SEISMIC MICROZONATION MAPPING VIA UNIFORM RISK SPECTRA

M. D. Trifunac

Department of Civil Engineering, University of Southern California, Los Angeles, U.S.A.

SUMMARY

A new method for seismic microzonation of metropolitan areas is proposed. It uses information on the location of active faults and their seismicity, the three-dimensional source to station geometry, the frequency dependent attenuation, the effects of local amplification and the scaling based on earthquake magnitude. The method does not require any new or difficult steps to gather data. The advantage of the method lies in its ability to properly balance different contributing factors to the seismic risk at a point, in time, space and frequency of strong ground shaking.

INTRODUCTION

The characteristics of strong earthquake ground shaking at a point, depend on numerous soil and geological features surrounding the site, as well as on the distribution and on the level of activity of earthquake sources in the area. These may be too detailed to include in typical seismic zoning maps (Ref.6), but can be included in and represent the basis for the detailed microzonation maps. The variety of published microzonation maps results from their many different uses in design (Refs.1,15), insurance (Ref.17), urban design and in the prediction of earthquake induced soil failures and land slides, for example.

A systematic program to develop zonation maps of the entire country, and to develop microzonation maps for large cities started in the U.S.S.R. in the 1930's. Their methodology is dominated by the concept of the largest observed intensity and by the local geologic and subsoil conditions at a site (Refs.1,14). In Japan the work on microzonation was influenced by the studies of Sezawa and Kanai and by the effort to measure the transfer function properties of each site experimentally, by studying the local amplitudes of microtremors (Ref.8). In various countries of Europe (Ref.9), Central and South America and in China (Ref.13), the zonation and microzonation work closely followed the Russian and the Japanese experience. In the United States, with few exceptions (Ref. 15) the microzonation work has not attracted many researchers.

During the last 20 years or so, the computational capabilities for evaluating seismic risk have been developed to a point (Ref.3,4,5,10 where this approach can be used now for constructing probabilistic microzonation maps. To illustrate this method in this paper the results of Lee and

Trifunac (Ref.10) are reviewed for microzonation maps of a hypothetical metropolitan area with geometry corresponding to that of the Los Angeles basin.

One of the most important assumptions underlying almost any microzonation method is that the local geologic and soil conditions possess some intrinsic wave amplification properties which are independent of the type and of the direction of seismic waves approaching the site. This is the basis of the experimental work of Kanai (Ref.8), who assumes that by measuring the "predominant period" of each site, through the experimental measurement of the site transfer function, it is possible to evaluate the local amplification effects (Ref.2). It is also assumed, in Kanai's work, that the repeated excitations by different earthquakes will continue to be dominated by the local site effects. For this to be so, it is essential that the local site transfer functions should play a major role in modifying the input ground motion (Ref.23). However, this may be so only when the local site consists of exceptionally soft soil and alluvium deposits, and when the wave excitation arrives from a limited pencil of azimuths. Detailed analysis of the two- and three-dimensional effects of wave propagation shows that the peaks of the transfer function of the local site effects can shift in their ''predominant period'' and in amplitude, and can disappear altogether with changing the direction of wave incidence (Refs. 18,19). Though there are many examples of the patterns of building damage following many earthquakes, which are clearly a consequence of the variations of the amplitudes of shaking on a very small (microzonation) scale, there are no adequate data to verify experimentally the extent to which such patterns will be repeated during future strong earthquake shaking. Theoretical wave propagation studies and the empirical descriptions of the wave amplitudes do lead to a consistent conclusion that those waves will be amplified which propagate from "hard" to "soft" material (Ref.24). However, this agreement is only in the sense of the mean overall amplitudes and does not involve any detailed description of the spectral amplification or deamplification at given frequencies or at given locations. This observation thus rules out the concept of the predominant period (Ref.8) as it has been associated with the depth of the soft soil deposits (Ref.14).

The detailed description of the empirical results which describe the dependence of strong earthquake ground motion amplitudes and duration is beyond the scope of this paper. The most recent results and detailed references on many earlier studies can be found in the reports by Trifunac and Lee (Refs.20,21). For the purposes of this work it is sufficient to state that the repeatable site effects are characterized by the amplification of the average wave amplitudes for periods longer than about 0.5 seconds at geologically "soft" sites.

In this paper the methodology for computing the uniform risk spectra, VRS, will not be presented in detail. This methodology was discussed and illustrated previously through many examples (Refs.3,4). Recently this methodology has been refined by Lee and Trifunac (Ref.10) but no new basic principles have been added to the original method.

The purpose of this paper is to show how, by repeating the calculation of URS at a discrete grid of points, a map of URS can be constructed, thus leading to a new method for seismic microzonation. By contrasting the procedures and the results presented with the classical methods for microzonation, the quantitative and the statistically balanced features of the method proposed here will become clear.

UNIFORM RISK SPECTRA

The methodology for estimating the uniform risk spectra at a site involves: (1) Description of the area surrounding the site in terms of all seismic sources, their activity and geometrical extent, (2) Site characteristics in terms of the depth of sedimentary deposits or the site geological classification and (3) Description of attenuation of strong motion amplitudes with distance from the earthquake source (Ref.22). Then the probability that some spectral amplitude will be exceeded at least once in Y years is

$$p[S(\omega)] = 1 - \exp\{-N_E[S(\omega)]\} \tag{1}$$

where $N_E[S(\omega)]$ is the expected number of times that $S(\omega)$ will be exceeded at the site. The recurrence time of a given amplitude is

$$T[S(\omega)] = N_E[S(\omega)]^{-1} \quad , \tag{2}$$

where the time unit is Y years (in all examples in this paper Y=50 years). The above equation (2) then gives the recurrence time of $S(\omega)$. Taking the logarithm of equation (1) gives

$$N_E[S(\omega)] = - \ell n\{1 - p[S(\omega)]\} \ . \tag{3}$$

Since, for ths example, a Poisson sequence of earthquakes in time has been assumed, equation (3) can be used to compute the probabilities of exceeding $S(\omega)$ during another observation period of Y years.

EXAMPLE: Seismic Microzonation of a Metropolitan Area

To show how the above methodology could be used to present a microzonation map of a metropolitan area (following Ref.12) the seismic region and the geometry of the Los Angeles basin in Southern California have been employed However, the seismic activity has been chosen arbitrarily. Detailed microzonation of a large metropolitan area like Los Angeles will require detailed studies of the active faults and of the distribution of all active zones and will call for much more detailed knowledge of the local soil and geologic conditions than what has been adopted for this illustrative example.

Figure 1 (modified from Ref.7) suggests that the distribution of major quaternary faults in Southern California Lee and Trifunac (Ref.12) presents all seismicity parameters which have been assigned to the sources in Figure 1 and which have been used in the computer program NEQRISK (Ref.10) to calculate the examples presented in this paper.

The scaling equations which relate PSV amplitudes at a given period of motion further require one to specify the "depth" of sediments beneath the station (Ref.21). Using the maps of Yerkes et al. (Ref.25) as a general guide, an idealized model of the depth of sediments has been developed for this study. The depth of sediments ranges from 0 to 31,000 feet.

The spectral amplitudes presented in Figure 2 represent Pseudo Relative Velocity Spectra (PSV) with 5 percent damping for horizontal ground shaking. The results can be corrected to vertical spectra by multiplying these amplitudes by the scaling factor which depends on period T (Ref.21).

The most recent presentation of the spectral scaling equations

(Ref.21) utilizes the frequency dependent attenuation of strong ground motion (Ref.22) and for scaling in terms of the earthquake magnitude M uses the focal depth H. Since most earthquakes in Southern California, which have been recorded by strong motion accelerographs, have H in the range from 0 to about 25 km (Ref.11) for simplicity in this paper it has been assumed that all activity occurs at H=5 km.

Figure 2 presents examples of the maps of URS for p=0.5, probability of exceedance, and for a chosen set of oscillator periods T. The reader can find many such figures for different probabilities of exceedance and for magnitude and MMI scaling in the report by Lee and Trifunac (Ref.12). There are many different ways in which the results such as those illustrated in Figure 2 can be viewed. One of the most direct ways is to interpolate from amplitudes at these four periods to obtain the URS for pseudo relative velocity at any desired location. By themselves the maps of the type illustrted in Figure 2 show the geographical distribution of horizontal PSV amplitudes, for 5 percent damping, for a given probability of exceedance during 50 years of exposure and for a given oscillator period T. It is seen that by and large the high frequency spectral amplitudes depend on the proximity of the site to "San Andreas" fault (Figure 1). At intermediate and long periods the deep sedimentary basin in the central region of the metropolitan area amplifies the longer seismic waves for all probabilities of exceedance.

CONCLUSIONS

The main conclusions of this work can be summarized as follows:

1. The method involving uniform risk spectra can be used to construct maps of spectral amplitudes with constant probability of being exceeded, at least once in Y years. The method offers excellent means to account for all sources of seismicity and to combine all sources of uncertainty in a uniform and balanced way. It is most efficient in showing the relative contribution to amplitudes and especially the shape of URS different sources, given the different epicentral distances, of the levels of source activity, of the largest magnitude expected at each source, and of the local geologic conditions beneath the site.

2. For the seismicity model selected in the examples presented here, the results are dominated by the expected earthquake occurrance on the "San Andreas" fault. Its contribution to the risk overshadows all other faults in the metropolitan area.

3. In the central region of the example area, the assumed depth of sediments (up to 31,000 feet) significantly amplifies long period ground motion.

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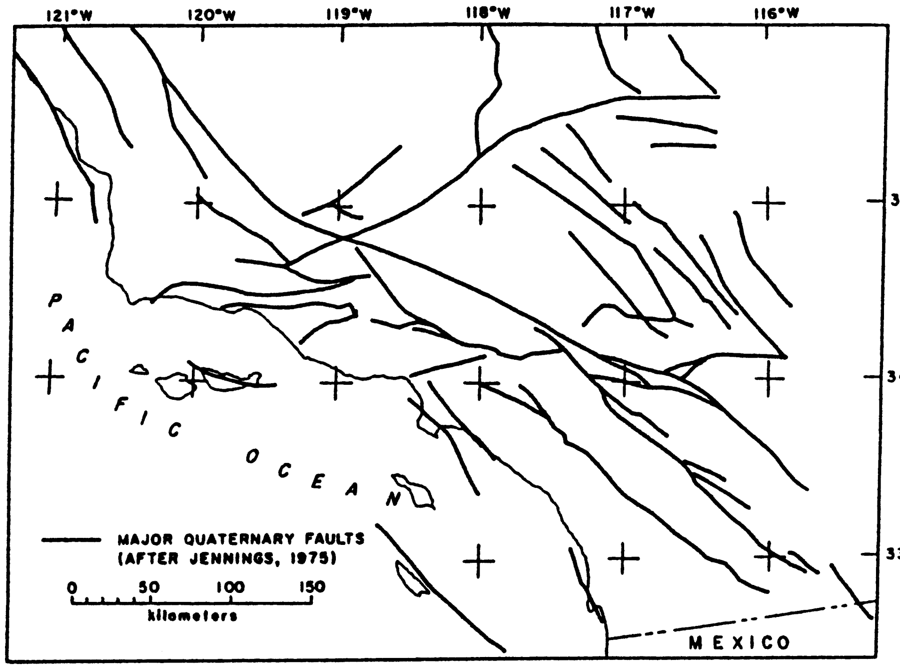

Figure 1

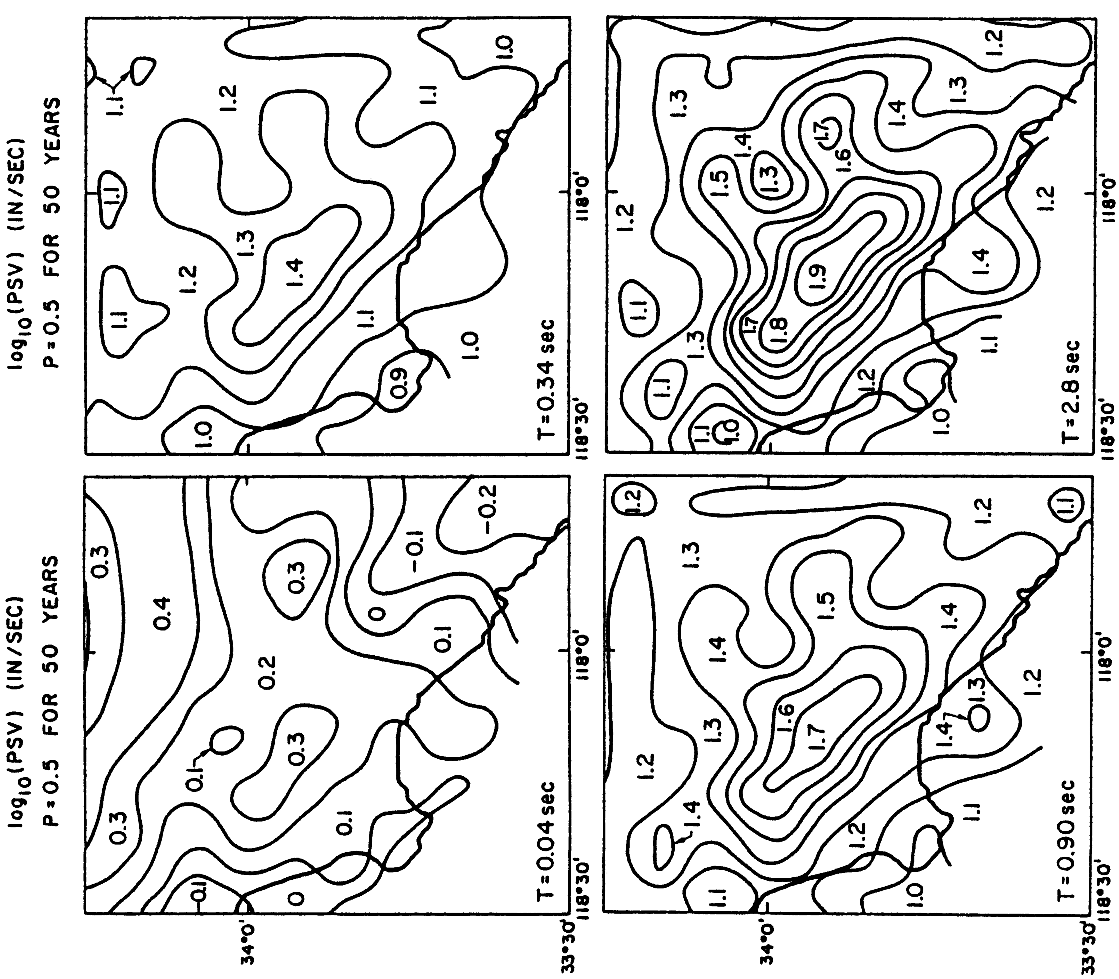

Figure 2