DESIGN EARTHQUAKES BASED ON THE STATISTICS OF SOURCE, PATH AND SITE EFFECTS

by

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SYNOPSIS

A method is proposed in which strong earthquake motion and its uncertainty can be predicted from statistical measures of source and propagation characteristics of a region. Three characteristics are used to represent earthquake strong motion: the shape of the power spectral density function, an energy related intensity parameter, and two time domain shaping factors. The risk associated with the estimation of these parameters can be computed from probability and statistical models. Design earthquake motion in the form of accelerograms and response spectra can easily be developed from these parameters for any desired level of risk.

INTRODUCTION

Earthquake risk models proposed to date have concentrated mainly on the random occurrence of earthquakes and have considered only in a preliminary way the uncertainties involved in predicting ground motion. However, several authors have pointed-out the importance of including these uncertainties in seismic risk studies (5, 10, 13).

In an attempt to overcome this deficiency, this study deals with statistically predicting ground motion at a site for an earthquake of a given magnitude and location. The risk associated with the prediction is defined as the probability that the ground motion will be exceeded at a site for the assumed event.

Although much of this work is still in progress, the basic methodology and a brief discussion of the elements of the proposed seismic wave propagation model are presented. Final results and applications will be presented in a later paper.

SYSTEM MODEL

The initiation and transmission of seismic energy in the earth's crust due to an earthquake is a very complex process. However, for engineering purposes it is convenient to model this process with a relatively simple model. Linear system theory has been used as a basis for such a model. The general linear system equation used by Duke and Mal (6) is given by,

$$G = G_B + G_S = E_B W_B X_B + E_S W_S X_S \tag{1}$$

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where

G is the Fourier transform of ground motion
E is the Source Spectrum (Source effects term)
W is the Regional transfer function (propagation effects term)
X is the Local transfer function (site effects term)
B stands for body waves
S stands for surface waves

Because of the great difficulty in separating the relative effects of body and surface waves in strong-motion records, Eq. (1) is simplified to the following form for the purpose of this study,

$$G = EWX \tag{2}$$

where E, W and X are composit transfer functions. Since such a simple model is used to model such a complex process, it is essential that the uncertainties in predicting G from E, W and X be included. Thus, it is suggested that the elements in Eq. (2) be treated as random variables.

CHARACTERIZATION OF STRONG MOTION (G)

The characterization of strong motion should be simple enough to be easily computed, yet sophisticated enough so as to include the important properties of strong earthquake motion. Commonly used indices such as Modified Mercalli Intensity and maximum acceleration have been increasingly criticized for their lack of sensitivity to the duration and frequency distribution of strong motion and are not believed to represent adequately the potential destructiveness of strong motion to man-made structures.

The properties used in this study to characterize strong motion are comprehensive enough so that design motions, such as accelerograms and response spectra, can be easily generated from them. Saragoni and Hart (11) have suggested the following properties: the power spectral density function (PSD), an energy-related intensity parameter, and two time domain shaping factors. From these properties realistic artificial accelerograms can be easily constructed. These properties, then, are used here to characterize strong earthquake motion. They are easily computed from existing digitized accelerograms.

The PSD should be characterized by a small number of points for ease in computations. For this reason it was decided to smooth the PSD in the frequency range 0.14 to 10 hz. (corresponding to periods of 0.1 - 7 sec.), then discretize the smoothed PSD at twenty points. To accomplish this, 10 resolution bandwidths were selected to represent the general level of the PSD for given period ranges of structures, e.g. 0.1 - 0.12, 0.12 - 0.14, etc., with these ranges generally increasing for longer periods. This is consistent with the design philosophy proposed by Blume (3).

The number of points used in the "boxcar" smoothing scheme was determined by the equation,

$$N = \frac{T}{B_e} \tag{3}$$

where T is the record length in seconds used to compute the Fourier transform and B_e is the resolution bandwidth in hertz. A comparison of the smoothed and raw spectra for several records showed that the smoothed spectra modeled the overall trends in the raw spectra quite well. The randomness in the raw spectra can be modeled from the observation that the deviations between the smoothed and raw spectra divided by the amplitude of the smoothed spectra were found to be uniformly distributed about zero for all frequencies.

SOURCE EFFECTS (E)

The effects of the source have recently become a subject of great concern in engineering seismology. The source displacement spectrum measured in the far field and plotted on a log-log scale has a distinctive shape that can be adequately described by a few parameters (2). This shape is characterized by a flat response at low frequencies, whose amplitude is proportional to seismic moment, and a constant decay rate at high frequencies. The transition between these trends is given by the corner frequency.

Several recent dislocation models (1, 4, 7, 12) suggest the presence of multiple corner frequencies and fault propagation effects in the source spectrum. However, do to limited resolution of observed spectra, these effects are not commonly found and cannot be justifiably included in a study of this scope (16, 17).

Regional differences have recently been shown to be important in modifying the shape of source spectra for events of similar magnitudes (15,16). For instance, earthquakes originating along the California-Nevada border are characterized by significantly smaller seismic moments and higher corner frequencies than those earthquakes originating in the Gulf of California. These regional differences would seem significant enough to be included in the prediction of source parameters.

PROPAGATION PATH EFFECTS (W)

Propagation path effects is a term used to refer to the transmission of seismic energy from the source region to the vicinity of the site. The primary effects are associated with the loss of energy as the seismic waves propagate away from the source region. There are two types of damping that contribute to the loss of energy: geometric attenuation that results from the reduction in energy density as the wave front propagates away from the fault surface, and internal damping due to frictional heat losses.

The distribution of seismic energy within the source region will have a significant effect on the attenuation with distance of strong earthquake motion, especially at near distances for larger earthquakes (9). Therefore, a propagation pattern that takes into account this elongated pattern of energy release along a fault is necessary. This can probably be incorporated in the geometric attenuation term.

A model commonly used to model the loss of energy due to internal damping is given by,

$$A(\omega) = A_0(\omega)\ \exp(-\omega r/2QV) \qquad (5)$$

where $A(\omega)$ is the spectrum at the source, ω is circular frequency, r is distance from the source, Q is a material damping factor, and V is the seismic velocity of the medium.

SITE EFFECTS (X)

Site effects is a term used to describe the modification of strong motion within the vicinity of the site. Several studies have shown that various types of site conditions have a significant effect on the recorded motion at a site. Most significant for this study are the studies of Hayashi et. al. (8) and Seed et. al. (14), which demonstrated differences in the shapes of earthquake response spectra for various site classes. These site classes consisted of sites grouped as to the firmness and depth of their overburden soils.

Since the PSD spectrum covers a broad frequency range, those factors affecting the short period portion of the spectrum would not be expected to be the same as the factors affecting the long period portion. Therefore, a site classification scheme should necessarily be flexible. For instance differences in the upper 50 feet or so of a soil deposit probably most significantly affect the short period portion of the spectrum, whereas, the depth to basement rock may be the controlling factor in the long period range.

The final result would be a relatively comprehensive set of geotechnical classifications. Each classification would be represented by amplification spectrum giving the expected increase in the discretized PSD at each frequency point over that of some reference group.

CONCLUSION

A basic methodology has been presented herein that briefly describes a model for predicting ground motion from the models of three important elements of the system: source, propagation and site effects. However, much more work is required to impliment the method. Models for each effect must be more fully developed and probability models must be incorporated in order to introduce uncertainty into the procedure. All available strong motion data will be used to formulate and calibrate these models.

In its final form, the model can be used to develop design ground motions, for a specified level of risk, in the form of power spectral densities, artificial accelerograms, and response spectra. When combined with a model of the random occurrence of earthquakes in space, time and magnitude (5) one would have available a means of predicting a comprehensive measure of strong motion, which takes into account all the uncertainties involved in modeling the occurrence and transmission of strong earthquake motion.

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