POSSIBLE SOURCE DEPENDENCE OF GROUND MOTION ALONG A PIPELINE

by

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SYNOPSIS

A spectral model incorporating source, travel path and local site characteristics was used to simulate ground motion along a pipeline. Emphasis was placed on the possible effects of the source on the spectral character of ground motion. Preliminary results indicate that the overall shape of the predicted spectra can differ as a function of the corner frequency of the source function. Variation in corner frequency may in part explain observed variability in spectral shape and location of spectral peaks for: (1) several events recorded at the same site; and (2) the same event recorded at several locations of similar geologic conditions.

INTRODUCTION

Lifelines, such as pipelines, may traverse extensive geographic areas that exhibit, on a region-by-region basis, different geologic and seismic characteristics. The Trans-Alaska pipeline is an example. Credible design earthquakes are needed for each seismogenic region traversed. However, due to the linear nature of a pipeline, a single event or dual level design earthquakes may be inadequate to explain in detail the spectral characteristics of ground motion for all points along the pipeline (or lifeline) route in the region.

The purpose of the following study was to qualitatively estimate some of the possible effects of the source on the spectral characteristics of ground motion. The results of the study were used to estimate the possible variability in spectral shape for a pipeline route where: (1) events of the same or different magnitude are recorded at the same site; and (2) the same event is recorded at several sites.

A simple but realistic model was used to simulate the body wave spectrum of surface motion, incorporating source, travel path and local site spectral characteristics. This model has been used successfully in simulating the near-source spectral characteristics of recorded strong ground motion in Managua, Nicaragua.(1)

SYSTEM MODEL

Fourier spectra combined with a body wave formulation of linear system theory provides an attractive spectral model with which to study ground motion because they furnish a convenient tool to isolate and evaluate how the various modulatory geologic parameters effect ground motion measured at a particular site.(2)

The general linear system theory equation is given by:

$$|G| = |E|\cdot|W|\cdot|X| \quad , \quad \text{(Fourier moduli)} \qquad (1)$$

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where G = free field ground motion,
E = source function,
W = crustal transfer function, and
X = subsurface trasnfer function.

All of the above quantitites represent Fourier transforms. The system model is shown on Figure 1.

One major aspect of ground motion that has been given little attention by earthquake engineers is the source. Recent investigations of earthquakes have indicated that knowledge of the source is vital to a detailed understanding of ground motion.

A convenient spectral model of the source for earthquake engineering purposes is that developed by Aki.(3) Aki divided Haskell's(4) dislocation model into a source term and a propagation term. Simplifying the source term and then calculating its Fourier transform, he estimated displacement source spectra as a function of magnitude. Aki's source spectra have constant amplitude for low frequencies, a well defined magnitude dependent corner frequency (ω_c), and a drop-off proportional to ω^2 in the high frequency end of the spectrum. Figure 2 is a representation of an Aki(3) source spectrum converted to Fourier modulus of acceleration (multiply Fourier displacement modulus by ω^2), displayed on a linear plot, with the abscissa converted from period to circular frequency. It should be noted that observational and theoretical studies indicate that corner frequency is greatly affected by both magnitude(1)(3)(5) and azimuth (i.e., direction from source to site).(6)

The crustal transfer function W is the transfer function between motion at the source and the incident motion at the soil/rock interface below the site (Figure 2). For W, we attempt to model the properties of the regional geologic structure and the material types along the travel path.

The crustal transfer function for spherical spreading of body waves (Figure 2) may be approximated as:

$$W = \frac{1}{r} \cdot e^{-\frac{\omega r}{2QV_s}} \qquad (2)$$

where r = real path length of body wave propagation, km,
V_s = average shear wave velocity along the travel path, m/sec,
ω = circular frequency (rad/sec), and
Q = average specific attenuation (damping) along the travel path.

The general characteristics of the frequency content of incident motion at the soil/rock interface below a particular site is given by the equation:

$$|I| = |E| \cdot |W| \qquad (3)$$

and is illustrated in Figure 2. The I spectrum represents motion at a rock outcrop provided the rock at the site does not have layers of different physical properties (i.e., layers of significant velocity contrast).

The subsurface transfer function X is defined as the ratio of the surface ground motion to the incident motion at the soil/rock interface. Mathematical formulations of the transfer function were expressed by Haskell$^{(7)}$ and by Matthiesen and others.$^{(8)}$ A general computer program for X was written by Lastrico$^{(9)}$ and Carriveau.$^{(10)}$ The model involves a series of horizontal layers composed of imperfectly elastic, isotropic and homogeneous earth materials. The incoming waves at the soil/rock interface are assumed to be normally incident, plan SH waves (Figure 3).

RESULTS AND CONCLUSIONS

Equation (1) provided the basis for a parametric study of the possible effects of the source on the frequency content of ground motion. Most of the parameters of each transfer function were kept constant with the exception of the corner frequency (ω_c) of the source function. The purpose of the study was to estimate the effects of the potential variability of the source (i.e., corner frequency) on the spectral character of ground motion.

Distance in the crustal transfer function was assumed to be constant. In representing W, Q was given a value of 100 and V_s was constant at 2.0 km/sec. The amplitude of E at frequencies above ω_c was held constant. Two different X transfer functions (X_1 and X_2) were used in the study. X_1 represents a single layer site with a short natural period (i.e., high frequency site). X_2 represents possible nonlinear soil behavior of X_1 or simply a "softer" or longer period single layer site. Figures 3 and 4 represent surface spectral calculations of Equation (1) using X_1 and X_2 as shown on Figure 2.

The following conclusions are appropriate:

(a) The predominant peak of the surface spectrum can be affected by the source, provided ω_c is at a higher frequency than the predominant frequency of the site.

(b) As the corner frequency of the event decreases, more low frequency motions are produced.

(c) It may be possible to estimate ω_c of the event directly from a recorded spectrum provided ω_c is less than the predominant frequency of the site.

(d) The shorter frequency (longer period) sites experience more energy input over a narrower frequency band (compare Figures 4 and 5).

(e) The potential variability of corner frequency due to magnitude and/or azimuth may explain the inconsistancy of spectral peaks for; (1) several events recorded at the same site, or (2) the same event recorded at several sites of similar geology.

(f) Small and/or moderate earthquakes (i.e., ω_c is less than the predominant period of the site) may not be useful in studying and predicting strong ground motion.

DISCUSSION

The following observations can be made on the possible effects of the source on ground motion along a pipeline or other linear lifelines or structures.

(1) If above ground portions of the pipeline and associated above ground structures are subject to earthquakes of significantly different magnitude for dual level events, the predominant spectral peak at a particular site or sites of similar geologic conditions may be different for each event.

(2) If azimuth or directionality significantly affects corner frequency, it may be important to know not only which faults are capable of producing destructive earthquakes, but where these events are most likely to originate on the faults.

(3) The combined effects of magnitude and azimuth may significantly effect the low frequency (long period) portion of the spectrum.

It should be noted that; (1) the above model study took into account only body waves (further refinements would have to be made to incorporate surface waves), and (2) it was assumed that the period of a site does not increase due to magnitude (i.e., generation of longer period waves that "feel" deeper layers).

In summary, if improvements are to be made in present techniques in estimating ground motion for important structures, the effects of the source will have to be taken into account.

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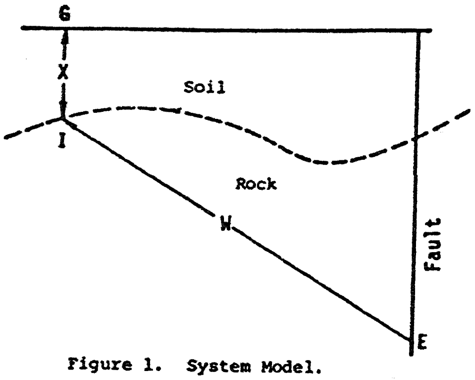


Figure 1. System Model.

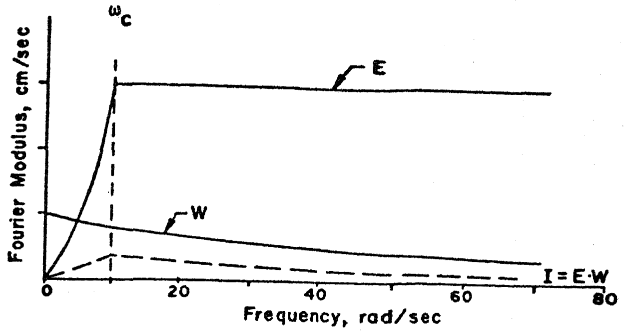
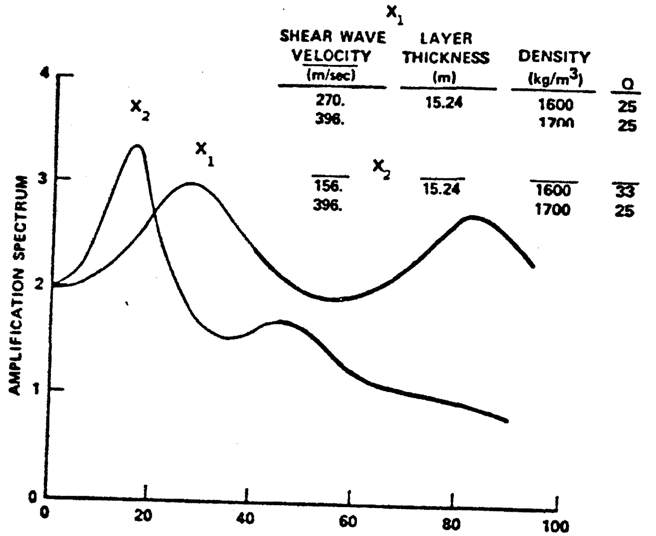


Figure 2. Comparison of E, W and I.



X_1

SHEAR WAVE VELOCITY (m/sec)	LAYER THICKNESS (m)	DENSITY (kg/m^3)	Q
270.	15.24	1600	25
396.		1700	25

X_2

SHEAR WAVE VELOCITY (m/sec)	LAYER THICKNESS (m)	DENSITY (kg/m^3)	Q
156.	15.24	1600	33
396.		1700	25

Figure 3. Subsurface Transfer Functions.

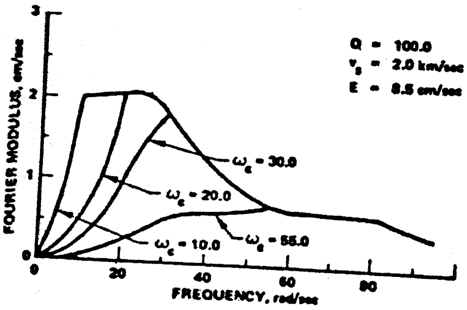


Figure 4. G = EWX, X_1.

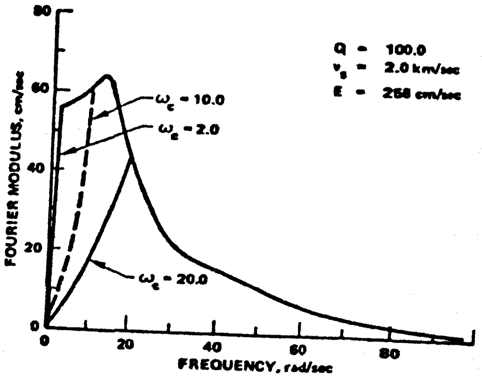


Figure 5. G = EWX, X_2.