AN ENGINEERING ASSESSMENT OF THE INFLUENCE OF SOURCE MECHANISM ON FIRM GROUND SHAKING

by

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SYNOPSIS

Non-stationary earthquake ground motion are generated by the superposition of stationary vibration originating from the foci of lower magnitude earthquakes, closely spaced along a fault. This vibration is modelled by a stationary Gaussian stochastic process restricted to a time interval s, and whose power spectral density of acceleration takes in account magnitude, focal distance and geologic conditions at the site of interest. The intensity of the resulting ground motion is assessed through the maximum acceleration, maximum velocity, maximum displacement, duration and response spectra.

INTRODUCTION

For high magnitude earthquakes the dimensions of the slipped portion of the fault may reach severall hundreds kilometers. Motion at any site is, then, due to vibration originating a wide distance apart. Rascon and Cornell (1968), Seed and Idriss (1969), and Rascon and Chavez (1973) devellopped approaches for simulating accelerograms of earthquake motions where this feature was recognized. In the present attempt to simullate type 2 ground motion (Newmark and Rosenblueth, 1971), a model is devellopped along simillar lines, but vibration at a station is described only by its probabilistic properties, no attempt being made to generate accelerograms. The assessment of the intensity of ground shaking is carried by inspection of expected maximum acceleration (a), maximum velocity (v), maximum displacement (d), duration (s) and response spectra, which are derived from the probabilistic description of the ground motion. This model can also be easily generalized to include the rotational components of ground motion and propagating phenomena; response of linear multidegree-of-freedom structures acted by this model of ground motion is analysed in a companion paper (Duarte, 1976)

CHARACTERIZATION OF THE POWER SPECTRAL DENSITY FOR AN EQUIVALENT STATIONARY GROUND MOTION

Earthquake motion may be idealized by a stationary Gaussian stochastic process restricted to a time interval "s". The influence of Magnitude (M), source properties, focal distance (r) and geologic site conditions are accounted for in the power spectral density of acceleration $S_a(f)$ and in the duration "s".

Duration is not a very influent parameter for the imediate purposes. Considering that only the strongest part of the motion shall be simullated, duration is taken as 0.9 of the velocity duration as defined by Trifunac and Brady (1975 a). $S_a(f)$ is derived from the values of "a", "v" and "d" for the site of interest. For $a/2\pi v$ to decrease with distance for all r, the formulas of Esteva and Villaverde (1973) were slightly altered to

$$a = 4\,800\ (r + 30)^{-2} \exp\ (0.8M)$$

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$$v = 34\ (M + 30)^{-1.7}\ \exp\ (M)$$

(r - km, a - cm/s^2, v - cm/s). The attenuation of displacement was derived from the reasonable behaviour of $v/2\pi d$ and ad/v^2: both may be expected to decrease with distance and the last to increase with magnitude. For about two hundred horizontal components of moderate to strong ground motion recorded in the Western Unided States (8), the median of ad/v^2 is 3.3 and the central 60% is comprised between 2.1 and 4.6 (9). Taking this in account, the attenuation of displacement is expressed by (d in centimeters):

$$d = 1.1\ (M + 30)^{-1.35}\ \exp\ (1.25M)$$

It is know that for low frequencies the Fourier spectrum of amplitudes (displacement) is constant; hence, for this range, the power spectral density of displacement $S_d\ (f) = (2\pi f)^{-4}\ S_a\ (f)$ will be constant. The high frequency range of the spectrum is associated with the rotational components of ground motion (Newmark, 1969). From the assumption that the second time derivative of the rotations is a band limited white noise process (The upper limit arbitrarily set at 20 Hz.), follows that the power spectral density of the derivative of the acceleration $S_{\dot{a}}\ (f) = (2\pi f)^2\ S_a\ (f)$ will be constant in the high frequency range. For intermediate frequencies $S_a\ (f)$ will be such that the expected maximum values of acceleration, velocity and displacement are equal to those of the ground motion; moreover, $S_a(f)$ is to have a reasonable shape. This last condition is easily met if the union of the low frequencie range to the high frequency range is made by three segments of elipse in a trilogaritm power spectral densities diagram. In this diagram abcissae are the values of $(2\pi f)^2$ in a logarithmic scale; ordinates are the values of the power spectral density of velocity $S_v\ (f) = (2\pi f)^{-2}\ S_a\ (f)$ in a logarithmic scale; the values of $S_a\ (f)$ = const. and $S_d\ (f)$ = const. are displayed also in a logarithmic scale along inclined straight lines, in the fashion of response spectra. The segments of elipses are calculated by an iterative process (9) based on the following facts: the value of "d" is related to the constant value of S_d (f) in the low frequency range; "v" and "a" are related to the maximum of S_v (f) and S_a (f), respectively; the constant value of S_a (f) in the high frequency range is related to the frequency in which maximum spectral acceleration occurs ($= a/\pi v$).

Following Trifunac and Brady (1975 b) geologic site conditions are classified as firm soil, soft alluvium and crystalline rock. The previous formulas for "a", "v" and "d" are assumed valid for firm soil. Maximum displacement in alluvium and maximum acceleration in rock are considered to be 125% of those on firm soil; maximum acceleration in alluvium and maximum displacement in rock are considered to be 80% of the corresponding quantities in firm soil, in concurrence with the trends detected by Trifunac and Brady (1975 b). Fig. 1 presents some power spectral densities for an M = 7 earthquake. Power spectral densities for severall other conditions are available elsewhere (9).

SOURCE MECHANISM

The basic idea of the present approach is to modell an high magnitude earthquake (main earthquake) as a superposition of the effects of an ensemble of lower magnitude earthquakes (elementary earthquakes)

The well know equation $\log_{10} W = 11.8 + 1{,}5\ M$ relating energy (W, in ergs) to magnitude (M) is used to establish the number and magnitude of the elementary earthquakes, on the assumption that the total energy relased by all elementary earthquakes must be equal to the energy of the main earthquake.

The vibration originating from the elementary earthquakes is characterized by the probabilistic properties described in the precedent section. For the present purposes the foci of the elementary earthquakes will be disposed on a line, simulating the causative fault. The intensity of shaking originating in each zone of the line, may be modelled either by varying the magnitude of the elementary earthquakes, or by varying the distance between foci: on practical grounds this last alternative is better. The breakage velocity is simullated by the time lag between the begining of the vibration irradiating from consecutive elementary earthquakes.

In the present paper a M = 8 earthquake is considered. The slipped length of the fault is assumed to be 250 km. Source mechanism is modelled by the sucessive trigering of 32 M = 7 earthquakes. Focal depth is uniform and equal to 25 km. The velocity of vibration propagation is taken as 3.5 km/s. Breakage velocity is taken as 3 km/s, as in previous models (1,2 and 3), altough this value may be now open question (Burridge, 1975).

Results obtained from two distributions of the foci of the elementary earthquakes on the fault will be presented. The first distribution will be characterized by an uniform distribution of the foci along the fault, and will be referred by EdS. for Equidistant Sources; the second will be characterized by an exponentially increasing distance between the foci, being the distance at the focus of the main earthquake four times lesser than at the end of the fault; this case will be referred by IdS. for Increasingly distant Sources.

ASSESSMENT OF THE INTENSITY OF GROUND MOTION

The assessment of the intensity of earthquake ground shaking is a central and difficult question in Earthquake Engineering (Housner, 1975). In the present paper this assessment is made by analysis of the maximum acceleration, maximum velocity, maximum displacement, duration of strong ground motion and response spectra.

The computation of expected maximum acceleration, velocity, displacement and response spectra are briefly indicated in (5) and will not be of concern here. For the present purposes, duration is the Trifunac and Brady (1975 a) velocity duration, defined as the time interval during which $\int_0^t v^2\,dt$ rises from 5% to 95% of its maximum value $\int_0^\infty v^2\,dt$ (In the present approach v^2 is replaced by its expected value $E\{v^2\}$).

In fig. 3,4 and 5 are presented the distribution of maximum acceleration, velocity and displacement for the EdS. and IdS. earthquakes in firm soil. From these figures can be seen that the distribution of the intensity of shaking on the fault isn't an important parameter for stations at moderate and long distance of the fault. Comparing the values on these figures with the values predicted by the attenuation formulas for "a", "v" and "d" taken as reference, it may be seen that the present approach slightly over estimates the maximum acceleration at long distances; and underestimates the maximum velocity and displacement near the fault.

Response spectra was found heavily dependent on the value of "a", "v" and "d". Typical response spectra are presente in fig. 2 , in instance, for the epicenter of the EdS. earthquake in firm soil. Taking for reference the Newmark and Hall (1969) response spectra, which depends on the values "a", "v" and "d", the present approach over estimates the spectral ordinates on the long and very short period range, and, for small damping, slightly under estimates the spectral ordinates in the short period range. The over estimation on the long period range may be explained on the grounds that, while this paper deals with a M = 8 earthquake, the Newmark and Hall spectra are based in the M = 6.3, Imperial Valley, 1940 earthquake: to the longer duration of an M = 8 earthquake may be attributed the increased spectral amplification in the long period range. The under and over estimates in the short and very short period range, respectivelly, may be attributed to the imperfection of the shape of the power spectral density in the high frequency range, which was delineated in order te have a band limited white noise process for the aceleration of rotation. On the evidence of these results, it now seems preferable to make $S_{\mathring{a}}(f)$ a decreasing function of frequency in this range: This would entail a transfer of power density from the very high to the high frequency range, and the response spectra may then be expected to conform more closely in this range with those of Newmark and Hall.

The importance of duration has recently been emphasized (Bolt, 1973, and Housner 1975). The duration of strong ground motion for the present cases is depicted in fig. 6. In contrast whit what happens to the distribution of "a", "v" and "d" the distribution of duration is strongly non-symetric. This surely has bearing on the safety of structures for which low-cycle fatigue is to be recognized.

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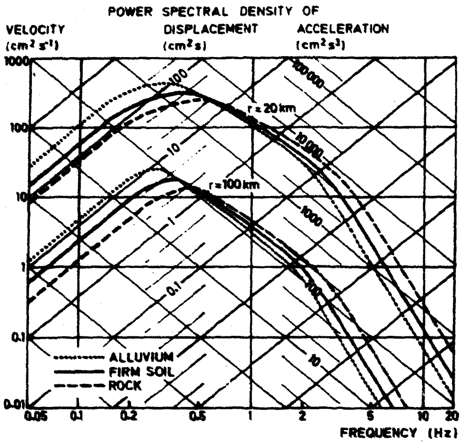

Fig. 1 — Power spectral densities for a M=7 earthquake.

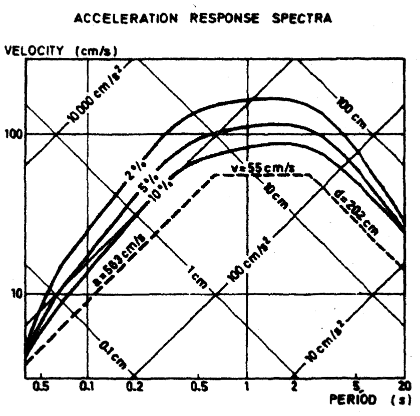

Fig. 2 — Response spectra at the epicenter of an EdS. earthquake.

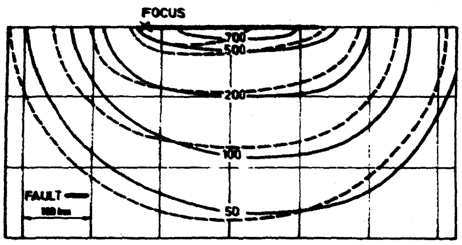

Fig. 3 — Expected maximum accelerations (cm/s²) for an EdS. (full) and an IdS. (dashed) earthquake.

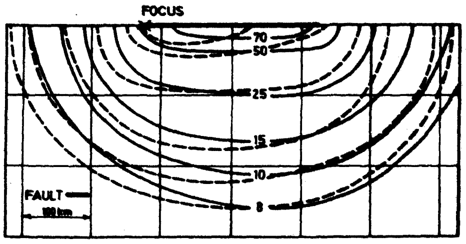

Fig. 4 — Expected maximum velocities (cm/s) for an EdS. (full) and an IdS. (dashed) earthquake.

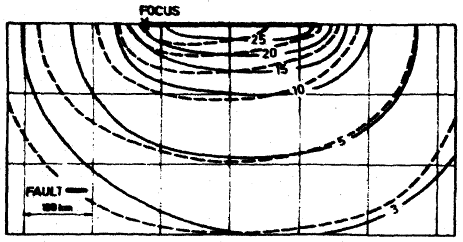

Fig. 5 — Expected maximum displacements (cm) for an EdS. (full) and an IdS. (dashed) earthquake.

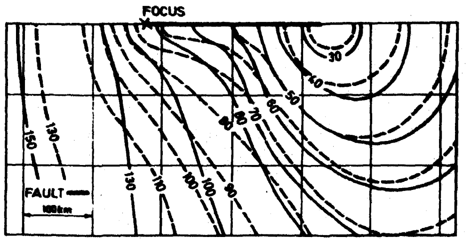

Fig. 6 — Duration of strong motion of an EdS. (full) and an IdS. (dashed) earthquake