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PARTICLE MOTION AND PRESSURE RELATIONSHIPS OF OCEAN BOTTOM NOISE: 3900 M DEPTH; 0.003 to 5 HZ

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Abstract. Samples of ocean bottom noise in the frequency band 0.003 to 5 Hz are analyzed for coherency and amplitude and phase relationships among pressure and the three components of particle motion. Data available from the Columbia-Point Arena ocean bottom seismic station (38° 09.2′N, 124° 54.4′W) provide examples of different noise conditions. Coherent energy peaks near 0.14, and 0.06 Hz suggest fundamental mode Rayleigh wave motion propagating shoreward. Coherent energy near .30 Hz appears to be variable. Pressure variations near 0.01 Hz and lower frequency correlate with wave heights along the California coast and appear to produce forced deformation of the bottom.

Introduction

Possibly the most extensive set of ocean bottom data on long period seismic background noise and signals was obtained from the Columbia-Point Arena Ocean Bottom Seismic Station (OBSS). OBSS operated for over six years and a number of papers [e.g., Auld et al., 1969; Latham and Nowroozi, 1968; Piermattei and Nowroozi, 1969; Sutton et al., 1965; Nowroozi et al., 1968 and 1969] have been published using OBSS data on, e.g., gravity and pressure tides and tidal currents; ocean bottom microseisms; Rayleigh waves from pure oceanic paths and across the continental margin; and local and regional earthquakes.

The Columbia-Point Arena OBSS was installed on 18 May, 1966 at 38° 09.2′N, 124° 54.4′W about 200 km west of San Francisco at a depth of 3903 meters. It was in continuous operation for more than six years, until 11 September 1972. The OBSS included a Lamont long-period (LP) triaxial seismometer (15 sec natural period, originally developed for lunar use); three-component short-period (SP) system (1 sec natural period); long-period (crystal) hydrophone; short-period (coil-magnet) hydrophone; ultralong-period (Vibratron) pressure transducer; thermometer; current amplitude sensor; and a current direction sensor.

Data

The data, recorded on two 7-channel instrumentation-quality FM tape recorders and on seismograph-type drum recorders and strip chart recorders, are currently stored at Lamont-Doherty Geological Observatory. Short- and long-period response curves are published in Sutton et al. [1965]. The long-period data are digitized at 8 sps and the short-period data at 80 sps; a four-pole Bessel anti-alias filter was applied at a frequency equal to one-fifth the sample rate. For each sample of signal or noise digitized, we also digitized seismometer calibration pulses for that date. After system responses are removed from simultaneous noise samples of long- and short-period data, for each of the three components of ground motion, the LP and SP noise spectra are very well matched between about 0.1 and 0.5 Hz (system noise limits the spectra above 0.5 Hz for LP data and below 0.1 Hz for SP data).

To further check the accuracy of the data, we digitized a few earthquakes to verify polarities for all eight components, to compare m_b magnitude determinations with those published, and to compare pressure-vertical relationships with theoretical values. The only potential problem we encountered was with the pressure data. Unlike the seismometers, the hydrophone channels have no daily calibration pulses. Comparison of observed and theoretical P/Z amplitude and phase relationships for digitized earthquake P-waves and Rayleigh waves has convinced us that the 6 dB/octave high-pass corner at 3 Hz, included in the original calibration curve for the coil (SP) hydrophone, does not exist and should be replaced with a 0.3 Hz, 6dB/octave high-pass corner. The original 3 Hz corner represents the effect of an hydraulic relief

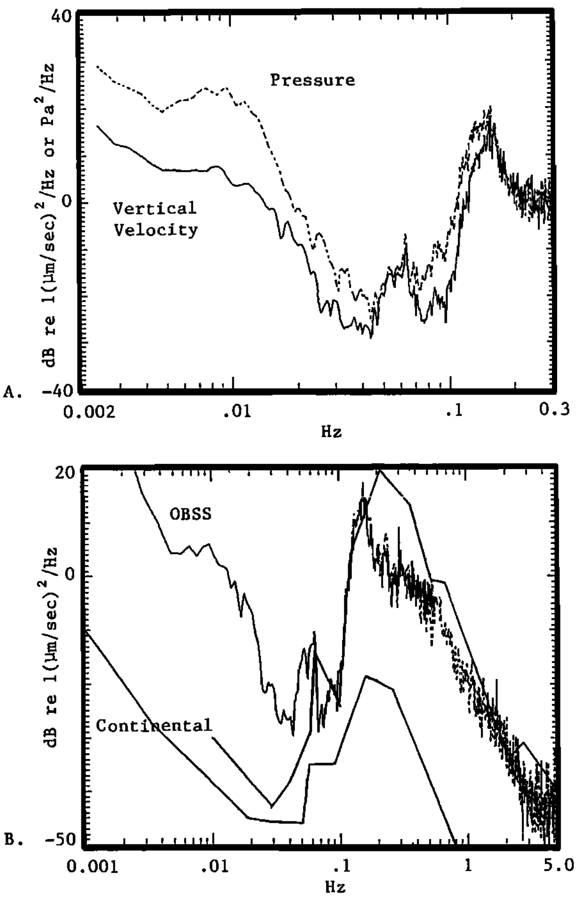

Fig. 1. (A) Instrument-corrected noise power spectra of pressure and vertical velocity. The pressure data may be up to 6 dB too low. (B) Vertical velocity power spectra for OBSS compared with spectra for continental stations under quiet and noisy conditions (Jon Peterson, USGS, unpublished data). The OBSS data are simultaneous samples from LP (solid line) and SP (dashed line) seismometers.

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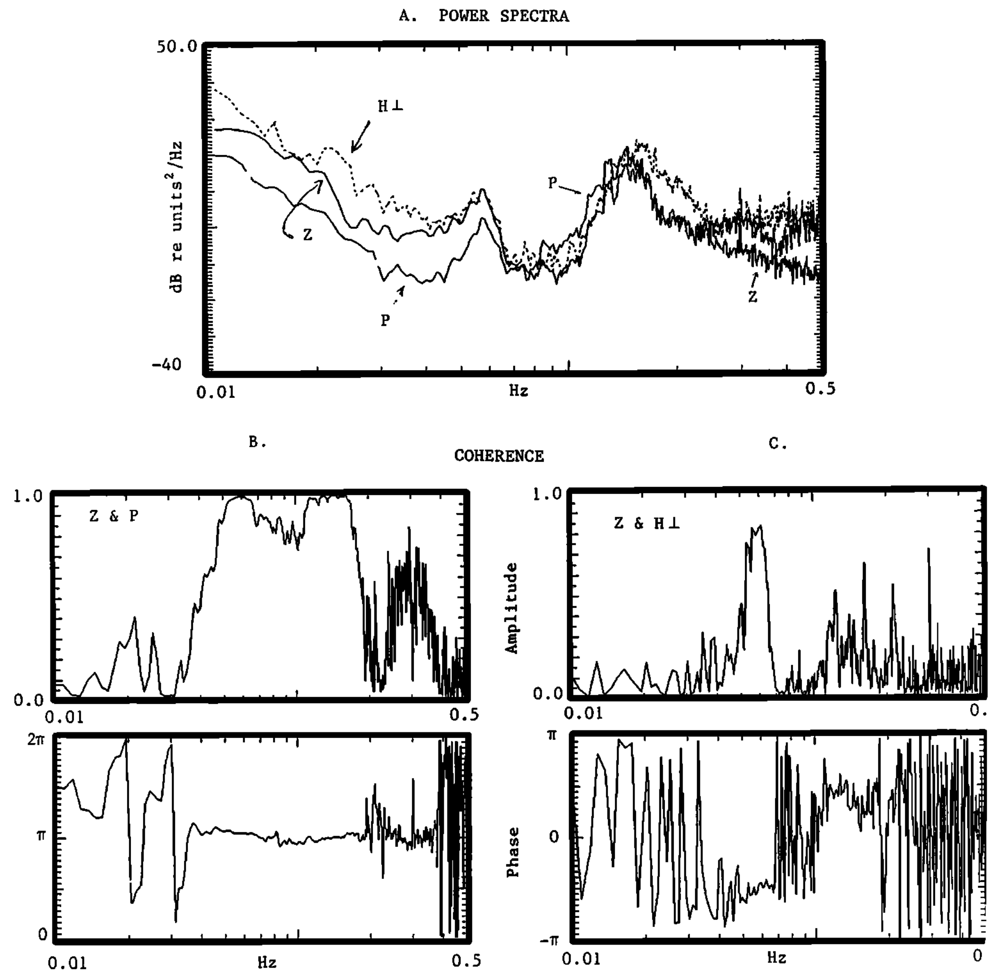

Fig. 2. (A) Instrument-corrected noise power spectra of pressure (P), vertical (Z) and horizontal (H⊥) motion. Units are Pa for P and μm for Z and H. (B) Coherency spectra, Z and P components, amplitude and phase of the data in A.; phase convention: P leads Z. (C) Same as 2B. but for Z and H⊥ components; +H⊥ is azimuth 246°; phase convention: H⊥ leads Z.

system required for installation in deep water. Corrected pressure spectra from the LP and SP (with the 3 Hz corner shifted to 0.3 Hz) hydrophones agree for phase and shape of amplitude between about 0.1 and 0.5 Hz (the overlapping frequency band), but the SP hydrophone data is about 6 dB higher than the LP hydrophone data; thus, the LP pressure power spectra presented in this paper may be up to 6 dB too low.

A final comment about the data: though one channel on both the LP and SP FM tapes measured compensation for wow and flutter during initial recording, we did not have the equipment to electronically compensate during playback. Instead, we subtracted the digitized compensation channel from each of the data channels and thereby improved data quality. Overall system noise limits background data above about 5 Hz and below about 0.003 Hz. (Except that the long-period horizontals record tilts down to at least 0.001 Hz.)

Results

Pressure and vertical velocity spectra, corrected for instrument response, are shown in Figure 1A. These spectra are calculated for a one hour period during which the bottom current velocity did not exceed 2 cm/sec. The pressure spectra agree with those obtained by Cox et al. [1984] and Webb and Cox [1986], showing a rapid decrease for frequencies below the "double frequency" microseism peak near .14 Hz to a strong minimum between about 0.03 and 0.1 Hz. At times, the "single frequency" microseismic noise, at about .06 Hz in this sample, is nearly absent, giving a deeper minimum. The pressure and vertical velocity spectra are generally similar except that the P/Ż ratio increases significantly below about .02 Hz. The P/Ż ratio for seismic waves is expected to decrease with decreasing frequency below about .07 Hz [Bradner, 1963] and appears to be correct for the .06 Hz peak. Below about .04 Hz P/Ż is not consistent with predictions for seismic waves. H. Bradner and M. Reichle (personal communication) have obtained comparable results for the P and Ż components of the OBSS between about 0.05 and 0.2 Hz for a different time period.

In Figure 1B the power spectrum from Figure 1A with SP vertical data added is compared with seismic noise on continents. Curves for continents represent noisy and quiet conditions on hard rock. [Similar curves for continents and islands are found in Murphy and Savino, 1975.] Between .06 and 5 Hz, the ocean bottom noise level pictured here is generally less than, but close to, the level of noisy continental data; below .04 Hz it is well above continental noise. The greatest

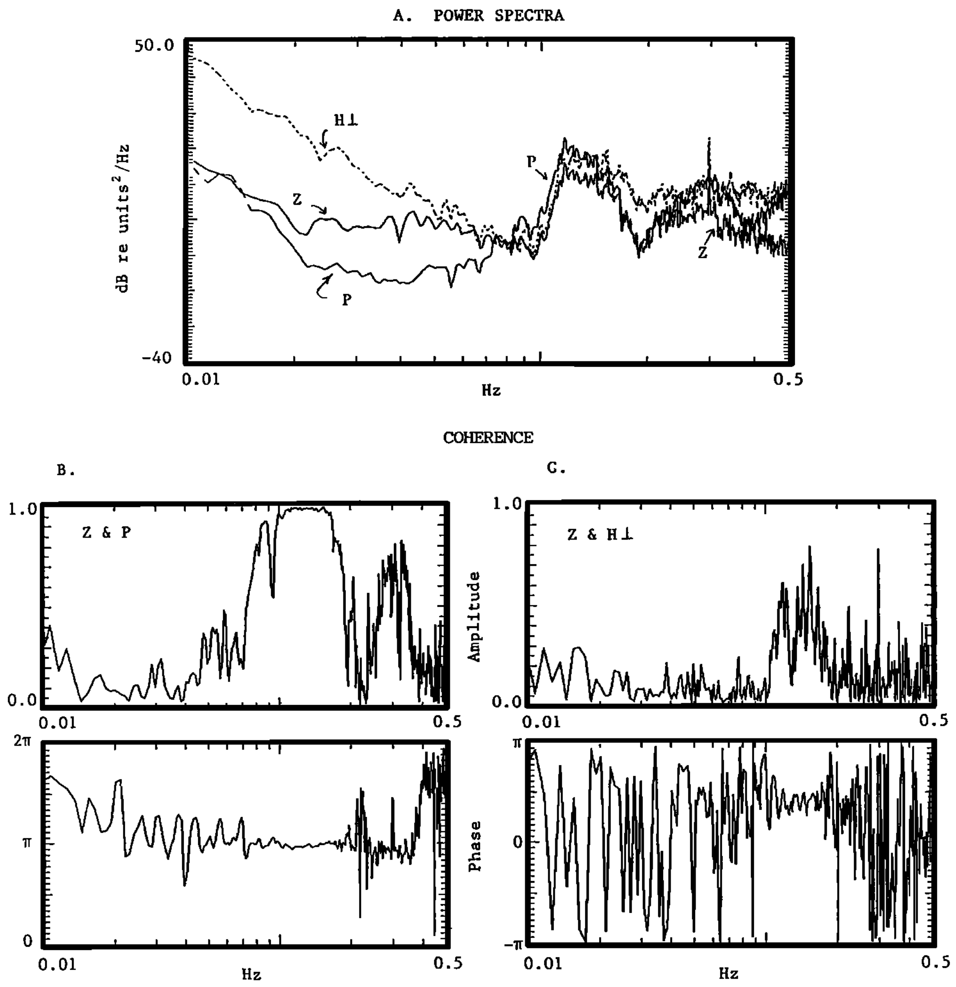

Fig. 3. (A) Instrument-corrected noise power spectra of pressure (P), vertical (Z) and horizontal (H⊥) motion. Units are Pa for P and μm for Z and H. (B) Coherency spectra, Z and P components, amplitude and phase of data in A. (C) Same as B. but for Z and H⊥ components. Phase conventions same as Figure 2.

"real" difference occurs near .01 Hz where the OBSS noise is over 32 dB above the "noisy" continental curve and it is possible that the "real" difference continues to decrease below .004 Hz. How much improvement would be obtained by better bottom-package design; shallow or deep burial within the bottom-sediment; or rigid coupling within the basalt of layer two are important questions to consider for the design of future OBS systems [e.g., Sutton and Duennebier, 1987]. The rise in spectral level at frequencies lower than the minimum is believed to be caused by ultra-long ocean waves and by meterological pressure disturbances on ocean-bottom and land stations, respectively [Webb and Cox, 1986; Murphy and Savino, 1975].

Power spectra and coherency among three components - pressure (P), vertical (Z), and horizontal motion perpendicular to shore (H⊥)- are calculated for two noise samples, 21 June and 4 July 1966 (Figures 2 and 3). The two samples illustrate time-variable features of microseismic noise. Strong coherency in Figure 2 near .06 Hz ("single frequency" microseisms) coincides with a peak in the power spectra of all three components. Between vertical displacement and pressure, coherency is strong from about .06 to .14 Hz and also at .30 Hz. Corrected phase relations and amplitude ratios for the spectral and coherency peaks near .06, .14, and .30 Hz are appropriate for fundamental mode Rayleigh waves. Theoretical results for appropriate velocity structures [Latham and Nowroozi, 1968] indicate that at .14 Hz fundamental mode Rayleigh waves are near the cross-over from retrograde (at the longer periods) to prograde particle motion. Thus, the observed phase relationship between Z and H⊥ indicates propagation toward shore at the OBSS location (about 160 km offshore) for the "single frequency" microseisms. Although Z - H⊥ amplitude coherency is not strong for the .14 and .30 Hz peaks, a stable phase coherency at .14 Hz indicates predominant $\pi/2$ phase difference, opposite the sign of the .06 peak. If the .14 Hz microseisms are prograde, their propagation is shoreward. The phase difference between Z and H⊥ around .30 Hz, though messy, looks more like $\pi/2$ than $-\pi/2$, again suggesting shoreward propagation of prograde fundamental Rayleigh waves. In contrast, the phase difference between Z and H⊥ in Figure 3 appears to be $-\pi/2$ which would indicate seaward propagation. The relatively poor coherency between Z and H⊥ for both the .14 and .30 Hz microseisms suggests variable propagation directions. Note also in Figure 3 that the "single frequency" microseism is not well developed.

In Figure 4 a P-Z coherency maximum near .01 Hz coincides with a spectral maximum most clearly observed from the hydrophone. The ratio of pressure to vertical velocity is much too high for fundamental mode Rayleigh waves. The amplitudes of these disturbances do not correlate in time with tidal currents but do correlate with ocean wave heights

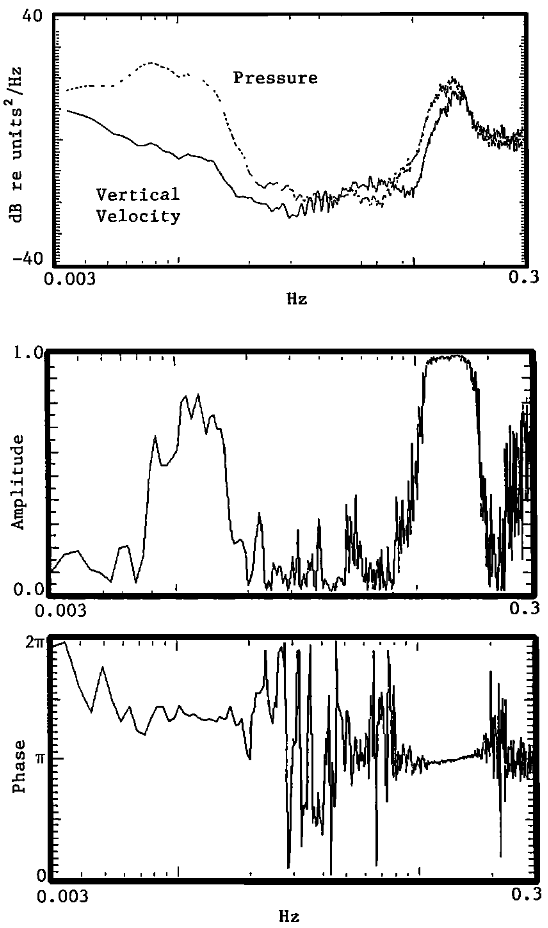

Fig. 4. Instrument-corrected noise power spectra and coherency spectra for Z and P components. Units are Pa for P and μm/sec for Z. Coherency spectra of the same data are calculated using vertical displacement; phase convention: P leads Z.

observed along the nearby California coast [Sutton et al., 1965]. The pressure signal is produced either by long (shallow water) waves non-linearly generated near shore from the ocean swell, or by differences in pressure beneath the high-amplitude vs. low-amplitude swell as varying amplitude wave-sets pass over OBSS, or a combination of the two. In the former case shoaling water is required, whereas in the latter case the disturbance would be observed wherever water depth is not large compared to the "wavelength" of the wave sets. In either case the velocities and wave lengths involved are much smaller than for seismic signals of the same period and the bottom moves as a forced deformation.

Summary

Results discussed is this paper are: 1) coherent spectral peaks are observed on vertical seismometers and hydrophones near .01, .06, .14, and .3 Hz; 2) the peak at .06 Hz also shows strong coherency with horizontal motion perpendicular to the coast; 3) peaks at .06, .14, and .30 Hz have comparable pressure-vertical velocity ratios and $\pi/2$ phase difference appropriate for free-running boundary waves; amplitude and phase relations, including horizontal components, suggest the .06 and .14 Hz peaks are predominantly fundamental mode Rayleigh waves propagating toward shore, but the .30 Hz peak is not as clear; 4) a peak at .01 Hz has 5-10 times greater pressure-vertical velocity ratio than shorter period peaks; the amplitude of the .01 Hz pressure peak correlates with ocean wave heights observed at nearby coastal stations; and 5) the noise spectra observed from the OBSS seismographs, including the deep (variable) minimum between about .03 and .1 Hz, are generally similar to published pressure spectra [e.g., Webb and Cox, 1986].

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