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SIMULATION OF EARTHQUAKE GROUND MOTION IN MEMPHIS, TENNESSEE

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ABSTRACT

The NCEER Loss Assessment of Memphis Buildings (LAMB) Project is a coordinated research program that combines talents from structural engineering, seismology, risk/reliability and socioeconomic researchers. The effort provides a demonstration of how these various disciplines can be integrated to estimate economic losses for a scenario earthquake in the Memphis area. We simulate ground motions that may be observed in Memphis during future earthquakes. These simulations account for wave propagation effects; duration of strong ground motion specific to the Mississippi embayment; and non-linear soil response. By simulating ground motions over a range of magnitude, stress drop, and distance combinations, we produce a time series data set appropriate for analyzing the structural vulnerability of buildings.

KEYWORDS

earthquake ground motion simulation, nonlinear soil response, loss assessment, buildings, Memphis, urban

INTRODUCTION

We simulate ground motions that could be observed in Memphis, TN from scenario earthquakes originating in Marked Tree, Arkansas. These ground motions are used in fragility analyses of Memphis buildings (see Kunnath et al., 1996; and Hwang and Huo, 1996, both in this volume). The fragility analyses are then used in a loss assessment associated with building damage (see Eguchi and Chang, 1996, this volume).

Figure 1 shows the current seismicity which delineates the New Madrid Seismic Zone (NMSZ). In 1811 and 1812 three earthquakes with estimated magnitudes of around 8 occurred within this zone. Marked Tree lies at the southern terminus of the current seismicity, and it could be one source area for another large earthquake. Since it is relatively close to Memphis, Marked Tree was chosen as the site for a scenario earthquake in this study.

Memphis is within the Mississippi embayment, which is a broad, southwesterly plunging trough of unconsolidated Upper Cretaceous and Cenozoic sediments that unconformably overlie Paleozoic sedimentary rocks. A large seismic impedance contrast exists at the sediment/rock interface due to the rapid change in velocity and

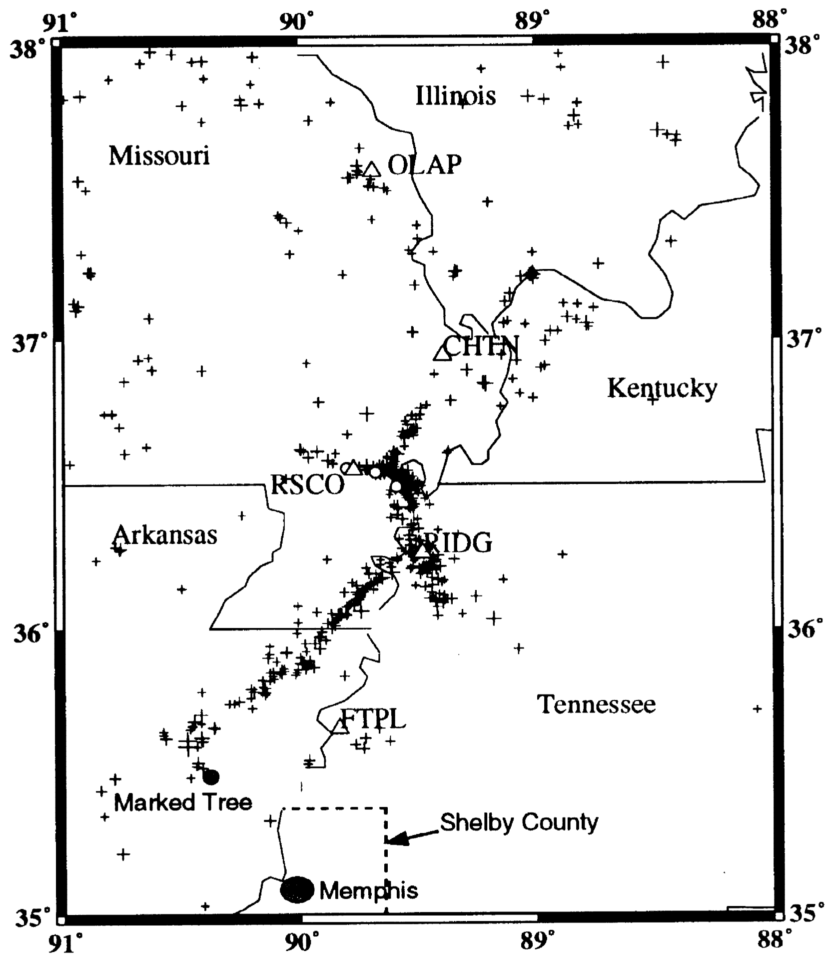


Fig. 1 Seismicity map of the New Madrid Seismic Zone. The location of strong ground motion sites are denoted as triangles.

density across the interface. This impedance contrast serves to amplify earthquake ground motions and to trap seismic energy within the embayment. This leads to long duration ground motions that can be strongly resonant. These effects can be substantial in the frequency band from 0.1 - 10 Hz, and the increased ground shaking can adversely affect "appropriately" tuned engineered structures.

GROUND MOTION MODELING

Since only small earthquakes have been recorded in the NMSZ, we must simulate ground motions that could be observed for larger earthquakes. The first step in modeling the ground motions is to produce "rock" motions. These motions are then modified to account for the nonlinear response of the uppermost soils in the Memphis area.

The rock motions are simulated using a technique (Horton,1994) that accounts for 1-D wave propagation and that provides a mechanism for calibrating the simulations against the durations from recorded embayment earthquakes. The procedure is illustrated in Fig. 2 where we simulate the observed ground motion at FTPL (distance of 99 km) for the Risco, MO earthquake. An embayment crustal model (Chui et al., 1992) with modifications to account for local site conditions is used to calculate synthetic seismograms, Fig. 2a, for a simple ω^2 source model. The work of Street et al., (1995) and Dorman et al. (1995), in which they measure detailed properties of the upper

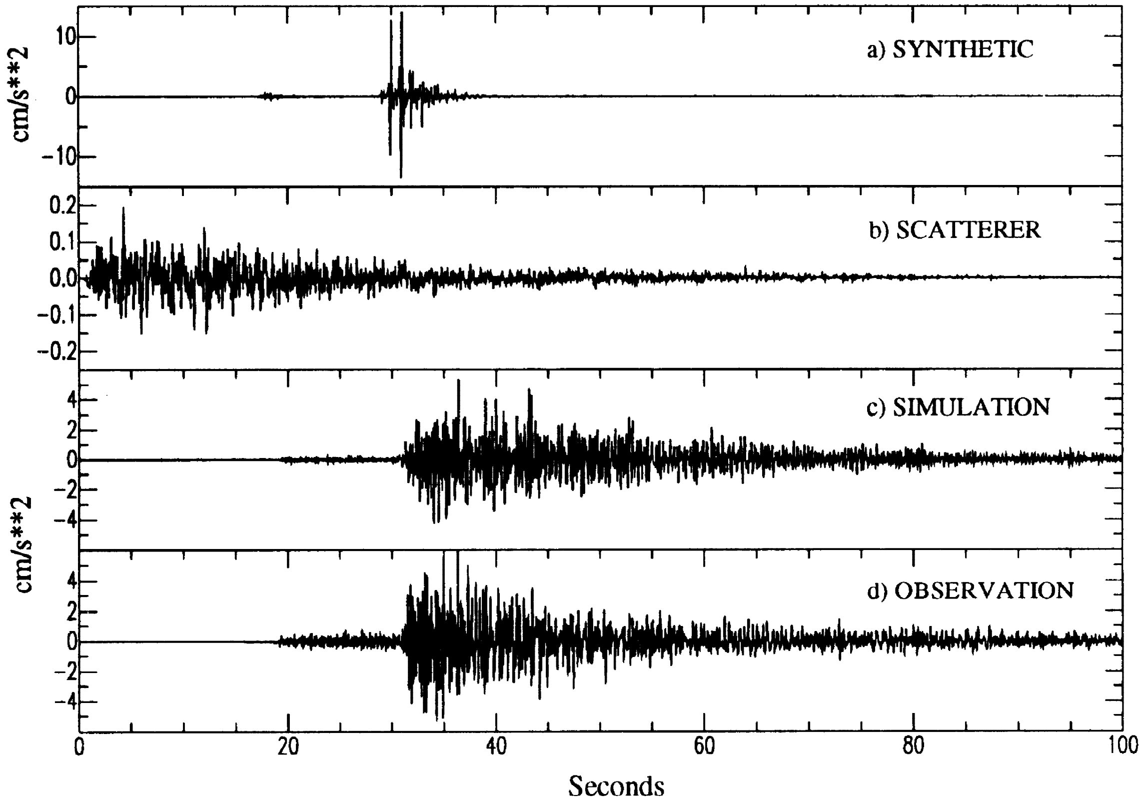


Fig.2 An example of the method for simulating earthquake ground motions compared to an observation at FTPL for the Risco MO earthquake (Mw=4.2) of May 4, 1991: a) synthetic ground motion computed for station FTPL; b) scattering function; c) simulated ground motion; d) observation.

27-100m of sediments beneath the strong motion sites, is helpful in determining the local site conditions. The synthetics account for the propagation of all seismic phases including supercritically reflected S-waves and Lg waves, as well as account for wave propagation effects controlled by a low velocity zone in the crustal model. The earthquake focal mechanism and the seismic moment used to calculate the synthetics are determined independently from observations; the stress drop for the synthetics is varied to obtain the best fit of the simulations to actual recordings of the Risco earthquake.

A region-specific scattering function, Fig. 2b, is used to randomize the seismogram. The form of the scattering function assumes dominance of forward scattering, and the envelope is calibrated to produce simulations with durations consistent with those (see Fig. 3) for the embayment. The mean duration (t_m) for the embayment observations is given by

$$t_m=3.25(r)^{0.5}+1$$

where r is epicentral distance (km). Convolution of the synthetic seismogram with the scattering function produces a simulation, Fig. 2c, that compares well with the observed earthquake ground motion from the Risco earthquake, Fig. 2d. The observation and simulation are also similar in the frequency domain (Fig. 4) indicating that the Risco earthquake can be adequately modeled with an ω^2 source model and a 250 bar stress drop. Thus, we use the Risco earthquake, along with duration observations of other small embayment earthquakes, to calibrate the technique so that it can be extended to model larger earthquakes.

For large ground motions, nonlinear soil behavior is predicted by laboratory experiments on Memphis soils (e.g. Hwang et al., 1990; and Hwang and Huo, 1994). To account for this behavior, the high-strain non-linear site response is simulated using a stepwise linear approximation technique (Barstow et al., 1994). Studies of the

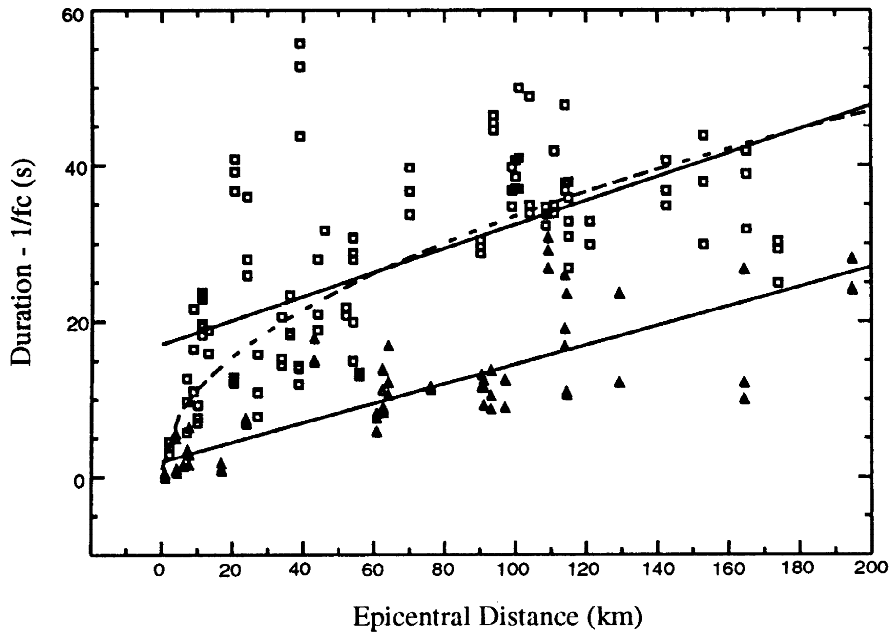


Fig. 3 Duration versus distance for the embayment in the central U.S. (squares) and eastern North America (triangles). Solid lines are the linear approximation of the mean duration for each regional data set. Dashed line is a square root dependence on *r*. Duration is defined as the time interval between the 95% and the 5% levels of the cumulative integral of acceleration squared. Source duration (1/fc) is subtracted from the observation.

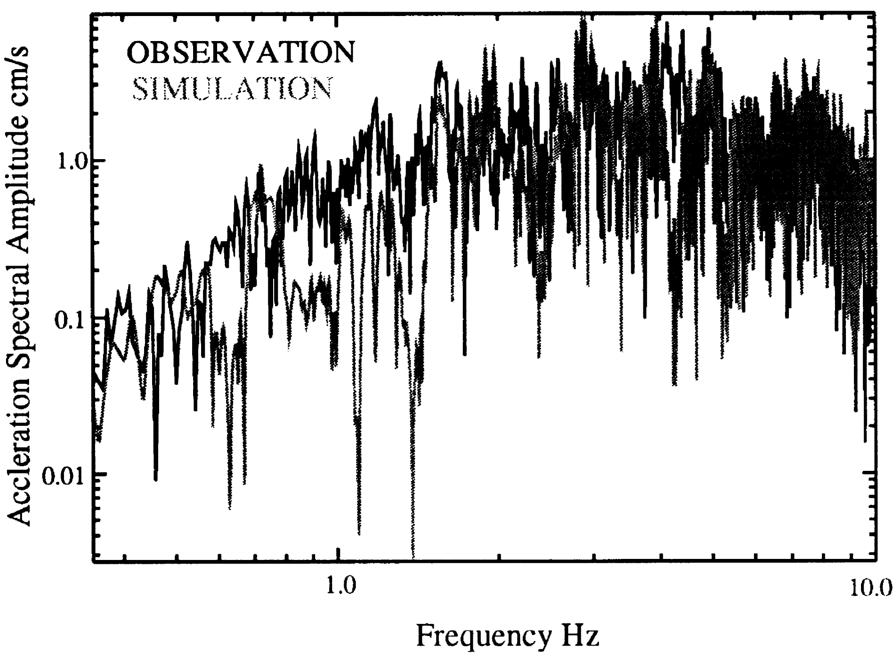
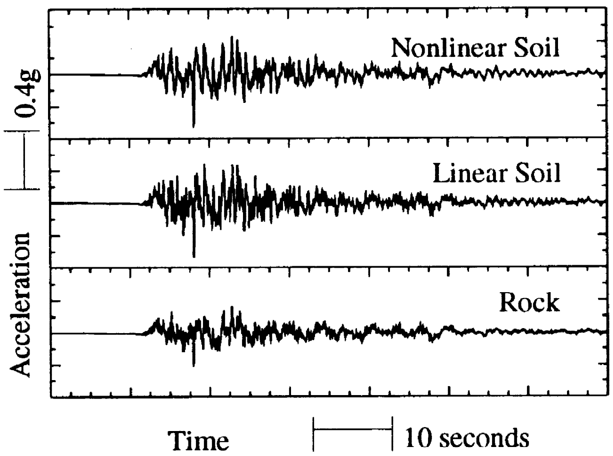


Fig. 4 Fourier spectra of observed and simulated ground motion at FTPL (see Fig. 2).



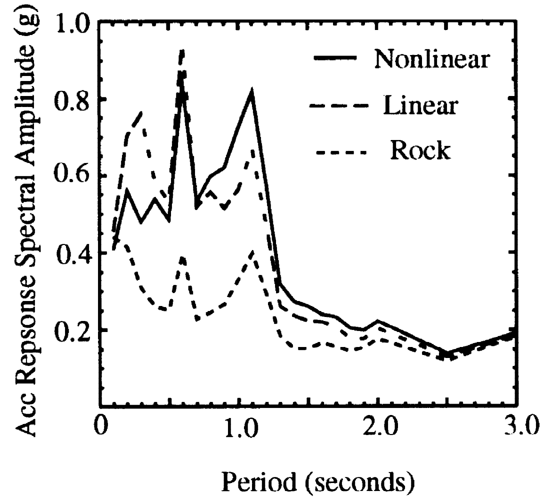


Fig. 5 Acceleration time histories and acceleration response spectral amplitudes comparing surface ground motions for rock and Memphis soils, both linear and nonlinear. The rock motions are used as input at the base of the soil profile after dividing by 2. The earthquake modelled is Mw=7.5, 100 bar stress drop, and 70 km epicentral distance. The response spectra are 5% damped.

dynamic properties of soils in the Memphis area include a number of geotechnical borings in addition to shear modulus reduction curves and damping ratio curves. These provide the basis for our non-linear analysis. Two different soil profiles are used: one for the Uplands and one for the Lowlands. The Upland low-strain model is a four-layer model shown in the table.

Table Upland low-strain sediment velocity model, Shelby CO., TN (adapted from Hwang and Huo, 1994)

Depth (m)	Th (m)	Initial Vs (m/s)	Vp (m/s)	density (g/cc)	Initial Qs	Qp	Description
0.0	10.37	373	746	1.95	30	60	clayey silt and silty clay
10.37	5.49	260	520	2.08	30	60	dense clayey sand to sand
15.86	14.64	307	614	2.14	30	60	dense sand
30.5	61	547	1094	2.06	30	60	stiff clay

Figure 5 shows an example where the rock surface ground motion is compared to the surface motion assuming linear and non-linear soil response through the Upland soil model. The comparisons both in the time and spectral domains clearly show how ground motions are amplified by the soil. The rock response spectra are peaked at 0.6s and 1.1s. These resonant peaks are characteristic of the Memphis crustal model for this distance range. These two peaks are also observed after propagation through the soil column suggesting that the input ground motions dominate the spectral shape in this period range. The nonlinear spectral response is damped at short periods (< 0.5s) and amplified at long periods relative to the linear response.

LAMB APPLICATION

For the LAMB project, the calculated ground motions are due to scenario earthquakes initiating at Marked Tree; epicentral distances from 40 to 90 km give the full range of distances to points in Shelby County, Tennessee. Marked Tree is located at the southern end of the southwest segment of the NMSZ (see Fig. 1). Earthquake epicenters delineate a northeast-southwest striking fault segment; well-constrained fault plane solutions (e.g. Hermann, 1978) demonstrate right-lateral strike slip movement along this fault. Therefore, we synthesize the scenario earthquakes using a strike-slip focal mechanism on a northeast striking, vertical fault; the simulations are for Shelby Co. which is, on average, at a 90° azimuth from Marked Tree. This azimuth corresponds to a maximum in the S-wave radiation pattern.

The ground motion simulations are being used in fragility analyses of Memphis buildings as part of the LAMB demonstration project. This fragility analysis requires a sampling of twenty acceleration time series for each of ten peak ground acceleration values ranging from 0.05g to 0.5g. We accommodate this requirement by systematically varying model parameters for each simulation; sorting the resulting time series by PGA value (0.05 g interval); and then randomly selecting 20 time series for each PGA category. The variable model parameters are moment magnitude, stress drop, and distance. Moment magnitude is varied from 5 to 7.5; stress drop is varied from 100 to 500 bars; and distance is varied from 40 to 90 km.

Examples of ground motions at one distance range and varying PGA are shown in Fig. 6. In general the low magnitude earthquakes have low PGA and high magnitude earthquakes have higher PGA. However, due to the interaction between magnitude and stress drop, there is not a simple relationship between these variables and PGA. The difference in ground motion duration at one distance is solely a function of the source duration which increases with magnitude. Figure 7 shows the average 5 percent damped acceleration response spectra for several PGA categories. The spectral level increases with increasing PGA at all periods. Spectral peaks occur near 1s and 0.6s that likely reflect the Memphis crustal model. These spectral peaks may affect the response of appropriately tuned structures.

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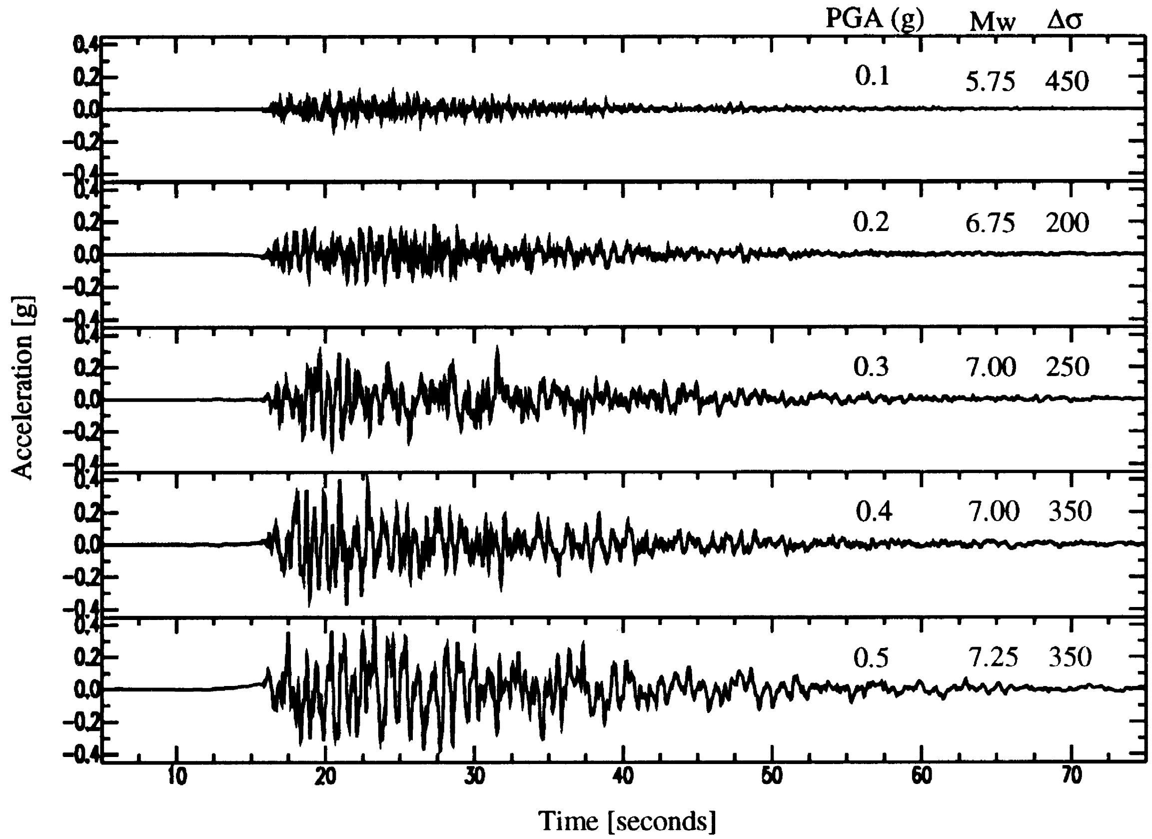

Fig. 6 Example of Memphis simulated earthquake ground motions having a range of PGA. Distance is fixed at 50 km in this example, and Mw and/or stress drop are changed to produce the range of PGA values required for the fragility analysis.

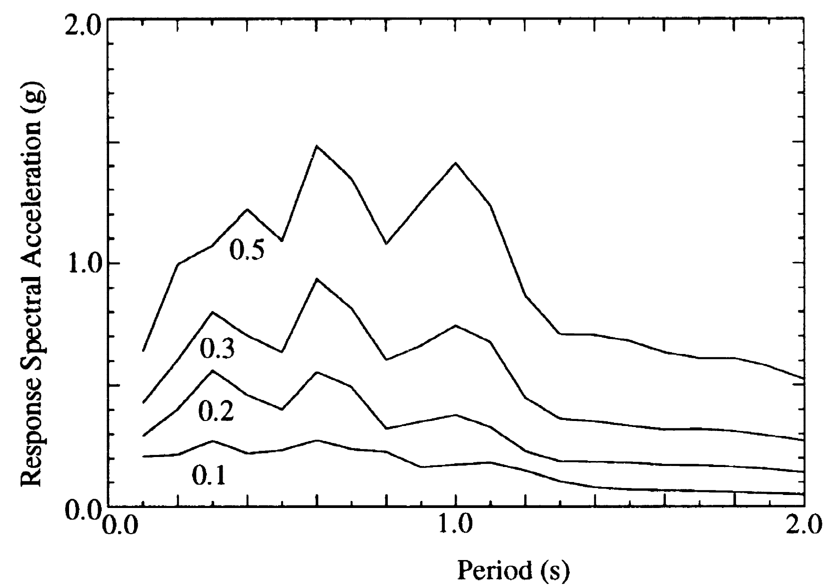

Fig. 7 Average response spectral amplitude (5% damped) for various PGA categories.

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