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UNIFORM RISK ZONING - A SIMPLIFIED SPECTRAL APPROACH

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SUMMARY

This paper demonstrates, by using the results of probabilistic hazard studies, that spectral acceleration values at specific periods can be a stable mapping parameter for seismic zoning. Comparisons between several different response periods suggest that a period of 0.33 second (3 hertz) is an optimal value. This is different from the value used in New Zealand. Periods of less than 0.33 second are unduly influenced by small magnitude events while longer response periods depress the overall sensitivity of the analysis. A spectral shape obtained from the hazard analyses is given in tabular form for use in scaling a soil site response spectrum from the 0.33 second spectral acceleration value obtained from either a hazard study or a zoning map.

CAVEAT

This paper recommends, for code purposes, the use of a constant spectral shape over a wide range of seismic conditions. The views of the author do not agree with the premise that spectral shapes should be considered constant. Pragmatic considerations relating to presentation of spectra in a code form require that simplifications be made. This paper attempts to show how the simplifications required for code presentation might be improved upon.

INTRODUCTION

Seismic design requirements and seismic zoning maps have followed as a reaction to damaging earthquakes. This has usually resulted in either reconstruction following the earthquakes being done to stricter requirements than before or to the area where the earthquakes occurred being placed in a higher seismic zone which also results in stronger construction. The weaknesses of such a reactionary approach has become more apparent as the understanding of the underlying causes of earthquakes has increased. Methods for improving seismic design and developing improved seismic zoning maps are now available and public awareness of the problem is increasing. A slow transition from reaction after an earthquake occurs to a situation of preparation for future events is taking place.

It is the aim of this paper to discuss possible approaches to preparation of the ground motion requirements that might be represented on future zoning maps. This study concentrates on soil site spectra. Most records are obtained from and most buildings are constructed on sites with soil profiles similar to either UBC soil type 2 or the Japanese profile classification as Type III. The emphasis of this paper is only on ground motion requirements. The representation of all the requirements for seismic design by a single zoning factor results in some design parameters being changed or ignored. The visible retention of some state boundaries in parts of the United States in the zoning map, see Figure 1, given in the 1988 edition of the Uniform Building Code shows that the ground motion requirements have been compromised in favor of other interests. When it is recognized that the ground motion requirements are not treated correctly when the regional seismic requirements are lumped together under a single zoning number it will be understood why this paper is restricted to a discussion of only the ground motion requirements.

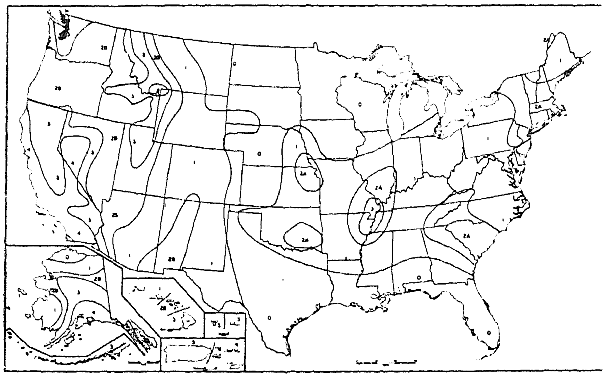

Figure 1. 1988 UBC Zoning Map

HAZARD ANALYSIS

It is now recognized that in seismic areas the hazard comes from many possible earthquake sources rather than a single source of infrequent large earthquakes. While the single source and the largest event which might occur on that source is used to provide an estimate of the design ground motion, such an approach does not consider the probability of the motion occurring. Maximum events are required for major facilities such as dams where the possible consequences of damage are unacceptable. For buildings a balance must be achieved between the level of seismic protection desired and the cost of providing that protection.

Procedures for considering both the distribution of seismic sources and the possible size of earthquakes are now well developed. When combined with attenuation relationships the annual probability of exceedance of specific ground motion parameters can be estimated. The parameter most often considered is peak acceleration. This has been an unfortunate choice because it is now recognized that the peak acceleration value is probably the seismic value which is the least sensitive to earthquake size. Some researchers consider peak acceleration to be size or magnitude independent at short distances (Refs. 1,2,3). There is a distinct need for the replacement of peak acceleration as the parameter used for seismic ground motion design scaling.

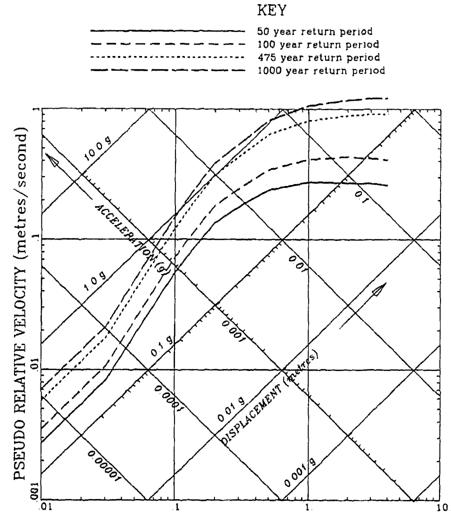

Figure 2. Uniform Risk Spectra, California soil site damping = 5 percent

SEISMIC ZONING PARAMETERS

The first maps recommended for possible code use based on probabilistic methods were prepared for the ATC3-06 study in 1977 (Ref. 4). The maps prepared for this study recognized that measured peak acceleration was a poor term for use in defining ground motion. It was also accepted that any changes must come gradually so the concept of scaling spectra to a term identified as an acceleration values was not abandoned. Instead a new term, effective peak acceleration (EPA), was developed for use as the scaling parameter. For rough descriptive purposes the EPA of a strong motion record can be described as the average response acceleration at 5 percent damping between the periods of 0.1 and 0.5 second divided by 2.5. This definition removes the influence of small earthquakes on the determination of the EPA and its use for scaling the response spectral shapes which are representative of medium to large earthquakes.

New Zealand has recently made major changes to the seismic design requirements of New Zealand Standard 4203. The use of peak acceleration parameters as a mapping parameter has been completely abandoned in favor of spectral acceleration at a response of 0.2 second. The New Zealand standard also adopted a single response spectrum shape as representing all magnitude and distance values. The concept of a magnitude and distance dependent spectral shape has not been supported in detailed US studies (Ref. 5). The practical limitations of the lateral force requirements in a code do not permit the more complex form that including these parameters would require. It should be noted that constant spectral shapes, with different shapes depending on soil conditions are now included in the 1988 revisions to the Lateral Force Recommendation of the Structural Engineers Association of California. The different conclusions reached for New Zealand can be explained on the basis of the seismic zoning and attenuation relationships used. The choice of a response spectral value as a mapping parameter represents a major advancement. The review of the New Zealand study raised an additional question which asked whether 0.2 second represents the most appropriate period value to be used for the mapping.

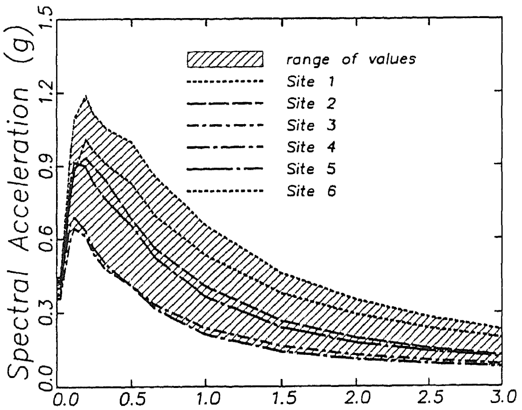

Figure 3. Uniform Risk Spectra for California sites. 475 year return. damping = 5 percent

Figure 2 shows the results of a probabilistic hazard study for a single California site. Uniform hazard response spectra were obtained for the site by combining the results obtained with 3 different spectral attenuation relationships (Refs. 6,7,8). As the annual probability decreases, or its reciprocal, expressed return period increase, the spectral amplitudes increase. This increase is not uniform. There is a change in spectral shape with the greater increase being in the longer period response. Two factors combine to produce

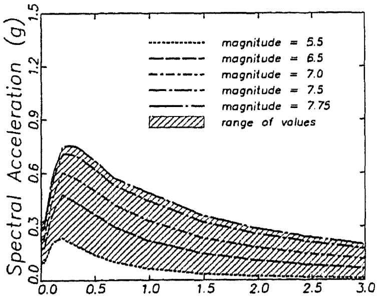

Figure 4. Computed response spectra – soil site. 15 kilometers from fault. damping = 5 percent

this difference. The first factor is the lower sensitivity of high frequency response to magnitude when compared with low frequency or longer period response. The second factor is the slower attenuation of the longer period response with distance.

The spectral shapes from a probabilistic hazard analysis represent a composite of the spectral shapes over which the hazard analysis has been integrated. The composite that results from the integration with the estimated uncertainty term included in the results leads to a spectral shape which has a relatively larger response at short periods. This can be seen by comparing Figures 3 and 4. Figure 3 shows a set of 6 different uniform hazard response spectra from scattered sites throughout California. In Figure 4 the response spectra were computed directly from the median attenuation relationships. The large spectral amplitude which peaks at a period of 0.2 seconds is only found on the probabilistic spectra in Figure 3. If not corrected this can lead to a bias which will result in a lowering of much of the response curve if the spectra are normalized at a period of 0.2 second. The converse situation will occur if mapped probability values of the spectral parameter are used with the directly determined spectral shapes of Figure 43. In this case the resulting spectra may be unacceptably large. This problem did occur in New Zealand with the result that a lower annual probability value is now used for zoning.

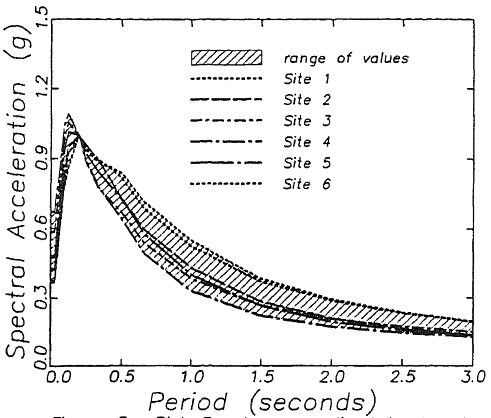

Figure 5a. Risk Spectra normalized to 1g at response period of 0.2 seconds. 5% damping

Each spectrum shown on Figure 3 has been replotted on Figures 5a through 5c. The spectral values are normalized in these three plots to have values of 1g at spectral periods of 0.2, 0.33 and 0.5 second respectively. Figures 5a through 5c show that the longer period response is more controlled by the normalization at 0.5 second while the short period values have a very large variation. It should be noted that the higher values at 0.2 second on both Figure 5b and 5c come from the spectra with the lowest absolute values on Figure 3. The variation of the long period response values is unacceptably large when normalization is made at 0.2

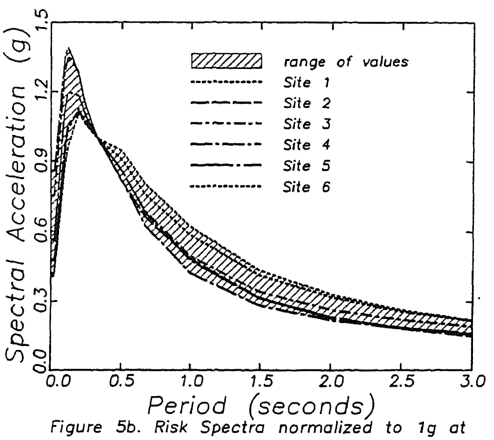

Figure 5b. Risk Spectra normalized to 1g at response period of 0.33 seconds. 5% damping

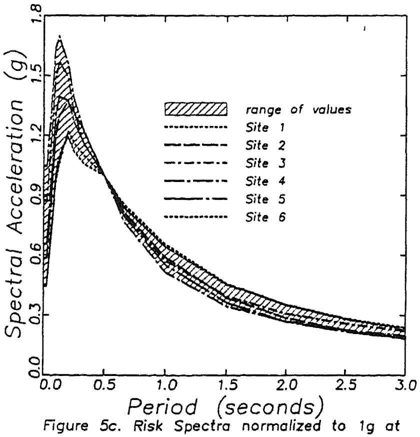

Figure 5c. Risk Spectra normalized to 1g at response period of 0.5 seconds. 5% damping

second. This suggests that the period of 0.33 second (3 hertz) may be more appropriate. This value also would appear to represent an optimum. Joyner and Boore observed little statistical difference between spectra from soil and rock sites for periods less than 0.3 seconds. The spectra shown on Figure 4 have also been normalized to 1 g at 0.33 second response period and are superimposed on the results of Figure 5b in Figure 6. It would be expected that the range of the normalized spectral shapes obtained by direct computation between magnitudes 5.5 and 7.75 would be greater than that obtained from the probabilistic hazard study. In the results from the probabilistic study each curve is based on the same recurrence interval. The larger values for the probabilistic curves at short periods are due to the spectral enhancement provided by smaller sized events.

Techniques are available to prepare a probabilistic hazard map that will list spectral acceleration values by using spectral attenuation equations. An example of the way such a map might be used is shown by the heavy line on Figure 6. The heavy line represents a spectral shape that can be used with the probabilistically developed spectral acceleration at 0.33 second period. Table 1 lists the values for this curve. This recommendation is made for highly seismic areas. Additional studies should be made to either confirm the validity of this curve or prepare an alternate recommendation for areas of moderate seismicity. A more preferable solution for a nation wide design procedure would, perhaps, be a pair of maps with the second map showing spectral parameters at a longer response period of say, one to two seconds. The normalized results of specific studies on Figure 3 can be used to show that the longer period response obtained by using the curve presented here is probably conservative. While the spectral shape presented on Figure 6 is designed to be scaled to only the 0.33 second period response acceleration the curve form could be readily adapted to accept the output results that would result from a system which used maps of two spectral acceleration coefficients.

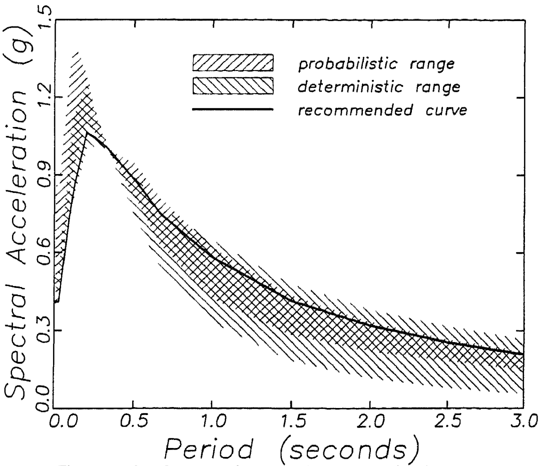

Figure 6. Comparison of spectral shapes, normalized to 1g at 3 hertz. 5% damping

CONCLUSIONS

Some conclusions can be reached from the comparisons of probabilistic results presented in this paper. The adoption by New Zealand of a zoning approach where the mapped parameter is based on probabilistic hazard studies using attenuation equations for response spectra represents a landmark achievement. It is hoped that this paper will help towards the procedure being emulated in the United States. Uniform hazard response spectra have different shapes from those directly computed using attenuation equations. Because the uniform hazard spectra are the result of integration across a wide variety of options, including uncertainties, the spectra values at short response periods are enhanced. This requires normalization at a longer period than used in New Zealand. Based on results from Californian studies a spectral acceleration at a period of 0.33 second (3 hertz) is recommended as the scaling value to be used for mapping. Spectral shapes are also sensitive to the return period used.

Table 1

Recommended Spectral Curve for Soil Sites
curve normalized to 1.0 g at 0.33 second

Period (sec)	Spectral Acceleration (g)
0.010	0.410
0.030	0.412
0.100	0.774
0.125	0.872
0.200	1.064
0.250	1.043
0.333	1.000
0.500	0.883
0.667	0.750
1.000	0.581
1.500	0.414
2.000	0.319
2.500	0.253
3.000	0.205
4.000	0.147

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