APPLICATION OF SEISMIC RISK PROCEDURES TO PROBLEMS IN MICROZONATION

by

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ABSTRACT

This study considers the seismic risk for the Los Angeles, California, metropolitan region. For sites there, the spectral amplitudes of shaking with a selected probability of exceedance are a function of location and geologic site conditions (but not including soil types or water table elevations, for example). However, the maximum difference, for the sites selected, among these amplitudes is smaller than the uncertainty involved in the estimate of shaking for a single site. It is difficult to justify contouring the expected amplitudes of ground motion with a contour interval which is significantly smaller than the uncertainty in ground motion for a single site. Thus, at most, only a small number of risk zones (e.g., 2 or 3) may be justified for the Los Angeles metropolitan area.

These results suggest that for metropolitan regions in similar locations it may be better to adopt a uniform level for estimated future amplitude of strong motion for the entire area or for large sub-areas. When and if methods for reducing the uncertainty in estimates of future amplitudes of strong shaking become available, the associated smaller uncertainties in the final result may allow a more detailed zoning of the Los Angeles region.

INTRODUCTION

This paper discusses how accurately seismic risk analysis can estimate probable amplitudes of future ground motion. The result is relevant to all aspects of seismic risk analysis, including microzonation.

The problem is studied by evaluating the accuracy for calculations which are based on one particular set of correlation functions, and in one particular region. One might expect that the results also apply to some other cases as well.

METHOD AND PRELIMINARY RESULTS

The study is for a portion of southern California. Figure 1 shows the major faults in southern California, after Jennings (1975), and a grid of points in the vicinity of Los Angeles. The seismic risk was found at each of the 210 points in this grid using the procedure described by Anderson and Trifunac (1977, 1978a). Their procedure is similar to that of Cornell (1968) to find the risk at each site. It is re-applied at several frequencies for each site as also suggested by McGuire (1974), but for brevity, the results here are discussed at only two frequency bands.

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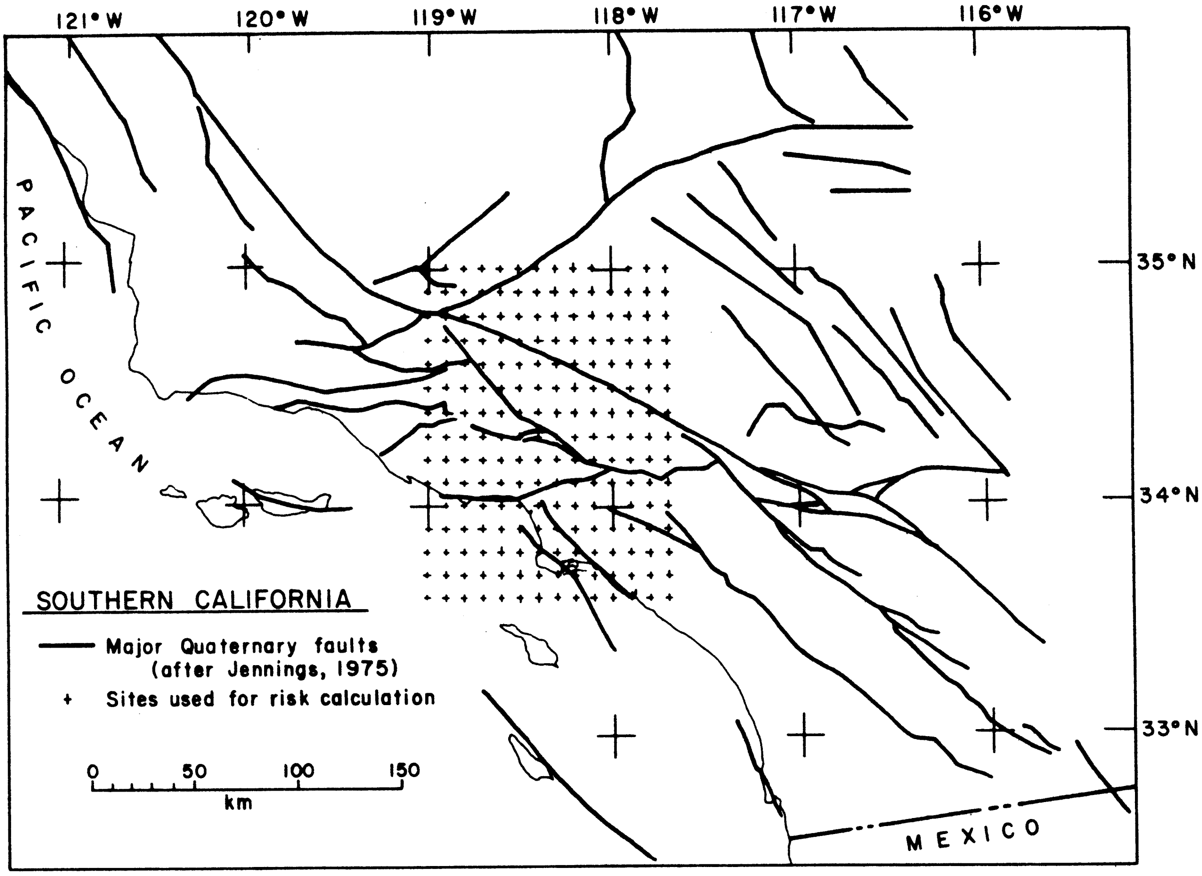


Figure 1

Let us regard the seismic risk analysis as a black box computer program. There are two sets of inputs for this program. The output is the risk at a site.

The first set of inputs is a description of the seismicity in the region. For that input the model of Anderson (1978) was used. His model finds a slip rate for most of the faults in Figure 1 which is consistent with the geology in the region, and then finds a rate of occurrence of earthquakes for these faults which is consistent with the slip rate at each fault. The resulting earthquake occurrence rates are consistent with historical seismicity.

The second input is a description of the attenuation of seismic waves as a function of distance from the seismic source. We use either the model by Trifunac and Anderson (1978) or by Trifunac and Lee (1979) for the attenuation of the amplitude of the pseudo-relative velocity spectrum (PSV) at period T. The first (Trifunac and Anderson, 1978) is:

$$\log_{10} PSV(T)\Big|_{p_\ell} = \begin{cases} M + \log_{10} A_o(R) - a(T)p_\ell - b(T)M_{min} - c(T) - d(T)s & \\ \quad - e(T)v - f(T)M^2_{min} - g(T)R & M \le M_{min} \\ M + \log_{10} A_o(R) - a(T)p_\ell - b(T)M - c(T) - d(T)s - e(T)v & \\ \quad - f(T)M^2 - g(T)R & M_{min} < M \le M_{max} \end{cases}$$

$$\log_{10} PSV(T)\Big|_{p_\ell} = \begin{cases} M_{max} + \log_{10} A_o(R) - a(T)p_\ell - b(T)M_{max} - c(T) - d(T)s \\ - e(T)v - f(T)M_{max}^2 - g(T)R & M_{max} \le M \end{cases} \quad (1)$$

In equation (1), M is the local magnitude of the earthquake, $\log_{10}A_o(R)$ is a description of the attenuation with distance (R) used by Richter (1958) to define the local magnitude, and v is a site condition variable set to 0 for horizontal motion and 1 for vertical motion. The other site condition variable s is set to zero for alluvial sites, 2 for sites on hard igneous rocks, and 1 for sites which are on consolidated sediments or are uncertain because of confusing geologic relationships. The values of M_{max} and M_{min} are 1-b(T)/2f(T) and -b(T)/2f(T), respectively; these cause the spectral amplitudes to grow less rapidly as magnitude increases, and to stop increasing for $M > M_{max}$. The terms a(T), b(T), ..., g(T) are empirical constants found in the regression analysis. Finally, p_ℓ is a linear approximation, for $0.1 < p_\ell < 0.9$, to the probability (p_a, say) that the spectral amplitude $PSV(T)|_{p_\ell}$ will not be exceeded. Trifunac and Anderson (1978) have suggested a way to recover p_a from p_ℓ.

Trifunac and Lee (1979) have developed a more refined correlation function, which for $M_{min} < M < M_{max}$ becomes

$$\log_{10}PSV(T) = M + \log_{10}A_o(R) - b(T)M - c(T) - d(T)h - e(T)v - f(T)M^2 - g(T)R \quad (2)$$

The term $a(T)p_\ell$ is dropped from this correlation, and the result is the mean value of PSV(T). Trifunac and Lee found coefficients which allow a direct determination of p_a. Also, the term s in equation (1) has been replaced by h in equation (2), where h is the depth to the geological basement rock. For $M < M_{min}$ and $M > M_{max}$, Trifunac and Lee (1979) recommend equations analogous to equation (1). This study uses the coefficients a(T), ..., g(T) appropriate for PSV spectra with damping at 5% critical.

Equations (1) and (2) have complementary uses, since in some cases, h can be determined, while in others, only the surficial geology, s, is known. Figures 2 and 3 show where, for the sites on Figure 1, the depth to basement h could be found, and where s had to be used. In the southeast corner of the study region (Figure 2), the depth to basement is known from results of Yerkes, et. al. (1965), and therefore, h can be assigned in this region. (The contour interval in Figure 2 is 10,000 feet, but the original figure in Yerkes, et. al. has a 1000 ft contour interval.) Outside of this region, s was picked using the 1:250,000 scale geologic map of California sheets (Rogers, 1967; Jennings and Strand, 1969). A site condition of s=2 is equivalent to h=0. Thus, for the region north of Figure 2, but south of the San Andreas fault, the correlation (2) could still be applied. Figure 3 shows a summary of all the site conditions used in the risk analysis.

Figures 4 and 5 are risk maps based on the above correlations and seismicity model. They represent one approximation to the actual risk, and should not be accepted uncritically. Figure 4 shows contours of equal value of $SA(T) \approx 2\pi/T\ PSV(T)$ (Anderson and Trifunac, 1978b) in units

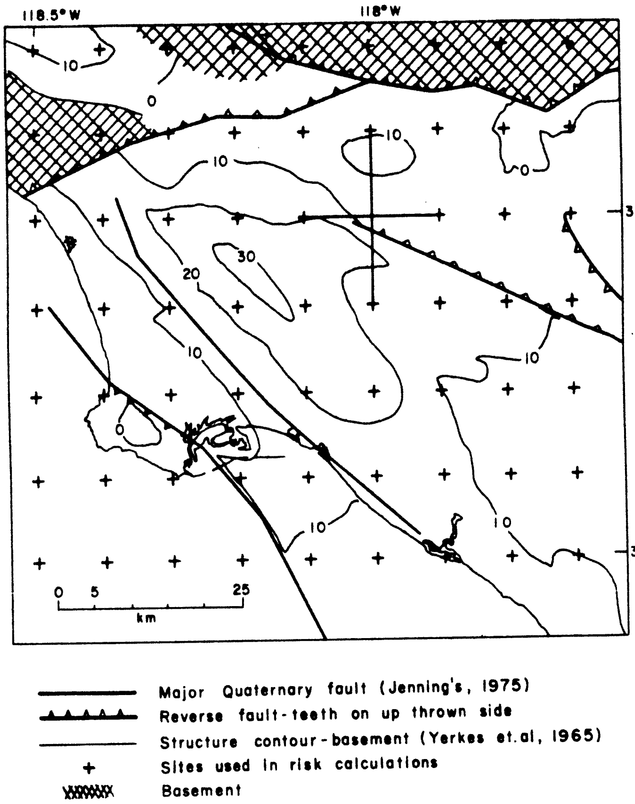


Figure 2

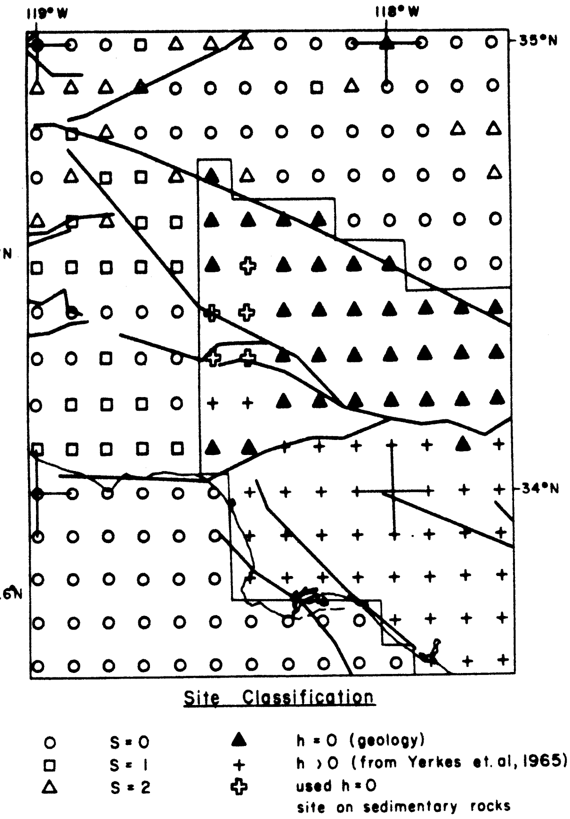


Figure 3

of fraction of the acceleration of gravity at a period T = 0.04 sec. At this high frequency, it approximates peak acceleration. The contoured

Absolute acceleration, SA, g's, at T = 0.04 sec
Probability of exceedance = 0.5 in 50 years

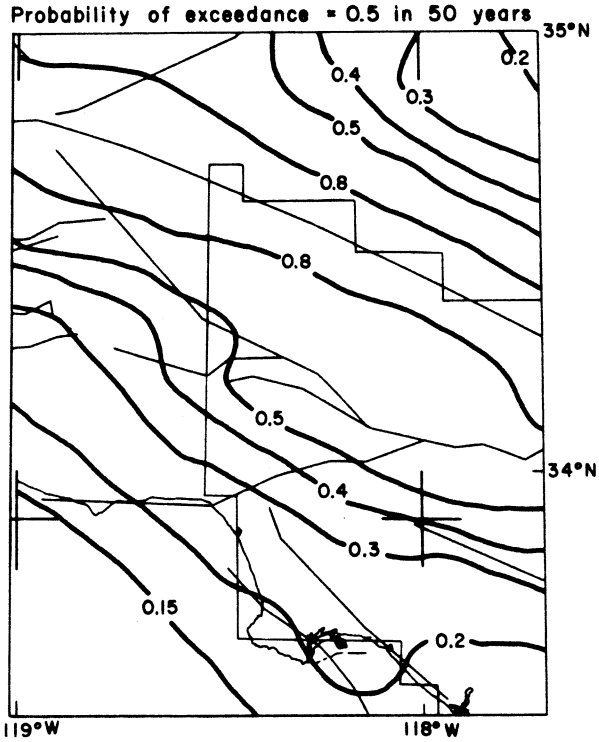


Figure 4

Pseudo relative velocity, PSV (cm/sec) at T = 15 sec
Probability of exceedance = 0.5 in 50 years

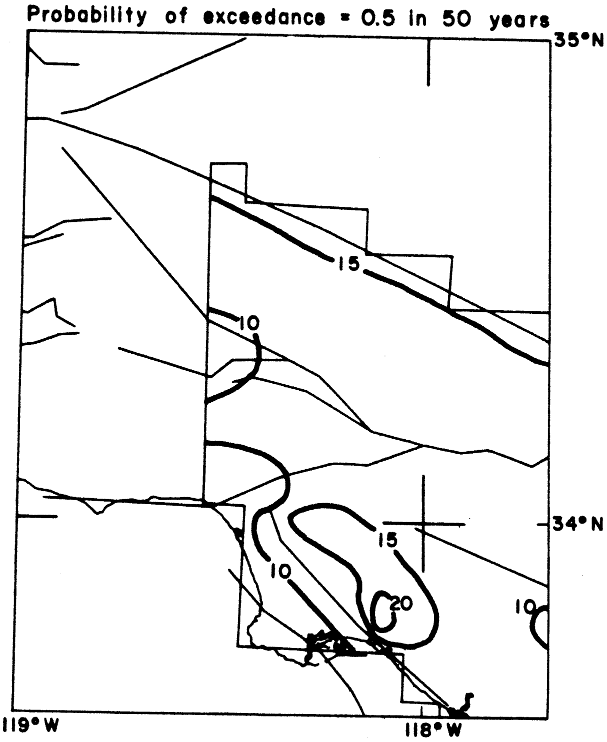


Figure 5

values have a probability of 0.5 of being exceeded once in a time interval of 50 years. There is no apparent discontinuity between the regions where equations (1) or (2) are used for scaling. Extreme values of SA (0.04 sec) range from about 1.2g for sites near the junction of the Garlock and the San Andreas faults, to about 0.1g in the extreme southwest corner of the map.

Figure 5 shows contours of PSV(T) at $T = 15$ sec. These were only found for sites which used correlation (2). The contoured values have probability $p = 0.5$ of being exceeded once in 50 years. While Figure 4 suggests that at high frequencies the predominant influence to the risk is nearness to the highly active faults, in Figure 5 the depth to geologic basement is a more important factor. This could have been predicted directly from the correlations, as the quantity d(T) in equation (2) does not differ significantly from zero at high frequencies, but it does at long periods.

SIGNIFICANCE OF THE RESULTS

The locations of contours shown in Figures 4 and 5 are determined to within about 2 to 3 kilometers. With a smaller grid spacing, one could draw more contours with more precisely determined locations. But such numerical precision would overlook significant uncertainties which are involved in the input to the computer program. This portion of the paper addresses these uncertainties, and examines how they may affect the results.

For each site the seismic risk can be described by a probability distribution function or its derivative density function of a desired strong motion functional. Examples of these density functions are shown in Figures 6 and 7. Figures 6 and 7 give the results for the probability density of the largest value of $\log_{10}$(PSV) observed in one year at three sites. Figure 6 is for an oscillator with $T = 0.04$ sec, Figure 7 is for an oscillator with $T = 15$ sec.

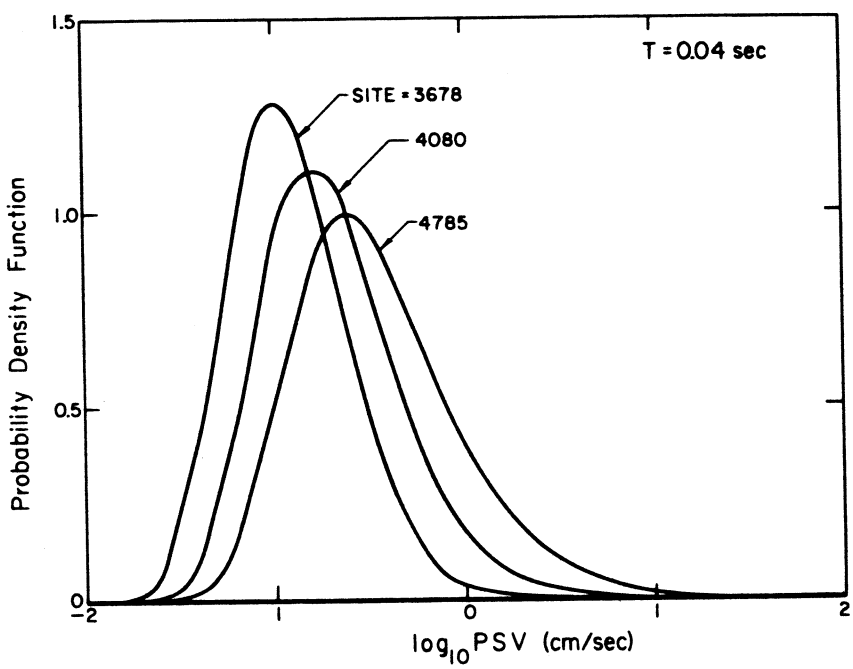


Figure 6

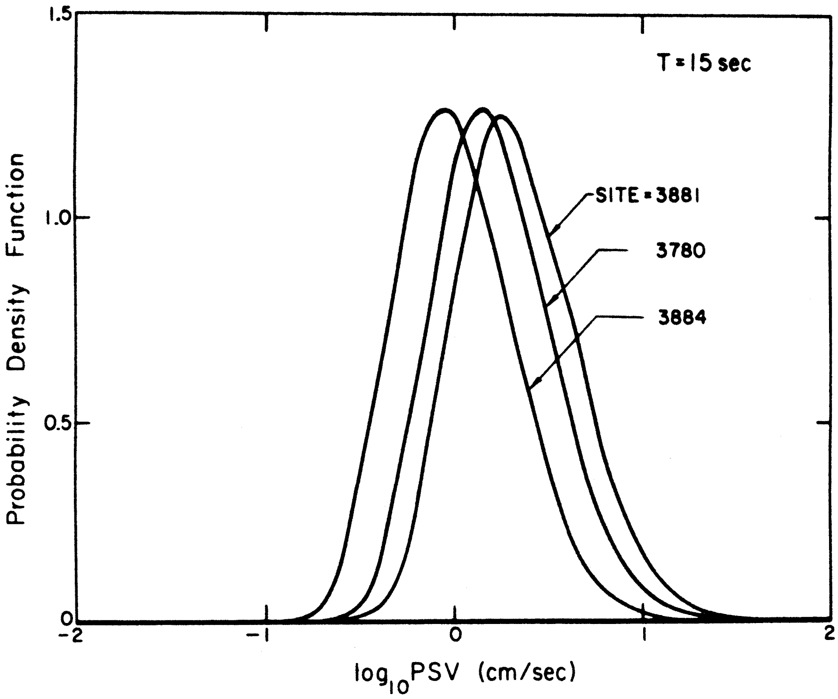


Figure 7

The distributions in Figure 6 are for three sites for which equation (2) was used in the risk calculations (Site 3678 is at latitude 33.6°N, and longitude 117.8°W). Site 3678 has the smallest spectral amplitude, Site 4785 the largest, and Site 4080 is about half-way between. The three sites in Figure 7 were chosen in the same way, again among those where the site condition was given by depth to basement h.

The inputs can affect these density functions in one of two ways: There can be systematic errors in the attenuation functions which may affect the absolute level of these distributions (i.e., the location on the longitudinal axis) or the shapes of the distributions. These would not necessarily affect the relative risk at two sites. There can also be errors in the model for the seismicity which affect the relative risks of sites. We therefore would like to know first what the absolute errors for the risk may be, and second, under what circumstances can we say with confidence that one site has significantly higher risk than another site.

There is the possibility that systematic errors coming from the attenuation functions will be large. At $T = 0.04$ sec, for example, Trifunac and Lee (1979) find that the one standard deviation bound for c(T) is $\sigma_c = 0.7$. At $T = 15$ sec, $\sigma_c = 1.7$. Since c(T) is an additive constant in equation (2), uncertainties in c(T) could apply directly to the uncertainty in logPSV(T). If the uncertainty in logPSV (0.04 sec) were as large as 0.7, this would correspond to a multiplicative factor of 5, and this would imply that the uncertainty could be greater than the differences between the density functions for the extreme sites in Figure 6. Similarly, the uncertainties implied from the equation (2) are greater than the differences between the extreme sites in Figure 7. At 25Hz, if we cannot rule out the possibility that there is a multiplicative factor of 5 uncertainty in the amplitudes of PSV, then the usefulness of Figure 4 is open to question when applied to the design of structures.

When the attenuation functions (2) were found, the distribution of spectral amplitudes about the mean values were found. These distributions would supposedly be different if the best estimate of c(T), for example, had been different. Therefore, the risk at the site may be uncertain by less than what the uncertainty of c(T) implies. But even if the attenuation function is assumed to be known exactly, significant uncertainties remain.

Suppose we ask how many observations (N, say) would be needed to prove statistically that the hypothetical distributions at two sites differed significantly. To determine N, one can use the non-parametric Kolmogorov-Smirnov test (Hoel, 1971). To apply this, one finds the maximum difference between the two distribution functions from which the density functions in Figure 6 or 7 were derived. This difference can, for a selected confidence level, be associated with N by referring to a table of the numerical values of the Kolmogorov-Smirnov Distribution (e.g., in Hoel).

Figure 8 shows an example for sites 3678 and 4785. The maximum difference between these probability functions is 0.45; the corresponding value of N is 9. By this test, we have derived N for each pair of sites represented by density functions on Figures 6 and 7; the results are compiled in Table I. These distributions are derived from input data, however, and so it is appropriate to ask if there is some number N which characterizes this input. If so, this would be a measure of the intrinsic reliability of the distributions.

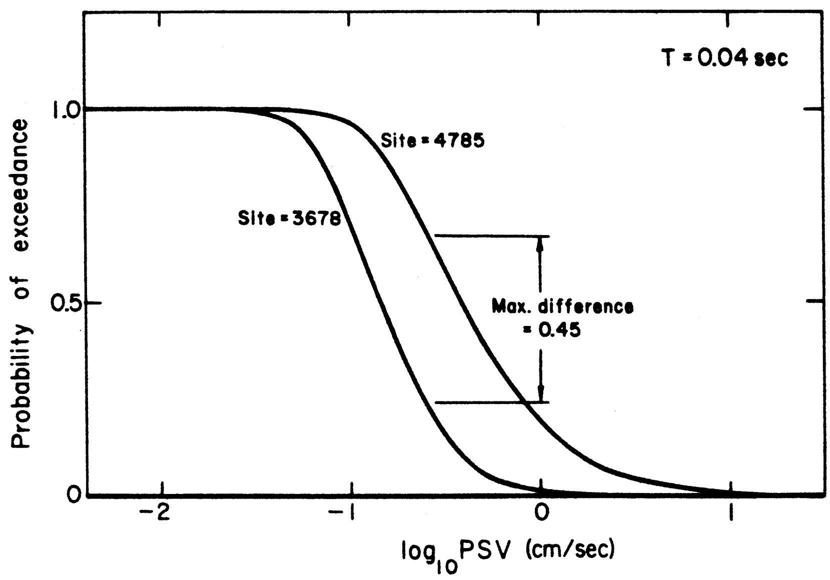


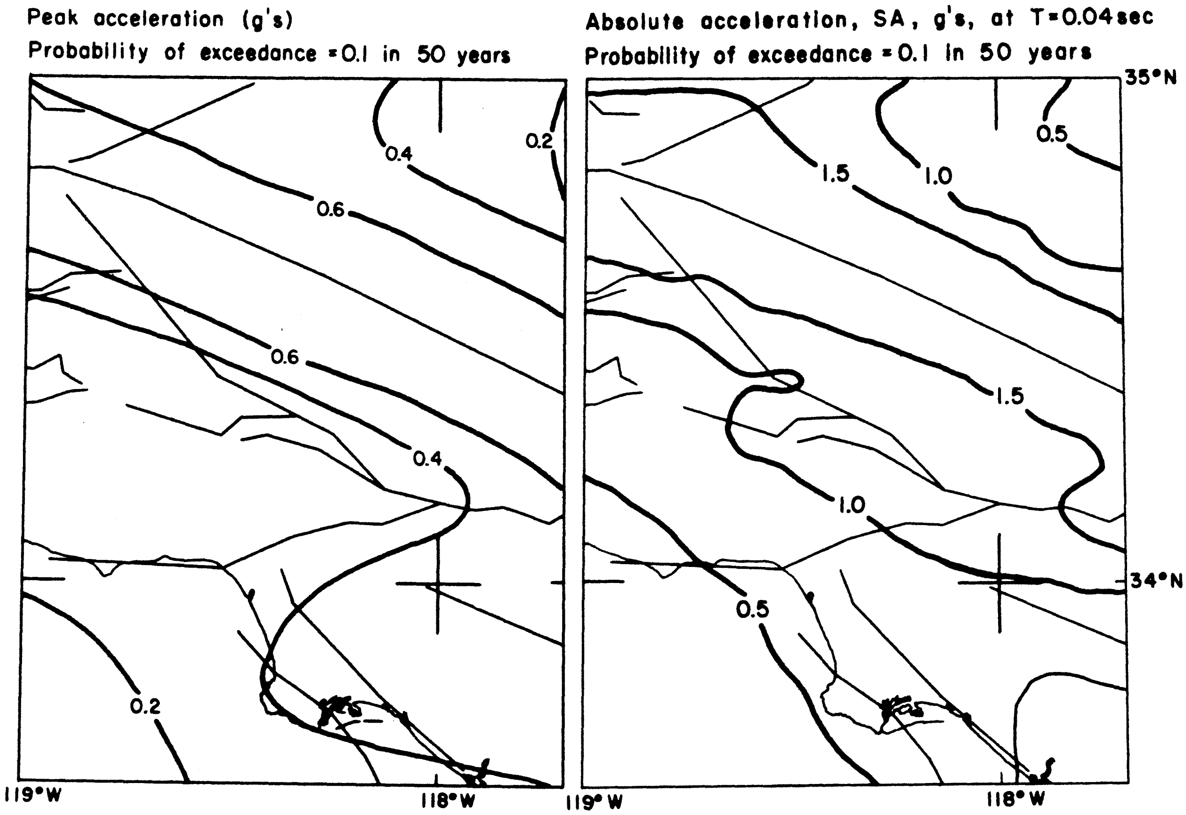
Figure 8

We can propose one method of finding a minimum value for N appropriate to these distributions. It is straight forward (but tedious) to eliminate from the seismicity model all the events which do not contribute significantly to the distribution of 1 year extreme amplitudes (such as Figures 6 and 7). When that is done for the model used here for a site near central Los Angeles (3881) about 15 events remain. Since at least 15 events are needed to compute these distributions, we suggest that at least 15 events have to be recorded so that these distributions would represent in some way all of the data, and therefore N is at least 15.

TABLE I

T = 0.04 sec				T = 15 sec			
Site	3678	4080	4785	Site	3884	3881	3780
3678	-	30	9	3884	-	11	26
4080	-	-	35	3881	-	-	87
4785	-	-	-	3780	-	-	-

Assuming N = 15, then the extreme density functions in both Figures 6 and 7 are significantly different, but the intermediate functions do not differ significantly from either extreme. Thus, by this test, we could support the division of the map into two zones: one with high risk and the other with low risk.



Algermissen and Perkins (1976) This Study

Figure 9

To carry these ideas one step further, we compare these results with results of the risk analysis by Algermissen and Perkins (1976). Figure 9 shows the maps derived by Algermissen and Perkins and by this study for the peak acceleration which has probability of 0.1 of being exceeded once in 50 years. It is assumed that the spectral response at 25 Hz is nearly the same as peak acceleration. The absolute levels of the amplitudes differ by about a factor of two; this is somewhat less than the factor of 5 discussed earlier as a possible limit to the systematic error at this frequency. In the northern section of the map, the contours generally have similar shapes, so that the relative risks are similar. In the southern section, the contours have significantly different shapes.

We examined sites near Algermissen and Perkins' contour for a peak acceleration of 0.4g. Among these, sites 4279 and sites 3874 represented approximately the extremes in our model of highest and lowest risk. The ratio of the peak accelerations at the two sites by our model is about 2.5. The density functions for these two sites are plotted in Figure 10; one would predict that N = 8 data points would be sufficient to determine whether the two sites differ significantly.

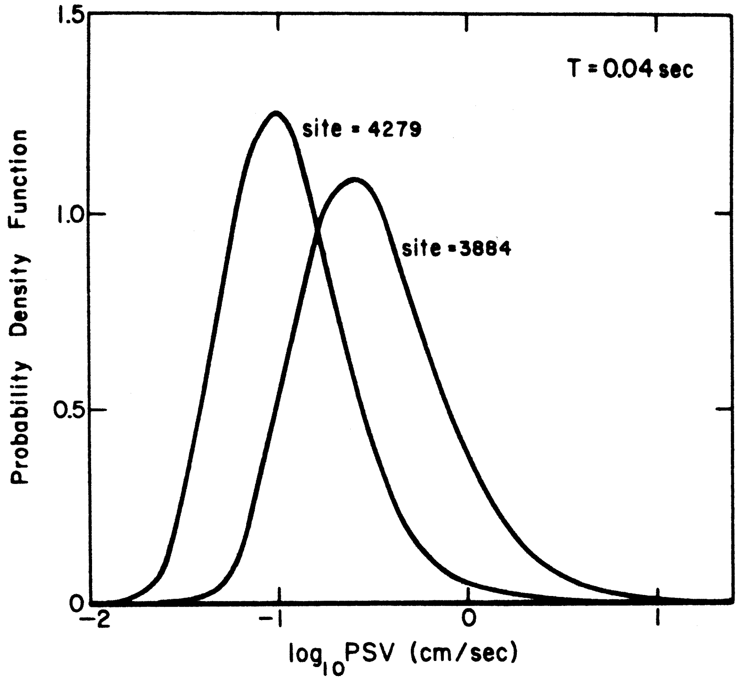


Figure 10

These density functions thus differ by more than sites 3678 and 4785 (Figure 6) at large probabilities, although their small probability tails differ by less. This result suggests that in the test suggested above, N may be smaller than the estimate of 15 which we found. The Kolmogorov-Smirnov test assumed that the seismicity model was known exactly; this result illustrates the important effect of judgement in defining the seismicity model.

Some seismic zonation studies (e.g., Fischer and McWhorter, 1972) have defined zones which correspond to units on Modified Mercalli, or an equivalent, intensity scales. An increase in one unit on the MMI scale corresponds to about a doubling of amplitudes (e.g., Trifunac and Brady, 1975). It seems from our results that the uncertainties of risk in the Los Angeles area may exceed a factor of 2. However, it is interesting to note that if a factor of 2 difference is assumed to be significant, then the smallest zone within the region would have a dimension of 10 - 20 km (10 km for the T = 15 sec data, 20 km for the T = 0.04 sec data).

CONCLUSIONS

This paper has addressed the question of how many zones of differing seismic risk could be justified within a selected region of southern

California. In general, it seems hard to justify more than two or three large zones. Uncertainties in the attenuation relationship for strong ground motion seem to be comparable to, or greater than, the extreme range of spectral amplitudes which are found with any selected probability of exceedance. If it is assumed that the attenuation model is known exactly, one can again look for relative differences in risk. Then the amount of information contained in the seismicity model seems to allow at least 2 zones, but differing interpretations of the tectonic relationships and historical seismicity of the region can lead to different patterns of relative risk throughout the study region. If it is assumed that the results from the model can be taken literally, and that a multiplicative factor of two difference is significant, then it is possible to define three zones within the study region; the minimum dimension of a zone is about 10 km.

These results depend on the model for the attenuation of strong motion. Our model does not consider details of the soil conditions or water table, for example, and thus does not consider all the factors that may be involved in a microzonation study. However, it suggests that the uncertainties involved in risk models can be larger than a factor of 2. This possibility should be considered in any microzonation analysis.

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