UNDERWATER SYSTEMS, INC.

TECHNICAL PROGRESS REPORT NO. 21

SPECTRAL ANALYSIS OF HYDROACOUSTIC SIGNALS GENERATED BY THE CHASE V, CHASE VII, NOL-VELA, AND ARCTIC EXPLOSIONS

Prepared by:

Mr. David F. Young
Mr. Daniel D. Woolston
Mr. Maurice Blaik

Sponsored by:

ADVANCED RESEARCH PROJECTS AGENCY (ARPA)
OFFICE OF NAVAL RESEARCH (ONR)

Contract No. NOnr 4026(00)
Project Code No. 3810
ARPA Order No. 218

30 July 1968

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Introduction

The purpose of this report is to present the results of narrow band analyses of the hydroacoustic signals generated by explosives in the following programs:

(1) CHASE V

(2) CHASE VII

(3) NOL-VELA Underwater Explosive Series (including SIR HORACE LAMB shots (February - March 1965)

(4) Arctic Ocean Underwater Explosive Series

This will complete the narrow band analysis of the CHASE Series. CHASE II, III and IV data was presented in Reference (1). Our analysis of the NOL-VELA and Arctic Ocean data has not previously been presented.

The CHASE program is an operation where reserve fleet vessels are loaded with obsolete materials, such as explosives, towed to sea and subsequently scuttled. The program, as it applied to the ONR underwater explosion experiment, involved the deliberate detonation* of the CHASE hulls at predetermined

* The CHASE II hull, it will be remembered, was not intentionally detonated. Its accidental explosion, however, triggered interest which resulted in the planned experiment which followed.

depths and subsequent analysis of the hydroacoustic and seismic signals generated. Of the hulls in the planned explosive series only CHASE VI failed to explode, having drifted into and sunk in water too shallow for detonation, Reference (2).

The NOL-VELA Explosive Series of February-March 1965 was of interest to us at that time since large charge data was not available. It was intended to use the hydroacoustic data from that series for extrapolation to larger yields and to confirm that the spectral characteristics were independent of range. The availability of large charge data from the CHASE Series made it unnecessary to utilize extrapolation procedures. However, the analyses performed are included here for completeness. It was planned that, in addition to numerous smaller explosions, three 1000 pound detonations would take place. However, none of the 1000 pounders detonated. The remaining smaller charges were monitored close-in at the USNS GILLISS, the drop ship, by NOL personnel and at the SIR HORACE LAMB by personnel from the Columbia University Geophysical Field Station, Bermuda. Also, the SIR HORACE LAMB personnel detonated three 1000 pound charges for one of their own programs during the NOL-VELA Series. Spectra obtained for one of the 1000 pound SIR HORACE LAMB shots as received at the Tudor Hill Observatory in Bermuda and two of the smaller NOL-VELA shots as monitored at the UNSN GILLISS are presented in this report.

The Arctic Ocean explosive signals were obtained from two separate series of underwater detonations. One series was detonated by the U.S. Coast Guard Icebreaker NORTHWIND and monitored at Fletcher's Ice Island (T-3). The other series was detonated by T-3 personnel and monitored at Ice Station Arlis II. Copies of the recordings were made available to us by the Lamont Geophysical Laboratory. Some typical spectra are presented here.

CHASE V Signal Analysis

The pertinent on-site data for CHASE V, Reference (3), is as follows:

Shot Location: Latitude 39° 28'N

Longitude 125° 48' W

(Shot location accuracy unknown; however, best guess is ± 1/2 n.m.)

Shot Instant: 24 May 1966

05:49:06.58 ± 00.00:00:25 Zulu (GMT)

Water Depth: 12,500 ± 100 feet

Shot Depth: 3,750 feet ± 250 feet

Yield: 1.0 ± 0.2 kilotons

The on-site signal was recorded at a distance of approximately 4.5 nautical miles from the detonation site. The broad-band signal (pressure-time curve) is shown in Figure (1) and described in Reference (3). As expected, and as can be calculated, the shock wave portion of the pressure-time curve is modified (cut-off) by the surface reflected signal. A bubble pulse period of 0.575 seconds is apparent, corresponding to a frequency of 1.74 Hz. The narrow band analysis of this signal is shown in Figure (2). A harmonically related series of spectral maxima with a fundamental frequency of approximately 1.7 Hz, corresponding to the bubble pulse frequency, is clearly exhibited.

Figures (3) and (4) present spectra obtained for the CHASE V signal as received at the ship GRASS VALLEY by Naval Radiological Defense Laboratory personnel. The ship was located approximately 87 nautical miles from the detonation site. The spectra were obtained for hydrophone depths of 90 feet, Figure (3), and 40 feet, Figure (4). The bubble pulse frequency as measured from these records is again found to be approximately 1.7 Hz.

Narrow band spectra of the longer range hydroacoustic signal are shown in Figures (5) and (6). Figure (5) is the spectral analysis of the hydroacoustic signal as monitored by the MILS station at the PMR facility at Midway Island in the Pacific, a range of about 2600 nautical miles. This analysis clearly displays the spectral maxima spacing of approximately 1.7 Hz. Figure (6) presents the spectrum of the hydroacoustic signal obtained by the MILS station at New Zealand, a range of about 5600 nautical miles. Although the interpretation is more difficult, the 1.7 Hz maxima spacing is still evident.

The spectral analyses performed for the CHASE V experiment clearly demonstrate that bubble pulse frequency can be monitored at all ranges.

CHASE VII Signal Analysis

The CHASE VII event occurred on 29 July 1966 about 100 miles east of Kitty Hawk, North Carolina. Pertinent on-site data for the detonation, Reference (4), is given below:

Shot Depth: ≈3,000 feet

Water Depth: 7,500 feet

Yield: 400 tons

(Various failures during the experiment precluded accurate shot instant and shot location determinations. A discussion of the test and estimates of these parameters are given in Reference (4)).

The spectral analyses presented here for the CHASE VII event, Figures (7)-(10), were performed for signals received at Columbia University Geophysical Field Station in Bermuda, a distance of approximately 540 nautical miles from the detonation site. The analysis band for each spectrum is 0 - 12.5 Hz with a bandwidth of 1/8 Hz. The signal arrivals investigated are the following:

Figure (7) - Direct arrival.

Figures (8) and (9) - Reverberation immediately following direct arrival.

Figure (10) - Reverberation approximately 255 seconds after direct arrival.

Each of the spectra clearly exhibits the harmonics in the bubbl pulse series. A bubble pulse frequency of 2.0 Hz is obtained.

It is observed that the direct arrival spectrum yields as clear a presentation of the bubble pulse series as does that of the reverberant arrival immediately following. This is in contrast to the findings of the analyses of the CHASE II, III, and IV events, Reference (1), where the reverberation yielded a significantly clearer spectrum than did the direct arrival. This is probably due to the fact that the CHASE VII direct signal does not exhibit the early discrete arrival pattern shown by those of the other events.

The reverberation about 255 seconds after the direct signal is the return from the U.S. east coast. Its spectrum differs from the other spectra presented in that the signal level is reduced at the low frequencies. This is the result of shallow water propagation effects, a discussion of which is given in Reference (1).

NOL-VELA and SIR HORACE LAMB Series

The US Naval Ordnance Laboratory (NOL) detonated a series of underwater charges during February and March 1965. The Columbia University Geophysical Field Station ship SIR HORACE LAMB also detonated several underwater charges during the same period.

Figure (11) shows the spectrum obtained from one of the large charges (1000 lbs) dropped from the SIR HORACE LAMB. The detonation depth was 8000 feet (nominal). Analysis was performed for the signal received at the Tudor Hill Observatory at Bermuda, a range of approximately 600 nautical miles. The measured bubble pulse frequency, 41 Hz, agrees with the predicted value based on the nominal depth figure. The relatively low amplitudes of the first and second harmonics may reflect in part the roll-off of the AM recording system used to obtain the shot data. It is observed that the position of the fundamental is shifted upward about 10 Hz from the value determined from the second, third, and fourth harmonics. This deviation is qualitatively consistent with the previous observation that the fundamental usually exhibits some shift. This is related to the strong negative going portion of the explosive signal which appears between the shock wave and first bubble pulse for deep low yield detonations, Reference (5).

Spectra for two of the charges from the NOL trials mentioned above are presented in Figures (12) and (13). The signals analyzed were those monitored close-in by the USNS GILLISS, the ship from which the charges were dropped. Pertinent shot information is given below:

Figure (12) - NOL Shot No. 79; yield 55 lb; detonation depth (nominal) 7000 feet.

Figure (13) - NOL Shot No. 42; yield 1 lb; detonation depth (nominal) 1200 feet.

A significant upward shift in the position of the bubble pulse fundamental is observed for both records. It is also observed in each of the records that the second harmonic is split. Bubble pulse frequency determinations, therefore, were based on the positions of maxima above the second harmonic.

A bubble pulse frequency of 103 Hz is obtained for the spectrum of Figure (12). This is slightly higher than the predicted value, 97 Hz, indicating that detonation occurred at a depth somewhat greater than 7000 feet. The spectrum of Figure (13) yields a bubble pulse frequency of approximately 86 Hz which agrees with the predicted value.

Arctic Ocean Signal Analysis

Two different series of explosion tests in the Arctic Ocean were analyzed. These are the charge series dropped from the U.S. Coast Guard icebreaker NORTHWIND and received at Fletcher's Ice Island (T-3) in September 1965 and the charge series dropped from T-3 and received at drifting ice station Arlis II in September 1962.

A typical real time signal from one of the T-3 shots as received at Arlis II is shown in Figure (14). Frequency dispersion causes the signal to be divided into two major arrivals. The spectral analysis of the interval indicated is shown in Figure (15). Loss of low frequency energy is expected because of the response of the recording system. Loss of high frequency energy is expected because of scattering at the rough surface of the ice cover. The resulting spectrum reveals the superposition of the band-limited spectrum and the spectrum of the bubble oscillation for harmonics 2 through 11 with a bubble pulse frequency of approximately 12.3 Hz. This corresponds quite well with the expected value for this detonation of 5.5 pounds at a depth of 200 feet.

Figure (16) shows the real time signal recorded at T-3 for one of the NORTHWIND cruise detonations. As can be noted, the time duration is quite short, and only one of the two major arrivals is received. The spectral analysis is shown in Figure (17). Major energy groupings give an apparent bubble pulse frequency of about 7 Hz which is in disagreement with the expected value of 3.8 Hz for this detonation of 44 pounds at a depth of 100 feet. This is the only case known to us where spectral analysis has failed to disclose the bubble pulse frequency. It is suggested that this is due to the short integration time available combined with spectral peaks controlled by mode effects. Mode effects are expected whenever water depths are several thousand feet or less and the frequencies of interest are several tens of Hz as in this case.

Another NORTHWIND shot analysis is shown in Figure (18). In this case, the combination of high pass (due to equipment response) and low pass (due to surface scattering losses in propagation) effects produce a usable band limited to the interval from about 15 Hz to 30 Hz. The three strongest spectral peaks are at approximately 18, 20, and 22 Hz. This set corresponds to the calculated harmonics 9 through 11 for the given charge weight of 1320 pounds at a depth of 200 feet.

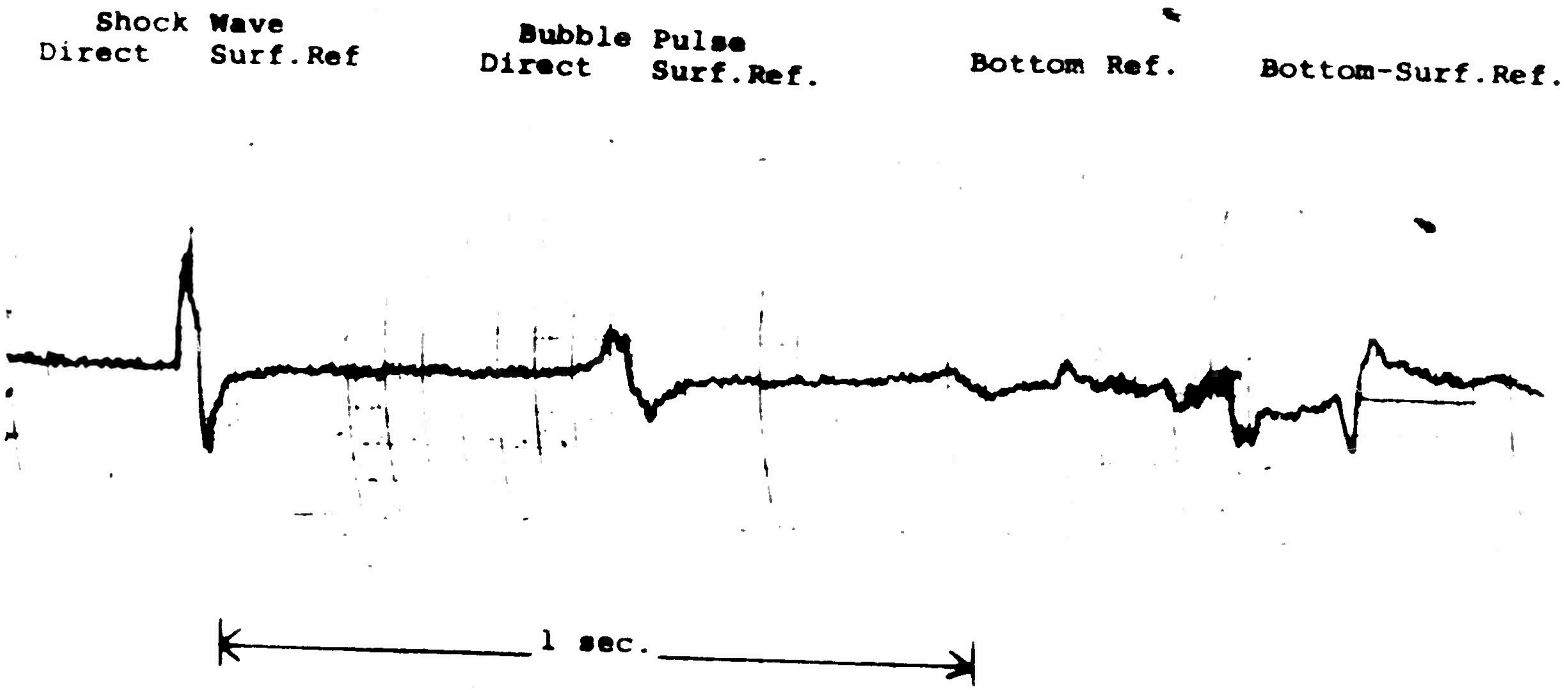

Figure [illegible]

Pressure-time history of CHASE [illegible] detonation at a range of approximately 4.5 n.m.

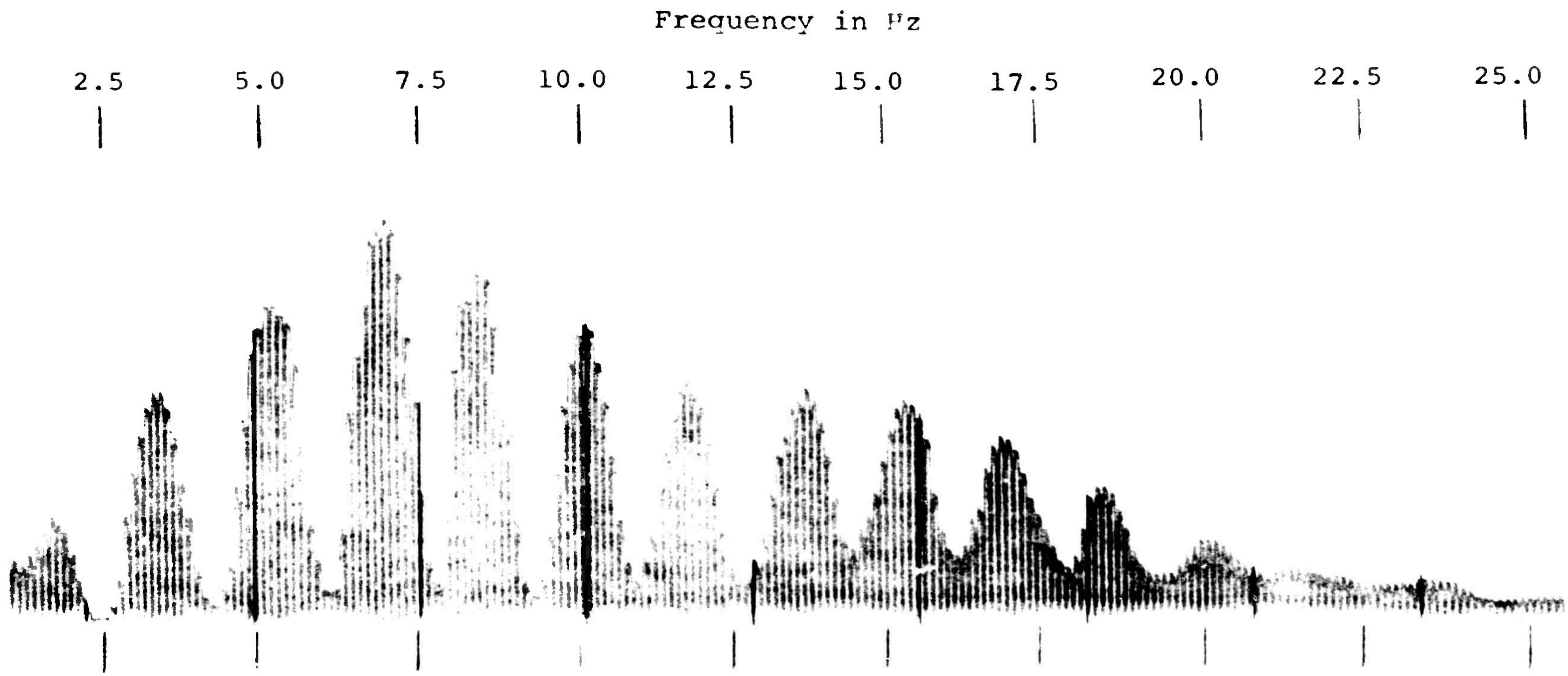

Figure (2)

Spectral analysis of hydroacoustic signal generated by CHASE V detonation as received at a range of approximately 4.5 n.m.

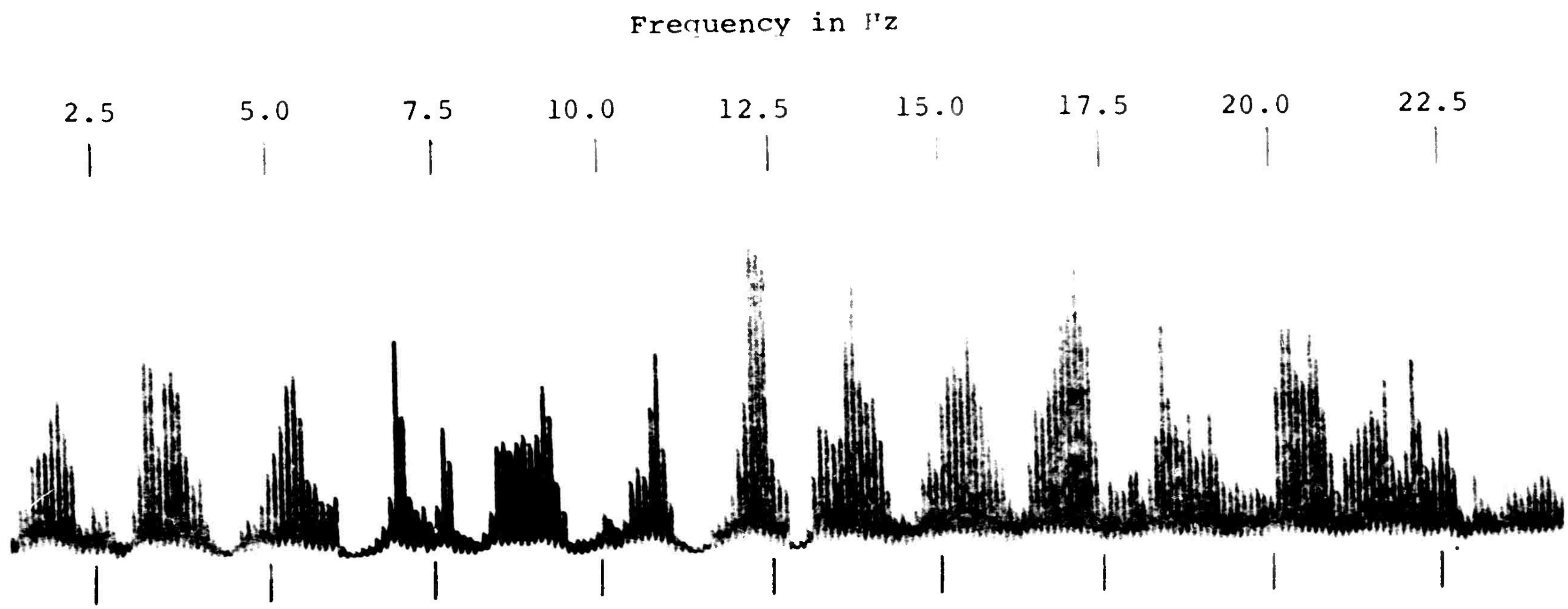

Figure (3)

Spectral analysis of hydroacoustic signal generated by CHASE V detonation as received at GRASS VALLEY. Direct signal. Hydrophone depth 90 feet; range 87 n.m. Bandwidth 1/8 Hz.

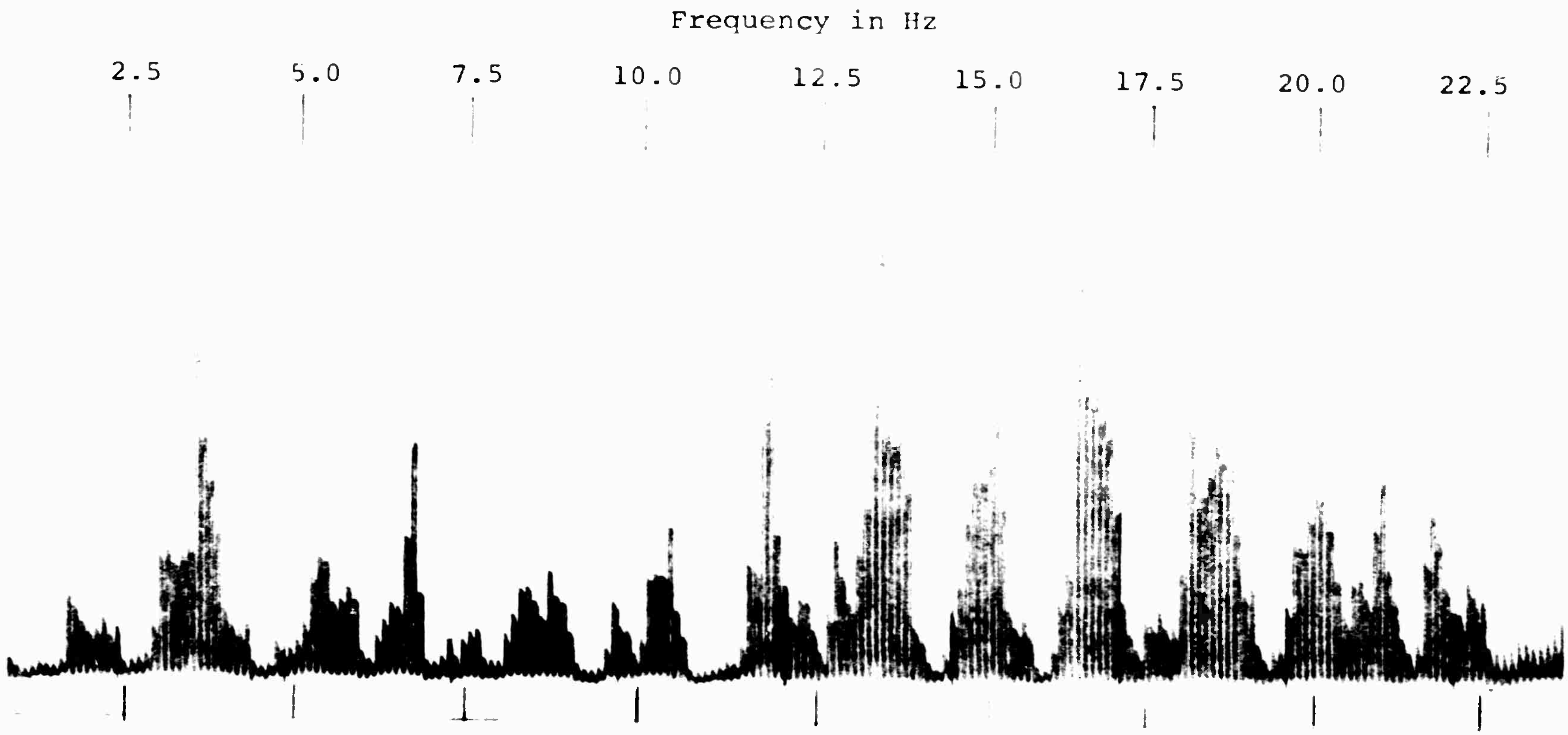

Figure (4)

Spectral analysis of hydroacoustic signal generated by CHASE V detonation as received at GRASS VALLEY. Direct signal. Hydrophone depth 40 feet; range 87 n.m. Bandwidth 1/8 Hz.

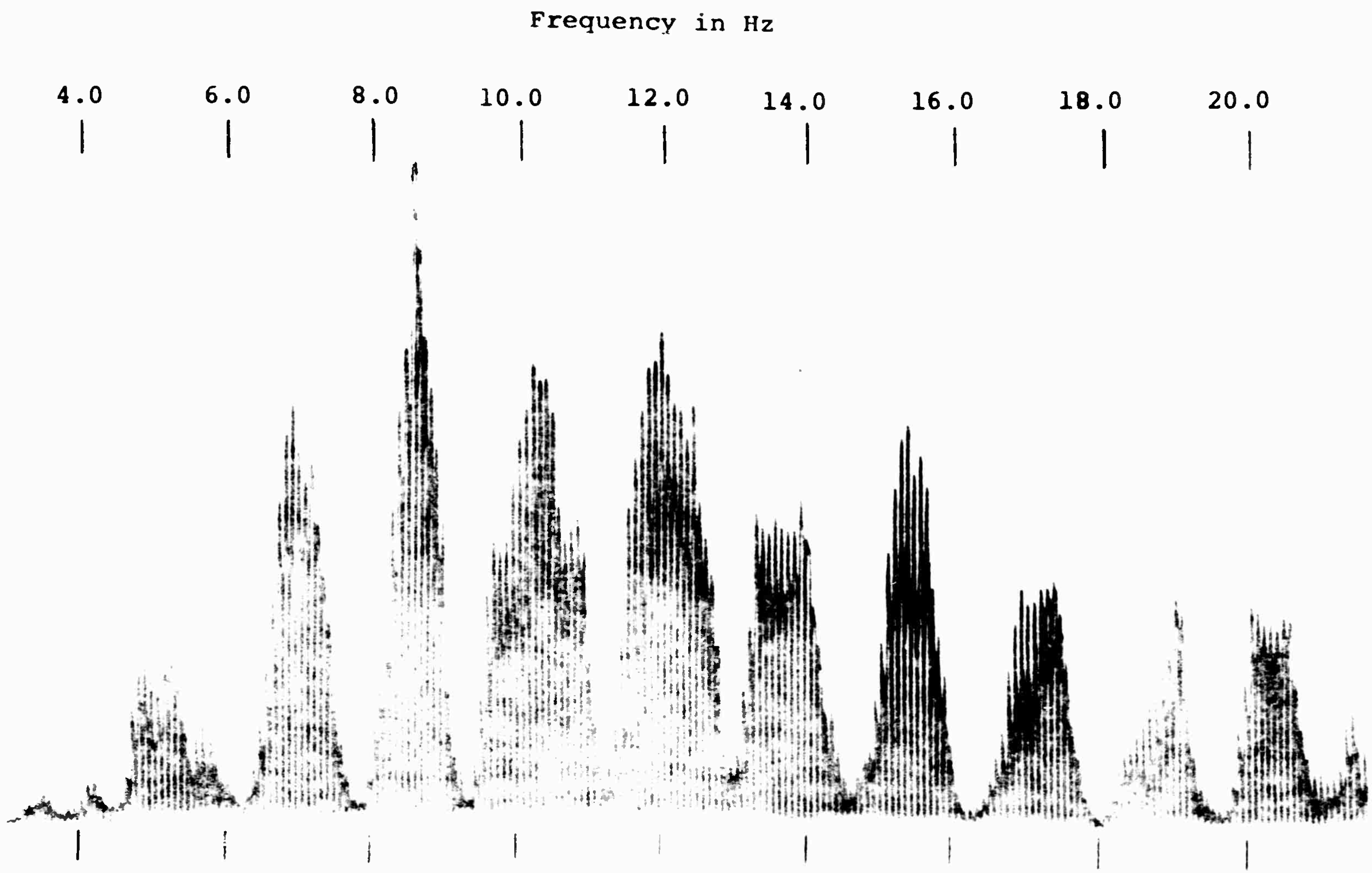

Figure (5)

Spectral analysis of hydroacoustic signal generated by CHASE V detonation as received at Midway Island. Reverberation following direct signal. Range ≈2600 n.m. Bandwidth 1/5 Hz.

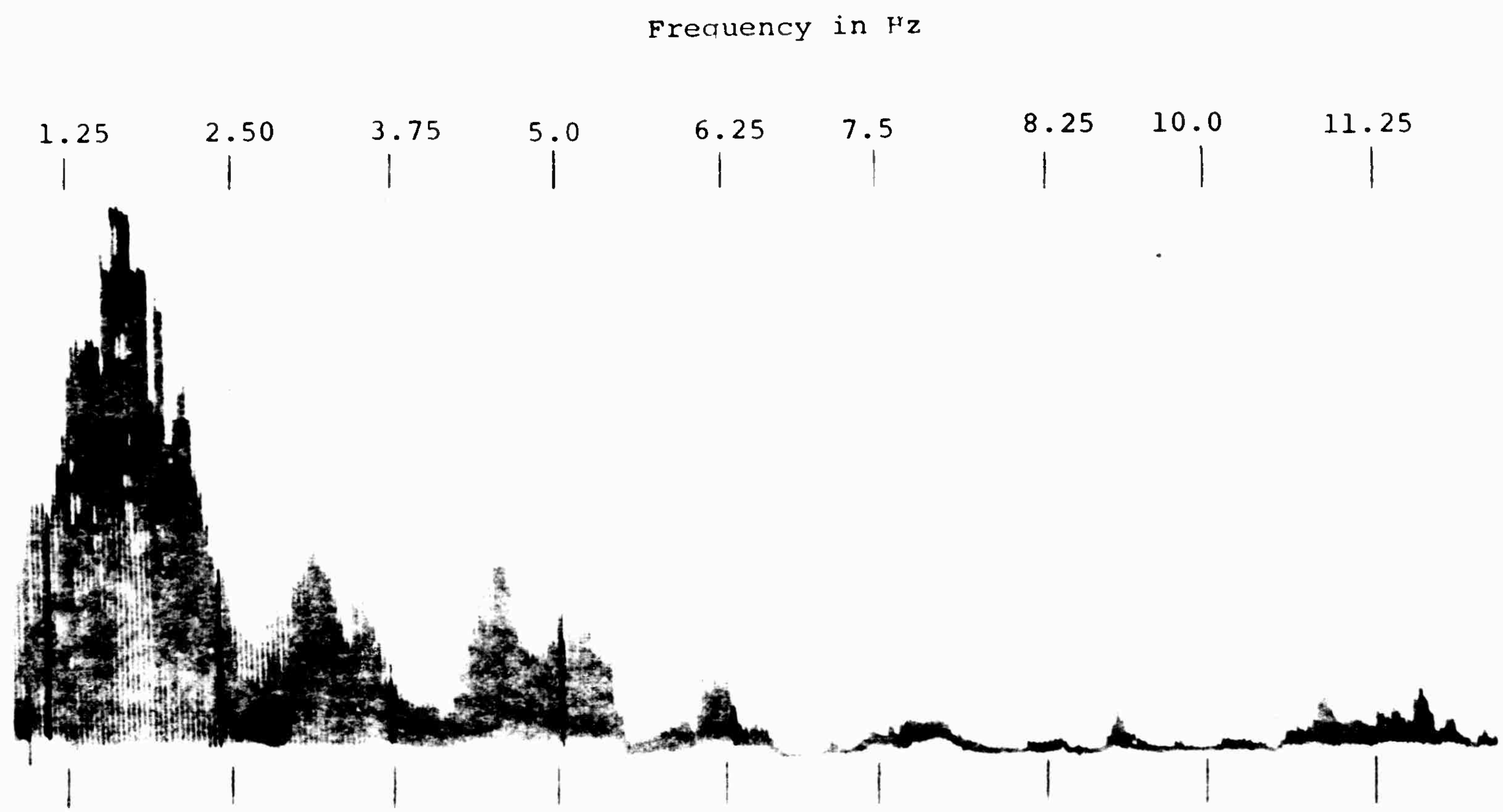

Figure (6)

Spectral analysis of hydroacoustic signal generated by CHASE V detonation as received at New Zealand. Reverberation following direct signal. Range ≈ 5600 n.m. Bandwidth 1/8 Hz.

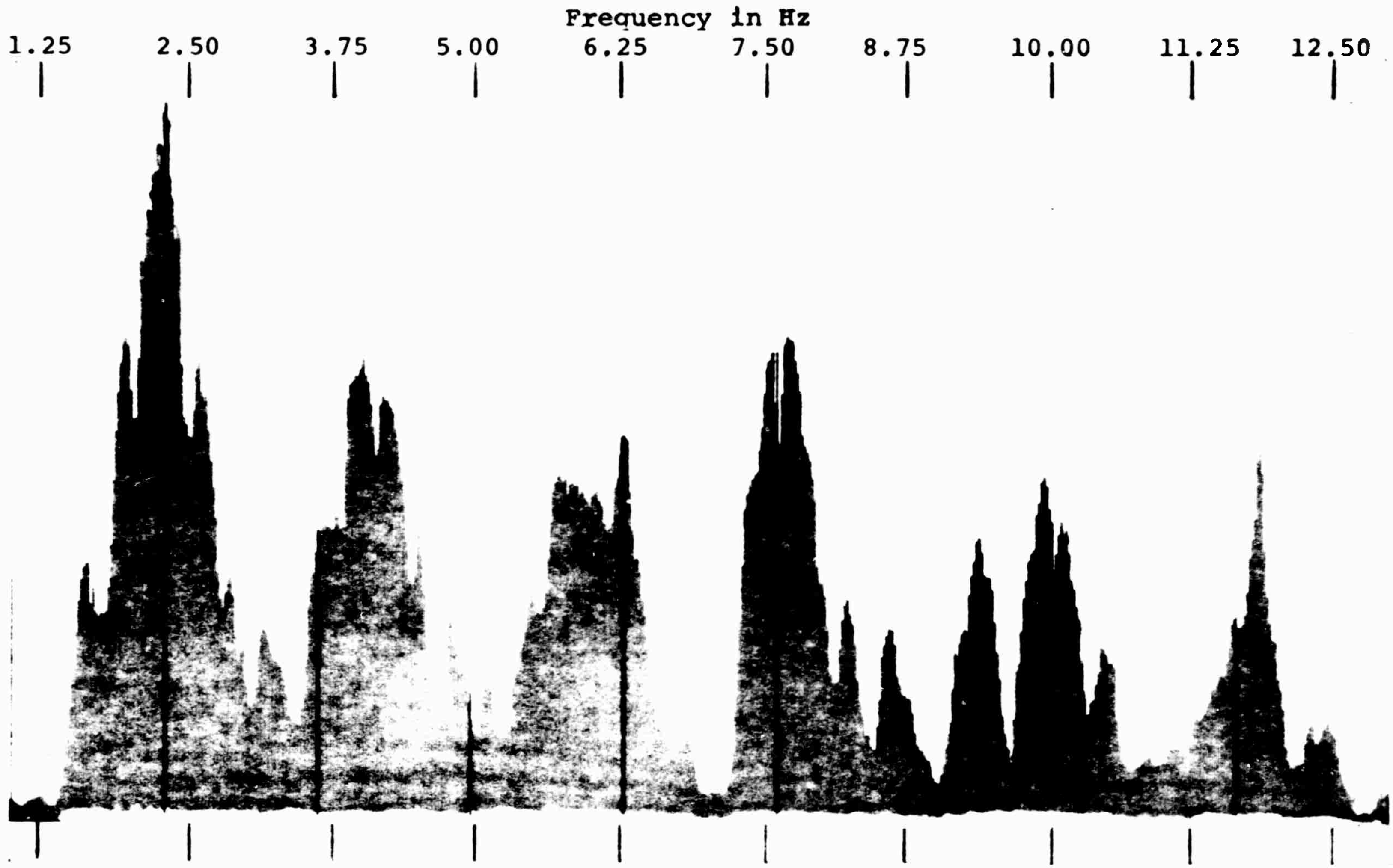

Figure (7)

Spectral analysis of hydroacoustic signal generated by CHASE VII detonation as received at Columbia University Geophysical Field Station in Bermuda. Direct signal. Range 540 n.m. Bandwidth 1/8 Hz.

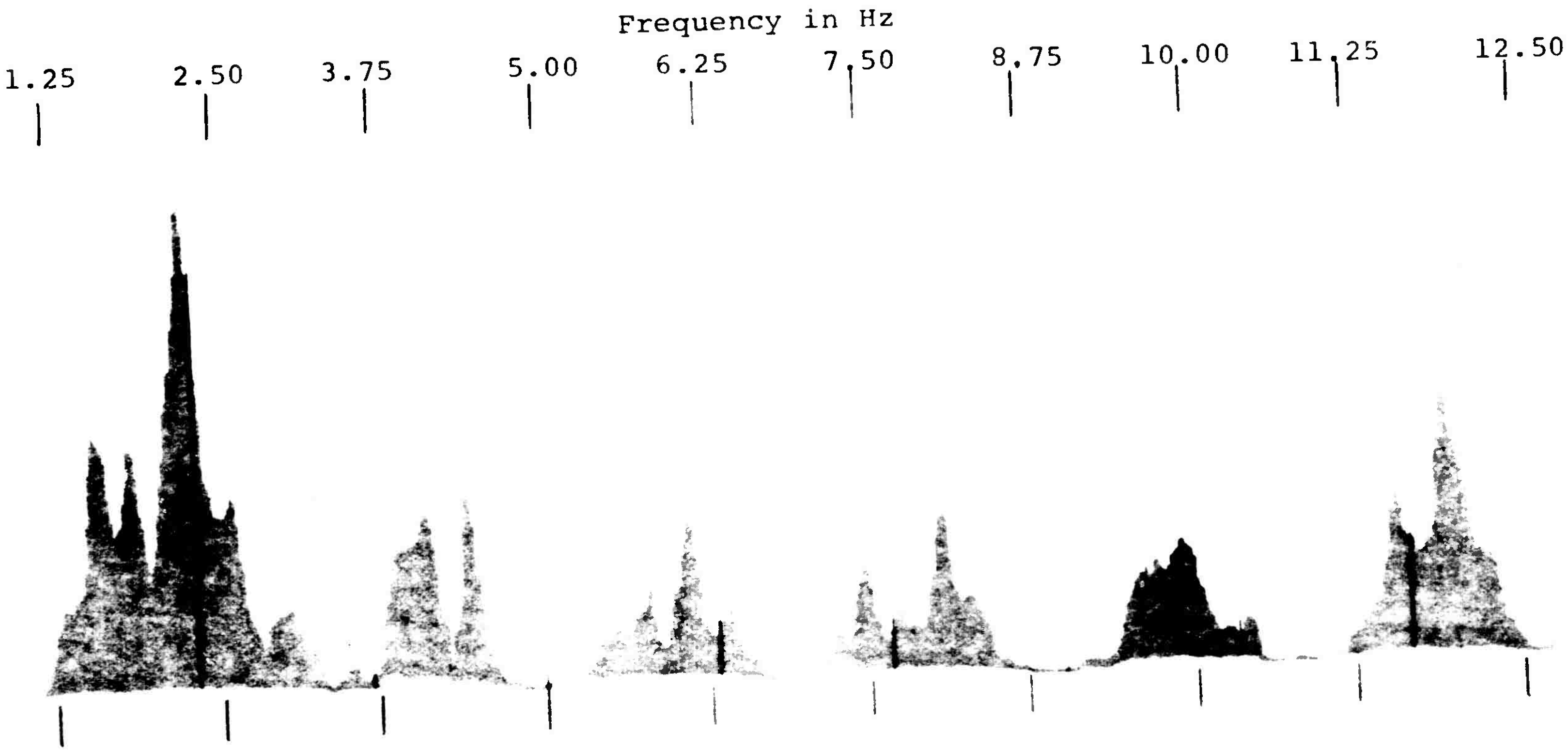

Figure (8)

Spectral analysis of hydroacoustic signal generated by CHASE VII detonation as received at Columbia University Geophysical Field Station in Bermuda. Reverberation immediately following direct signal. Range 540 n.m. Bandwidth 1/8 Hz.

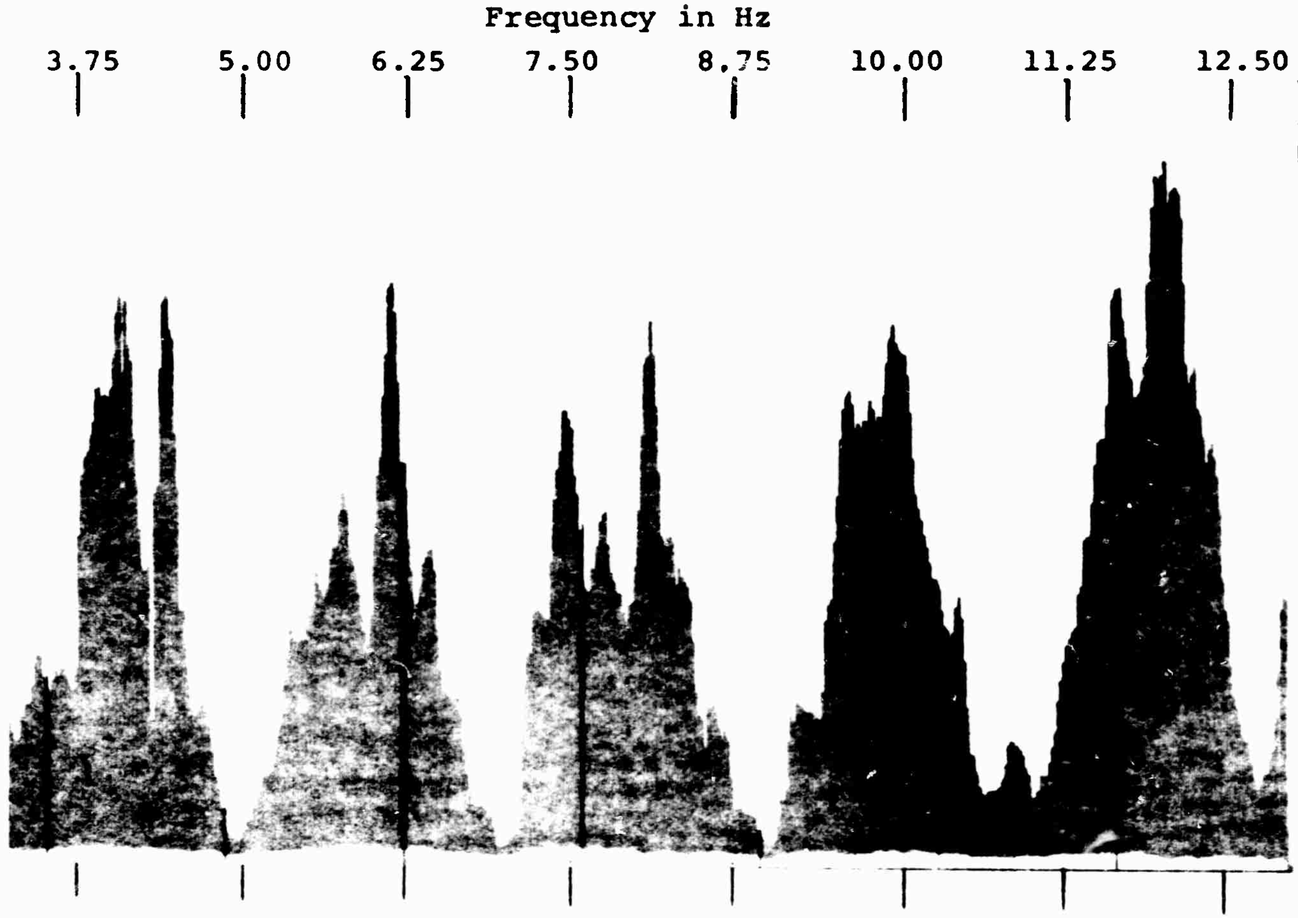

Figure (9)

Spectral analysis of hydroacoustic signal generated by CHASE VII detonation as received at Columbia University Geophysical Field Station in Bermuda. Reverberation immediately following direct signal. Range 540 n.m. Bandwidth 1/8 Hz.

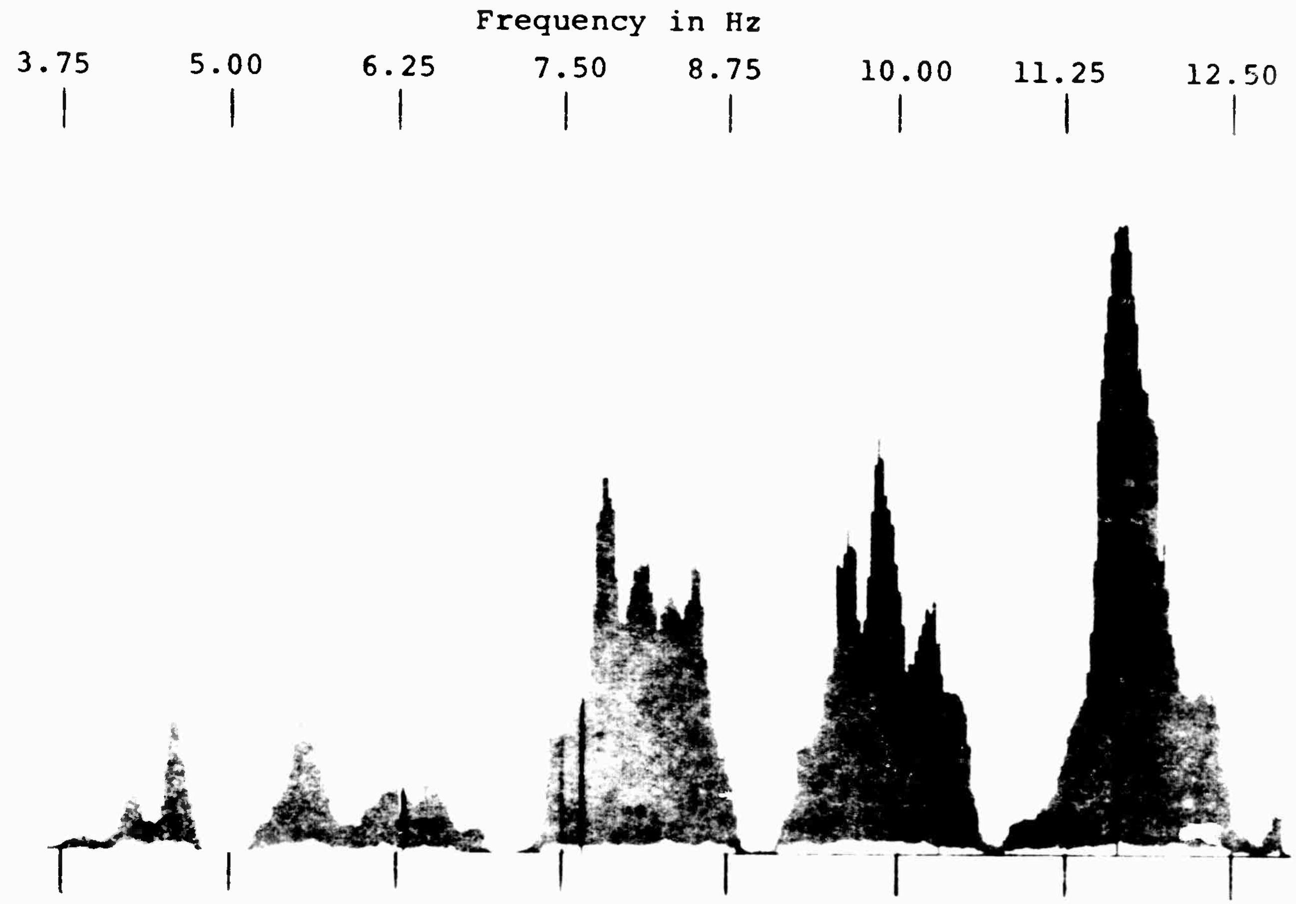

Figure (10)

Spectral analysis of hydroacoustic signal generated by CHASE VII detonation as received at Columbia University Geophysical Field Station in Bermuda. Reverberation about 255 seconds after direct signal. Range 540 n.m. Bandwidth 1/8 Hz.

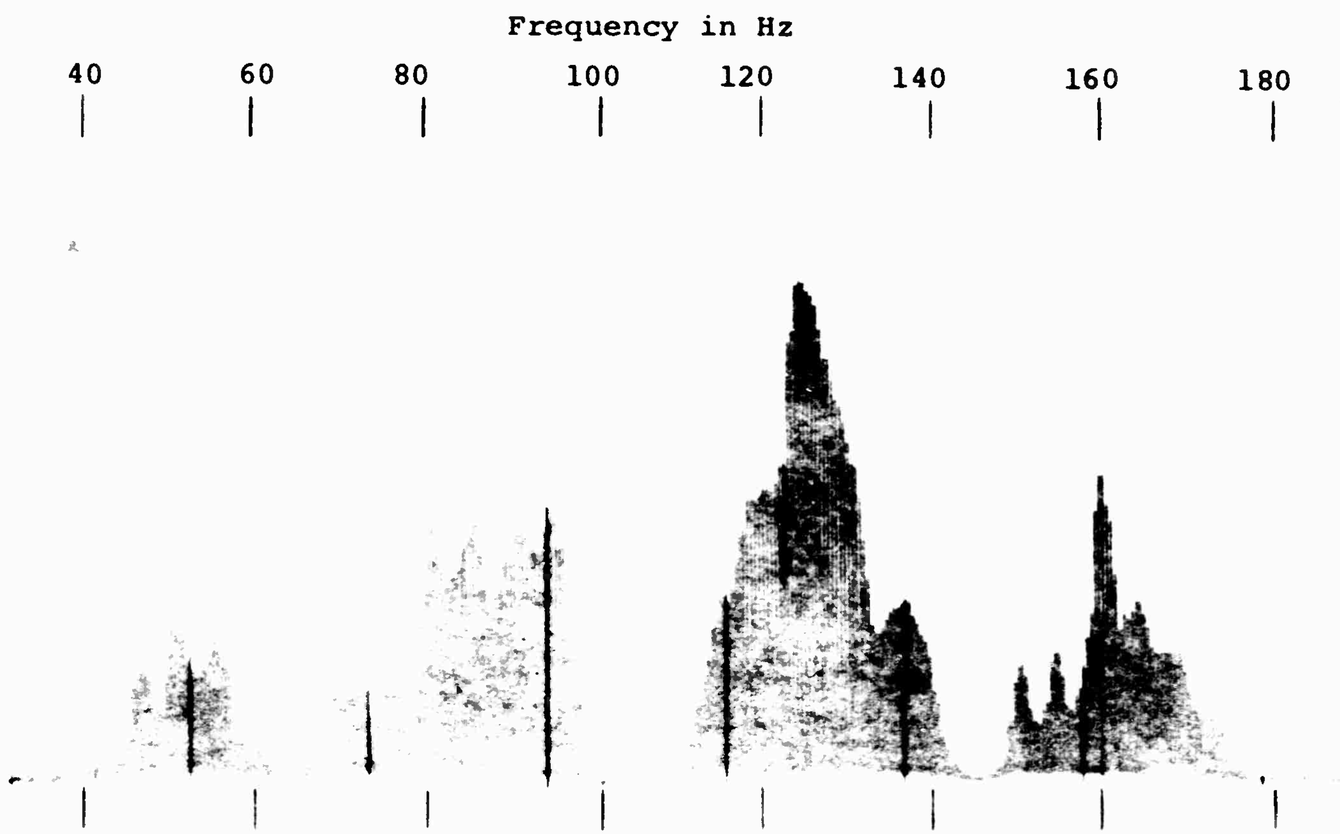

Figure (11)

Spectral analysis of hydroacoustic signal generated by a 1000 pound charge in SIR HORACE LAMB series as received at the Tudor Hill Observatory at Bermuda. Direct signal. Detonation depth 8000 feet; range ≈600 n.m. Bandwidth 2.5 Hz.

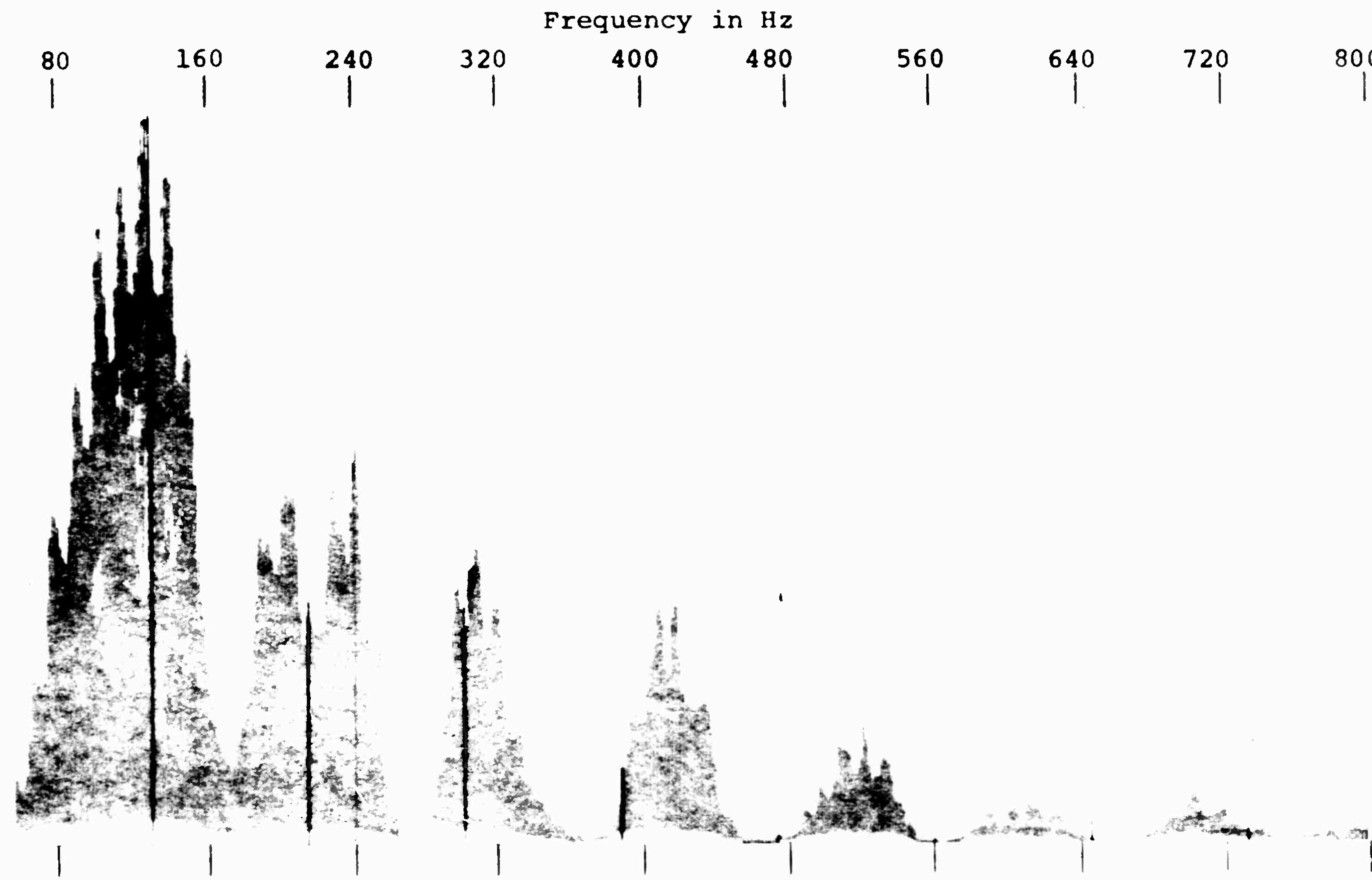

Figure (12)

Spectral analysis of hydroacoustic signal generated by a 55 pound charge in NOL series as received at USNS GILLISS at very short range. Detonation depth 7000 feet. Bandwidth 8 Hz.

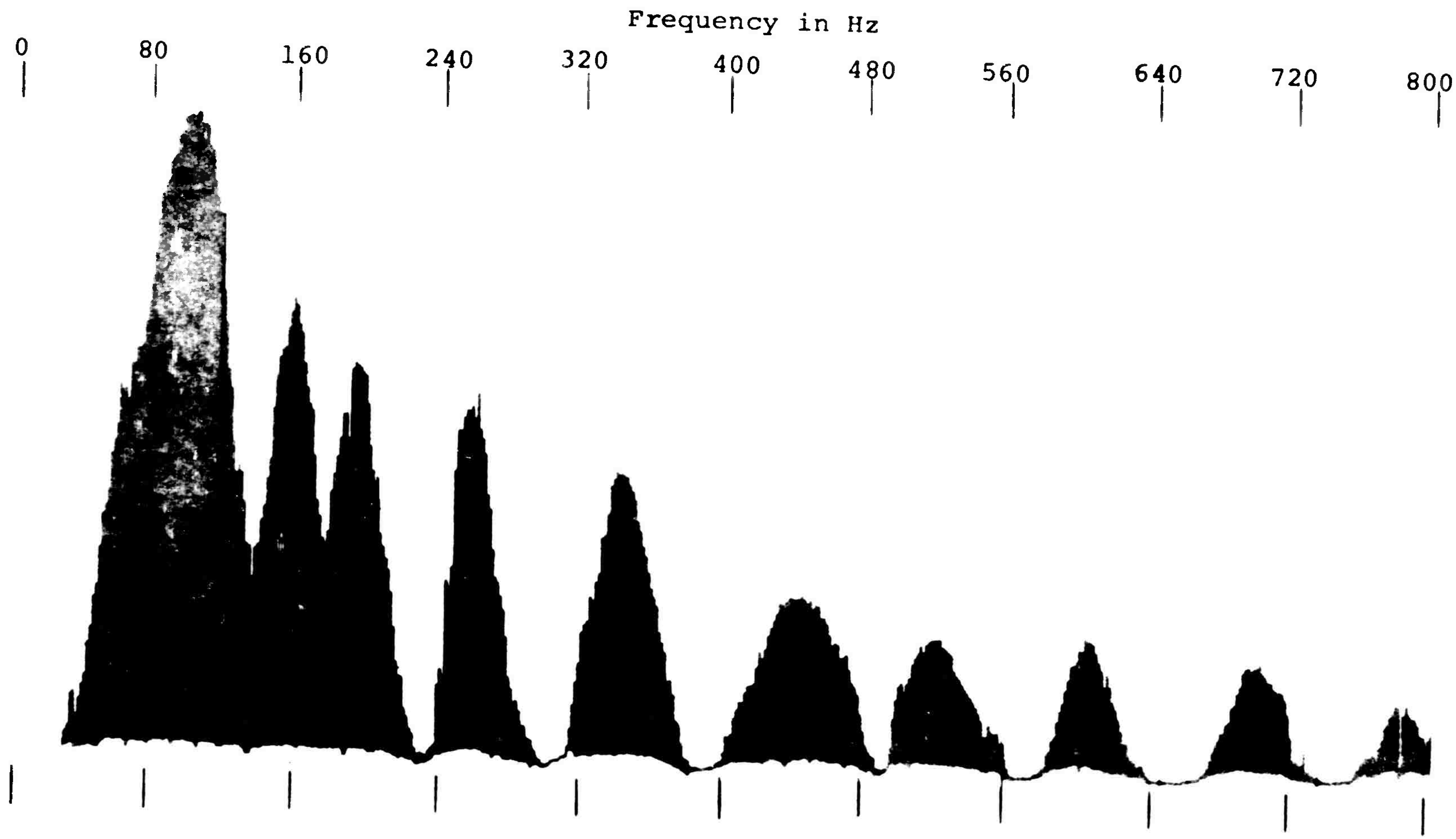

Figure (13)

Spectral analysis of hydroacoustic signal generated by a 1 pound charge in NOL series as received at USNS GILLISS at very short range. Detonation depth 1200 feet. Bandwidth 8 Hz.

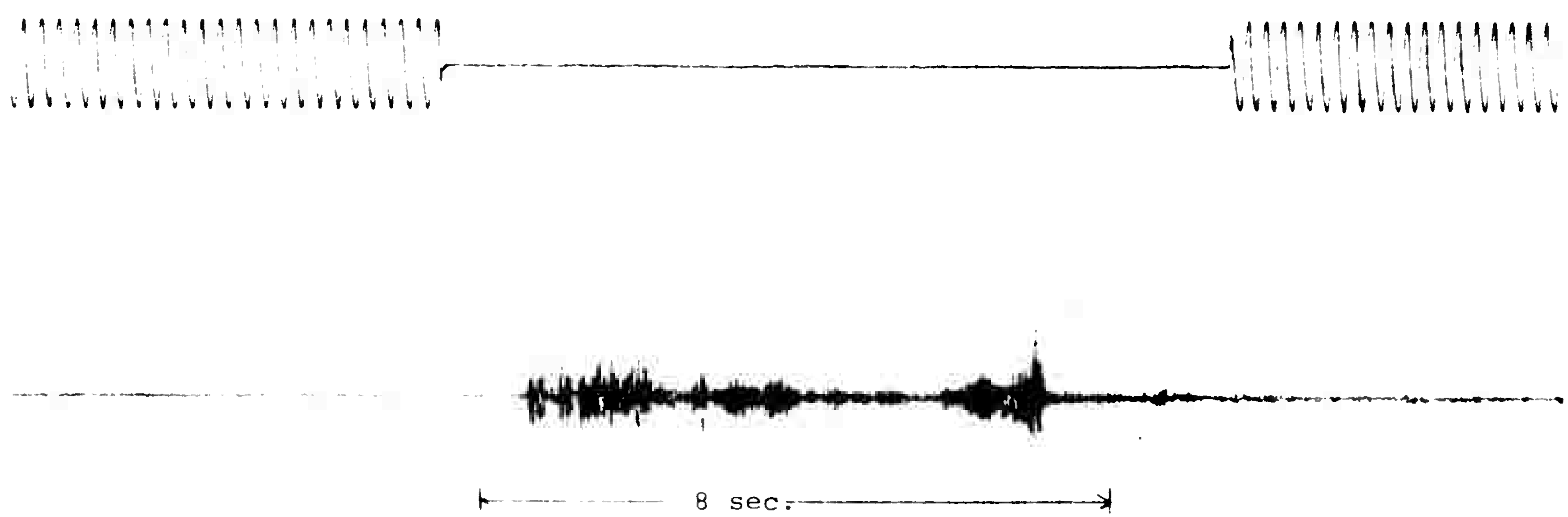

Figure (14)

Hydroacoustic time signature at 150 foot hydrophone for 5 pound TNT charge at a depth of 200 feet and range of 2,000 kilofeet. This Arctic Ocean propagation path is over uniform water depths of about 10 kilofeet.

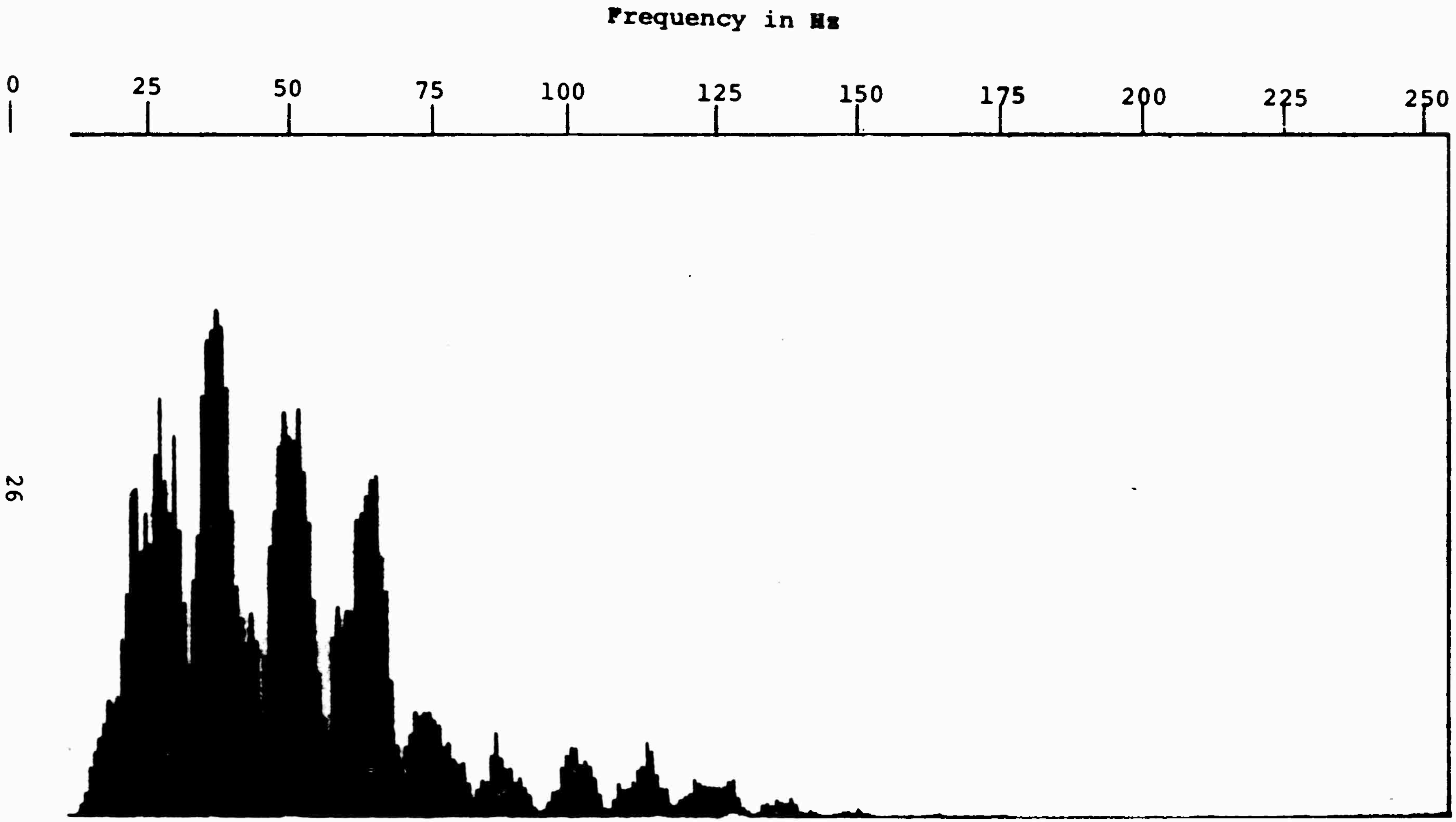

Figure (15)

Spectrum analysis of time interval indicated in Figure (14) by stop and start of sine wave (approximately 10 seconds duration). Note the clear indication of bubble spectrum harmonics 2 through 11. Bandwidth 1.25 Hz.

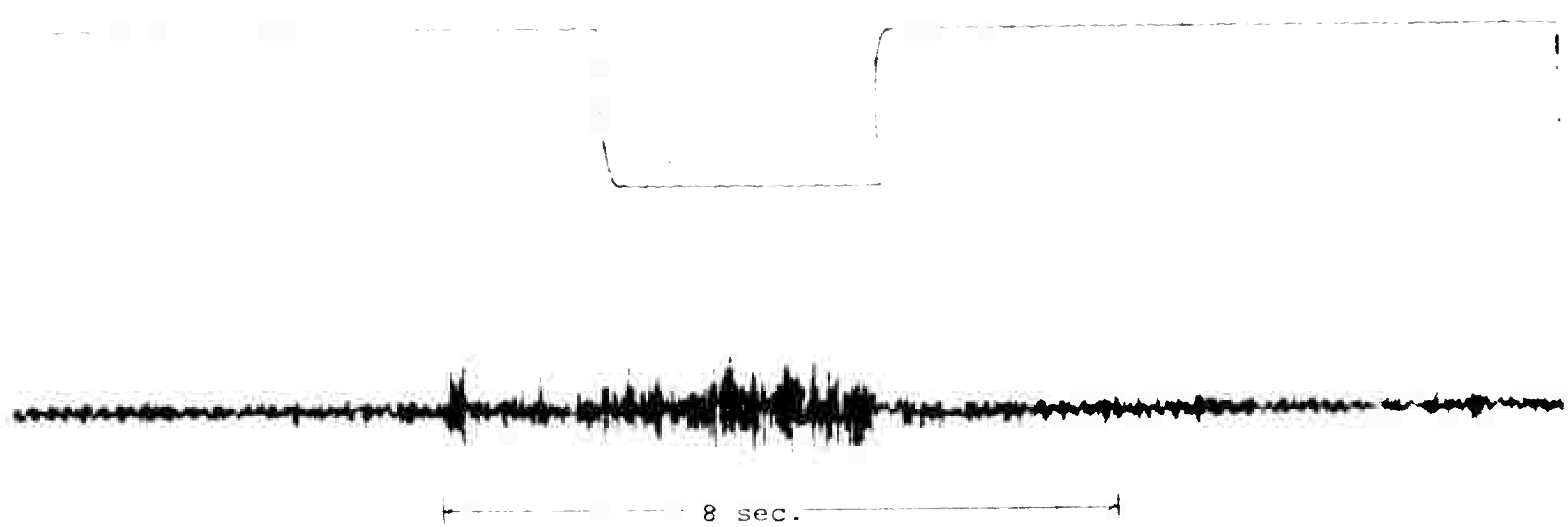

Figure (16)

Hydroacoustic time signature for 44 pound TNT charge at a depth of 100 feet and a range of about 1,540 miles.

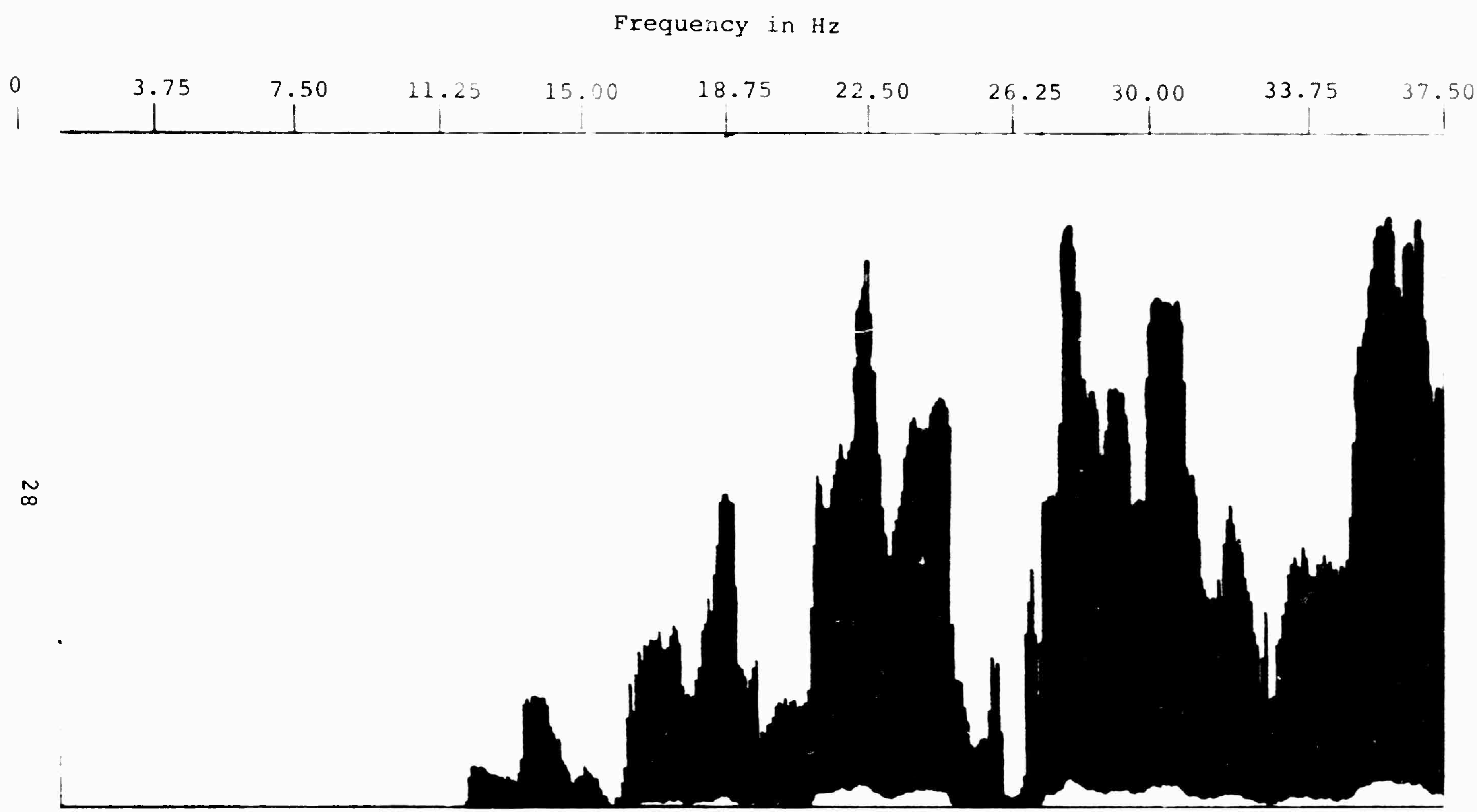

Figure (17)

Spectrum analysis of time interval indicated in Figure (16) (approximately 3.2 seconds between steps in upper trace). Bandwidth 5/8 Hz.

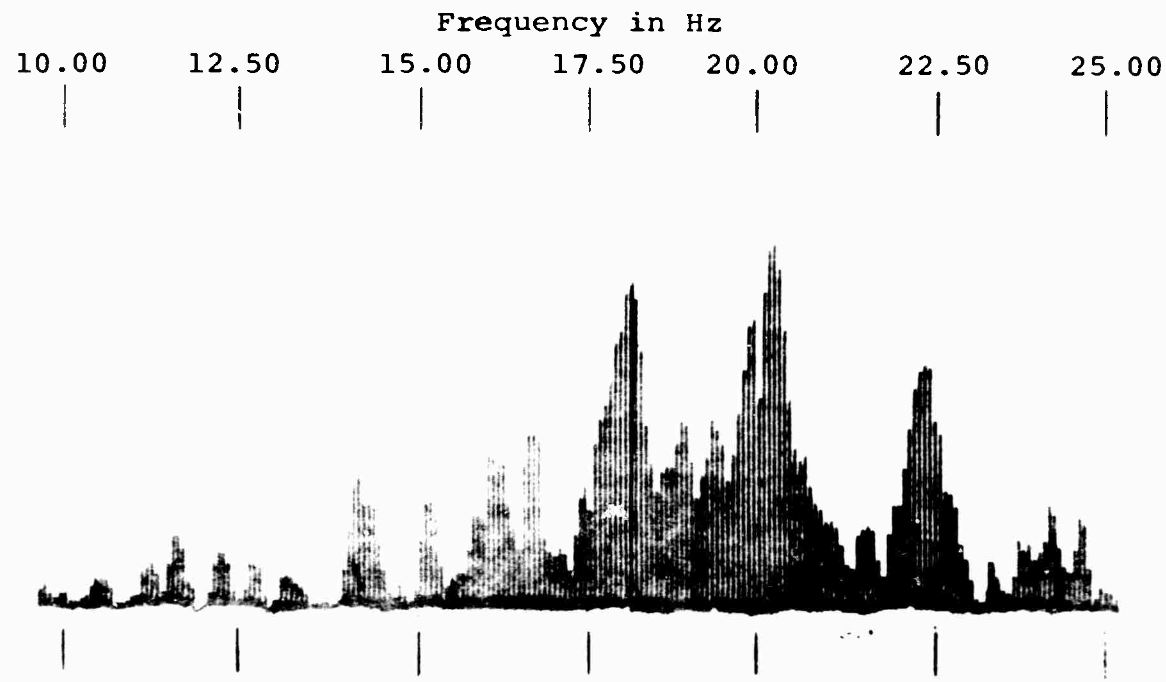

Figure (18)

Spectral analysis of hydroacoustic signal received at T-3 from a 1350 pound charge dropped by NORTHWIND in shallow water (1150 feet). Direct signal. Detona- depth 200 feet; range 1660 n.m. Bandwidth 1/4 Hz.

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13. ABSTRACT

Results of narrow band spectral analyses of hydroacoustic signals generated by underwater explosions in several programs are presented. Analyses were performed for explosion data obtained at ranges varying from several kiloyards to thousands of miles.

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