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"Infrasonic Sea Noise Measurements and Experimental Problems"

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1. INTRODUCTION

This paper reports the results of omnidirectional third-octave measurements of underwater microearthquakes from center frequencies of 5 to 32 Hz, discusses some experimental problems in making acoustic measurements in the infrasonic and low-frequency bands and suggests two experiments to establish a quantitative relationship between sources of infrasonic sea noise and their spectrum levels

2. BACKGROUND

One source of sea noise in the 1- to 100-Hz band identified by Wenz [1] is seismicity. Underwater noise due to seismic sources is estimated in Wenz's curves [1, Fig. 13] to reach levels as high as 125 dB/ /μPa at 10 Hz. Estimates of sound pressure spectrum levels by Urick [2], however, using sea-bed motion measurements due to seismic activity vary from between 93 to 123 dB/ /μPa at 10 Hz. Acoustic observations [3, 4, 5] show that seismicity yields maximum spectral levels at frequencies between 2 to 25 Hz and may affect spectral levels at frequencies as high as 200 Hz [6].

Insufficient acoustic data exist from either Pacific Ocean or North Atlantic Ocean experiments to characterize microearthquakes in terms of their spectrum levels, spectra and level statistics. Teleseismic signals originating in the Pacific Ocean were detected over great distances by land-based seismological laboratories; the resulting underwater acoustic signals have been recorded by various oceanographic facilities [3, 4, 6]. Teleseismic events in the North Atlantic Ocean originate mostly along the Mid-Atlantic Ridge [7]; no acoustic signals from teleseismic events have been reported. Except for Spindel *et al.* [5] and Northrop [6], no acoustic spectra of underwater earthquakes are reported in the literature; these investigators show remarkably different results. Spindel, using sonobuoys, show seaquake noise which peaks in the 15- to 25-Hz band and which affect frequencies as high as 200 Hz. Northrop's spectrum using Pacific MILS (Missile Impact Location System) hydrophones, shows distinct spectral lines in the 1- to 20-Hz band. Other acoustic techniques employing ocean bottom seismographs [8] and sonobuoys [9, 10, 11] have been used to record sound from low-intensity seaquakes taking place at remote locations but provide only a limited data base to characterize these events.

3. EXPERIMENT

A. General

The experiment was a joint US-UK effort conducted by the Naval Research Laboratory (NRL) and by the Institute of Oceanographic Sciences near Reading, England, to record underwater seismic noise and to identify sources of infrasonic sea noise. Continuous recordings of acoustic and seismic signals were successfully made for seven days by two ocean bottom seismographs (OBS) in a seismically-active area.

B. Location

The area selected for the experiment was based on two considerations. First, observations [5, 10] at the Mid-Atlantic Ridge near the Azores verified that the area is seismically active. Second, since the sea floor was subjected to extensive scientific study as part of Project FAMOUS (French-American Mid-Ocean Study); bathymetric and other sea floor characteristics were known in considerable detail [12] and were used to develop preliminary models of the sea floor area [13, 14]. The rift valley, principal feature of the area, was laterally offset several kilometers by Fracture Zones A and B and was flanked by a steep underwater mountain system.

C. Equipment

The OBS unit is a free-fall, pop-up, calibrated instrument. In operation it rests on the ocean floor, FM-recording four data channels. One channel each is used to record a wide-band (1-40 Hz) hydrophone signal, a narrow-band (3-7 Hz) hydrophone signal, and a short-period (2 sec) vertical and horizontal seismometer signal. Specific details concerning the functional and operational characteristics of OBS have been reported by Francis *et al.* [15].

Three identical OBS units were deployed at the Mid-Atlantic Ridge near Fracture Zone A. OBS 2 and OBS 3 recorded useful acoustic and seismic data, but the OBS 1 tape recorder failed to operate. The acoustic data presented in this paper were obtained from an NRL hydrophone (type H-58) signal recorded by OBS 2; acoustic data processing and analysis were performed at NRL.

4. RESULTS AND DISCUSSION

A. Observed Seismicity

Measurements made by Francis *et al.* [16] using OBS playback records and calculations of the compression- and shear-wave speeds permitted estimates of about 50 epicenters. These shallow-focus events varied in Richter magnitude from 0 to about 2.5 and were centered in two locations: near the steep western rift valley wall and along a single active fault. OBS 3 was further than OBS 2 from epicenters and had a higher electronic noise level.

Analysis of analog records showed that OBS 2 recorded 515 seaquakes while OBS 3 recorded 184. Using acoustic and seismic records to identify the occurrence of seaquakes, the mean seismic activity rate during the OBS 2 recording period was about 2.9 events/hr. Spindel *et al.* [5] and Reid and Macdonald [10], both using sonobuoys near the OBS deployment site, reported seismic activity rates of 1.5 and 0.4 events/hr, respectively. Thus, the use of acoustic sensors led to estimates of seismic activity rates which are less than would have been determined by an ocean bottom system using both acoustic and seismic sensors. The addition of a hydrophone to ocean bottom recording systems provides another means of detecting seaquake epicenters.

B. Spectra

Spectral data spanning the entire recording period of OBS 2 are shown in Fig. 1. These data result from digital processing of the recorded NRL hydrophone signal to provide one-minute averages, yielding over 10,000 spectral estimates in each 1/4-Hz band from 5 to 32 Hz. Overloads caused by intense seaquakes and by ships occasionally passing nearby amount to less than 3% of the total data and were excluded from the data base during processing.

Flow noise levels generated by water flowing past H-58 hydrophones have been measured and reported by Finger [17]; these are also shown in Fig. 1. It is concluded that flow noise levels during the recording period did not interfere with the measurement.

C. Comparison of NRL Spectra to Wenz's Curves

Infrasonic and low-frequency sea noise in shallow water show considerable variability (levels range from 90 to 110 dB/ /μPa at 10 Hz) and a spectral slope of −8 to −10 dB/octave as shown in Fig. 2. Both level variability and the spectral slope are supported by Piggott's measurements [18]. Mean, maximum (system overload threshold) and minimum NRL levels are shown in Fig. 2 for frequencies from 5 to 32 Hz. Mean spectrum levels range between 80 to 87 dB/ /μPa for frequencies of 10 to 32 Hz, respectively. The spectral slope of mean NRL data in this band is about +4 dB/octave. It is concluded that NRL spectrum levels and slope are comparable to those associated by Wenz with distant shipping traffic noise resulting from increased merchant ship population and from changing marine design. (Spectrum level differences between Wenz's curves and NRL data are discussed in a subsequent section.)

For frequencies less than 10 Hz, the mean spectrum levels do not exceed 80 dB/ /μPa; the spectral slope is about +2.5 dB/octave. Thus, the contribution of shipping to noise is less significant at the lower frequencies.

The usual shipping noise curves shown in Fig. 2 are adapted from Wenz's [1] Fig. 13 to reflect an estimated increase of about 8 dB, based on NRL measurements obtained in the North Atlantic Ocean, Mediterranean Sea and Pacific Ocean over the past 7 years [19]. The noise increase stems directly from the reported [20] increase during the 1962-to 1974-period in total merchant ships (26%). Bulk carriers, numbering about 4100 vessels (or about 18% of the world's merchant fleet) have lengths commonly between 600 to 800 feet. Supertankers (ships non-existent prior to 1968) presently number about 480 vessels, or 10% of the world tanker fleet, and have average dimensions: length 1084 feet, beam 163 feet and draft 66 feet. These large ships are likely the dominant contributors to sea noise in the infrasonic and low-frequency bands. Seasonal, economic and political considerations can unpredictably affect shipping noise levels.

D. Time-Series Records

Acoustic data acquired using OBS 2 are shown in Fig. 3. These data are sound pressure spectrum levels, SPSL, obtained from third-octave levels and adjusted to 1-Hz bands; the absolute levels have been established using prerecorded calibration tones of 6, 8, 12, 18, 24 and 32 Hz. Each time series is composed of more than 10,000 data points, each representing a one-minute power average in its third-octave band.

Several observations are drawn from these time-series records. First, the scatter of individual points especially at the lower frequencies is due to seaquakes, while the increase and subsequent decrease of SPSL amplitudes over periods from 1/2 to about four hours result from nearby ship passages. Second, ships passing near OBS 2 affect different one-third octave bands owing to their differing propellor blade rates and specific machinery and hull vibration modes. Third, nearby ship passages appear to affect lower frequency levels earlier and for longer periods than higher frequency levels within the recorded band.

5. MEASUREMENT PROBLEMS

Acoustic measurements in the infrasonic and low-frequency bands are susceptible to instrumental problems which can increase the measuring system's self-noise levels. Oceanic currents and turbulence produce direct and, often, indirect instrumental problems by virtue of relative motion between the hydrophone-suspension system and the adjacent water mass. The direct instrumental problem is flow noise; the indirect instrumental problems include: (1) triboelectric noise, (2) Aeolian noise, (3) displacement noise and (4) acceleration noise. Mechanical noise is usually, but not always, independent of oceanic currents.

Flow noise is an electrical signal generated by the active element responding to the hydrophone's turbulent wake. Turbulence, characterized by random pressure fluctuations, has been termed pseudosound by Ffowcs-Williams [21] in this case and is localized. The radiation process is very inefficient but can produce spectrum levels in excess of ambient levels in the infrasonic band as demonstrated in laboratory tests [17, 22 and 23], in an inland lake [24] and at sea [25]. In the NRL experiment the flow noise levels developed by the H-58 hydrophone were at least 10 dB below the mean infrasonic sea noise levels; flow noise did not impair the hydrophone's performance. Flow noise is reduced by placing hydrophones on or near the ocean bottom [16], where currents are weak, or by equipping hydrophones with flow shields [26, 27].

Triboelectric noise is an electrical signal generated by the changing hydrophone cable capacitance resulting from ocean current-induced mechanical deformations. These consist of bending, twisting and compression modes which Donovan [28] reports can produce peak-to-peak voltages ranging from 10μV to 100 mV, larger than hydrophone signals due to sea noise. (For example, broadband acoustic noise of 105dB/ /μPa which is detected by a hydrophone of sensitivity of -190 dB re 1 V/μPa generates a voltage signal of -85 dB re 1 V or about 32μV.) Triboelectric noise can be avoided by careful selection and testing of cables and by choosing a bottom location where ocean current-induced cable deformations are minimized.

Aeolian noise [29] is sound, usually at a frequency below 50 Hz, produced in the presence of a uniform fluid flow by mechanical vibration of suspension cables. The mechanical vibration is caused by fluctuating lift forces acting on taut suspension lines, in this case near the hydrophone. These forces can be suppressed by designing a complaint suspension system, by using faired cables [30] or by placing the system (as in the NRL experiment) near the ocean bottom to avoid significant currents.

Displacement noise is generated by a hydrophone in response to changing hydrostatic pressure. In this experiment displacement noise was not present since the hydrophones, in deep water, were not suspended.

Cable vibrations and ocean floor movements can affect the performance of suspended hydrophones and rigidly-bottomed hydrophones, respectively. The active hydrophone element generates electrical signals [31], termed acceleration noise, whose spectrum levels can exceed ambient sea noise levels. Acceleration noise is minimized by using acceleration balanced units, such as the H-58 hydrophone used in the NRL experiment. Its acceleration sensitivity is -46dB/ /1 V/g at 5 Hz so that an ocean floor displacement of one micron would produce 5×10^{-7}volts. This corresponds to a spectrum level of +52 dB/ / 1 V/μPa, about 16 dB below the OBS electronic noise level.

Mechanical noise is often produced by rotating devices and by transient mechanical operations within the instrument package. Mechanical noise can also result from uncoated chains, shackles, swivels and other mechanical fittings on or near the instrument package. The OBS unit is not equipped with such exterior fittings; aural monitoring of the tape did not indicate any evidence of mechanical noise.

Bottomed hydrophones are less likely to suffer from instrumental noise of the types discussed above than suspended hydrophones and are thus preferred, particularly for infrasonic measurements.

6. SUGGESTED EXPERIMENTS

Two experimental efforts are recommended to expand the acoustic data base and to develop a quantitative relationship between noise sources and sea noise levels in the infrasonic and low-frequency bands at and above 1 Hz. The first experiment needs to relate weather effects to sea noise levels in deep ocean basins. For this purpose, long-term (one-year) omnidirectional measurements using ocean-bottom hydrophones are suggested. These acoustic data would then be compared to synoptic wind-speed and wind-direction estimates in the hydrophone area.

Required from the second experiment are the spectral content and intensity of representative merchant ships, especially bulk carriers and supertankers. Sonobuoys suitably modified to avoid spurious cable and hydrophone signals [32] and to function in moderate seas are a feasible means for such an investigation. Data from these experiment can be incorporated in an acoustic model of the noise field at very low frequencies, i.e. less than 25 Hz.

7. SUMMARY

Distant shipping noise is concluded to be the principal source of infrasonic and low-frequency sea noise at the Mid-Atlantic Ridge, a result of measurements taken in an area near numerous seaquakes. Distant shipping noise dominates sea noise levels about 90% of the time during the recording period.

Seaquakes recorded within the dynamic range of the OBS equipment raised noise levels by at least as much as 20 dB across the acoustic band, 5 to 32 Hz. Many (over half) seaquakes exceeded the dynamic range of the recorder causing clipped and blocked hydrophone signals. Increased dynamic range is a first requisite for future experiments utilizing acoustic sensors.

Instrumental problems in making acoustic measurements in the infrasonic and low-frequency bands are discussed. It is concluded that infrasonic measurements are best taken using bottom hydrophones.

Two experiments are suggested to increase the infrasonic data base and to relate quantitative infrasonic sea noise levels to their sources: long-term weather-induced noise experiment in a deep-ocean basin and an experiment to measure representative merchant shipping noise. The development of sonobuoy capable of making infrasonic sea noise measurements is needed to implement the second experiment.

8. ACKNOWLEDGMENTS

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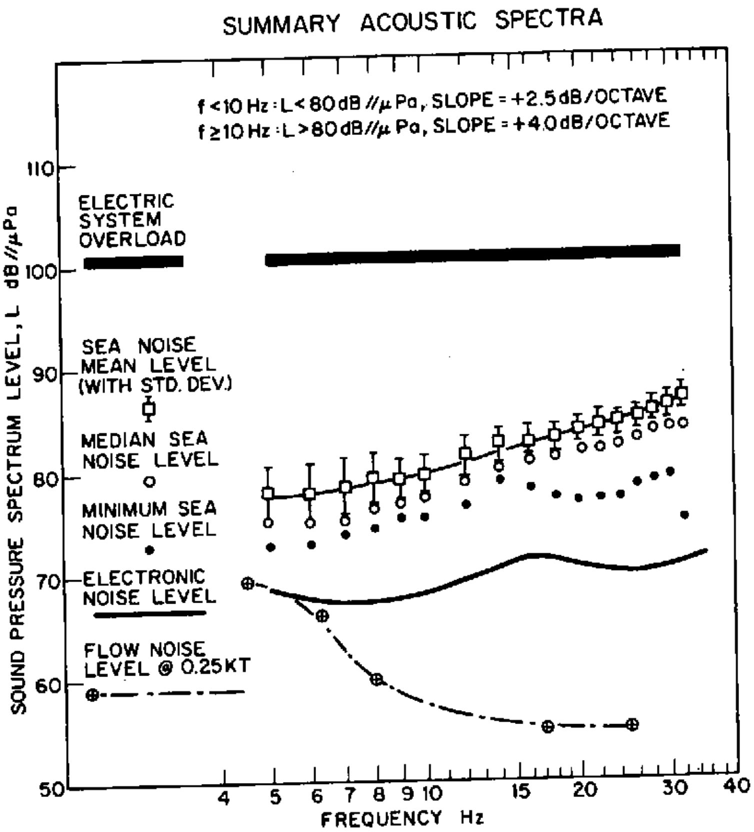


FIGURE 1

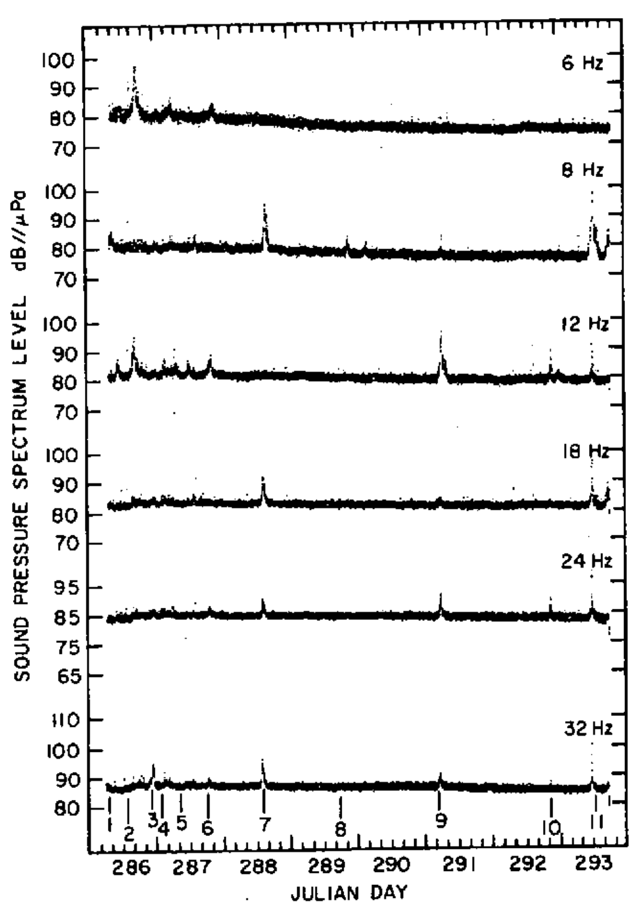
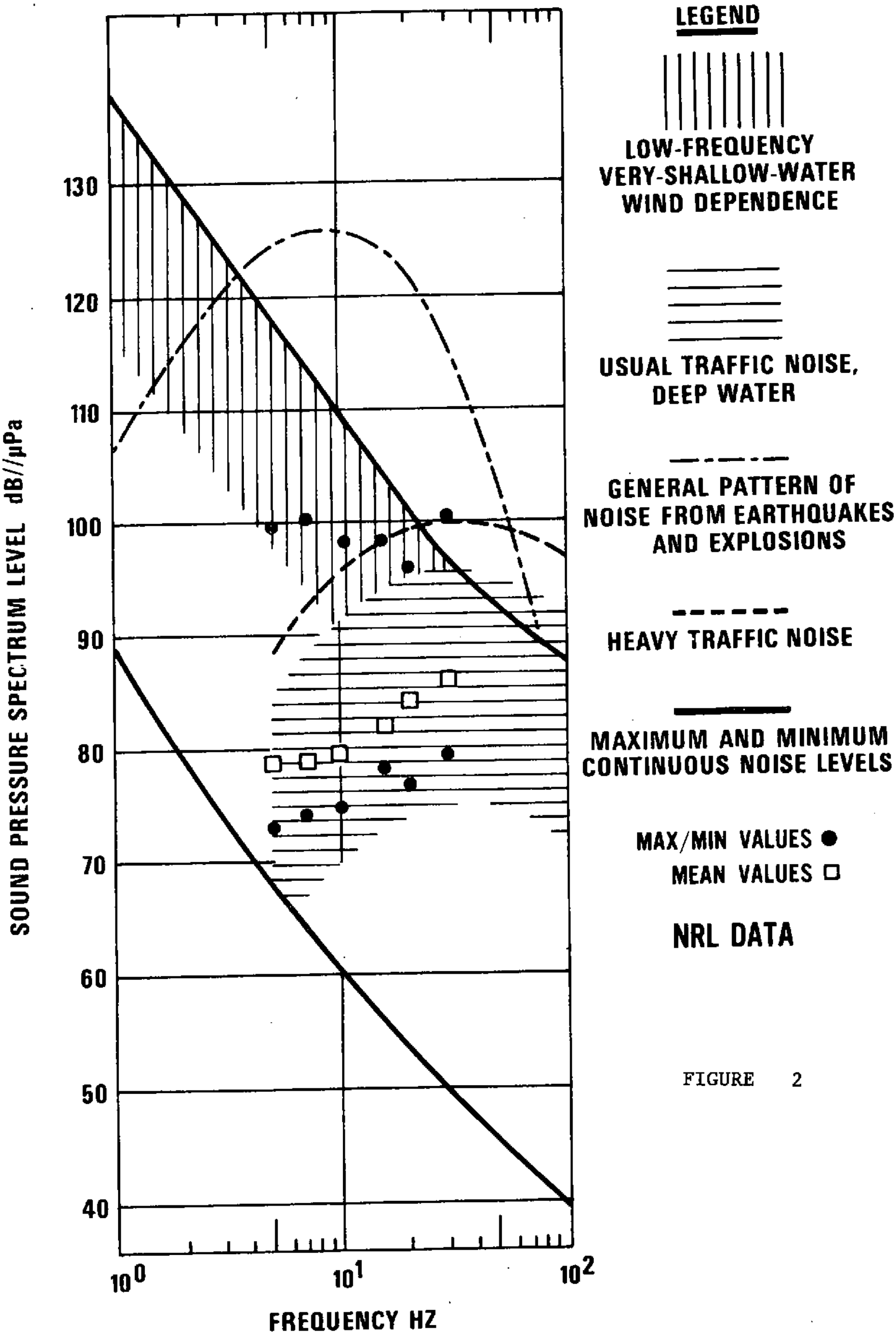


FIGURE 3



SOUND PRESSURE SPECTRUM LEVEL dB//μPa
130
120
110
100
90
80
70
60
50
40
10^0
10^1
10^2
FREQUENCY HZ
LEGEND
LOW-FREQUENCY VERY-SHALLOW-WATER WIND DEPENDENCE
USUAL TRAFFIC NOISE, DEEP WATER
GENERAL PATTERN OF NOISE FROM EARTHQUAKES AND EXPLOSIONS
HEAVY TRAFFIC NOISE
MAXIMUM AND MINIMUM CONTINUOUS NOISE LEVELS
MAX/MIN VALUES
MEAN VALUES
NRL DATA

FIGURE 2