INSTRUMENT CALIBRATION OF OCEAN BOTTOM SEISMOGRAPHS

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Abstract:

To increase the accuracy of measuring sea floor motion with ocean bottom seismometers, we calibrate the seismometer system on the ocean floor. Data from the sea floor calibration, augmented with electronic and land calibration data, enables us to find the OBS transfer function to an accuracy of 0.5% in the frequency range of 0.1 to 32 Hz. We are able to distinguish between temperature, instrument and OBS ground coupling effects, all of which alter the transfer function. This paper reviews our method of calibration and discusses the effects of temperature and some of the instrument design features on the vertical seismometer transfer function.

1. Introduction

The goal of seismic instrument calibration is to relate the data recorded by the seismometer to the ground motion, unperturbed by the instrument’s presence. Calibration can be divided into two parts: 1) finding the instrument transfer function relating recorded data to seismometer motion, and 2) finding the effect of the instrument’s presence on sea floor motion. The instrument transfer function (t.f.) is found by applying a known electric signal to a calibration coil within the seismometer. Before calibration, the ocean bottom seismometer (OBS) t.f. is accurate to 10 or 15%, the tolerance of the capacitors used to filter the analog data prior to digitization. By calibrating the analog filters and the entire OBS, we are able to distinguish between the effects that different portions of the OBS have on the data and reduce the t.f. error bounds to less than 0.5% for frequencies from 0.1 to 32 Hz. Results from sea floor calibrations and the effect the OBS has on sea floor motion will be discussed in another paper.

2. Instrument Calibration

We calibrate the system utilizing the two coils inside the OBS Mark Products L4C-seismometer. The calibration coil drives the mass and the sensor coil measures the motion. Ground motion causes the suspended coils to move with reference to a fixed magnet generating an electric current, and conversely, an electric current passing through the calibration coil generates a magnetic field that forces the coils to move. In both cases, magnetic flux lines cut through the sensor coil creating a voltage that is filtered, digitized and recorded by the OBS. The output of the sensor coil is a measure of the differential movement between the seismometer mass and the OBS.

By applying a known electric signal to the calibration coil, we can find the OBS t.f. A random telegraph (r.t.) signal is used for the calibration input. This signal consists of a sequence of square waves each of duration $\tau$ seconds. The amplitude of each section of length $\tau$ is either 0 or $A$ amperes depending on the corresponding output of a pseudo-random binary generator; $A$ is chosen so that the output signal is large but unclipped. The generator is non-repeating for $2^{14} - 1$ intervals but is reset for each calibration run so all the r.t. sequences are identical. The time con-
stant \( \tau \) is chosen to be three sampling intervals (for our OBS this is \( 3/128 \approx 0.0234 \) seconds) so the power spectrum of the input signal falls off to zero at \( \approx 43 \text{Hz} \).

A set of calibration data consists of 3 to 5 minute recordings of the r.t. output from each seismometer component. We record at least three sets of calibrations for every OBS deployment; the redundancy allows us to remove occasional errors in the data and to increase the amount of signal averaging for noise reduction.

The processing method for finding the corrected t.f. involves the use of spectral ratios as described in Berger et al. (1979). The required spectra are generated from the r.t. signal output and from an estimate of the r.t. signal output. Generation of the estimated output will be described below. The cross-spectral ratio of the measured r.t. output and the estimated r.t. output is divided by the power spectrum of the estimated r.t. output to obtain a correction term \( \Delta F \). When \( \Delta F \) is multiplied by the estimated t.f. a corrected t.f. \( \tilde{F} \) is formed which more closely approximates the true t.f. as follows:

\[
F_{\text{OBS}} \approx \tilde{F} = \Delta F \cdot F_{\text{est}},
\]

where

\[
\Delta F = \frac{O_{\text{est}}^* \cdot O_{\text{OBS}}}{O_{\text{est}} \cdot O_{\text{est}}^*};
\]

\( O \) is the Fourier transform of the output (estimated or OBS), and \( O^* \) is its complex conjugate. The approximation improves with greater cross spectral averaging, and as the noise of the OBS output decreases.

When the cross spectrum of two unaligned series is taken, the computational necessity of time series segmentation and windowing with a function peaked at zero lag causes a biased result (Jenkins and Watts, 1968 p. 399). The input r.t. signal is shifted in phase with reference to the output signal, so the straightforward method of dividing the cross spectrum of the input and output by the power spectrum of the input does not give the best estimate of the t.f. For this reason, we use the estimated output, which is closely aligned with the actual output (there is little relative phase shift between the two signals), and thereby reduce cross spectral biasing. Our method differs from that of Berger et al. (1979) in how we generate the expected output. They form their expected output by convolving a first-differenced, sampled instrument step response with the digitized random telegraph signal. Our instrument step response is too long to allow easy convolution with the r.t. input, therefore we start with an estimated OBS t.f. derived from the OBS filter and seismometer motion equations:

\[
F_{\text{electronic}} = B \prod_{i=1}^{5} \frac{(s-S_i)}{\prod_{j=1}^{10} (s-S_j)} \text{ counts/volt}
\]

\[
F_{\text{seismometer}} = C \frac{s^3}{\prod_{k=1}^{2} (s-S_k)} \text{ volts/meter displacement},
\]

where \( B \) and \( C \) are constant gains and \( s = i\omega \), \( \sqrt{-1} \) times the angular frequency. The electronic response is complicated by the prewhitening filter, included to make the best use of the 66 dB dynamic range of the 12 bit analog to digital converter (Moore et al., 1981; Dorman et al., 1978). The transfer function estimate for the entire OBS is:

\[
F_{\text{est}} = F_{\text{electronic}} \cdot F_{\text{seismometer}} \text{ (counts/meter displacement)}
\]