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Report to the Scientific Director

UNDERWATER PRESSURES OF SEISMIC WAVES

By

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La Jolla, California
October 1953

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ABSTRACT

Underwater pressures from the seismic waves of the Ivy Test shots were recorded in a 4- to 12-cps band, with the equipment used in the seismic survey carried out concurrently with the test. Mike shot was received on USS Lipan, 48 km easterly from Ground Zero, with a hydrophone suspended at 200 ft depth. Peak pressure of 10 millibars and mean pressure amplitude of 6 millibars were recorded. King shot was recorded on a hydrophone suspended in the Parry Island test drill hole. Peak pressures were off scale, but the mean pressure of the initial seismic-wave group was estimated to be 2 millibars. From intensity measurements of seismic refracted waves made during the Bikini Survey of 1950, it is estimated that these pressure levels correspond to TNT shots, fired above ground or water, of charge size 5 megatons and 0.5 megaton, respectively, with a probable error of a factor of 10.

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ILLUSTRATIONS

UNDERWATER PRESSURES OF SEISMIC WAVES

1 INTRODUCTION

During the seismic refraction studies of Eniwetok Atoll,[1] made in conjunction with the Ivy Tests, seismic waves from Mike and King shots were recorded with the same recording equipment used in the seismic survey. These observations are of interest for a number of reasons, among which are the following:

1. Measurement of the pressure levels gives the magnitudes of the seismic-wave intensities in the 5- to 10-cps frequency range.
2. Comparison with TNT shots made at similar distances enables rough estimates of the TNT equivalent weight required to produce the observed wave intensities.

2 OPERATIONS

Mike shot was received on USS Lipan (ATF-85) at estimated position 11°34.4′ north latitude, 162°38.3′ east longitude. This is 48 km (26 sea miles) from Ground Zero. The Lipan was underway at about 2 knots, towing a small dry dock. The receiving hydrophone was towed at a depth of 200 ft, about 100 yd astern. Firing instant was picked up on a photocell from a light meter furnished by Loris Gardner of Task Unit 8, Technical Photography Unit, Task Group 132.1.

King shot was received at the Parry Island drill hole,[2] which is at coordinate position 48,240 ft north, 131,371 ft east (latitude 11°23.76′N, longitude 162°22.49′E). This is 18.5 km (10 sea miles) from the nominal target Ground Zero at coordinates 108,150 ft north, 124,130 ft east. The receiving hydrophone was lowered to a depth of 250 ft into the drill hole. The firing instant, as in Mike shot, was picked up on a light-meter photocell.

3 OBSERVATIONS*

The recorded waves for both Mike and King shots are illustrated in Fig. 1. The record of King shot shows the amplified output of the light meter which recorded the light wave. The pips

*A "bar," as used in this report, is defined as 10^6 dynes/cm^2; "pressure amplitude" is measured on a recording from the zero line to a peak or trough; and "intensity measurements of the refracted seismic waves" refers to the pressure level expressed in decibels relative to 1 microbar (thus "pressure level" equals 20 log p, where p is the pressure amplitude). "Mean pressure amplitude" is the average of the pressure amplitudes for the first four successive peaks and troughs following the wave arrival, beginning with the first trough (pressure minimum). For example, if the departures from the zero line were 2 bars for the first trough, 4 bars for the first peak, 6 bars for the second trough, and 8 bars for the second peak, the mean pressure amplitude would be 5 bars.

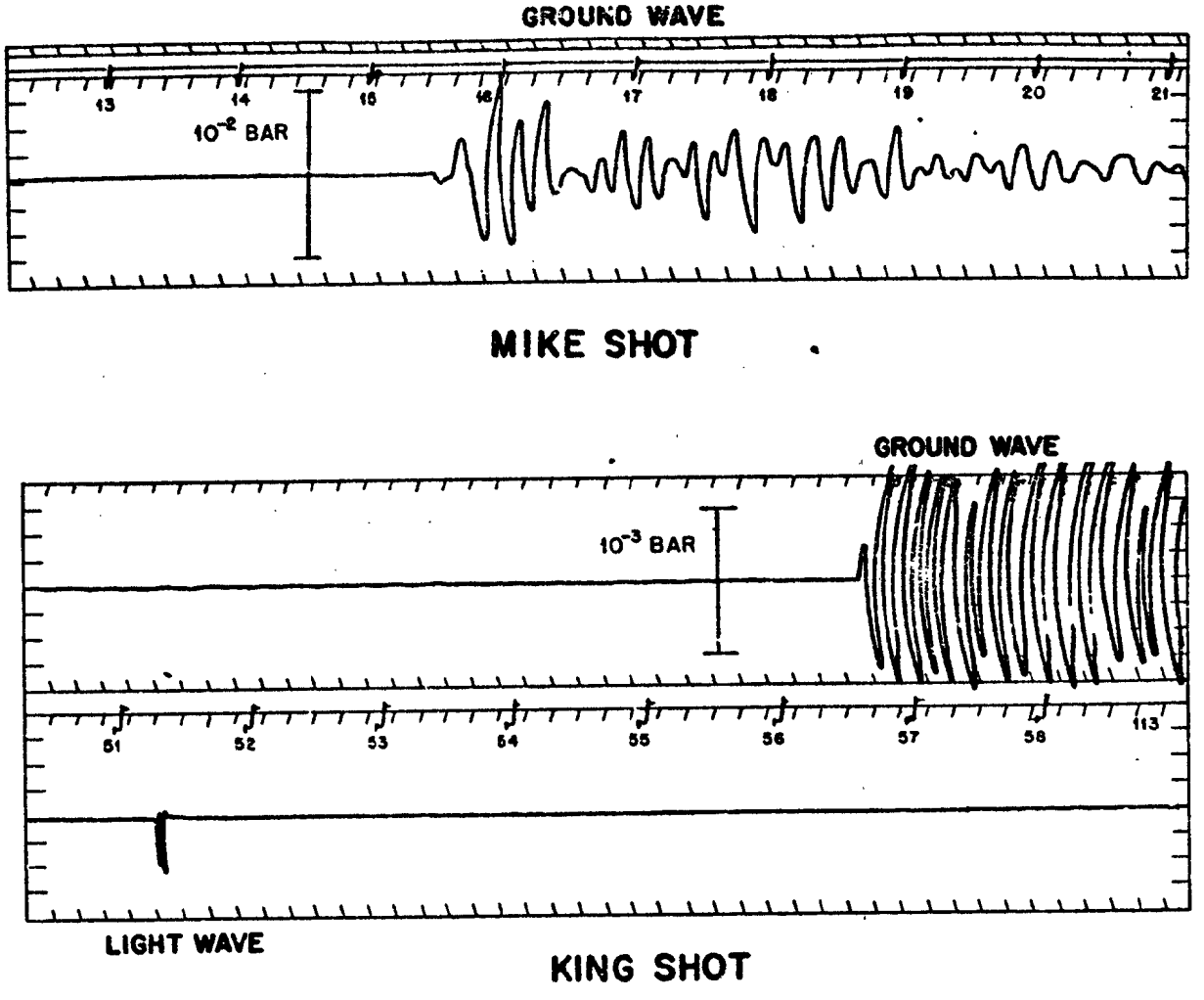

Fig. 1—Oscillograms of first arrivals of seismic waves.

shown between the light-wave and ground-wave traces were recorded from a break-circuit chronometer and occur at 1-sec intervals. Before and after each shot, the chronometer was calibrated by recording the radio time signals from WWV. The drift curves of chronometer error were linear within 0.01 sec, which is the order of the error of reading the record. Hence, it is estimated that the time of firing is known (with respect to WWV time) to about 0.02 sec. Firing instants, in the Marshall Islands time, were 0714: 59.18 ± 0.02 sec for Mike shot and 1129: 59.77 ± 0.02 sec for King shot. Travel times of the ground waves were 13.00 and 5.31 sec, respectively.

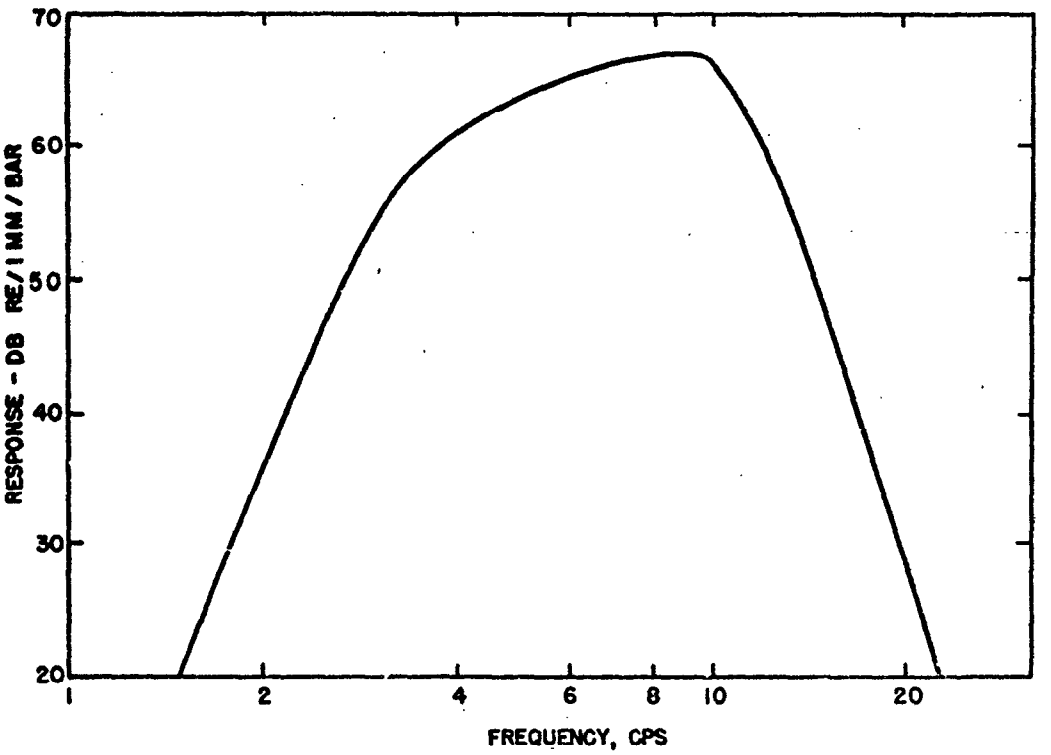

Fig. 2—Frequency response, Mike shot, 1 November 1952.

For each shot, after the level of seismic waves had dropped to background level, the receiving system was calibrated for sensitivity as a function of frequency by the standard procedure of injecting signals of known voltage and frequency across a calibrated resistor placed in series with the piezoelectric crystal in the hydrophone. Since the hydrophone had been previously calibrated in a pressure chamber, the pressure sensitivity was known in terms of equivalent voltage input to the calibration resistor. From these calibrations the over-all pressure sensitivities as a function of frequency were determined for each of the two setups and are plotted in Figs. 2 and 3.

In order to indicate the magnitude of the pressure level, the amplitude expected for signals of 10^{-2} bar amplitude of the dominant frequency of 5 cps for Mike shot and of 10^{-3} bar amplitude and 8 cps dominant frequency for King shot is drawn on the respective oscillograms. The peak recorded amplitude for Mike shot was 10 millibars. The mean amplitude, defined as the mean of four successive peaks and troughs of pressure starting with the first trough, was 6 millibars.

The peak pressure amplitudes of King shot were well above the level at which the recording amplifier "clips" the signal to prevent pen damage. Consequently they cannot be measured, but they can be roughly estimated by comparing the initial "unclipped" swings with the initial swings of the Mike record and assuming similar form of the initial group of waves. From this, an estimate of 3×10^{-3} bar for the peak pressure and 2×10^{-3} bar for the mean pressure amplitude was obtained for the initial King shot.

At Mike shot, the air wave was heard plainly, but the record showed only a very small increase of level above the seismic waves then arriving. The beginning of this signal occurred 141.16 sec after the firing instant. The air wave from King shot was much stronger and was picked up by the hydrophone and also by the light meter. Its travel time was 46.74 sec.

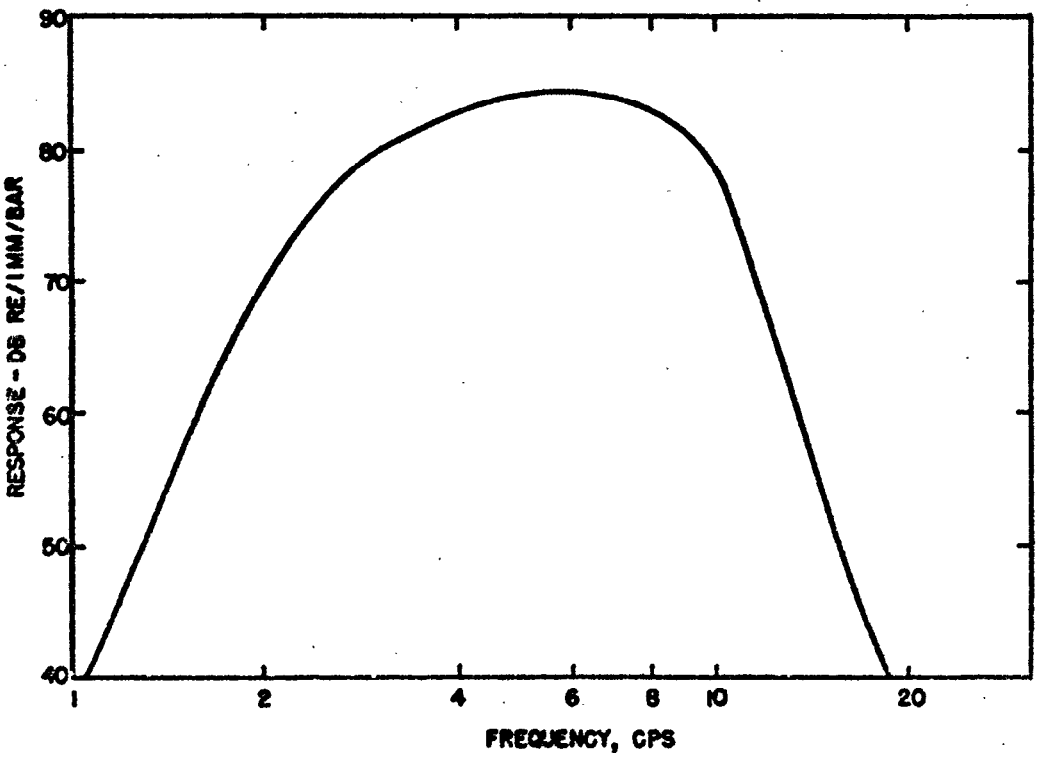

Fig. 3—Frequency response, King shot, 16 November 1952.

4 CONCLUSIONS

There are very few published data on the pressures produced in overlying water by seismic waves. The records of the Eniwetok seismic survey have not been studied for pressure level. Furthermore, many of these records are unsuitable for intensity measurements because the simplified portable equipment used on this survey was set up for travel time rather than intensity measurement. Fortunately, however, there were available some unpublished measurements made at Bikini in the course of the seismic survey at Bikini[3] in 1950, which are directly pertinent. These consist of mean pressure measurements as a function of frequency for a profile extending southerly from a point just inside the lagoon in the Enyu Channel out to a distance of 50 km. Shots varied from 1 to 50 lb of TNT and were fired at depths between 100 ft for the

1-lb shots to 200 ft for the 50-lb shots. Shot comparison experiments have shown that, under these conditions and with frequency responses comparable to those shown on Figs. 2 and 3, the mean initial pressure amplitudes are proportional to the square root of charge weight.

Figure 4 shows the resultant mean pressure levels, corrected to a 1-lb charge. A large scatter is observed, but on the average the intensity decreases systematically with range at a rate between the inverse third and fourth power of the range. The scatter is typical of measurements of this kind and illustrates that a single intensity measurement can be expected to indicate merely a rough order of magnitude of the source energy, even when the average transmission loss is well established by many measurements.

The extrapolation of the data of Fig. 4 can be tested by comparison with data from the Heligoland blast of 18 April 1947 (in which 4000 tons of high explosives was fired in rock

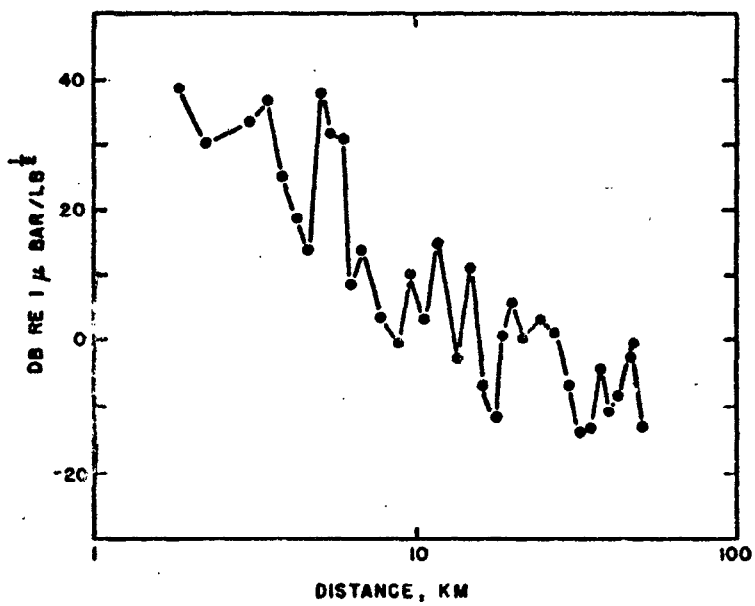

Fig. 4—Seismic-wave intensities as a function of distance at Bikini.

tunnels), which were recorded underwater[4] by HMS Nepal at a distance of 52 km. A peak pressure of 1200 microbars was recorded. Neither the signal frequency nor the system band width was given. From Fig. 4, the average level of a 1-lb shot at 52 km is about −10 db, or 0.3 microbar. Hence for 4000 tons the predicted mean pressure amplitude is 800 microbars. The agreement with the observed peak pressure of 1200 microbars is much better than could be expected, and it gives some confidence that extrapolation to greater charge size would be reasonable.

The greatest remaining uncertainties are (1) the allowance to be made for shots placed above the ground or sea surface instead of well beneath the surface as in the observations of Fig. 4 and the Heligoland blast, and (2) in the case of King shot, the allowance to be made for the response in the cased hole in the ground as compared with the response of the same hydrophone suspended in water above the ground. Both these considerations have considerable practical importance and deserve theoretical work, which, as far as the author is aware, has not been undertaken. Rough estimates of these effects can be obtained from observations by the author that (1) 50-lb shots give 10 to 20 db lower level of refracted ground wave when fired at the water's surface than when fired at a 200-ft depth and (2) signals received on a hydrophone

in the Elugelab island drill hole in the seismic survey[1] were about 10 db below those received on the same hydrophone in water at comparable ranges.

From the above considerations, taking the level at 48 km in Fig. 4 to be −10 db, it is estimated that the intensity from Mike shot corresponds to approximately 4×10^8 lb of TNT fired underwater or underground or to between 4×10^9 and 4×10^{10} lb if fired aboveground.

Similarly, taking the level at 18.5 km in Fig. 4 to be 0 db, King shot equivalent is estimated to be between 1×10^8 and 4×10^9 lb if fired aboveground.

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