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Threshold magnitudes which cause the ground motion exceeding the values expected during the next 50 years in a metropolitan area

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Uniform Risk Response Spectrum Technique has been used to compute the geographical distribution of the threshold magnitude below which (1) there should be no damage in the well engineered structures and (2) future earthquake predictions should not cause much concern. It is shown that, if the long range planning of the seismic resistance of man made structures is based on the realistic estimates of seismic risk during their expected life, the moderate to large earthquakes, that may occur in the area, are not likely to cause much serious damage or disruption.

Granične magnitude koje nadmašuju očekivane parametre gibanja tla u sljedećih 50 godina na jednom velegradskom području (SAD)

Upotrebom spektara odgovora uz primjenu jednolikog rizika izračunata je zemljopisna razdioba granične magnitude ispod koje (1) – ne bi trebalo biti šteta na dobro građenim objektima i (2) – buduća prognoza potresa ne bi trebala biti od većeg značenja. Pokazano je da umjereni do jaki potresi koji se na razmatranom području mogu dogoditi ne bi trebali uzrokovati veće štete ili razaranja ako se provede dugoročno planiranje seizmičke otpornosti objekata osnovano na realističnim procjenama seizmičkog rizika u njihovu eksploatacijskom periodu.

1. Introduction

With the development of the understanding of the physical mechanisms, which govern the energy release during earthquakes, it will become possible, in the future, for the earthquake predictions to be more frequent and more reliable. In this paper it is assumed that the earthquake predictions will become possible and one aspect of the many consequences of such predictions will be examined from the engineering viewpoint. Of course, there are many implications and many possible consequences of an earthquake prediction. Those span, for example, the general public reactions, public policy, local state and federal agencies response, those responses which are planned, anticipated and those actually experienced following a major earthquake, economic readjustments in an anticipation of an earthquake and planning and action to respond to a given prediction. Given that an earthquake prediction has been issued, many complex decision processes will have to take place, to determine what should be the optimum response in the framework of the anticipated consequences. Enumeration and the analysis of all of these decision processes are beyond the scope of this paper. Only one simple question is considered here as an example. Given that the earthquake prediction has been issued, how and if it will affect various engineering structures in the area. It is possible to analyze this question in at least two different ways. In one approach it may be assumed that detailed maps exist of the distribution and of the type of the structures in the area. Given the location and the magnitude of the predicted earthquake and the confidence with which such a prediction is made, one can construct a mathematical model to calculate the distribution of the expected consequences. Depending on the outcome of such computations the prediction may be ignored or it may become a major contributor to the overall societal responses, depending on the extent of damage which is predicted by the model. In another simpler approach, which is considered in this paper, it may be supposed that the seismic risk during the next say 50 years, has been characterized by a family of maps which present the Uniform Risk Spectra (*URS*) of Pseudo Relative Velocity (*PSV*) (Trifunac, 1988a). Furthermore, assuming in this idealized example that one is dealing with highly developed and technologically advanced society, it might be supposed that all structures in the area have been constructed to meet the expected *URS* amplitudes during the next 50 years. The effect of the predicted earthquake then can be viewed by simply comparing the expected *PSV* amplitudes for the predicted earthquake and by finding the extent to which those exceed the *URS* amplitudes for which all structures have been designed already. Or, by comparing the *URS* amplitudes in the area with the *PSV* amplitudes of an earthquake at its epicenter, it is possible to compute the magnitude of an earthquake for which the URS estimated for the next 50 years at the epicenter would just be exceeded. These magnitudes can be computed and plotted for a grid of points to show the distribution of this "threshold magnitude (*TM*)". Then, for example, if a prediction is made for an earthquake with a magnitude which is less than the *TM*, there should be no structural damage and the decision and planning actions for the response to the prediction can essentially ignore the consequences of the ground shaking for the engineered structures.

In the development of modern strategies for the computer assisted response to earthquake disasters, it is necessary to develop fast and real time algorithms for assessment of the distribution and of the extent of damage immediately following destructive earthquake. Recognizing that such algorithms will depend on actual observations and on the recorded data on strong shaking at some selected points (e.g. Trifunac, 1988b) it is seen that the bulk of the calculations on different response scenarios and their optimization will deal with the data available on the inventory of structures and the geology in the area. Since all this data is available before the earthquake, whether (1) all structures have been designed for the seismic risk estimates during the next 50 years using *URS* methodology or its equivalent, or (2) the inventory of actual strength of the existing structures is available, it can be seen that it is possible to evaluate the threshold levels where damage will begin to occur, the distribution of damage for larger earthquakes exceeding the threshold magnitude, and the corresponding optimum responses of the local and state government offices. Since the first step in this work will also require estimation of the threshold magnitudes, the aim of this paper is to illustrate a method for preparing such *TM* maps.

2. Microzonation maps constructed from *URS*

The method for the computation of Uniform Risk Spectra has been first described by Anderson and Trifunac (1977, 1978). It involves integration of all contributions from various seismic sources in the area, to compute the distribution of spectral amplitudes at a site. The *URS* has a property that at every period the probability is constant that the *URS* amplitudes will be exceeded by any future events during the period of *Y* years. The seismic sources contributing to the seismicity of the model can be approximated by a Poissonian sequence in time and/or can be assumed to occur with certainty (e.g. for the predicted events). The method takes into consideration the uncertainties in describing the seismicity of different sources, detailed geometry of the sources, and the local geologic conditions at the recording station (Lee and Trifunac, 1985). By computing the *URS* for a grid of closely spaced points it is possible to construct maps of the *PSV* amplitudes, for selected oscillator periods, time of exposure (e.g. $Y = 50$ years), and the probability of at least one exceedance (Trifunac, 1988a).

Figure 1 shows the major quaternary faults in Southern California (after Jennings, 1975). For the hypothetical example involving the assumed slip rates on these faults, Lee and Trifunac (1987) have calculated the maps of *URS* in the Los Angeles metropolitan area, to illustrate their method of constructing the microzonation maps of strong ground

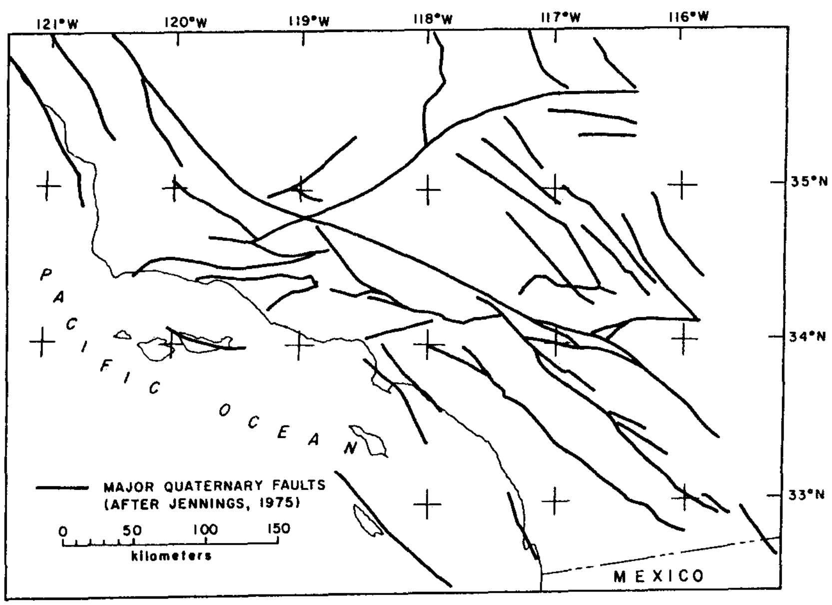

Figure 1. Major quaternary faults in Southern California

shaking. Figure 2, taken from Lee and Trifunac (1987), for $p = 0.5$ (p is probability of at least one exceedance), illustrates these results for the oscillator period 0.90 seconds. The amplitudes in this map correspond to the $\log_{10}(PSV)$ in inches/sec. The PSV amplitudes have been computed for the fraction of critical damping $\zeta = 0.05$.

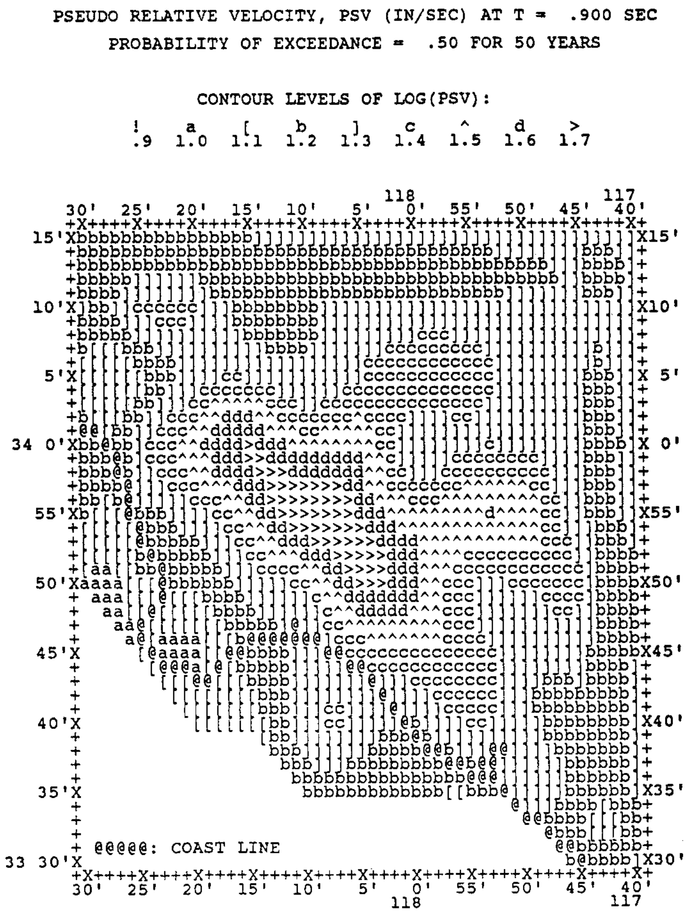

Figure 2. Pseudo relative velocity spectra at $T = 0.9$ sec. (after Lee and Trifunac, 1987)

3. Maps of magnitudes which locally coincide with *URS*

Next, in this example, it is supposed that the maps like that illustrated in Figure 2 represent the distribution of seismic risk (quantified in terms of the PSV amplitudes with $\zeta = 0.05$) during the next $Y = 50$ years. It can also be supposed that such maps reflect the levels of ground motion for which the structures in the area have been designed to withstand the strong earthquake shaking. Then, if an earthquake prediction is made, that an earthquake will occur with magnitude M at location (x, y) the question arises whether this earthquake will result in spectral amplitudes which may exceed the *URS* amplitudes around (x, y). Detailed consideration of this question from the probabilistic point of view will require the specification of the confidence, P_{CE}, with which the earthquake prediction is made, and the confidence, P_{CM}, or the density distribution function $\phi(M)$, that it will have magnitude M. Furthermore this may require modification of the originally assumed seismicity for the computation of *URS* (Figure 2), since the predicted earthquake could have occurred as a member of the original Poissonian sequence of earthquake sources, or as an event assumed to occur with certainty, but at any time during Y years (see discussion of p^* in Anderson and Trifunac, 1977). Such detailed considerations are beyond the scope of this brief note. Here it is assumed that the maps, as those shown in Figure 2, for the purpose of this example, do reflect the geographical distribution of *PSV* amplitudes for which the structures have been designed. Then we assume that the prediction is issued with $P_{CE} = 1$ and $P_{CM} = 1$. To determine whether the predicted earthquake will exceed the *URS* amplitudes we calculate the magnitude for which the *PSV* spectra with $\zeta = 0.05$ and $p = 0.5$ coincides (in the least square sense) with the *URS* amplitudes for $p = 0.5$. This single earthquake spectrum has been computed for the applicable local depth of sediments, for the source depth $H = 5$ km and for the epicentral distance $R = 0$ km.

The above calculations can be repeated at all grid points for which the *URS* amplitudes are available and a map of magnitudes for which the spectra of the predicted earthquakes coincide with the *URS* amplitudes can be constructed. This is illustrated in Figures 3 and 4. Figure 3 shows the maps of the resulting threshold magnitudes (*TM*) computed via uniform risk calculations in which the seismicity at all faults (Figure 1) and the attenuation of strong shaking are all described by the magnitude scale. Figure 4 shows

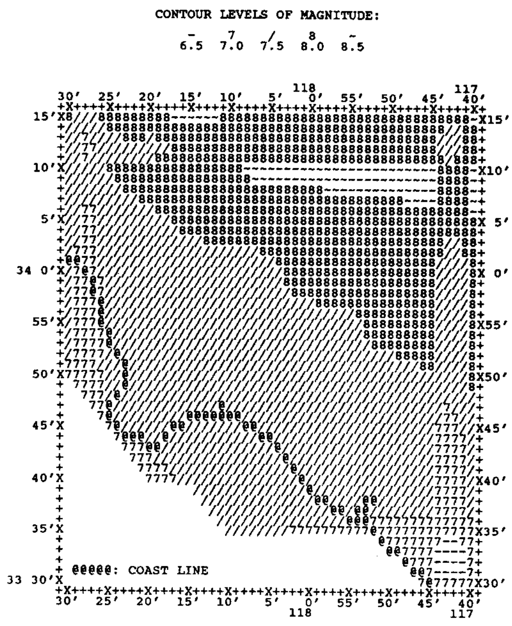

Figure 3a Probability of no exceedance = 0.99 for 50 years calculated from magnitude–depth regression model.

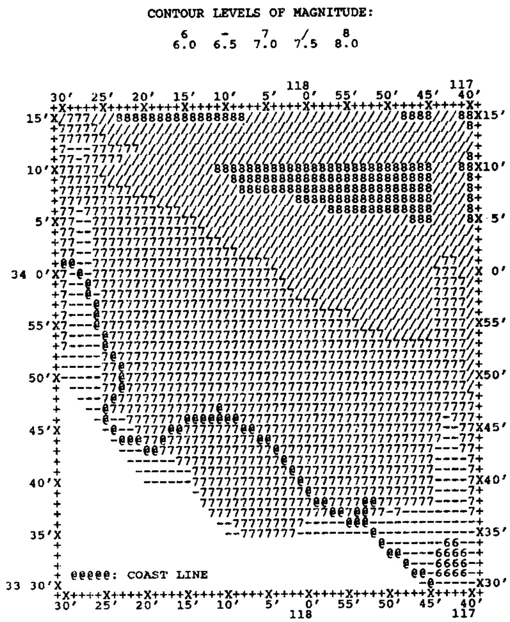

Figure 3b. Probability of no exceedance = 0.90 for 50 years calculated from magnitude–depth regression model.

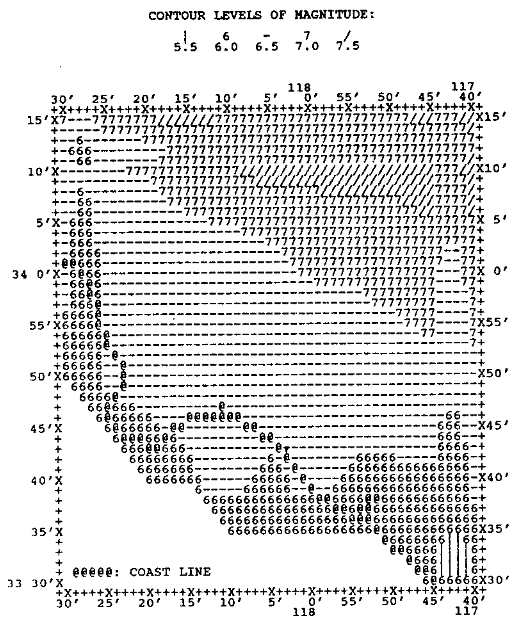

Figure 3c. Probability of no exceedance = 0.50 for 50 years calculated from magnitude–depth regression model.

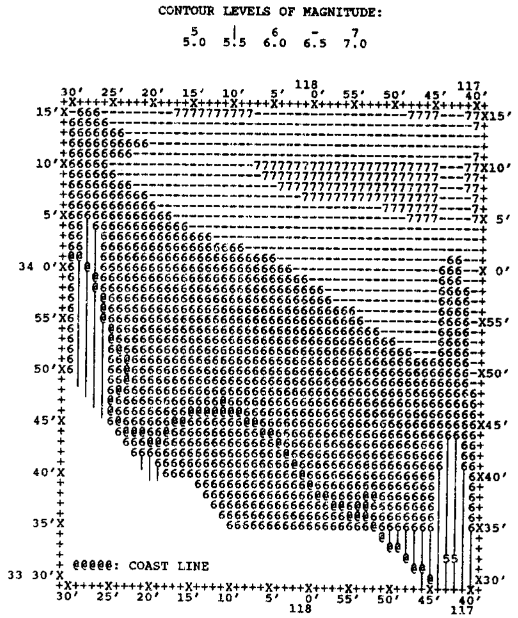

Figure 3d. Probability of no exceedance = 0.10 for 50 years calculated from magnitude–depth regression model.

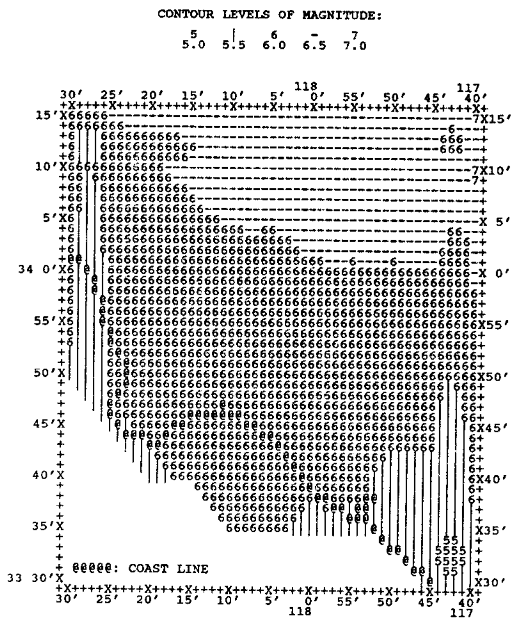

Figure 3e. Probability of no exceedance = 0.01 for 50 years calculated from magnitude–depth regression model.

analogous but independent calculations using Modified Mercalli Intensity for scaling the earthquake events at their sources as well as in the description of the attenuation functions (see Lee and Trifunac (1987) for more detailed discussion of the steps involved in such computations). Figure 5 shows the comparison of the results inferred from Figures 3 and 4 at a station located at 33° 55' N and 118° 5' W. It is seen that both methods of computation lead to essentially the same results.

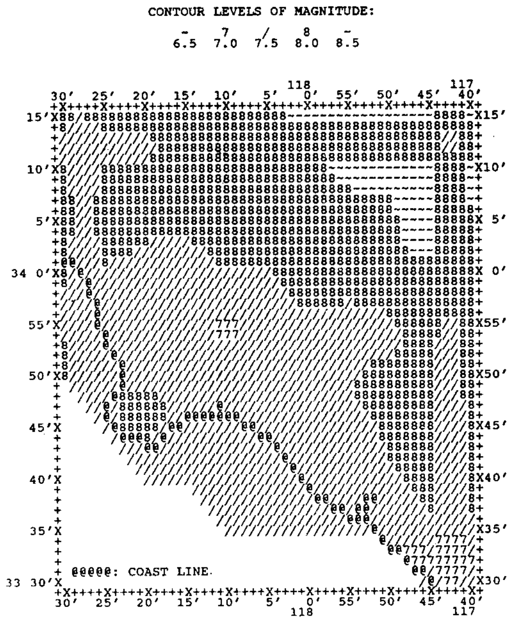

Figure 4a. Probability of no exceedance = 0.99 for 50 years calculated from MMI–depth regression model.

4. Discussion and conclusions

Figure 3 and 4 show gradual increase of *TM* from south-west towards north-east. This results from the assumed seismicity of the San Andreas fault (Lee and Trifunac, 1987) and from its prominent effect on the *URS* in this metropolitan area. The contributions of most smaller local faults, though significant are not apparent from these figures.

The interesting and perhaps unexpected result is that the computed *TM* are larger and beyond what could be associated with the background seismicity. Lee and Trifunac (1987) emphasize that their choice of seismicity, for the calculation of their results on the *URS* (here exemplified by Figure 2), is arbitrary and for illustration purposes only, yet their assumptions are not too different from what could be expected in the Los Angeles area during the next 50 years or so. Thus the results on the *TM* in Figure 3 and 4 here, though only illustrative, may be close to the realistic estimates. This then suggests that if the *URS* such as those in Figure 2 were to be used as a starting point for the development of the design strength of the new buildings in this area, during the next 50 years, such buildings should be able to withstand earthquake like the Long Beach 1933 or the San Fernando 1971, at almost any point in this region.

Another interesting observation, which results from the analysis of Figure 3 and 4 is that unless the future earthquake predictions are made for the magnitudes larger than

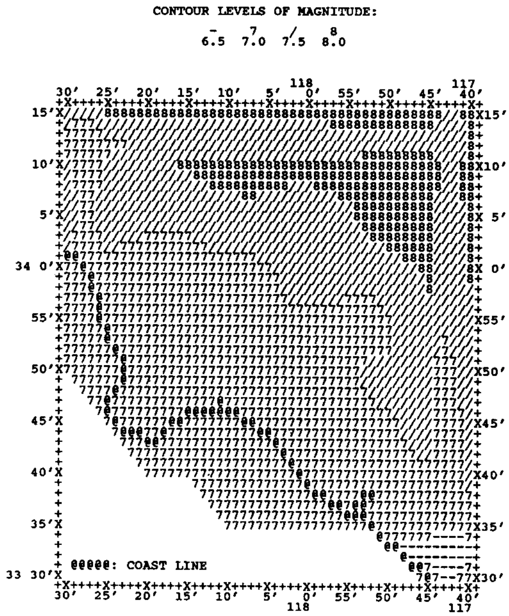

Figure 4b. Probability of no exceedance = 0.90 for 50 years calculated from MMI–depth regression model.

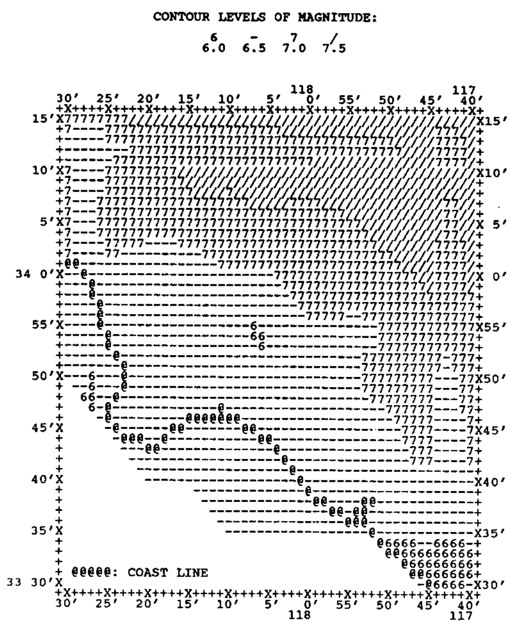

Figure 4c. Probability of no exceedance = 0.50 for 50 years calculated from MMI–depth regression model.

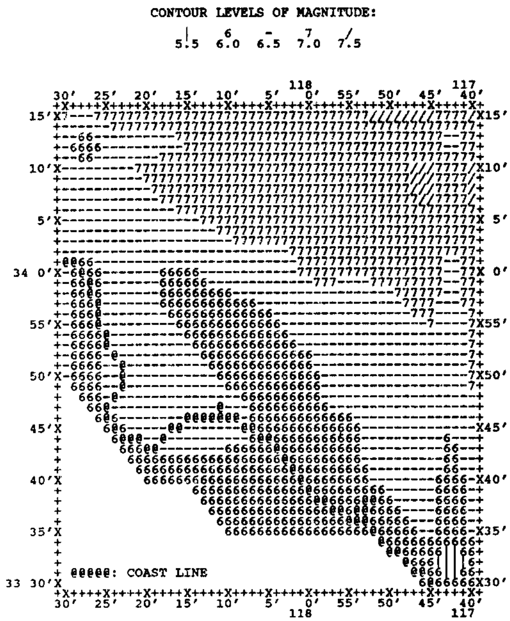

Figure 4d. Probability of no exceedance = 0.10 for 50 years calculated from MMI–depth regression model.

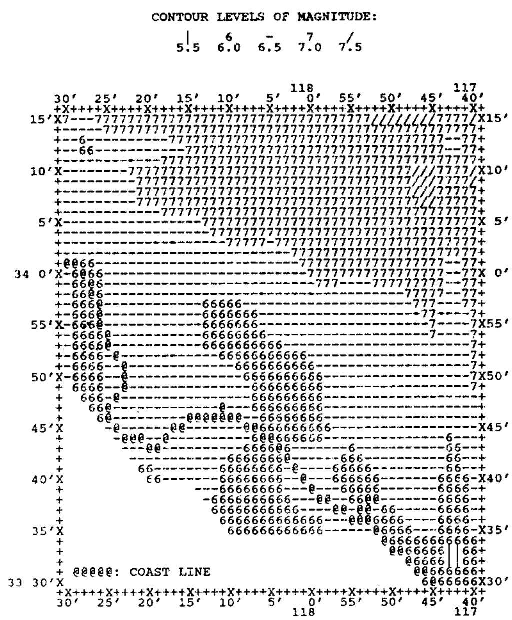

Figure 4e. Probability of no exceedance = 0.01 for 50 years calculated from MMI–depth regression model.

those shown here, the impact of such predictions should be minimal. This assumes of course, that the *URS* maps such as those in Figure 2 have been fully considered in the planning and optimizing the design of the future and in the retrofit of the existing structures in the area, as well as in the response of the population to such predictions.

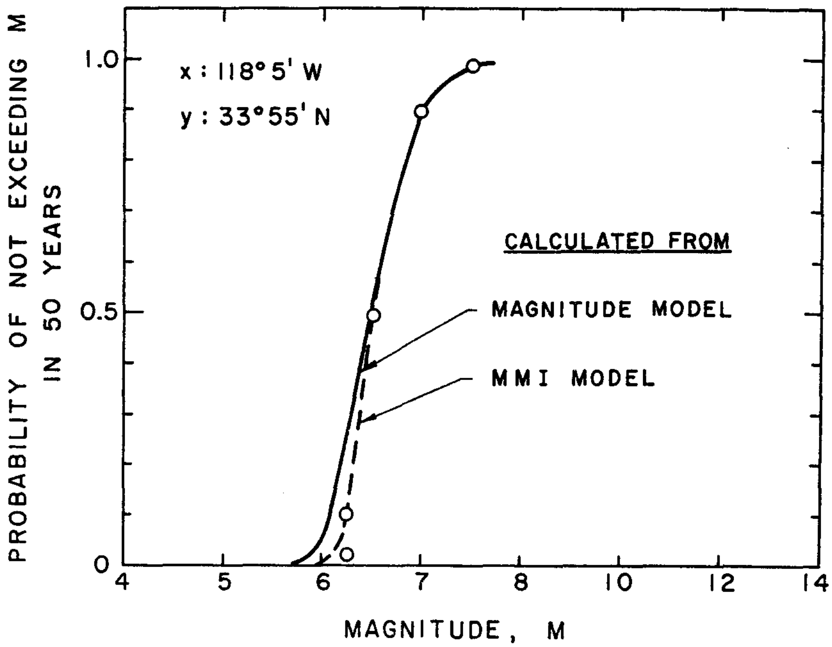

Figure 5. Comparison of the results based on M.M.I. and magnitude models.

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