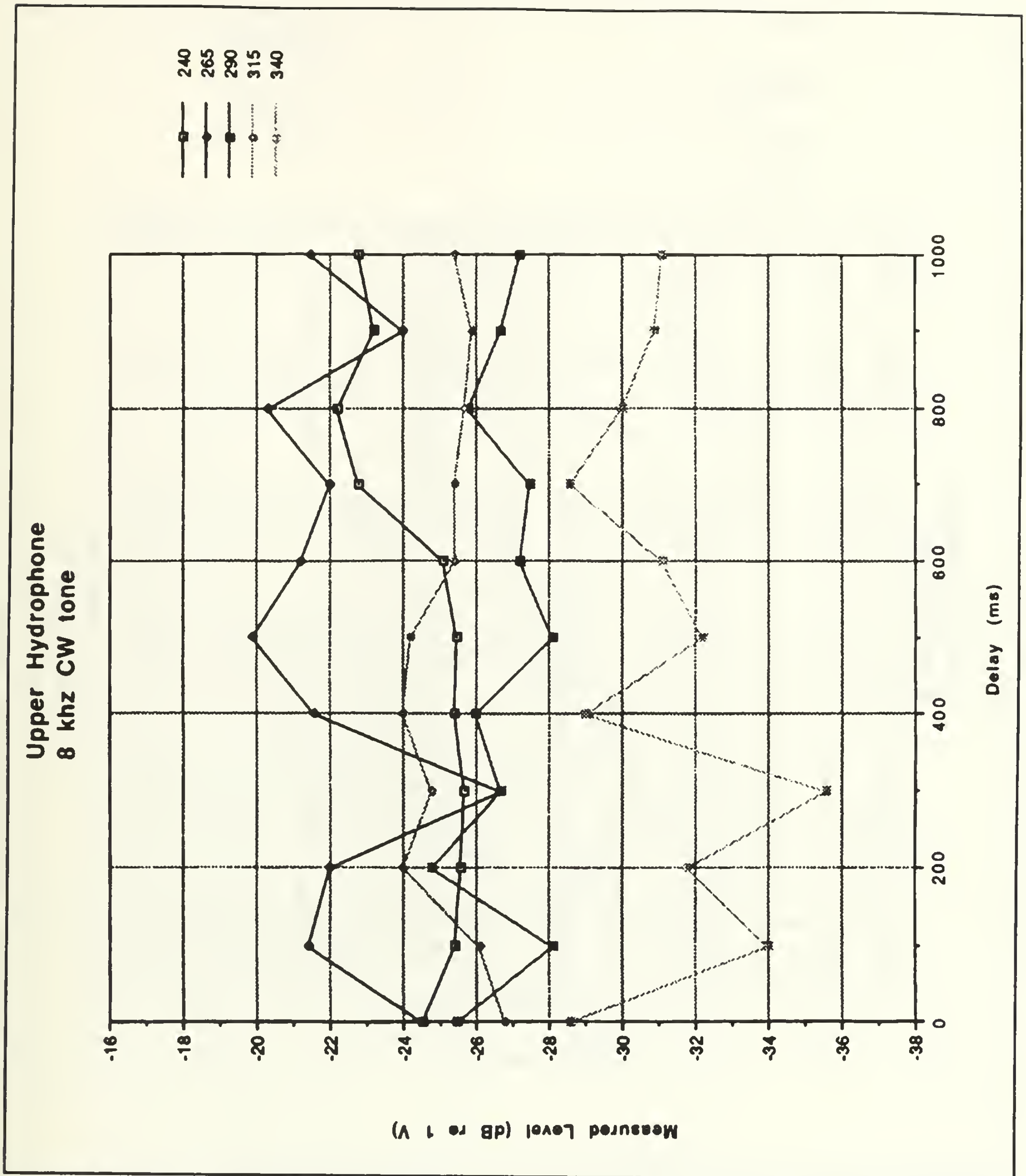

Figure 23 8 kHz CW tone
Upper hydrophone only

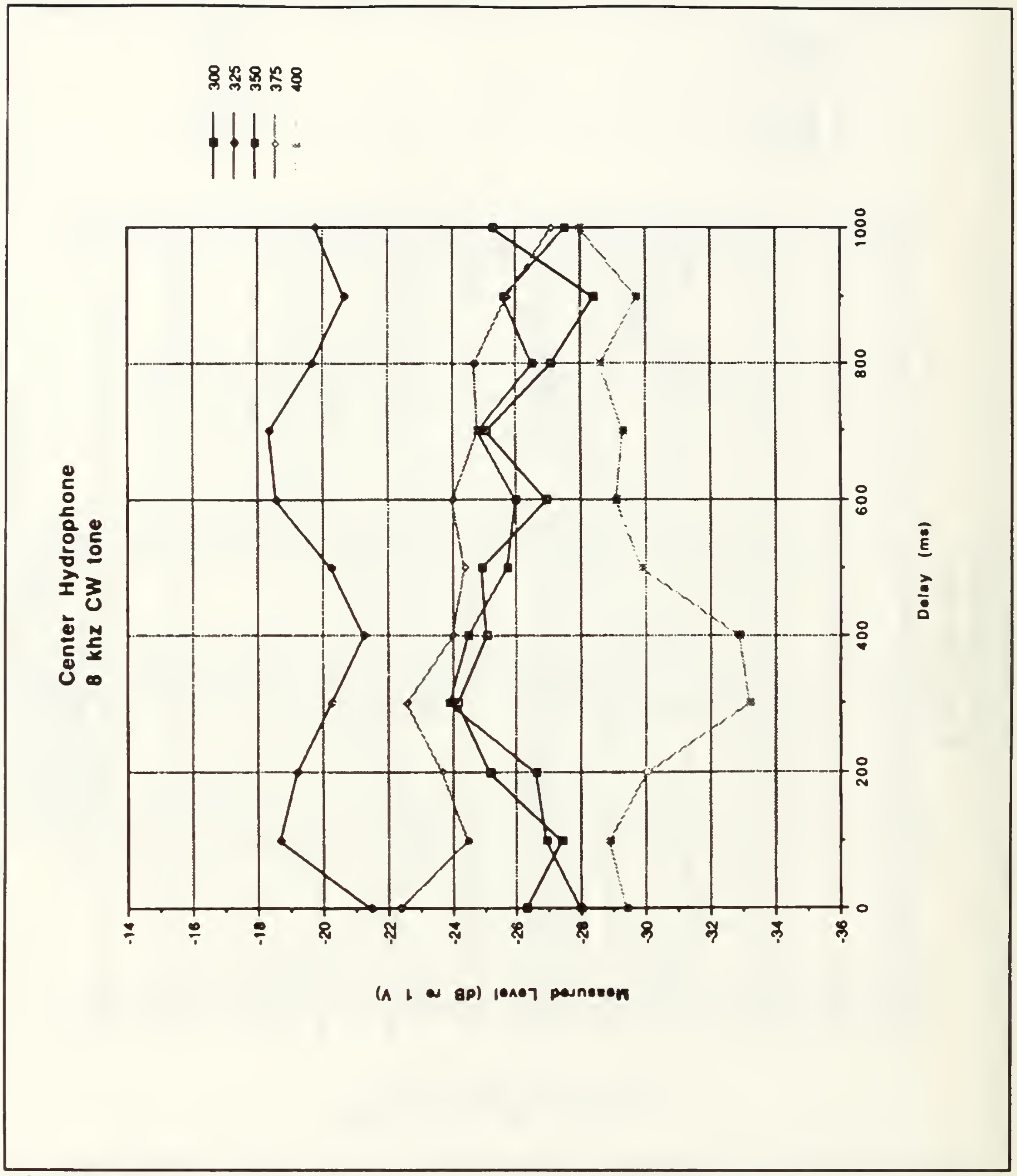

Figure 24 8 kHz CW tone
Center hydrophone only

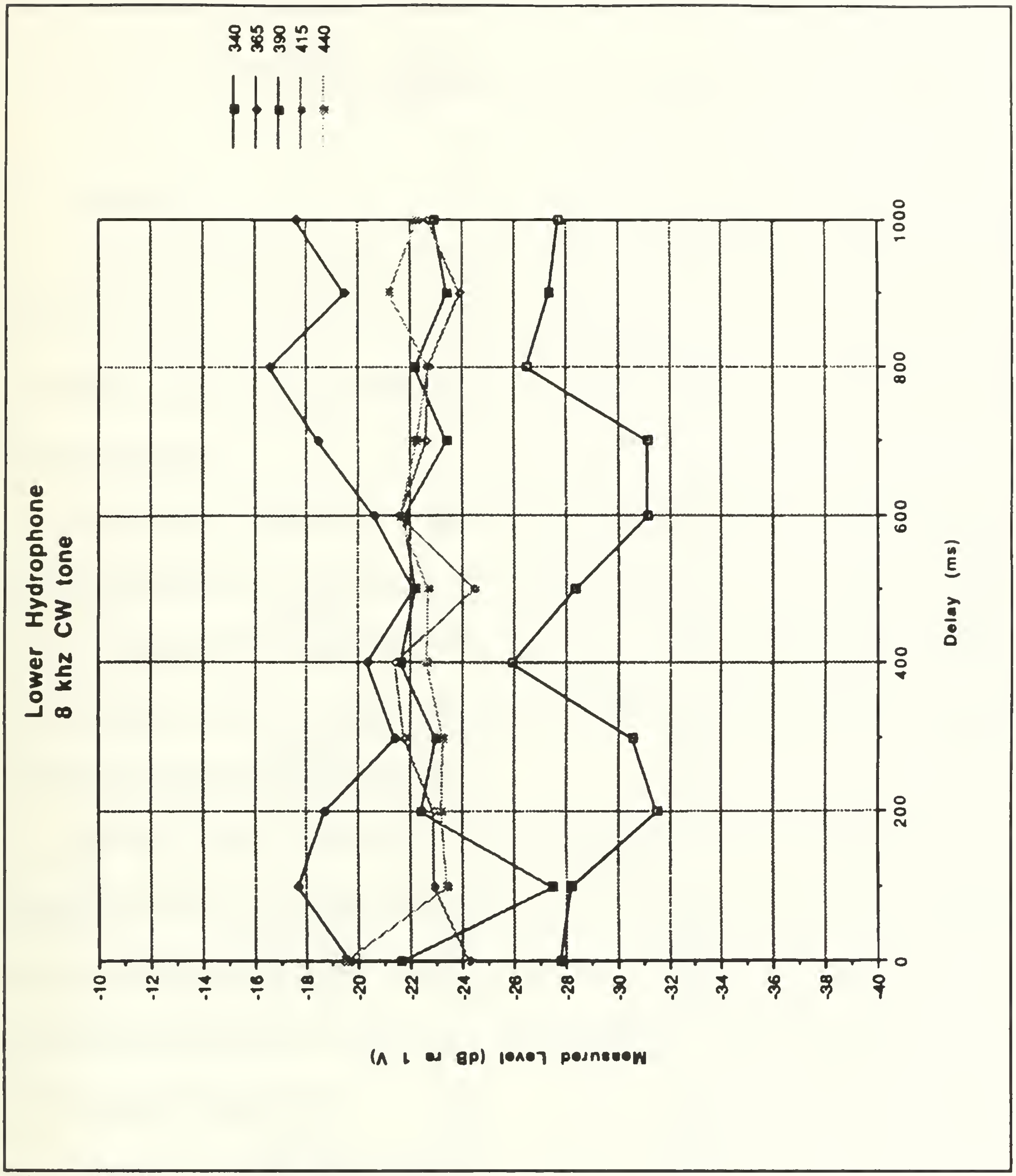

Figure 25 8 kHz CW tone
Lower hydrophone only

Table III AVERAGE LEVEL AND STANDARD DEVIATION OF EACH HYDROPHONE FOR AN 8 KHZ CW SIGNAL

Hydrophone	Depth	Average Level (dB)	Standard Deviation (dB)
	Figure 18		
Upper	240	-24.2	+1.3 , -1.7
Center	300	-25.8	+1.1 , -1.5
Lower	340	-28.4	+1.6 , -2.4
	Figure 19		
Upper	265	-21.9	+1.4 , -1.4
Center	325	-19.7	+0.9 , -1.2
Lower	365	-19.0	+1.4 , -2.2
	Figure 20		
Upper	290	-26.6	+1.0 , -1.2
Center	350	-25.8	+0.9 , -1.5
Lower	390	-22.7	+1.1 , -1.4
	Figure 21		
Upper	315	-25.2	+0.9 , -1.0
Center	375	-24.1	+1.0 , -2.6
Lower	415	-22.7	+0.9 , -1.2
	Figure 22		
Upper	340	-30.7	+1.6 , -2.5
Center	400	-29.7	+1.2 , -1.6
Lower	440	-22.1	+1.2 , -1.6
	Figure 23		
Upper	240	-24.2	+1.3 , -1.7
	265	-21.9	+1.4 , -1.4
	290	-26.6	+1.0 , -1.2
	315	-25.2	+0.9 , -1.0
	340	-30.7	+1.6 , -2.5
	Figure 24		
Center	300	-25.8	+1.1 , -1.5
	325	-19.7	+0.9 , -1.2
	350	-25.8	+0.9 , -1.5
	375	-24.1	+1.0 , -2.6
	400	-29.7	+1.2 , -1.6
	Figure 25		
Lower	340	-28.4	+1.6 , -2.4
	365	-19.0	+1.4 , -2.2
	390	-22.7	+1.1 , -1.4
	415	-22.7	+0.9 , -1.2
	440	-22.1	+1.2 , -1.6

VI. DISCUSSION AND CONCLUSIONS

A. Discussion

The ultimate goal of this research is to determine the transmission loss along each propagation path in Dabob Bay as a function of frequency. At a minimum, the goal is to develop a reasonable understanding of the importance of the reflected paths to the sound propagation.

To accomplish this goal, a modified TDS technique developed by Brekke [Ref. 1], and a continuous-wave technique were implemented. Unfortunately, due to the inability to acquire data at 8 kHz using the TDS method, a direct comparison of the two methods is not possible. However, comparisons between the lower frequency TDS data and the continuous wave 8 kHz data are useful.

The TDS results showed a difference between levels for direct- and surface-reflected paths from 2 to 10 dB at frequencies from 10 to 12 kHz. The continuous-wave results showed a similar variation in level difference. Therefore, the results of each test are consistent with respect to the relative contribution of the surface-reflected path to the overall received signal.

A calculation demonstrating the effect of the surface interference is useful at this point. A typical difference between the levels of the direct- and surface- reflected signals is approximately 6 dB, corresponding to a pressure ratio of 2 to 1. The ratio of the pressure when the signals combine constructively, to the pressure when the signals combine destructively is 3. Therefore, the total level change is 20 log3 or approximately 9.5 dB. This total level change is consistent with the results obtained using the continuous- wave method.

A closer examination of the transmitting characteristics of the Mark 69 source provides additional insight into the significance of the surface reflections. Referring back to Figure 1, θ is the angle made with the horizontal of the sound ray which reflects from the surface and is received by the appropriate hydrophone of the NRS array. Using source depths of 200, 300, and 400 feet, with the NRS array hydrophone depths of 240, 300, and 340 feet, it can be shown the minimum and maximum values of θ are 12.7 and 20.7 degrees, respectively. At 20 kHz and θ = 20 degrees, the output of the Mark 69 is down approximately 3 dB. This would imply the effect of the surface reflection is even more pronounced than the above calculation shows.

Although the TDS program has in the past been proven to be an effective tool, several situations arose which prevented achieving a satisfactory end. The first consideration was the geometry used for the range testing. Since funding was a critical factor in the planning and execution of these tests, existing range equipment was used. Consequently, as discussed in Chapter IV, several data points failed to meet the most important criterion of the modified TDS technique, namely the requirement that the time delay of the reflected-path signal relative to the direct-path signal be greater than the analyzer observation time. Examination of expected propagation times versus range in Dabob Bay yields a maximum realistic TDS range of 400 yards. Ranges beyond this can easily produce situations such as those experienced in this research where the reflected signal time delays are less than the analyzer observation time.

Another concern was the attempt to obtain too much data. Due to the length of time needed to process data using the TDS program, analysis of data from 8 to 40 kHz was too ambitious. A more reasonable and useful approach would have been to examine one or, at most, two 10 kHz frequency ranges, for example, 10 to 20 kHz.

The TDS software developed by Brekke, and modified by Prudhomme, has been modified yet again. The most recent modifications allow the program to be used in the general case where the reflected signal can be either surface, bottom, or if inadequate separation exist, a combination of both. This modification requires no additional action by the operator, with the exception of being presented more options from which to choose while making signal identification.

Employment of this software in the future should entail one additional modification. The plotting routine utilizing the HP 7470A plotter is extremely slow and somewhat unreliable. In the future, it is recommended the numerical output produced on the HP Thinkjet printer be used with a personal computer to produce the desired plots. This would significantly reduce waiting time and therefore would result in more productive analyses.

B. Conclusions

Both the modified TDS and the continuous-wave techniques provide the ability to collect useful information about a signal propagating by direct and reflected paths. Due to fluctuations inherent in propagating sound in a large body of water, large quantities of data typically need be collected in order to estimate the transmission loss parameters. The expense and manpower required to collect and analyze such data indicates that the use of either technique is not realistic.

The application of the continuous-wave technique has an additional drawback, namely that data is taken for only one frequency at a time. For this reason, the amount of data required for the range, depth, and frequencies desired would be rather large, and this again raises the question of practicality.

Despite the drawbacks of these methods, several conclusions can be drawn. Both techniques confirm that the surface-reflected path is a significant contributor to the observed sound levels. Another conclusion from the TDS testing is that the bottom-reflected sound is much smaller than the surface-reflected sound at the ranges and depths used in these tests.

In consideration of the above conclusions, two recommendations are presented. One recommendation is to develop a system which actually determines transmission loss for the current range conditions shortly before a test. Another prospective approach is to use a vertically oriented directional receiving array located at the same depth as the source to be measured. Properly designed, this system would effectively eliminate the surface-reflected sound from the direct-path signal.

LIST OF REFERENCES

1. Brekke, Bjoern, Development of a Modified Time Delay Spectrometry Technique for Underwater Acoustic Measurements in a Multipath Environment, M.S. Thesis, Naval Postgraduate School, Monterey, California, December 1984.

2. Heyser, Richard C., "Acoustic Measurements by Time Delay Spectrometry," Journal of the Audio Engineering Society, Vol. 15 (4), pp 370-382, October 1967.

3. Albers, V. M., Underwater Acoustics Handbook, Pennsylvania State University Press, 1960.

4. Prudhomme, Louis L., Application of a Modified Time Delay Spectrometry Technique in Modeling of Underwater Acoustic Propagation, M.S. Thesis, Naval Postgraduate School, Monterey, California, March 1987.

INITIAL DISTRIBUTION LIST

1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 1424 Naval Postgraduate School Monterey, CA 93943-5000	2
3.	Professor O.B. Wilson, Jr., Code 61WL Department of Physics Naval Postgraduate School Monterey, CA 93943-5000	3
4.	Professor S.R. Baker, Code 61BA Department of Physics Naval Postgraduate School Monterey, CA 93943-5000	1
5.	Commanding Officer Attn: John Burwell, Code 70C Naval Undersea Warfare Engineering Station Keyport, WA 98345-5000	1
6.	Commanding Officer Attn: Shaari Unger, Code 70C Naval Undersea Warfare Engineering Station Keyport, WA 98345-5000	1
7.	Commanding Officer Attn: Al Lindstrom, Code 70 Naval Undersea Warfare Engineering Station Keyport, WA 98345-5000	1

Thesis
M63855 Mitchell
c.1 Acoustic propagation
loss modeling for Dabob
Bay, Wa.