MINIMIZING INSTRUMENT EFFECTS IN AN OCEAN BOTTOM SEISMOMETER

D. J. Dodds
GeoAcoustics Inc., Box 790, Aurora, Ontario, Canada L4G 4J9
D. M. F. Chapman, J. C. Osler, and W. C. Risley
Defence Research Establishment Atlantic, Box 1012, Dartmouth, Nova Scotia, Canada B2Y 3Z7

1. Introduction

Ocean acousticians have traditionally made measurements of the pressure component of the sound field. An earlier paper[1] described initial tests by one of the authours on an existing ocean bottom seismometer (OBS) which uses velocity sensors (geophones). Geophysicists have used OBS instruments primarily to time discrete seismic events. This paper describes a new OBS designed to measure sea floor vibration amplitudes, down to the ambient noise level, in the 1-50 Hz range. The design goal was to minimize both the self noise (an additive effect), and the multiplicative effect of the transfer function which relates sea floor motion to the motion recorded by the OBS.

2. Self noise of an OBS

A geophone consists of a "seismic mass" suspended in a geophone case. Relative motion between them is detected by a magnet and coil. Mechanical energy is coupled from the sea floor motion into the mass-spring system of the geophone, transformed into electrical energy by the magnet and coil, and input to an amplifier. Electrical energy is also generated by noise sources: thermal ("Johnson") noise in the resistance of the wire forming the coil, Brownian noise (also a form of thermal noise) in the mechanical parts of the geophone, and electrical noise in the amplifier.[2] Thermal noise is a fundamental phenomenon which cannot easily be reduced. So, to achieve a specified signal-to-noise ratio, some minimum mechanical power must be coupled from the sea floor motion into the seismic mass and transformed into electrical power. This puts a lower bound on the seismic mass, magnet mass, and coil mass, and an upper bound on resonant frequency. Geophones with a resonant frequency <10 Hz must be precisely leveled to function properly, which adds to the mass of the geophone system. Consequently, a self-noise specification puts a lower bound on the geophone mass.

3. Coupling to the Sea Floor

For practical reasons, an OBS must be recoverable, so it must sit on the water side of the sediment-water interface, and be denser than water. When the sea floor moves vertically, the system will act like a mass (the mass of the OBS, less the mass of water it displaces) on a spring (representing sea floor compliance). Near to, and above the resonant frequency of this system, the relative motion between the sea floor and OBS may be significant compared to the motion of the sea floor in the absence of the OBS. When the sea floor moves horizontally, there are more complicated effects. Horizontal motions are discontinuous across the sea floor-water interface. Under horizontal movement of the sea floor alone, the system will again act like a mass on a spring. However, the mass of the OBS is augmented by the effective mass of its entrained water, which increases the relative motion between the sea floor and the OBS by comparison to the case of vertical motion. The OBS may rock (since its center of mass must lie above the sea floor), and horizontal motion of the water alone can excite motion of the OBS. For these reasons, coupling of the OBS to the sea floor can be expected to be poorer in the case of horizontal motion than in the case of vertical motion. Analyses in the literature show that the ideal OBS package should have a low profile, substantial anchor area, a small mass, and a density near that of the surrounding water or sediment.[3,4] A further requirement is that the OBS be effectively rigid, so that the geophones follow the motion of the anchor.

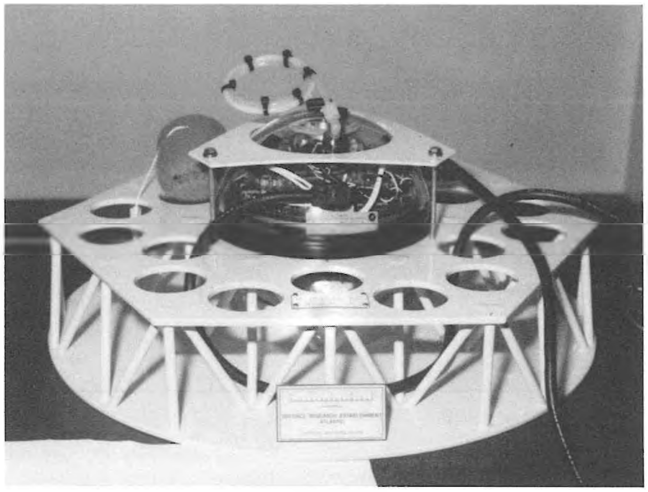

Fig. 1. The geophone package. The spherical glass pressure vessel is supported in the middle of the aluminum anchor disk.

4. Design of the OBS

The OBS was intended to have the capability to measure ambient noise. Its geophones are a triad of the smallest commercially available models which give a predicted self-noise spectrum 20 dB below typical ambient noise in the 1-50 Hz range. They have a resonant frequency of 4.5 Hz, a seismic mass of 52 g, a total mass of 0.35 kg (per geophone), and require leveling to an accuracy of about 1°. Their outputs are digitized by 24-bit delta-sigma analog-to-digital converters, giving a dynamic range of more than 120 dB. The function of the remainder of the OBS is to level the geophone triad, protect it from ambient pressure, couple it to the sea floor, and transmit its outputs in digital form.

To minimize the mass coupled to the sea floor, the components of the system related to deployment and recovery are installed on a frame connected to the geophone package by cords which are designed to lie slack when the OBS is on the sea floor. The geophone package with its anchor disk is shown in Fig. 1. The anchor is an aluminum disk 0.6 m in diameter, which is large enough to prevent excessive rocking of the OBS in response to horizontal excitation. To achieve rigidity, the disk is stiffened by a space frame based on a regular tetrahedral cell. (A simple disk of sufficient thickness to achieve rigidity at 50 Hz would be so massive as to impair coupling to the sea floor.) The 0.25 m spherical glass pressure vessel (which is rated for operation to 6,700 m depth) sits in a cradle in the anchor disk.

The geophones are mounted on a block which rests on the inner surface of the pressure vessel. The leveling mechanism functions by raising the geophone block so that it is freely suspended from a point at the center of the spherical pressure vessel. When the geophone block has settled in a level attitude, it is lowered again to rest firmly on the inside of the pressure vessel. The geophones are arranged in the Gal'perin configuration, meaning that they are mutually perpendicular, but each is inclined equally to the vertical direction. This results in a compact, symmetrical configuration which fits conveniently within the spherical pressure vessel. The three components of motion measured by the geophones can be resolved into horizontal and vertical components by the digital electronics within the pressure vessel.

Table 1 shows the mass of various parts of the OBS. The self-noise requirement puts a lower bound on the geophone mass, but that is only a small part of the total mass coupled to the sea floor. The leveling mechanism contributes significant mass, and it also occupies a large volume which contributes to the mass of the pressure vessel. A more integrated design (e.g. integrating the leveling mechanism into the geophones) could further reduce the mass, thereby improving coupling to the sea floor.

Table 1. Mass of OBS components

Seismic mass of geophones (3)	0.16 kg
Geophones (3)	1.1 kg
Leveling mechanism, electronics	3 kg
Pressure vessel	4 kg
Anchor disk	12 kg
Total mass coupled to the sea floor	20 kg
Deployment/recovery system	≈200 kg

5. Measuring Sea Floor Coupling

To provide a means of evaluating the quality of coupling achieved, a small vibrator (consisting of a miniature dc motor driving an eccentric mass of about 1 g) is mounted to the inside of the pressure vessel. The motor axis is horizontal, so that the excitation has both vertical and horizontal components. The motor can be driven at frequencies from 2 Hz to 50 Hz. The vibrator is driven at selected frequencies with the OBS on the sea floor, and the response is compared to the response with the OBS suspended in water. If the OBS is stiffly coupled to the sea floor, its motion will be less than when it is suspended in water.

6. Results

Typical results of a coupling test are shown in Fig. 2. The "suspended" response show a slope of about 20 dB/decade, indicating that the OBS is constrained by inertia, as would be expected. In the horizontal axis, the "grounded" response is less than the "suspended" response, showing good coupling, up to about 8 Hz. A resonant peak occurs at 10 Hz, and above 20 Hz there is little difference between the "grounded" and "suspended" cases, indicating that the OBS is poorly coupled to horizontal sea floor motion at these frequencies. In the vertical axis, the "suspended" response is substantially less than in the horizontal axis because the anchor disk entrains a large mass of water (about 100 kg) in vertical motion. A resonant peak occurs in the "grounded" response at 20 Hz. The effect of the entrained water mass must be considered when evaluating the results. Without the entrained mass, the vertical "suspended" response would be similar to the horizontal "suspended" response, and therefore greater than the vertical "grounded" response. Thus good coupling is achieved for vertical motion up to 50 Hz. Results have been obtained at several sites, and show significant variations in the quality of coupling depending on sea floor sediment type. It may be possible to improve horizontal coupling by attaching vertical vanes to the bottom of the anchor disk.

7. Conclusions

This OBS uses coil-and-magnet geophones and has a noise floor below typical ambient noise levels in the 1-50 Hz range. The design achieves good coupling to vertical sea floor motion, but the quality of horizontal coupling depends on sea floor characteristics. Horizontal coupling may be improved by vertical vanes attached to the bottom of the OBS anchor disk.

8. Acknowledgment

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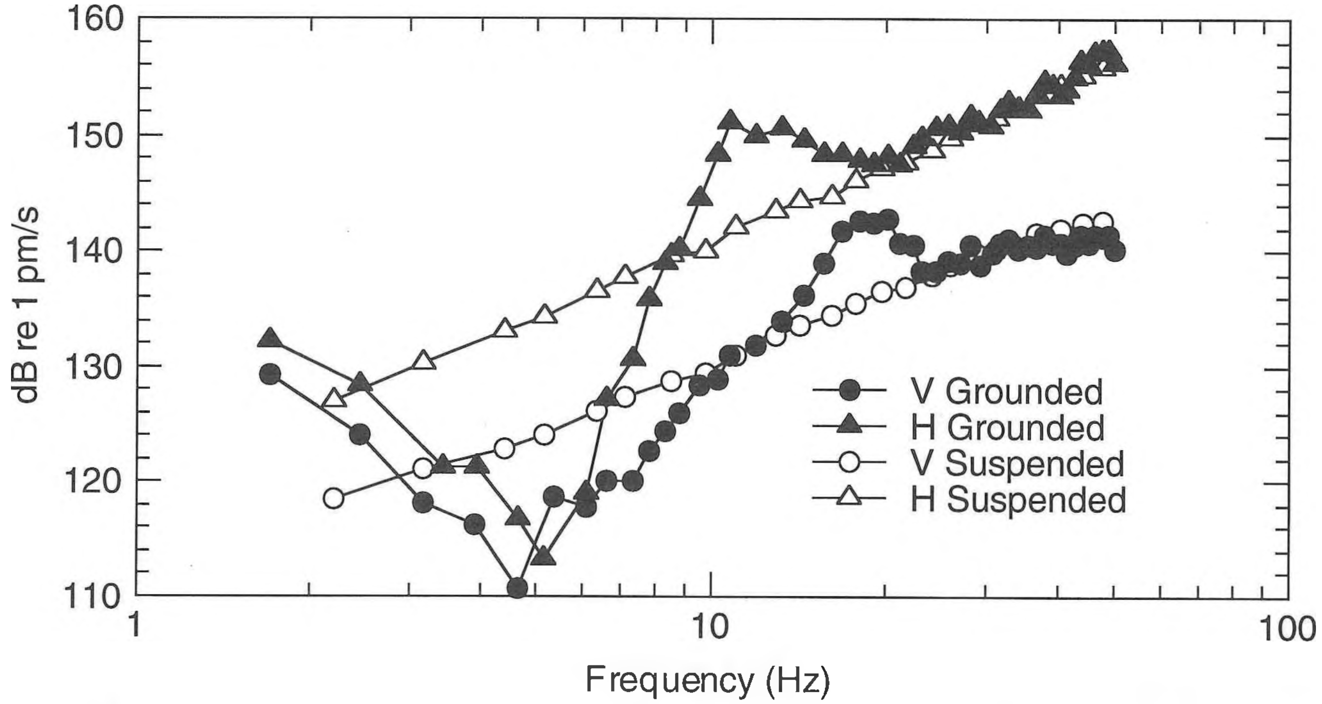

Fig. 2. Results of a coupling test. The values shown are the vertical and horizontal amplitude response of the OBS to an integral vibrator in two conditions: suspended in water, and grounded on a typical sea floor.