SEPARATION OF BODY AND SURFACE WAVES IN STRONG GROUND MOTION RECORDS

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SYNOPSIS

A method[1] to separate body and surface waves in strong motion accelerograms is presented. This method incorporates a linear system model which accounts for the behavior of both body and surface waves. To demonstrate the method, Fourier spectra of the mainshock records from the 1971 San Fernando earthquake are used. Spurious peaks occurred in many calculations due to divisions of Fourier spectra. A multi-station scheme which eliminates the spurious peak problem is presented.

INTRODUCTION

A number of strong motion accelerograms were collected from the 1971 San Fernando earthquake. These records were digitized and corrected for errors by the California Institute of Technology. Among these records, three mainshock accelerograms at ground levels, that is 8244 Orion Avenue, 15250 Ventura Blvd. and 1800 Century Park East, are used in this presentation. Fig. 1 illustrates the relative locations of these stations with respect to the epicenter.

SYSTEM MODEL

In order to understand fully the behavior of the ground during an earthquake, it is desirable to incorporate the source, the transmission path, and the local site geology simultaneously in the analysis. An approach may be made using linear system theory. This theory manipulates the accelerograms in the frequency domain by making use of the concept on transfer function[2]. A simple linear system model[3] which incorporates the characteristics of both body and surface wave is shown in Fig. 2. The symbols E, R, W, X, and G represent respectively the source functions, the radiation patterns, the path transfer functions, the local site characteristics, and the ground motions; with the subscript b denoting body wave and s denoting surface wave. All the functions are in frequency domain. These functions are related by the following two linear equations.

$$G_s = E_s \, R_s \, W_s \, X_s$$
$$G_b = E_b \, R_b \, W_b \, X_b \qquad (1)$$

The computation of the radiation patterns R_b and R_s are obtained[1] using a model of a double couple source in a semi-infinite medium. The path transfer functions W_b and W_s are modeled using damped spherical

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equations for body waves and damped cylindrical spreading equations for surface waves.[1,2] The modeling of the local site characteristics for the body waves, X_b is based on the Haskell-Thomson method[4] with SH-waves propagating vertically through horizontal layers. Actual soil profiles for the sites[5] are used for the modeling. The local site characteristics for surface waves, X_s, is not so well defined as yet. It is assigned unit amplitude for all frequencies in this analysis.

METHOD OF SEPARATION

The method for separating body and surface waves makes use of two stations and one earthquake event. Based on the system model presented in Eq. (1) and Fig. 2, the following set of linear equations can be written.

$$\begin{aligned} G_{s1} + G_{b1} &= G_1 \\ G_{s2} + G_{b2} &= G_2 \\ G_{s1} / G_{s2} &= M \\ G_{b1} / G_{b2} &= N \end{aligned} \qquad (2)$$

where G_{s1}, G_{s2} and G_{b2} are the body and surface wave components at stations 1 and 2. These are the unknowns in the above set of linear equations. G_1 and G_2 are the Fourier transforms of the actual accelerograms recorded at the two sites, and M and N are known quantities which can be calculated from the equations shown below.

$$M = \frac{R_{s1}\, W_{s1}\, X_{s1}}{R_{s2}\, W_{s2}\, X_{s2}} \qquad N = \frac{R_{b1}\, W_{b1}\, X_{b1}}{R_{b2}\, W_{b2}\, X_{b2}} \qquad (3)$$

A set of equations for calculating the body and surface wave contents for the two stations can be obtained by solving the set of linear equations in Eq. (2). These equations are shown below.

$$G_{s2} = \frac{NG_2 - G_1}{N - M} \;; \qquad G_{s1} = \frac{M(NG_2 - G_1)}{N - M}$$

$$G_{b2} = \frac{G_1 - MG_2}{N - M} \qquad G_{b1} = \frac{N(G_1 - MG_2)}{N - M} \qquad (4)$$

where all the variables are functions of frequency.

Two sets of calculated body and surface wave spectra for station Orion are presented in Fig. 3 and 4. The station pairs used for the computations are Orion and Ventura; and Orion and Century Park East. Fig. 5 shows the psectrum for the recorded ground motion at Orion.

SPURIOUS PEAKS

The separated body and surface wave spectra shown in Fig. 3 and 4 are not quite satisfactory due to the presence of spurious peaks. This is especially pronounced in Fig. 4. These spurious peaks tend to dominate the records, thus yielding undesirable inverse transform time histories.[1]

A multi-station procedure is used for eliminating these spurious peaks. By making use of the separated body and surface wave spectra at the same station obtained from two independent sets of calculations, an acceptable set of separated body and surface wave spectra can be obtained. This is done by combining these sets of independently calculated spectra for the same components using different weighing factors. Fig. 6 shows the combined results for station Orion. Note that the spurious peaks are reduced quite significantly.

RESULTS

This presentation provides a method to separate body and surface wave contents in strong motion accelerograms. The method requires Fourier transforms of the accelerograms at two stations. In addition, the complete transfer functions from the source to the site for both stations are also needed. Two sets of separated spectra for the body and surface wave contents are presented. A method for eliminating spurious peaks from the calculations is also examined. However, all these calculations provide only a preliminary evaluation on the separation technique. The reliability of these calculations is yet quite rough. In order to achieve better reliability, the modeling of the transfer functions ought to be improved so that all the important influences on the seismic waves can be incorporated. Also, a better method for avoiding spurious peaks is needed.

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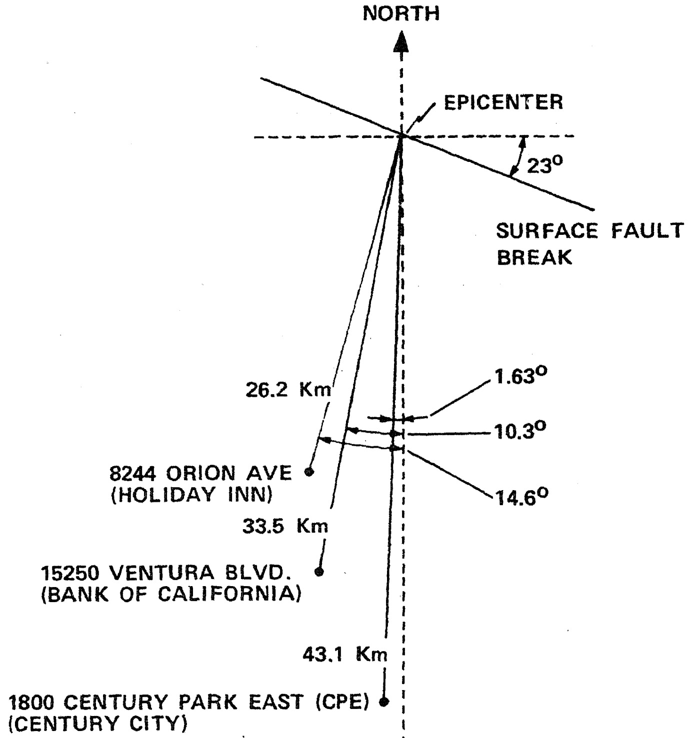

Figure 1. Stations Used in the Analyses.

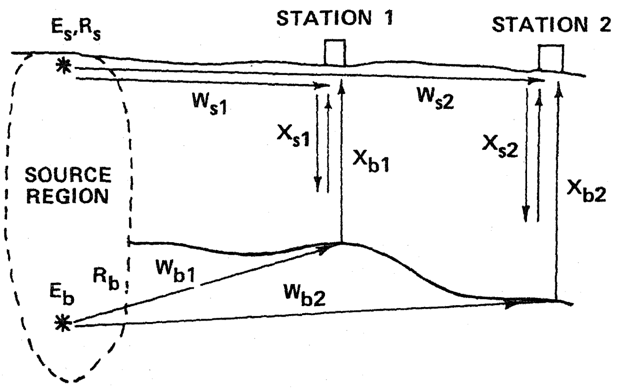

Figure 2. Linear System with Two Stations.

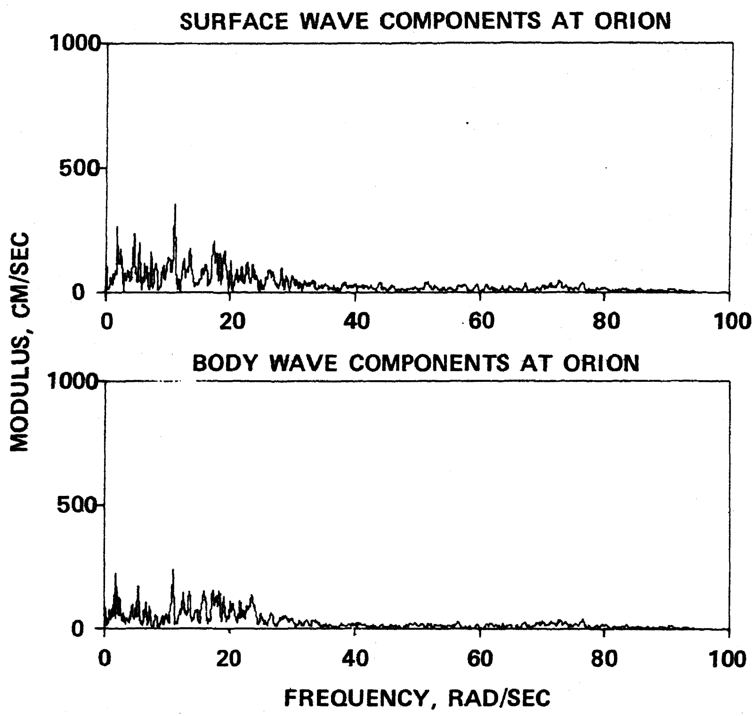

Figure 3. The Separated Spectra for Orion, Orion and CPE Pair.

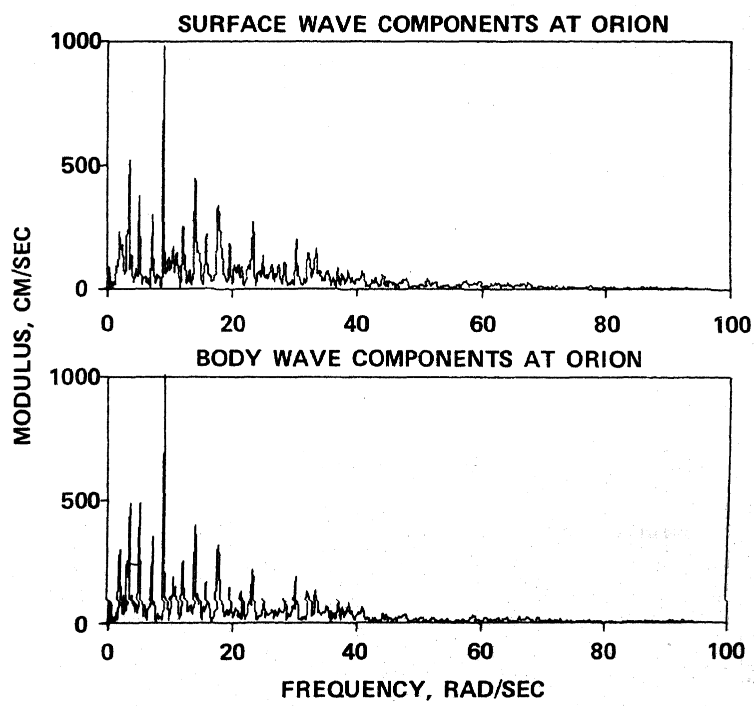

Figure 4. The Separated Spectra for Orion, Orion and Ventura Pair.

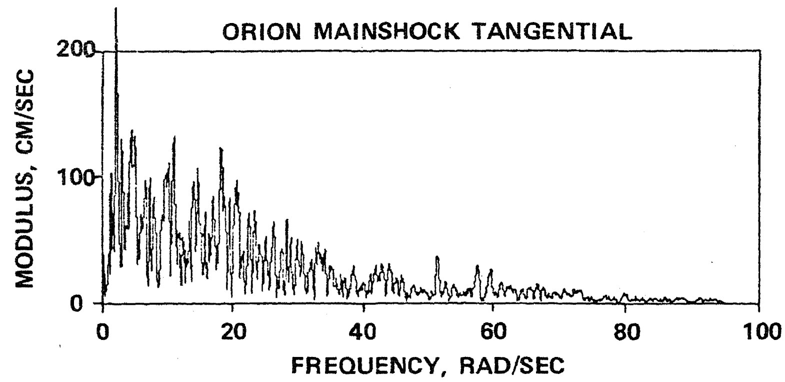

Figure 5. Spectrum of Recorded Ground Motion at 8244 Orion.

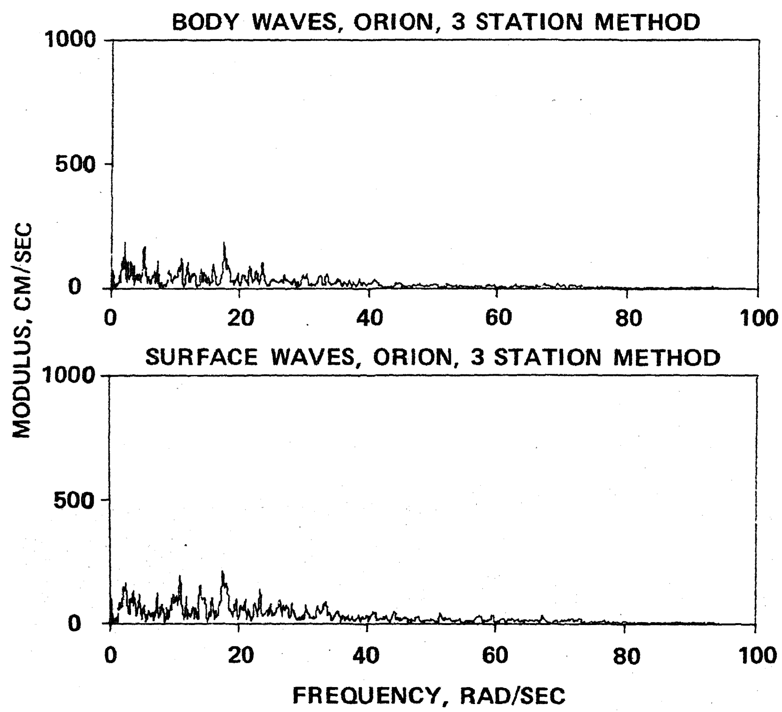

Figure 6. Combined Spectra for Body and Surface Waves at 8244 Orion.

DISCUSSION

P.N. Agrawal (India)

The records at distances equal to or less than the focal depth and those at larger distances should show very different results due to better development of surface waves. Can your method be used to see this effect ?

D.J. Dowrick (U.K.)

Has the author any idea of the maxinim likely displacement amplitudes of surface waves ?

Author's Closure

With regard to the question of Mr. Agrawal, we wish to state that while we have not done an example for this case, we believe that the method can be used to see the body and surface wave separation. A careful modeling of the several transfer functions will be necessary.

With regard to the question of Mr. Dowrick, we wish to state that the Orion accelerogram of the 1971 San Fernando earthquake showed double integration displacements of the order of 20 centimeters at associated periods of 3 to 6 seconds. These represent the total motion, including both body and surface components. Representative surface wave parts might be responsible for half of the amplitudes mentioned.