HIGHLIGHTS OF BOTTOM TOPOGRAPHY INFERRED FROM RECEIVED DEPRESSION AND BEARING ANGLES

by

F.M. Phelan, R.B. Williams* and F.H. Fisher
University of California, San Diego
Marine Physical Laboratory of the
Scripps Institution of Oceanography
San Diego, California, U.S.A.

ABSTRACT

Statistical properties of the acoustic reflection from the ocean floor have been studied for a variety of bottom types including deep, smooth, flat topography to rough, jagged bottom in shallower ($\approx$ 1 km) depths. Explosive sources are used with ranges from 4 to 20 km, while the receiver array is mounted on a moored stable platform (Marine Physical Laboratory's FLIP). High coherence is found from the first part of the return, and degradation in the coherence is noted as more of the return is processed. A simple empirical model is offered for this coherence versus signal processed. Due to the initial high coherence, 3-D coordinates of the bottom bounce point can be calculated, and fine features (highlights) of the bottom can be deduced.

* *Now at NATO SACLANT ASW Research Centre La Spezia, Italy*

INTRODUCTION

The statistical modelling of bottom reflection phenomena is in an infant stage at the present time. Many basic questions need attention before an adequate basis can be formed upon which these models can proceed. Over the last several years, our group at the Marine Physical Laboratory of the University of California at San Diego have been involved in studies of reflected signals from various bottom topography. Part of our study has addressed itself to a few of these "basis building" questions: what is the level of coherence of the bottom reflected return, and under what conditions or with what processing procedures can the coherence be enhanced? Is the energy reflected from a small fraction of the bottom surface with well defined regions (highlights), or is there energy reflected from most of the bottom (reverberation)? Under what conditions can we expect highlights or reverberation? If there are highlights, are they well enough defined to apply pattern recognition techniques? How may we model the distribution of highlights, if they do indeed exist? At present, the study is far from having clear answers to these questions, but some results are emerging, and as the study proceeds we are hopeful that further knowledge will be forthcoming. This paper sets down our knowledge of these questions to date, and the procedure we have used.

Our work thus far has covered several types of bottoms off of the coast of California and near Hawaii. Those near California include deep (4 km), smooth, flat bottoms, rougher bottoms with average slopes up to 5 degrees, and very rough bottoms with average slopes up to 20 degrees and depths from 700 to 1400 meters. The Hawaii area studied varied in bottom type from rough volcanic to smooth hard bottoms with depths from 600 to 1100 meters. In this paper, we will present results from the Hawaii areas, pointing out similarities to the California areas also studied.

1. INSTRUMENTATION AND EXPERIMENTAL SET-UP

While the receiver vessel, FLIP, was stationary over the bottom in a three-point moor, the source ship opened range from 4 up to 20 km, setting off SUS mark-61 explosive "shots" every 200 meters. Many different runs were made thus, each time the source ship's beginning point was offset perpendicular to the run direction by 200 meters, forming a grid of "shot" positions 200 by 200 meters. A trailing hydrophone at the source ship connected to a radio link to FLIP allowed a precise measure (taking into account the delay from the shot to the trailing hydrophone) of the acoustic travel time to FLIP. Using a precise sound velocimeter, the range of the shot could be measured to a relative accuracy of a few meters.

Mounted aboard FLIP was an array of four hydrophones; two at a 90 meter depth horizontally separated by 13.5 meters, and another pair at 85 meter depth with the same horizontal separation. All four hydrophones were in a plane roughly perpendicular to the sound path, and optically surveyed to a position accuracy better than 1 cm. In addition, a fifth or "sync" hydrophone was situated on a 5 m mast projecting toward the source ship so as to receive the sound before the others. The "sync" hydrophone signal was used for initiating data sampling and data validation described below.

Profiles of sound speed and temperature were made from FLIP by lowering a f.m. multiplexed system of sensors developed at the Marine Physical Laboratory (MPL). The package consisted of a Lockheed sound-speed sensor, an MPL-developed f.m. thermometer, and a vibrating-wire depth sensor. The various separated signals were fed into a multi-channel f.m.-to-digital converter, which is a component of an MPL computer system centered around a Hewlett Packard 2116B computer. The hydrophone signals were sent up cables aboard FLIP, analog high-passed at 300 Hz and fed into a multi-channel analog-to-digital converter capable of digitizing eight signals simultaneously, up to a rate of 50 kHz. This unit is also a component of the MPL computer system: the selection of one of eight sets of the eight signals to be digitized, and the rate of digitization are dynamically set by the computer program. A radio link signal described above was also used for facilitating data collection described below, and validating data. Fluctuations in the radio link due to the equipment were about two milliseconds.

2. DATA COLLECTION PROCEDURES

Data collection was performed under computer control, valid data being stored on digital magnetic tapes. Rather elaborate procedures were used to collect the data, in anticipation of competing signals from other ships in the area, energy received from our own shots by unwanted paths, and biological noise. The procedure taken was based on using as much information of our signal as possible: knowledge of when the pulse was initiated (via radio link information), the range (computed from the previous valid signal or weighted information of previous signals), length and character of the signal and the repetition rate of the shots were all used.

The computer was instructed to "look" for a radio link signal and then wait for a time based on the range calculated from a previous signal (originally estimated by the computer operator at the beginning of a run). At that time, minus a small safety factor, the computer then repeatedly sampled at a 10 kHz rate, the signal energy of the "sync" hydrophone. When this energy rose above a threshold dynamically set by the program, digitization at a 50 kHz rate of the hydrophone signals took place for about 10 ms. This data thus gathered was temporarily stored in the core of the computer. Inspection of the gathered data by the program was then done to see if the signal received was of proper character to be a direct (water-borne) signal. This procedure guards against short noise pulses of biological origin previously encountered, or confusion resulting from missing the direct signal. If the signal was not long enough to be valid the data was ignored and the "sync" energy sampling was reinstated. If the signal was "good", a time was set before "looking" for the bottom-reflected signal, based on the current range, water depth and sound speed profile. When the reflected signal arrived and was validated by the above procedure, all of the data were logged on magnetic tape, real-time analysis was performed, a new expected time for receipt of the next signal was calculated, and the cycle reinitiated. If valid data were not received in a set "window period", a new expected time was calculated, the "window" widened somewhat and the process reinitiated.

3. REAL-TIME ANALYSIS

Between shots (90 seconds for most runs), analysis of the data took place and various displays and calculations were made. The digitized data of the different hydrophones were presented on a scope display to show personnel aboard FLIP whether or not proper sampling was taking place. Due to a lead time from the sync hydrophone, sampling of the data signals took place about one or two milliseconds before actual receipt of the signal, guaranteeing a sampling of the beginning of the signal and also obtaining a sample of the noise for signal-to-noise analysis. Correlations between the various signals were made and, using an iterative routine, approximate bottom-bounce coordinates were calculated. However, refinements to the procedure were made at a later time, and more exact solutions were obtained.

4. BOTTOM REFLECTION POINT COORDINATE CALCULATIONS

In order to obtain a solution for the three coordinates (x,y,z) of the (effective) reflection point on the bottom, the following information is needed: (1) horizontal and vertical arrival angles of the received wavefront with respect to FLIP for both the water-borne (direct) and bottom-reflected signals, (2) the precise travel time of both types of signals, (3) the sound speed profile, and (4) FLIP's orientation in space. Due to the refraction effects, the equations for (x,y,z) are non-linear. We have used an iterative technique for the solution, starting the iteration with the solution without refraction, and find that convergence of the solution is always possible provided the input data are reasonable. Studies of the approximate sensitivity of the various input values on the solution have been done. [See, for example, Fig. 4, showing uncertainty in (x,z) by estimating uncertainties in the input values]. However, a more extensive study of this is presently underway.

5. SOME RESULTS AND DISCUSSION

Figure 1 is characteristic of vertical-arrival angle data in "rough" and "semi-rough" topographies. This particular data was from a "semi-rough" area 100 miles from the coast of California. An interesting feature of this data is the existence of plateaus, such that the arrival angle at the receiver is constant even though the source to receiver range is opening. This feature has been interpreted by us to mean that a small part of the bottom surface is responsible for reflections for several different ranges. As the range is opened further, the reflection points shifts to the next "highlight". Note also that sometimes two arrival angles are seen, corresponding to reflections from two "highlights" simultaneously. This is manifested by two peaks in the vertical correlation function.

Figure 2 shows a plot of X vs Z coordinates of the calculated bottom bounce points for a run in the same area. This "side view" is a result of connecting the bottom bounce points by straight lines, and then projecting the resulting line (in 3D space) onto a vertical plane roughly parallel to the propagation of sound. The vertical exaggeration is ten to one. The X value does not always increase as the source range increases, but sometimes doubles back, depending on the topography (for example, the loop near X = 8 km).

The plan view (X vs Y) of the results of several runs made near Hawaii (Fig. 3) illustrates features of rough and smooth areas. Toward the east, the topography has high average slopes and is much rougher than to the west, where more gentle slopes are found. Note that the bottom bounce points tend to cluster in the rough regions. In fact, the radius of some clusters is within the uncertainty of our measurements. In the smoother bottom areas, the bottom-bounce points form more of a line (with slight deviations), as would be expected of reflections from a plane. These slight deviations can be correlated with known bottom topographic features such as valleys with as little as a meter or two of depression in a depth of 700 meters.

As mentioned earlier, coherence between pairs of hydrophone signals is degraded as more of the reflected signal is used. We believe this is due to the increase of the number of reflections that are received simultaneously as time increases. We have attempted to describe this in a single mathematical model that fits our data. A two parameter formula which is consistent with our result is

$$ccc(t) = b + (1-b)e^{-t/a} \qquad \text{[Eq. 1]}$$

where t is the length of signal processed starting from the initial reception of the signal, a and b are constants that depend on the statistics of the bottom. At this time, we feel it is premature to put forth a physical argument for this, but merely offer it as an empirical result. Figure 4 shows some data from Hawaii in the rough and smooth areas, with Eq. 1. Typical values for a are about 2 ms, while b ranges from 0.7 to 0.9.

CONCLUSIONS

High correlations (> 0.95) were found between receiver signals spaced 5 and 13.5 meters apart when the first 0.5 ms of the bottom-reflected signal was processed. This high correlation is believed due to reflection from a single small area (highlight) of the bottom topography. As more of the received signal is processed, the correlation is degraded, which is consistent with the simultaneous reception of reflections from other highlights. The degradation of the correlation can be summarized in a empirical model:

$$ccc(t) = b + (1 - b)e^{-t/a}$$

where ccc is the correlation coefficient between receiver signals, t is the length of signal processed and a and b are constants that depend on the statistics of the bottom topography. Typical values are $a = 2$ ms and $b = 0.90$ for the vertical receiver separation, $b = 0.80$ for horizontal receiver separation.

For some topography one distinct highlight dominated the reflection signal: whereas the source receiver was varied such that for a flat bottom, the reflection point would be expected to cover an area of 800×800 m , the measured reflection points were concentrated in a 50 m radius. In all rough and semi-rough bottom topography measured to date, single reflection points could be well discerned. The distribution of these highlights was not uniform over the bottom, but formed clusters. In contrast, the smooth bottoms showed a distribution much closer to being uniform.

There is other information regarding the bottom topography that can be extracted from the data. It is possible at a bottom-bounce point to calculate the two components of the slope vector, and thus generate slope statistics. We believe that the data is also good enough for some runs to identify the coordinates of several highlights from one shot. These are some of the specific aspects of our future work.

ACKNOWLEDGMENTS

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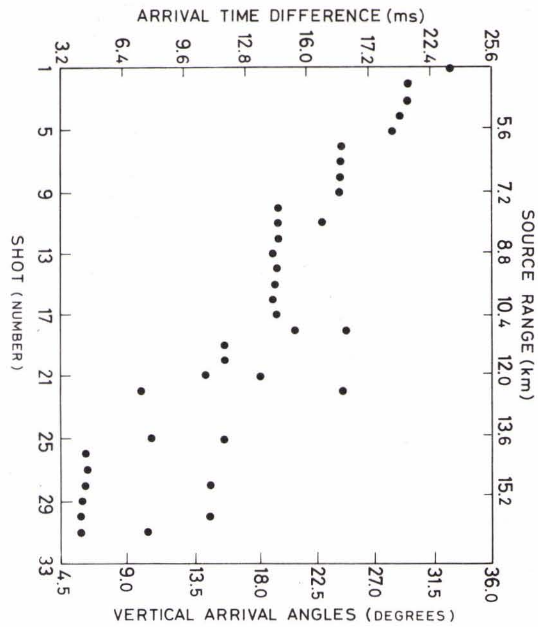

FIG. 1 VERTICAL DELAY TIMES

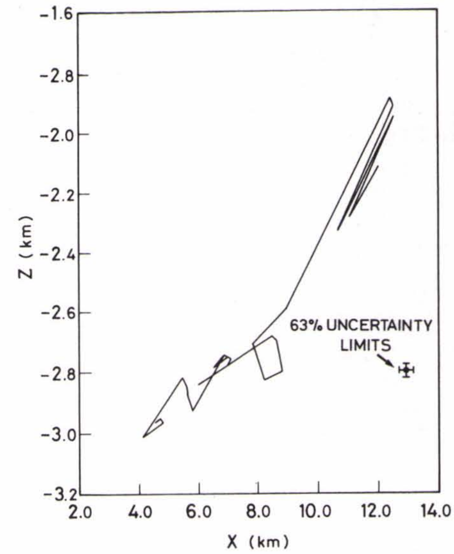

FIG. 2 BOTTOM BOUNCE COORDINATES SIDE VIEW

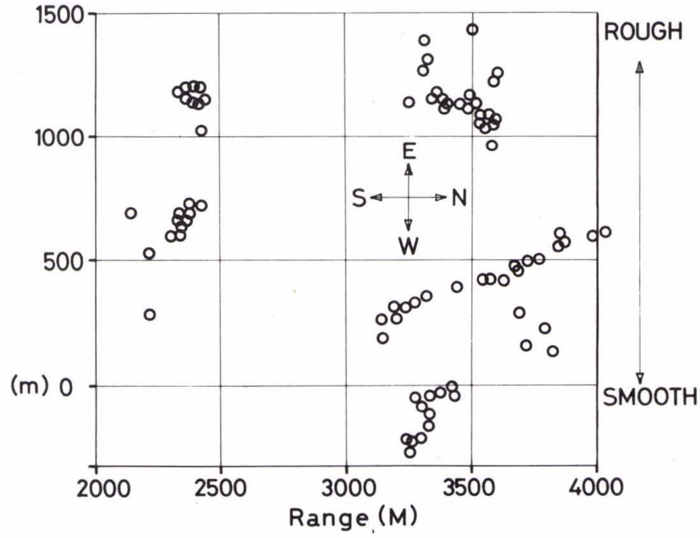

FIG. 3 BOTTOM BOUNCE POINTS PLAN VIEW

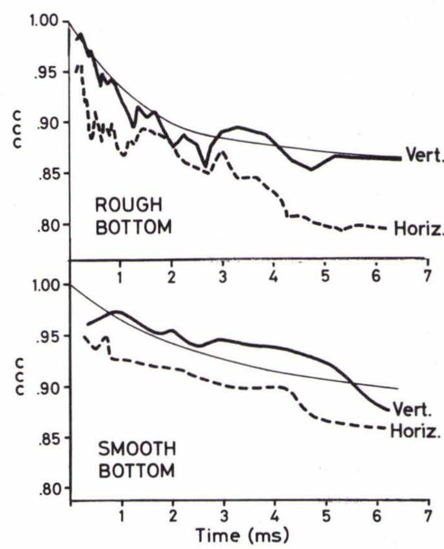

FIG. 4 CORRELATION COEFFICIENT VS SIGNAL PROCESSED