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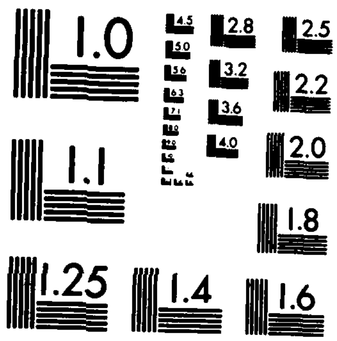

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Seismic Hazard Study for Selected Sites in New Mexico and Nevada

JANET C. JOHNSTON

27 DECEMBER 1983

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Seismic hazard evaluations were conducted for specific sites in New Mexico and Nevada. For New Mexico, a model of seismicity was developed from historical accounts of medium to large shocks and the current microactivity record from local networks. Ninety percent confidence levels at Albuquerque and Roswell were computed to be 56 gals for a 10-year period and 77 gals for a 20-year period. Values of ground motion for Clovis were below these values. Peak velocity and displacement were also computed for each site. Deterministic spectra based on the estimated maximum credible earthquake for the zones which the sites occupy were also computed. For the sites in Nevada, the regionalizations used in Battis (1982) for the "uniform seismicity" model were slightly modified. For 10- and 20-year time periods, peak acceleration values for Indian Springs were computed to be 94 gals and 123 gals and for Hawthorne 206 gals and 268 gals. Deterministic spectra were also computed. The input parameters were well determined for the analysis for the Nevada sites because of the abundance of data. The values computed for New Mexico, however, are likely upper cont

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limits. As more data are collected from the area of the Rio Grande rift zone, the pattern of seismicity will become better understood. At this time a more detailed, and thus more accurate, model may emerge.

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Seismic Hazard Study for Selected Sites in New Mexico and Nevada

1. INTRODUCTION

1.1 Purpose of the Study

This study was undertaken to gather data for the MX missile program. Current missile basing schemes are not final; however, certain specific areas have been considered. In this report, two of these areas, the states of New Mexico and Nevada, are examined for seismic hazard. Within these areas specific localities are used as foci for the calculations (Table 1). The results of this study may be applied not only to the construction of missile systems and support but to the siting of any type of structure.

Battis[1] computed the seismic hazard for the state of Utah. This report is a continuation of his work. Although the probabilistic risk to facilities in New Mexico and Nevada from earthquakes is different, the techniques employed to compute the seismic hazard are the same. The two states also share the same broad tectonic setting. Accordingly, the results of the hazard study for both New Mexico and Nevada are presented in this one report.

(Received for publication 20 December 1983)

1. Battis, J.C. (1982) Seismic Hazard Study for Utah, AFGL-TR-82-0319, AD A129238.

Table 1. Focal Sites for Hazard Study

Site	Lat	Long
Focal Sites in New Mexico		
Clovis	34.40	-103.200
Roswell	33.40	-104.533
Albuquerque	35.05	-106.380
Focal Sites in Nevada		
Hawthorne	38.533	-118.653
Indian Springs	36.567	-115.667

2. THE SEISMIC HAZARD METHOD

The rate of occurrence of earthquakes has been found to be described approximately by

$$\log N = a - bM \quad , \tag{1}$$

where N is the number of earthquakes of magnitude M per unit time. For the entire earth from 1918 to 1964 the constants of this equation have been found to be a = 8.73 and b = 1.15, where N is the number of events per year and is based on earthquakes in the range 6.0 to 8.9 M.[2] The slope, or b-value, of the curve is normally found to lie between 0.5 and 1.5. It is not clear whether the variations are caused by scatter or are indicators of the seismic processes in a region. The value of the intercept a is, of course, highly variable, since it reflects the level of activity in an area.

Equation 1 implies that

$$F(M) = 1 - e^{-\beta(M - M_o)} \quad , \quad M \geq M_o \quad , \tag{2}$$

2. Bath, M. (1973) Introduction to Seismology, John Wiley and Sons, New York.

where F(M) is the cumulative distribution function, $\beta = b \ln 10$, and M_o is some cutoff magnitude considered negligible for engineering risk.[3] For our purposes we will assign $M_o = 4.0$ (M_L).

Two approaches have been developed by seismologists to estimate potential strong ground motion levels at a site for engineering purposes. The deterministic method attempts to predict the maximum ground motion possible while the probabilistic approach predicts the likelihood of a given ground motion over some specified period of time such as the useful lifetime of a structure. Brief descriptions of these methods are presented in the following sections. The two methods need not be mutually exclusive. Ideally, the most physically realistic model would incorporate elements common to both.

The deterministic approach to seismic hazard evaluation requires a knowledge of faults in the vicinity (radius of 100 km or more) of the facility of interest. In general, faults that have shown any activity during the Quaternary (approximately 2 million years before present) are considered to be capable of sustaining seismic activity. The maximum length of each fault that could rupture in one earthquake is estimated, and this value is used to evaluate a maximum credible earthquake, the largest earthquake with a reasonable chance of occurring on the given fault. The hazard is evaluated using any of several empirical equations relating magnitude to maximum fault rupture length.[4] This phase of the deterministic approach, estimating the maximum possible earthquake, is the most difficult. Often the length of the fault is unknown and estimates of magnitude of past events from geological examination of fault offsets do not always yield unique values. When the estimate is made, strong ground motions at a site can then be evaluated using empirical relations between magnitude and distance and acceleration, velocity, or displacement. A compilation of various relationships can be found in McGuire.[5] Caution must be used, however, in selecting a set of equations since they are not all valid worldwide; some were developed for specific areas, such as California. These equations can be modified to compensate for local site conditions.

One problem with a purely deterministic approach is that the return period of the maximum event may be so large that it is logistically and financially unreasonable to design a relatively short-lived facility to a very high value. For example, if a magnitude 7.0 event had a return period of 100,000 yr, the annual

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3. Cornell, C.A. (1968) Engineering seismic risk analysis, BSSA, 58(No. 5):1583-1606.

4. Slemmons, D.B., Jones, A.E., and Gimlett, I. (1965) Catalog of Nevada earthquakes, 1852-1960, BSSA, 55:531-583.

5. McGuire, R.K. (1976) EQRISK, Evaluation of Earthquake Risk to Site, USGS Open File Report 76-67.

rate of occurrence would be 1×10^{-5}. If the life of the structure in question is 40 yr, then the probability of an earthquake exceeding magnitude 7 during the lifetime of the structure would be approximately 4×10^{-4}. For this problem, the probabilistic approach should be utilized.

These relationships for acceleration do not predict the level of ground motion over the entire frequency range. Standardized spectra have been developed (for example, Nuclear Regulatory Guide 1.60), which can be anchored at a peak acceleration value. As yet, modification of the shape of the spectra for the type of soil at the site and for the magnitude of the event is not a routine process.[6] Standard design spectra that will be presented in later sections are plots of calculated peak pseudo relative ground motion versus frequency. The values of velocity presented can be converted to acceleration or displacement by multiplying (acceleration) or dividing (displacement) the values by ω, equal to $2\pi f$, where f is the frequency.

Using seismic hazard estimates to design structures has gained acceptance in recent years. A computer program[5] will perform the necessary calculations. Since the concepts and assumptions that make up the calculation must be understood to assess the appropriate uses and the limitations of the method, a brief overview is presented in this section.

Once the site of interest has been selected, a catalog of earthquakes giving date, location, and size (magnitude or intensity) is examined. If the catalog is not homogeneous, then conversions from one magnitude scale to another (for example, m_b to M_s) or from intensity to magnitude must be made. Care must be taken to select the proper conversion relationship. A range of scenarios is tried, using source zones of various sizes to model the seismicity [Figure 1(a)]. After source zones are defined, the enclosed seismicity is tabulated. Earthquakes are counted according to magnitude (or any other measure of size) and time interval. The seismologist decides on the appropriate time intervals using judgments of the completeness of the catalog for various years for the different magnitude ranges. A recurrence curve is derived from each source zone [see Figure 1(b)]. These curves represent the modeled cumulative number of earthquakes that will occur in a given source zone at any magnitude (per year if the calculations are for annual risk). Next, all the modeled seismicity that occurs annually in this zone is distributed evenly throughout the zone. Even if the naturally occurring seismicity is clustered in a small area within the zone, it will be spread out uniformly. This is important because of the distance calculation [Figure 1(c)]. Therefore the geometry of the zones plays an important part.

6. Johnston, J.C., Cybriwsky, Z.A., and LeBlanc, G. (1980) The regulatory guide 1.60: Its content and applicability, Abstract, Earthquake Notes 51:(No. 3).

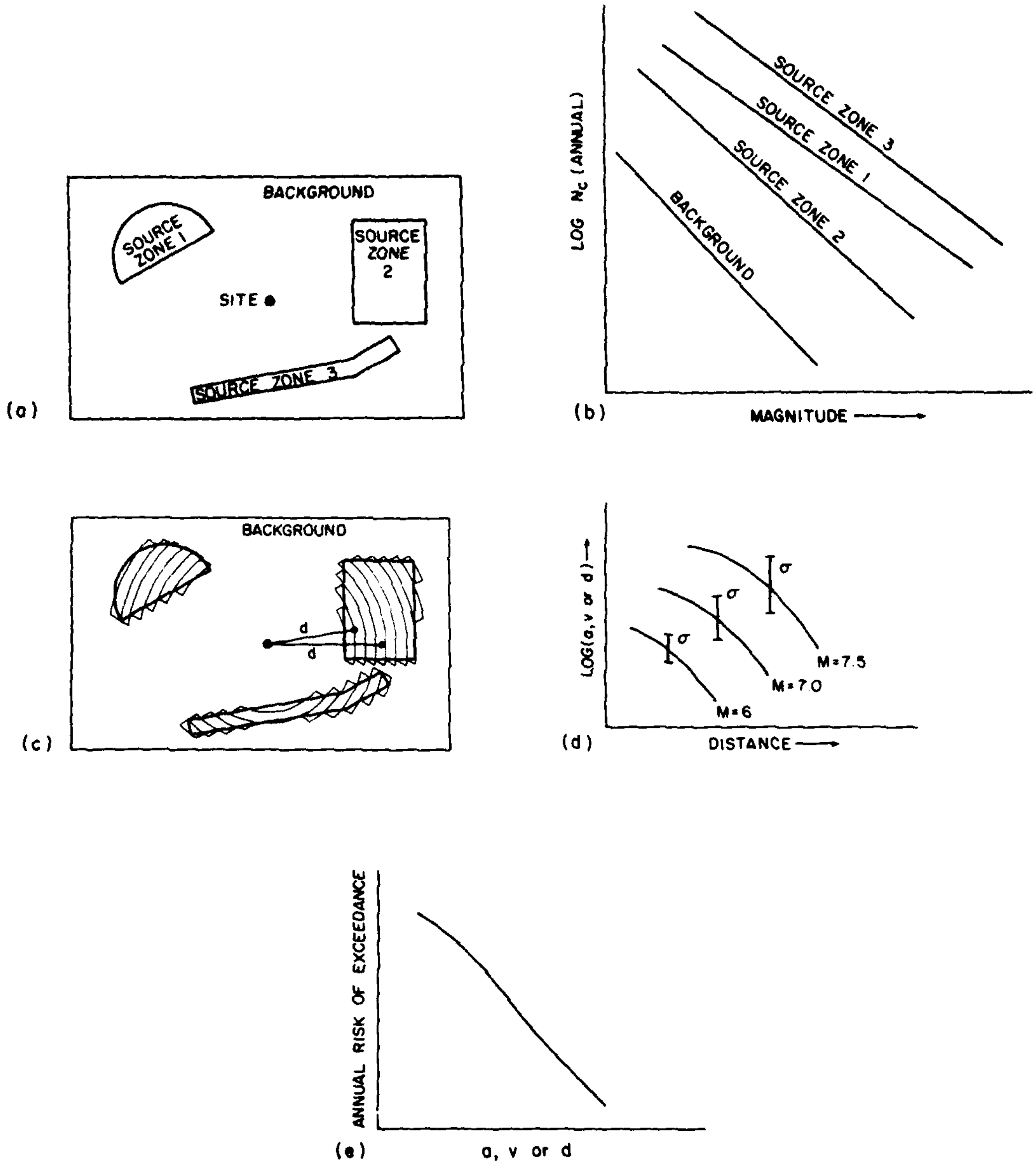

Figure 1. Seismic Hazard Methodology

The next step requires an attenuation relationship that relates magnitude to acceleration, velocity, or displacement, and to the distance to the site [Figure 1(d)]. Then, distances are computed to the seismicity that is now distributed evenly in the zone. When all this has been tabulated, the result is Figure 1(e), the annual risk of exceeding the ground motion parameter used Figure 1(d).

This result can be expressed mathematically by

$$P[A] = \iint P[A \mid s \text{ and } r] \; f_S(s) \; f_R(r) \; ds \, dr \quad , \tag{3}$$

where P[A] is the probability of exceedance of ground motion value A, s is the earthquake "size" parameter (magnitude, for example), r is the distance from the site of interest, f_S and f_R are the independent probabilities of s and r, respectively, and P[A | s and r] is the conditional probability of A, given s and r.

It should be noted that this analysis assumes that earthquake occurrence is a Poisson process, that is, earthquakes occur randomly in time, independent of the previous history. This condition is not met in the case of swarming; a limitation that should be considered when evaluating the results for New Mexico where much of the seismic history consists of earthquake swarms.

This type of analysis is the most useful for comparison purposes. That is, given two distinct sites that both have a fairly accurate earthquake catalog, performing this calculation for both locations will yield a good estimate of the relative seismic hazard of the two regions. Since there are some elements of the deterministic approach incorporated into the hazard calculation such as the choosing of the source zone boundaries and an event upper magnitude cutoff, this method gives more information on the actual hazard to a facility during its useful lifetime (typically 30 to 50 yr). It also allows designers or regulating agencies to quantitatively incorporate conservatism into the design or to set guidelines. Often, a 10,000-yr return period is considered to be an acceptable hazard. The actual probability of damage to a structure calculated using the seismic hazard as input and engineering methods is called the seismic risk.

A limitation of the hazard method is that the duration of the ground motion contributing to the annual risk is not included. Seismic waves from a magnitude 7.0 earthquake 100 km away may, for example, have higher amplitude ground motion and longer duration at periods greater than approximately 0.08 sec than will a magnitude 5.5 earthquake located within 10 km of the site. Since structures respond to periodic signals more readily than to a single spike of motion and have specific natural frequencies, all these complications must be considered.

In summary, the degree to which the deterministic methods should be incorporated into the design of a facility relative to the probabilistic elements, that is, the amount of conservatism, is judgmental. If a large earthquake should occur during the lifetime of the structure, the resulting damage is the same whether the probabilistic return period of that event a million years or ten. The critical need for operation of the facility must be weighed against financial and design practicality.

3. DISTRIBUTION OF EARTHQUAKES IN WESTERN NORTH AMERICA

3.1 Tectonic Regionalization of Western North America

The division of the western United States into tectonic regions, on which the zonation schemes for the seismic hazard studies of Sections 4 and 5 are based, is from the work of Greensfelder et al[7] and Smith and Sbar.[8] The most prominent seismic feature of western North America is the San Andreas fault system, which marks the boundary between the Pacific plate and the North American plate. There are numerous studies dealing with the evolution of this boundary.[9] Estimates for slip along this boundary range from approximately 5 cm/yr near San Francisco to 8 cm/yr near the Imperial Valley. However, unlike many areas of the world, seismicity is not confined to the area of this boundary fault. Whatever the "underlying" cause for this phenomenon, the fact is that there is a consistent pattern to the seismicity that occupies the western half of the U.S. to such a degree that it is possible to define relatively aseismic provinces (such as the Colorado plateau and the Snake River plain) and seismic zones (such as the Wasatch Front and Rio Grande Rift) in a manner analogous to rigid tectonic plates and plate boundaries. In this study such zones will be defined where there is sufficient data to ensure conservative results.

4. *NEW MEXICO - THE RIO GRANDE RIFT*

The Rio Grande Rift (RGR), which cuts through the middle of the state of New Mexico, has been the subject of many scientific studies. The geology, seismicity, faulting, heat flow, gravity, and related features have been intensively studied by geophysical techniques and microearthquake networks especially in the vicinity of Socorro, the location of a subsurface magma body.

For a hazard study the maximum credible earthquake from the region must be estimated along with the likely seismicity distribution with respect to magnitude in the future. For the time period of interest (the next 50 yr) this task is particularly difficult in the region of the Rio Grande Rift because the seismic

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7. Greensfelder, R.W., Kintzer, F.C., and Somerville, M.R. (1980) Seismotectonic regionalization of the Great Basin, and comparison of moment rates computed from Holocene strain and historic seismicity: summary, Geol. Soc. Am. Bull. **91**:518-523.

8. Smith, H.B., and Sbar, M.L. (1974) Contemporary tectonics and seismicity of the Western United States with emphasis on the inter-mountain seismic belt, Geol. Soc. Am. Bull. **72**:1205-1218.

9. Atwater, T. (1970) Implications of plate tectonics for the cenozoic tectonic evolution of western North America, Bulletin GSA, **81**:3513-3536.

activity does not appear to be stationary in time. Historical earthquakes have occurred in swarms and the geologic record suggests the occurrence of earthquakes that have been much larger than those observed in historical times.

4.1 Tectonic History

Rifting in the Rio Grande Rift zone began approximately 30 million yr ago in a pre-existing north-south zone of weakness that had developed during the late Paleozoic and late Cretaceous-early Tertiary orogenies. The main portion of the rift can be divided into three segments.[10] The northern segment, from Leadville to Alamosa, is a north-northwest trend that parallels late Paleozoic grain. Extension, characterized by a broad zone of block faulting, continues northward to the Wyoming border. The central segment, from Alamosa to Socorro, exhibits a north-northeast trending series of en echelon basins separated by transverse structures. The southern segment of the rift, from Socorro to El Paso, exhibits widening at Socorro into a north trending series of basins and ranges. The rift bifurcates near Socorro into the San Augustine rift, which extends southwestward into Arizona, while the RGR continues south to El Paso. A crack, labeled the San Marcial fissure, located approximately 12 miles south of Socorro, formed sometime within the last two years.[11] The fissure, which runs east-west, is 1 mile long and 30 to 50 ft deep in places (the depth is believed to be partially the result of erosion). The mechanism has not been extensively studied but it does demonstrate the presence of unusual activity in this area, however localized it may be. An extensive magma body has been mapped with reflection data at a depth of 19 to 20 km near Socorro. The magma apparently exists as a thin flat sill beneath the central part of the rift.[12] The total uplift of the rift area has been estimated to be 1100 m with a total extension of 100-150 percent.[10] Despite the magnitude of these estimates and the density of Quaternary faulting in the region, at present there seems to be a relatively low level of earthquake activity along the entire Rio Grande Rift. The exception is in areas with recently intruded magma. This observation suggests a low level of present day east-west expansion, and, in fact, geodetic measurements confirm that there is little or no east-west expansion. The normal fault plane

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10. Chapin, C.E. (1979) Evolution of the Rio Grande Rift - a summary, Rio Grande Rift: Tectonics and Magnetism, R.E. Riecker, Ed., AGU, Washington, D.C.

11. Reinke, R., and Stomp, B. (1983) Air Force Weapons Laboratory, Personal Communication.

12. Rinehart, E.J., Sanford, A.R., and Ward, R.M. (1979) Geographic extent and shape of an extensive magma body at mid-crustal depths in the Rio Grande Rift near Socorro, New Mexico, Rio Grande Rift: Tectonics and Magnetism, R.E. Riecker, Ed., AGU, Washington, D.C.

solutions found in the Socorro area[13] may be the result of upwarping of the upper crust because of magma intrusion. The uplifting of the Rio Grande Rift since Miocene times may be the result of a mantle upwelling, similar to the Great Basin model.[10]

4.2 Seismicity

Since the beginning of the historical record (1849), the largest pre-instrumental earthquakes to occur along the Rio Grande Rift (RGR) in the New Mexico area occurred near Socorro. The three largest shocks are listed in Table 2 with magnitude estimates based on the equations of Slemmons[4] for magnitude-versus-felt-area. For the period 1849 to 1961 there have been over 600 earthquakes felt in New Mexico[13] (assuming a "felt" report corresponds to Intensity III, N_c ($M_L \geq 3.3$) = 5.4 per yr); 95 percent of these have occurred along a 150 km section of the RGR from Albuquerque to Socorro. There have been six events of intensity VII or greater; these were also associated with the RGR. One event, of instrumental magnitude 5 1/2 and felt area of 22,000 km^2, occurred off the RGR in the Gila National Forest on 17 September 1938. Since 1938 the largest earthquake to occur in the New Mexico area was the 23 January 1966, Dulce event, m_b = 4.6. This event definitely occurred off the RGR in what is widely accepted to be the Colorado Plateau Province. Studies of this earthquake suggest that the tectonic stress in the area is similar to that in the RGR (east-west).[14]

Table 2. Largest Pre-instrumental Events Along Rio Grande Rift

Date	Max Intensity	*Felt Area (km^2)	Magnitude Estimate
12 July 1906	VII-VIII	125,000	5.3
16 July 1906	VIII	175,000	5.5
15 November 1906	VIII	245,000	5.7

*Values from Sanford et al.[13]

13. Sanford, A.R., Olsen, R.M., and Lawrence, M.J. (1979) Seismicity of the Rio Grande Rift, Rio Grande Rift: Tectonics and Magnetism, R.E. Riecker, Ed., AGU, Washington, D.C.

14. Herrmann, R.B., Dewy, J.W., and Park, S. (1980) The Dulce, New Mexico earthquake of 23 January 1966, BSSA, 70(No. 6):2171-2183.

Microactivity has been well studied in New Mexico. A seismic network in the northern part of the state run by the Los Alamos Scientific Laboratory has been in operation since 1973. With a detection limit of M_L = 1.5 or better, LASL suggested a recurrence formula for a 5-year period in northern New Mexico to be

$$\log_{10} N_c \text{ (5 year)} = -0.76\, M_L + 3.5 \text{ (Wechsler et al}^{15}\text{)} \tag{4a}$$

$$\log_{10} N_c \text{ (annual)} = -0.76\, M_L + 2.8 \quad , \tag{4b}$$

where N_c is the cumulative number of local magnitude M_L and greater. This relation is not inconsistent with the historical record of large shocks,[13] which lists six shocks of magnitude 5 to 6 in 93 yr (annual rate is 0.06/yr) in the area. The M_L's were computed by a coda formula (duration of signal) that was derived by a study of corresponding Wood-Anderson M_L's calculated at seismograph station ALQ.

The seismicity seems to be distributed over a broad zone [see Figure 2(a), a cumulative plot for September 1973 through December 1979]. Some of this is attributable to location errors, however, inspection of the locations for the year 1979 [Figure 2(b)], presumably the best located of the data, still finds events distributed from the east end of the state to the west. The belts of seismicity seen in the 5-yr accumulation are clearer in the 1979 plot, however.

Special studies of the RGR near Socorro have been undertaken by the New Mexico Institute of Mining and Technology. A recent study by Weider, et al[16] utilized an array of high-gain short period seismographs. They detected approximately 1200 microearthquakes during 316 recording days between 1975 and 1978 (1400 per year assuming a random process). From these, 336 hypocenters were obtained, the majority with shallow focus (less than 11 km depth). Composite fault solutions did not necessitate a correspondence with mapped surface fractures. Figure 3 is a map of Quaternary faulting and Plio-Pleistocene volcanoes in New Mexico.

Sanford et al[17] studied a microearthquake swarm that occurred 14 km southwest of Socorro. They detected 60 shocks in three days ranging from M_L of -1 to 2.

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15. Wechsler, D.J., Cash, D.J., Olsen, K.H., McFarland, N.J., and Wolff, J.J. (1980) Earthquake Catalog for Northern New Mexico September 1973-December 1979, LA 8579-PR LASL.

16. Weider, D.P., Sanford, A.R., and Carpenter, P.J. (1983) Nature of contemporary faulting in the Rio Grande Rift near Socorro, New Mexico, Abstract, Earthquake Notes, 54(No. 1).

17. Sanford, A.R., Carpenter, P.J., and Rinehart, E.J. (1983) Characteristics of a microearthquake swarm in the Rio Grande Rift near Socorro, New Mexico, Abstract, Earthquake Notes, 54(No. 1).

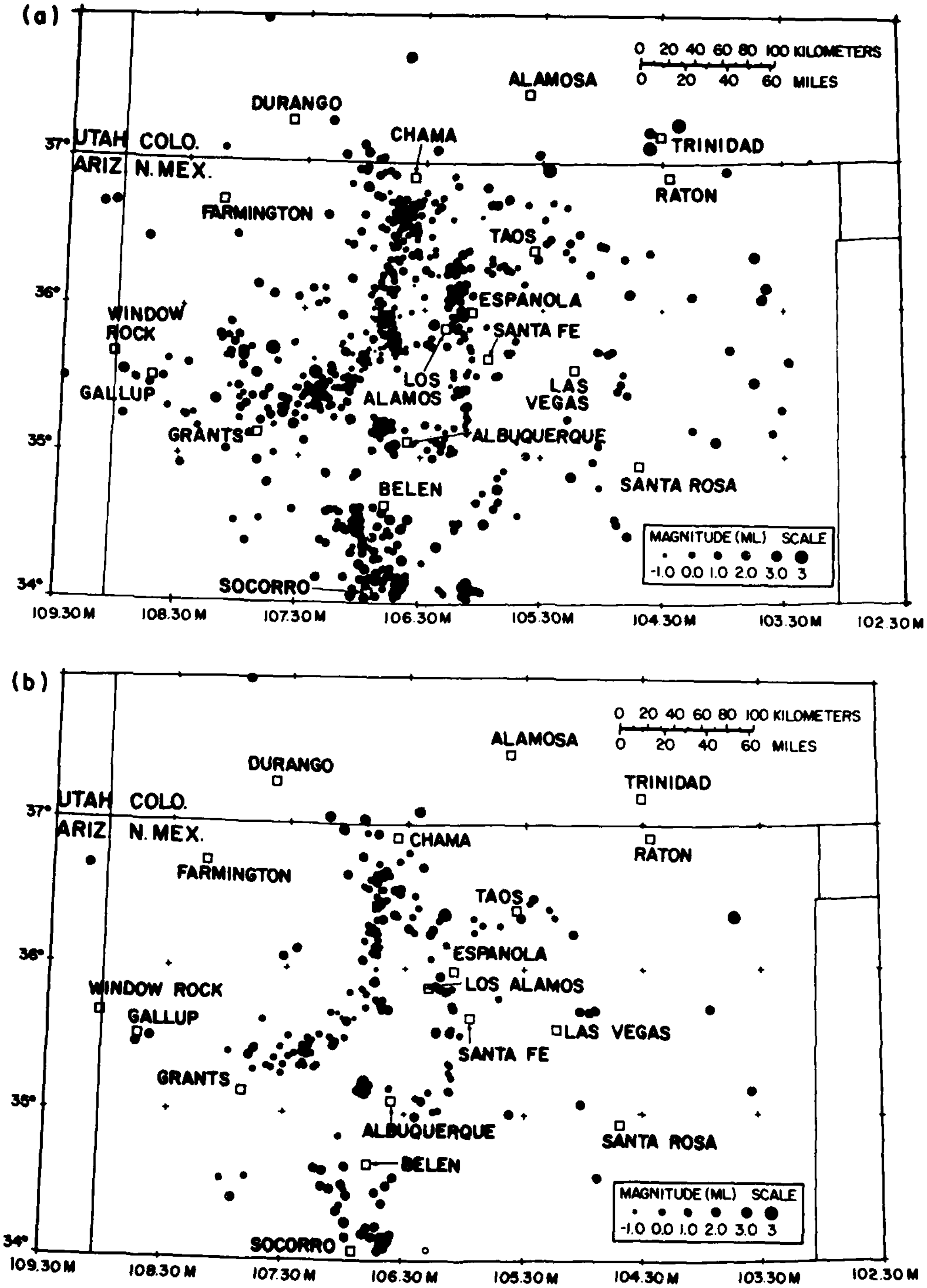

Figure 2. Microactivity of Northern New Mexico as Recorded by the LASL Net: (a) September 1973-December 1979 and (b) Only 1979

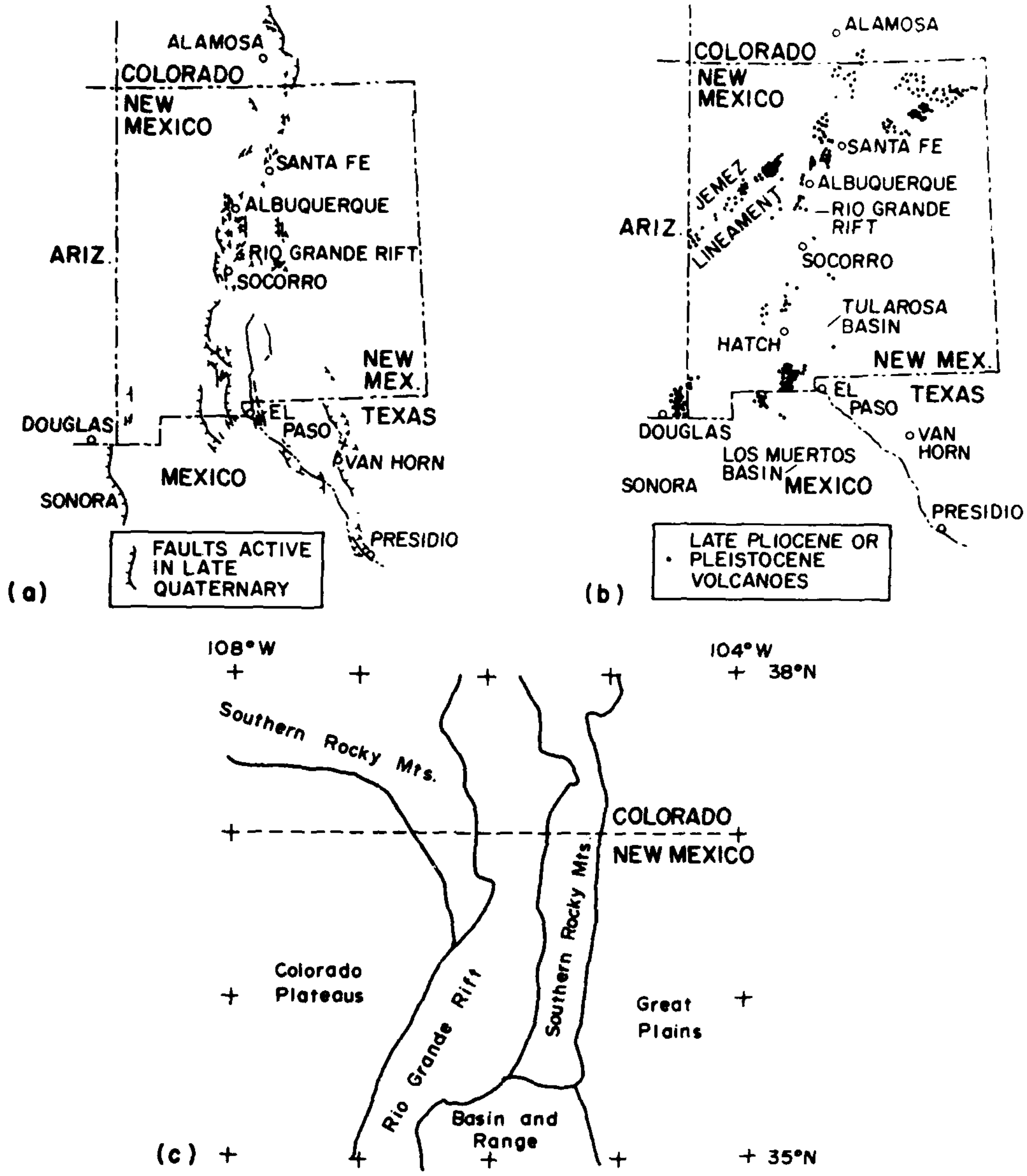

Figure 3. New Mexico - (a) Quaternary Faulting, (b) Plio-Pleistocene Volcanoes (Seager and Morgan[18]), and (c) Physiographic Provinces (After Herrmann et al[14])

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18. Seager, W.R., and Morgan, P. (1979) Rio Grande Rift in southern New Mexico, West Texas and northern Chihuahua, in Rio Grande Rift: Tectonics and Magnetism, R.E. Riecker, Ed., AGU, Washington, D.C.

To summarize, the RGR in New Mexico is fairly active on the microearthquake scale. This is to be predicted given the hot, volcanic tectonic environment. Such areas of recent magmatic intrusion are historically not prone to the largest of earthquakes because faulting is generally confined to shallow depths. Also, as well defined a zone as the RGR is, it is definitely not a major plate boundary and therefore does not have the potential for numerous large events such as are found along the San Andreas fault in California.

4.3 New Mexico Hazard

4.3.1 PROBABILISTIC CALCULATION

In the hazard study, a homogeneous treatment of the seismicity in New Mexico is considered. The broad pattern of seismicity is modeled with a zone encompassing the length of the RGR and the width of the state. "Seismic gaps" observed along the RGR are ignored for the sake of conservatism. This model is conservative because it assumes that the level of activity observed in some areas along the RGR can occur anywhere along its length. There have been belts observed with a finer structure [Figure 2(a)], however, the seismic pattern is diffuse throughout the state and, pending better definition of the seismic belts, does not warrant a more complex model. The southern extension of the RGR zone is taken from the analysis of Seager and Morgan,[18] shown in Figure 4.

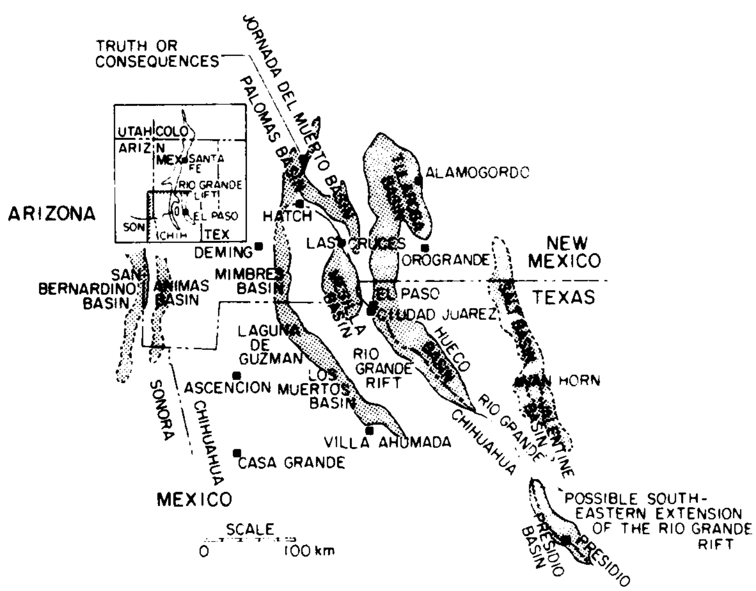

Figure 4. Southern Extent of the Rio Grande Rift
(From Seager and Morgan[18])

Separate zones are not created for the Socorro area or other "hot spots", although the high rate of microactivity and the many larger events occurring there are probably tied to the intrusive magma structure and are not free to migrate along the RGR.

A limitation of this study should be emphasized, which is the non-Poisson distribution of the activity along the RGR. Any probabilistic hazard assessment presents expected exceedance levels based on an average of past seismicity. Since much of the New Mexico activity occurs in swarms (decidedly not a Poisson process as assumed in the calculations), it would be expected to continue in swarms in the future. In a swarm year the annual risk of exceedance would be higher than in a non-swarm year. A more applicable set of statistics could be applied, incorporating a swarm model. However, because of time constraints and in the interests of integrating the effects of non-swarm seismicity off the RGR at the sites of interest, a Poisson occurrence is modeled. That is, the occurrence goes as $1\text{-}e^{(\text{expected number})}$. This would widen the bounds of the data, because a Poisson distribution is more random than the real scenario, a fact to be recognized when examining the percentile exceedances above the median.

Table 3 lists the seismicity parameters used as input to the program (zone, area, recurrence estimate, cutoff magnitude, etc.). Because of the high attenuation, hazard was calculated only from a distance of 500 km. Beyond that distance the frequency and duration of the ground motion contributing to the hazard are so different that they should not be added to the closer-in data.

Table 3. Seismic Hazard Input Parameters - New Mexico

Source Zone	Area $(km)^2$	Log N_c^* = A - B M_L A	B	Min M_L	Max M_L	Return Period of M_L Max (years)
TZ	6.15×10^7	2.2	0.7	4.0	6.5	223
RGR	7.38×10^5	3.7	0.8	4.0	7.0	79
B7	1.86×10^5	4.2	1.0	4.0	6.75	354
WFA	6.56×10^4	3.3	0.8	4.0	7.0	200
WFB	1.29×10^5	2.3	0.5	4.0	7.75	38
CP	3.5×10^5	4.2	1.0	4.0	7.0	630

*N_c = cumulative number of events per annum of magnitude greater than or equal to M_L for each source zone (not normalized to area).

In summary, more complex zoning is not warranted by the data. Despite the obvious division into neighboring physiographic provinces, Sanford et al[13] found the seismicity along the RGR structure during an 11-yr period was no greater. How soon an episodic outbreak of activity will occur is not incorporated in the hazard calculation. In short, the activity rate in this part of the United States is not high compared to areas like California where a major tectonic plate boundary is present. The method works best when high levels of activity are present and form well-defined source zones.

The attenuation relationships used are from Battis[1] (Table 4a) and conversions from intensity and m_b to M_L are from special regional studies by Brazee[19] (Table 4b). The upper limit cutoff magnitude used for our RGR New Mexico zone is an $M_L = 7.0$, which is at least one magnitude unit higher than any historical event. Earthquakes will be sampled out to 500 km from each site and events down to $M_L = 4.0$ will be considered. At this distance the attenuation relationship gives negligible (~ 0.02 g) acceleration from the maximum magnitude event.

Table 4a. Peak Ground Motion Attenuation Function Parameters (Battis[1])

$g = a_1 e^{a_2 M}(R + a_3)^{-a_4}$					
Ground Motion	a_1	a_2	a_3	a_4	σ
Acceleration (cm/sec^2)	1602.0	0.908	25.0	2.076	0.707
Velocity (cm/sec)	5.64	0.921	25.0	1.20	0.629
Displacement (cm)	0.393	0.990	25.0	0.88	0.76

Table 4b. Magnitude Conversions (Brazee[19])

$m_b = 1.276 + .749\ M_L$
$m_b = 2.666 + .385\ I_o$

19. Brazee, R.J. (1976) An Analysis of Earthquake Intensities With Respect to Attenuation, Magnitude and Rate of Recurrence, Final Report, NOAA Technical Memorandum EDS NGSDC-2.

Several sources for determining the recurrence parameters for the RGR zone were examined:

(a) Normalization of the microearthquake recurrence rate found by Wechsler[15] over a 5-year period to the entire area of the RGR source zone. The resultant curve lies between $\log N_c = 3.34 - 0.76\ M_L$ and $\log N_c = 3.4 - 0.76\ M_L$, depending on what is taken to be the area completely sampled by the network.

(b) Search of the PDE (Preliminary Determination of Epicenters) file of the NOAA Earthquake Data File Summary over the entire zone. The result for the last 20 years, with all events converted to M_L and fit between magnitude 4.0 and 6.0, gives $\log N_c = 5.086 - 1.09\ M_L$.

(c) The historical record of large shocks for New Mexico from Von Hake.[20] Normalized result: approximately $N_c\ (M \geq 5.5) = 0.12$ per year.

(d) The historical record of events felt in New Mexico as listed by Sanford et al[13] for 112 years. This yields $N_c\ (M_L \geq 3.3) = 9.3$ per year, normalized over the area of the zone, assuming "felt" denotes M M I ≥ III.

It was found that both the microearthquake derived recurrence model (source a) and the 20-yr search of the PDE (source b) were consistent with the historical record of large shocks (M_L 5 to 6). However, the model from 20 yr of PDE data over-predicts the number of small earthquakes relative to "felt" reports (source d) over the last century and to the microearthquake network data taken over the course of 5 years (source a). There can be several reasons for this discrepancy. The slope determined from the PDE catalog based on a fit between $M_L = 4$ and $M_L = 6.0$ may not be a valid extrapolation to much smaller events. Historical felt reports are most certainly incomplete at the low magnitudes because of uneven population distribution and poor reporting. "Felt" reports might correspond to larger intensity events. The level of microactivity is probably not constant. Since the pattern of historical seismicity exhibits temporal swarming, that is, is not stable in time, the 5 yr sampled by the network may not be representative of the long term. The final model used in this study for the RGR zone ties the recurrence relation to the large-shock recurrence rate and takes a slope that is halfway between the microearthquake study and the PDE slope to approximate the smaller magnitude event recurrence.

This discussion assumes that the microactivity and the larger size shocks share the same causative mechanism. This is not necessarily true. The microactivity may be the result of local magma movement while the larger events may be the expression of active rifting. The recurrence relation used in this study

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20. Von Hake, C.A. (1975) Earthquake history of New Mexico, Earthquake Information Bulletin, 7(No. 3).

for the RGR zone was obtained by fixing the point at the magnitude 6.0 and greater to be 0.10 per year in the zone (agreement with sources a, b, and c) and at 3.6 at magnitude 4 and greater (average of sources a and b). The final relation is $\log N_c = 3.68 - 7.8\ M_L$.

The recurrence relation for the Texas zone was calculated from events listed in the PDE as compiled by the NOAA Earthquake Data File Summary. Twenty years of data were converted to M_L by the relations derived for the western U.S. by Brazee.[19] A fit was performed between $M_L = 4$ to 6 and checked against the historical record of magnitude 5's and 6's as listed by Von Hake[21] for Texas east of 103° W, normalized for the area encompassed by the entire Texas zone, which includes some of Oklahoma and Kansas. The recurrence for the CP (Colorado Plateau) and WF (Wasatch Front) zones were taken from a special study by Battis[1] (his zones 5, 7, 6A and 6B; zones 7 and 5 boundaries were modified). A map of the area with source zone boundaries with PDE epicenters superimposed is shown in Figure 5. Epicenters from various historical catalogs as listed in the NOAA tape have been added to the state of New Mexico in this map.

Results of the hazard calculation (Tables 5a, b, c; Figure 6) show that, as could be predicted, Roswell and Albuquerque have higher risk than Clovis. This is because they are closer to the RGR, which has a higher level of seismicity than the Texas zone (see map, Figure 5). Since the seismicity model is basically linear in the north-south direction, points along lines of longitude in New Mexico can be expected to have similar hazard in this model.

Design response spectra corresponding to the 90 percent confidence level, 10-yr lifetimes, (100-yr return period) and 20-yr lifetimes (200-yr return period) have been generated utilizing the amplification factors of Newmark et al[22] for various critical damping ratios (Table 6). The different damping ratios should be used according to the stiffness of the soil and the type of structure (generally the appropriate damping is selected by a civil engineer). None of the computed peak ground motions have been corrected for soil amplification effects, that is, they are estimates of ground shaking on rock. Figures 7a and b are spectra generated for Albuquerque and are valid for Roswell, N. Mex., since the values are so close. Figures 7c and d are for Clovis, N. Mex. The anchoring values are determined by the equation

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21. Von Hake, C.A. (1977) Earthquake history of Texas, Earthquake Information Bulletin, 9(No. 3).

22. Newmark, N.M., Blume, J.A., and Kapur, K.K. (1973) Design Response Spectra for Nuclear Power Plants, Am. Soc. Civil Eng., Structural Eng. Meeting, San Francisco, California.

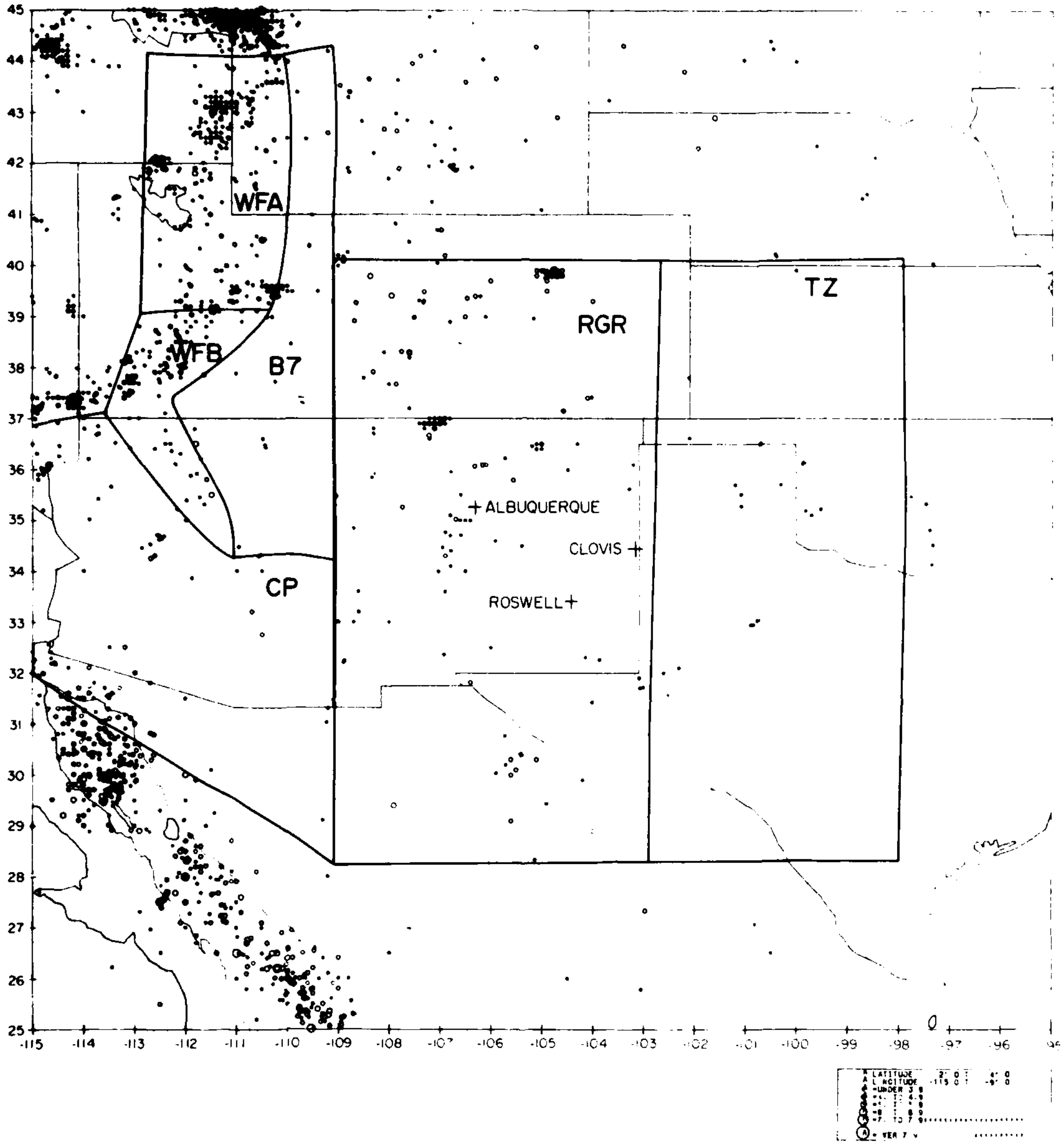


Figure 5. Map of State Boundaries, Source Zone Boundaries and PDE File Epicenters. Historical (pre-instrumental) events from other catalogs listed on NOAA tapes have been added to New Mexico interior only

Table 5a. Peak Ground Motion for Albuquerque, N. Mex.

Annual Risk	Return Period (yr)	Accel (cm/sec^2)	Vel (cm/sec)	Disp (cm)
0.5	2	6.7	1.2	.7
0.2	5	12.1	2.0	1.3
0.1	10	17.7	2.8	1.8
0.05	20	25.3	4.0	2.5
0.02	50	39.9	6.1	3.7
0.01	100	55.7	7.9	5.0
0.005	200	77.3	10.9	6.6
0.002	500	117.6	15.6	9.0
0.001	1,000	159.1	20.1	11.9
0.0001	10,000	399.7	43.3	24.8
90% confidence level in 10 years		55.7	7.9	5.0
90% confidence level in 20 years		77.3	10.9	6.6

Table 5b. Peak Ground Motion for Roswell, N. Mex.

Annual Risk	Return Period (yr)	Accel (cm/sec^2)	Vel (cm/sec)	Disp (cm)
0.5	2	6.7	1.1	0.6
0.2	5	12.1	2.0	1.2
0.1	10	17.6	2.8	1.7
0.05	20	25.1	3.9	2.3
0.02	50	39.6	5.9	3.6
0.01	100	55.3	7.7	4.8
0.005	200	76.9	10.8	6.4
0.002	500	116.9	15.5	8.8
0.001	1,000	158.1	20.0	11.6
0.0001	10,000	396.8	43.1	24.6
90% confidence level in 10 years		55.3	7.7	4.8
90% confidence level in 20 years		76.9	10.8	6.4

Table 5c. Peak Ground Motion for Clovis, N. Mex.

Annual Risk	Return Period (yr)	Accel (cm/sec^2)	Vel (cm/sec)	Disp (cm)
0.5	2	4.8	0.9	0.5
0.2	5	10.4	1.7	1.1
0.1	10	15.2	2.4	1.5
0.05	20	21.7	3.3	2.1
0.02	50	34.4	5.1	3.1
0.01	100	48.3	7.0	4.2
0.005	200	67.4	9.3	5.6
0.002	500	103.2	13.5	7.7
0.001	1,000	140.8	17.7	10.3
0.0001	10,000	361.1	39.2	22.1
90% confidence level in 10 years		48.3	7.0	4.2
90% confidence level in 20 years		67.4	9.3	5.6

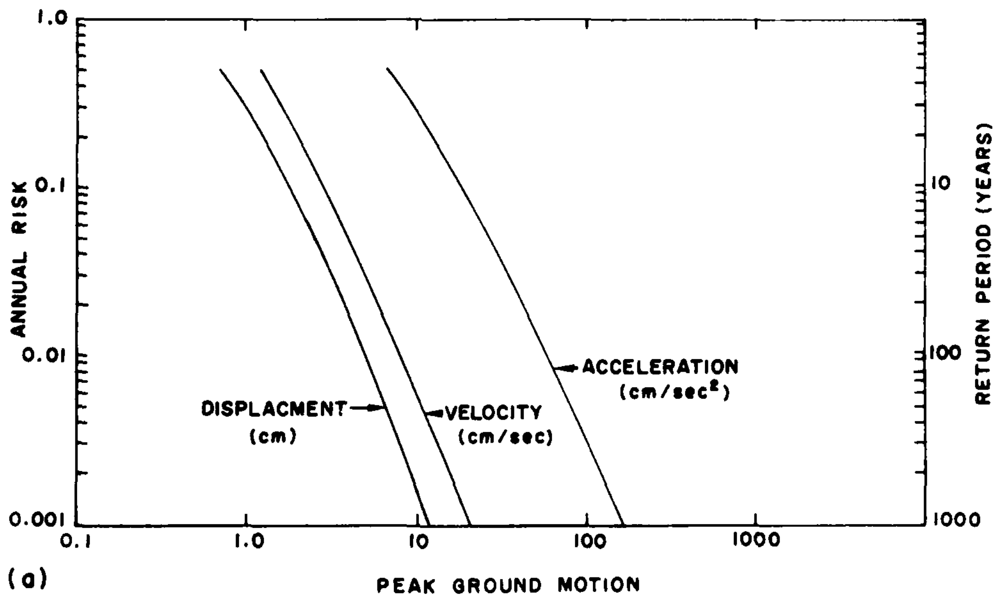


Figure 6a. Annual Seismic Risk for Albuquerque

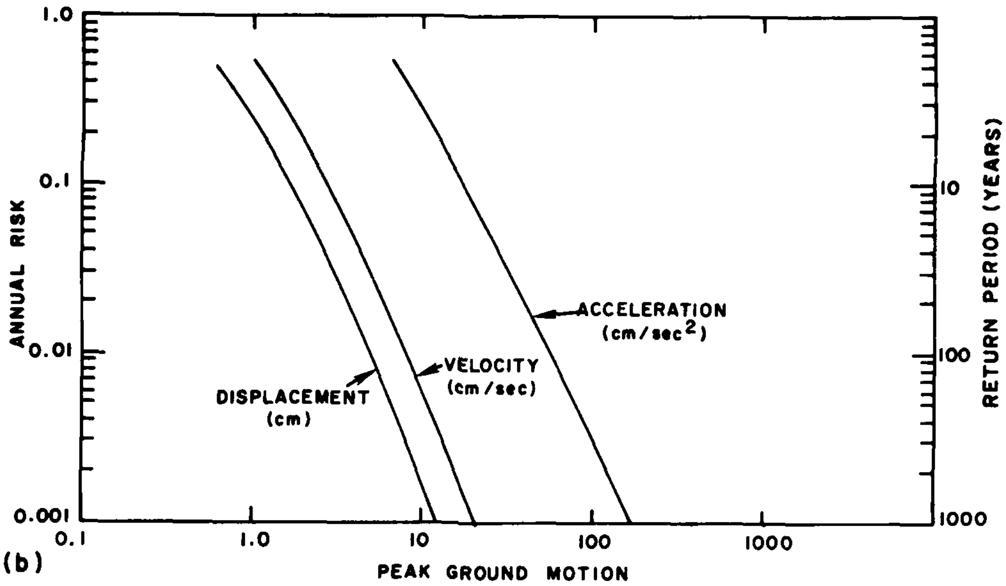


Figure 6b. Annual Seismic Risk for Roswell

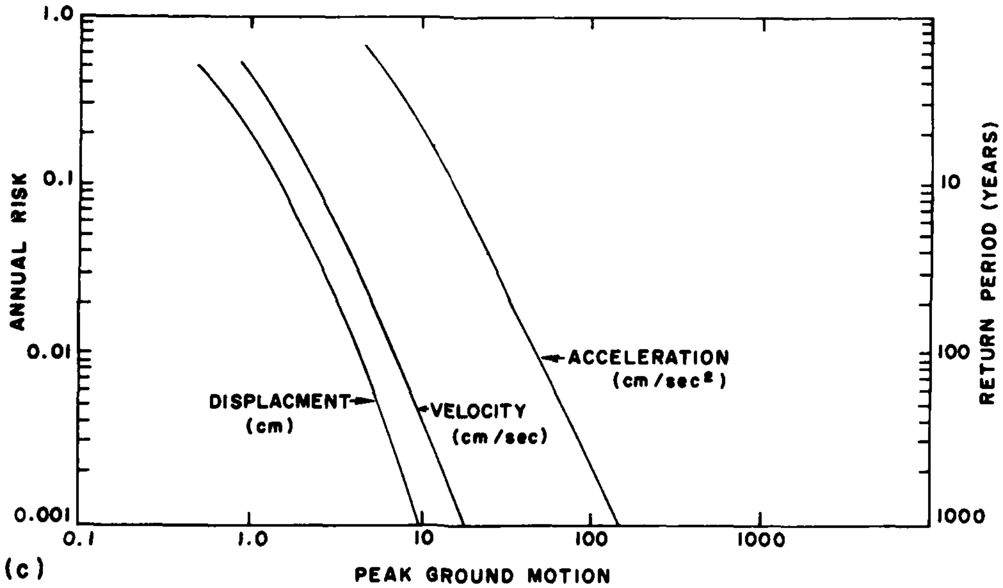


Figure 6c. Annual Seismic Risk for Clovis

Table 6. Horizontal Design Response Spectra Amplification Factors

Critical Damping %	Acceleration			Displacement (cm)
	33 Hz	9 Hz	2.5 Hz	0.26 Hz
0.5	1.0	4.96	5.95	3.20
2.0	1.0	3.54	4.25	2.50
5.0	1.0	2.61	3.13	2.05
7.0	1.0	2.27	2.72	1.88
10.0	1.0	1.90	2.28	1.70

$$R_N = 1 - (1 - R_A)^N \quad , \qquad (5)$$

where N is the time period desired (usually the estimated useful lifetime of the structure in question), R_N is the risk that corresponds to the chosen confidence level (for 90 percent confidence, $R_N = 0.1$), and R_A is the annual risk. The results confirm the expected: the two sites nearest the RGR (Albuquerque and Roswell) have the higher hazard while the site farthest from the RGR is lower (Clovis). The difference is enhanced in the deterministic calculation.

4.3.2 DETERMINISTIC CALCULATION

Deterministically, the largest event reasonably expected to occur in the lifetime of a contemporary structure in New Mexico would be a magnitude $(M_L) = 6.0$. If this occurred "at the site", say at a distance of 15 km, the attenuation relation gives the maximum acceleration to be 175 gals, approximately 0.18 gravity. The probability of such an event occurring within 15 km of a given particular site is even smaller than the annual recurrence rate for a magnitude 6.0 for that zone. It can be estimated by the ratio of the area of the epicentral region susceptible to that acceleration level to the local area for which the annual recurrence was computed.

For the probabilistic hazard assessment, an absolute cutoff magnitude (associated with the "maximum credible event") is chosen to be an $M_L = 7.0$, for the RGR zone. This is approximately 10 times the amplitude of the maximum ground motion experienced by the sites in almost 100 yr. The chosen attenuation relationships yield peak ground motion values of 436 gals, 43 cm/sec, and 16 cm for a distance of 15 km. Standardized spectra are shown in Figure 8. This event, one should note, is highly improbable. Here we have assumed basically that the event is "at the site" by attenuating it by only 15 km.

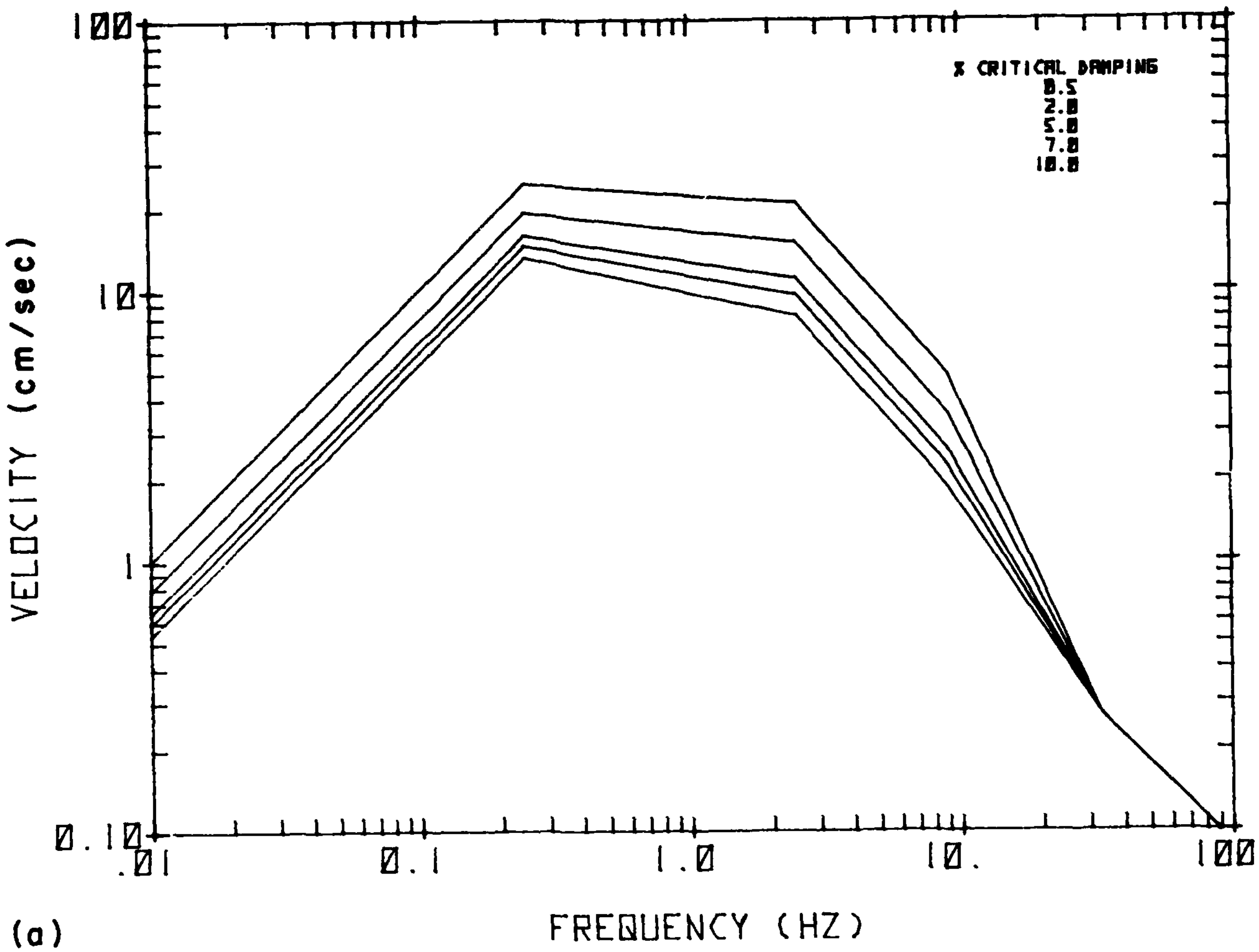


Figure 7a. 90 Percent Confidence Level Spectra for Albuquerque (and Roswell), 10-Year Lifetime

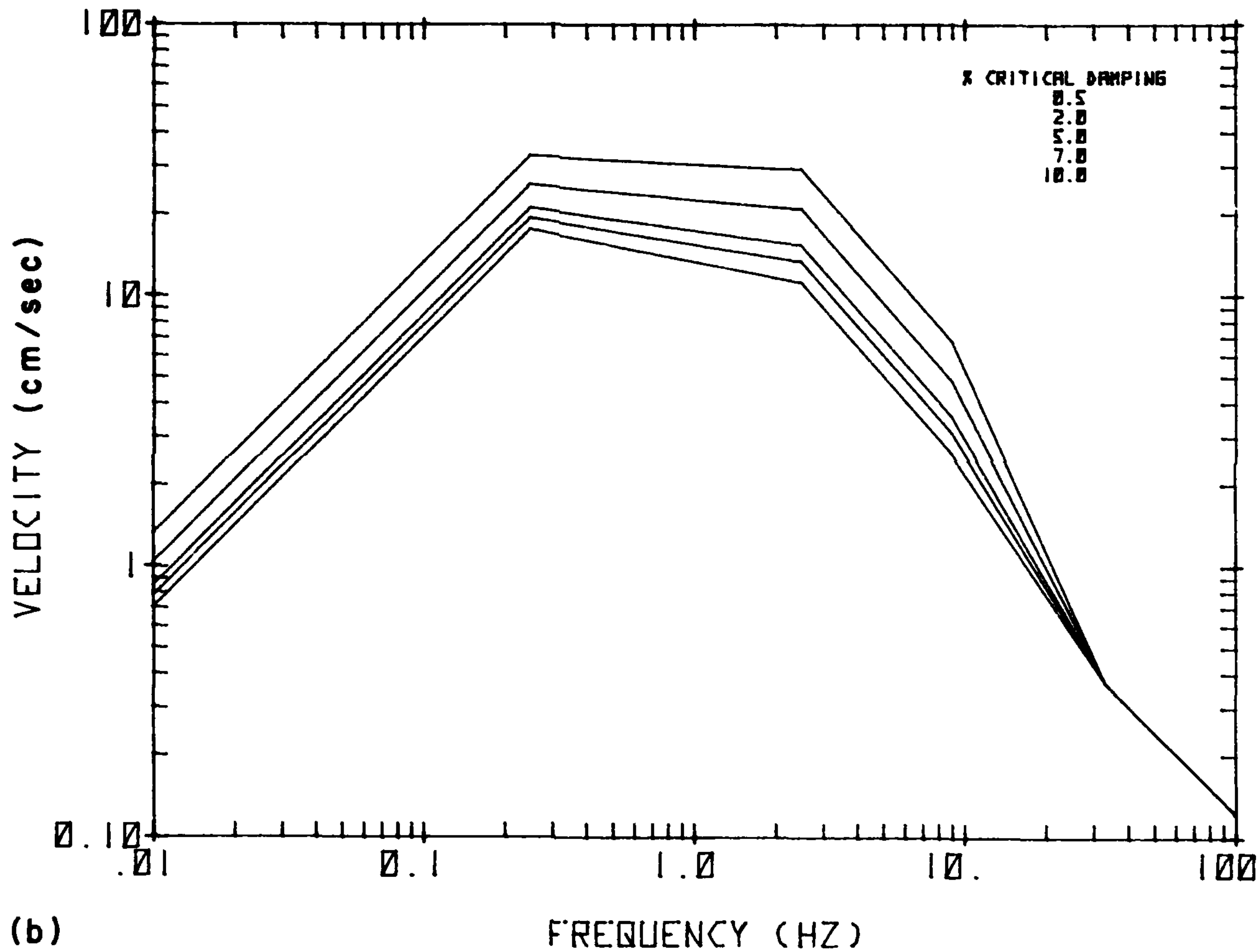


Figure 7b. 90 Percent Confidence Level Spectra for Albuquerque (and Roswell), 20-Year Lifetime

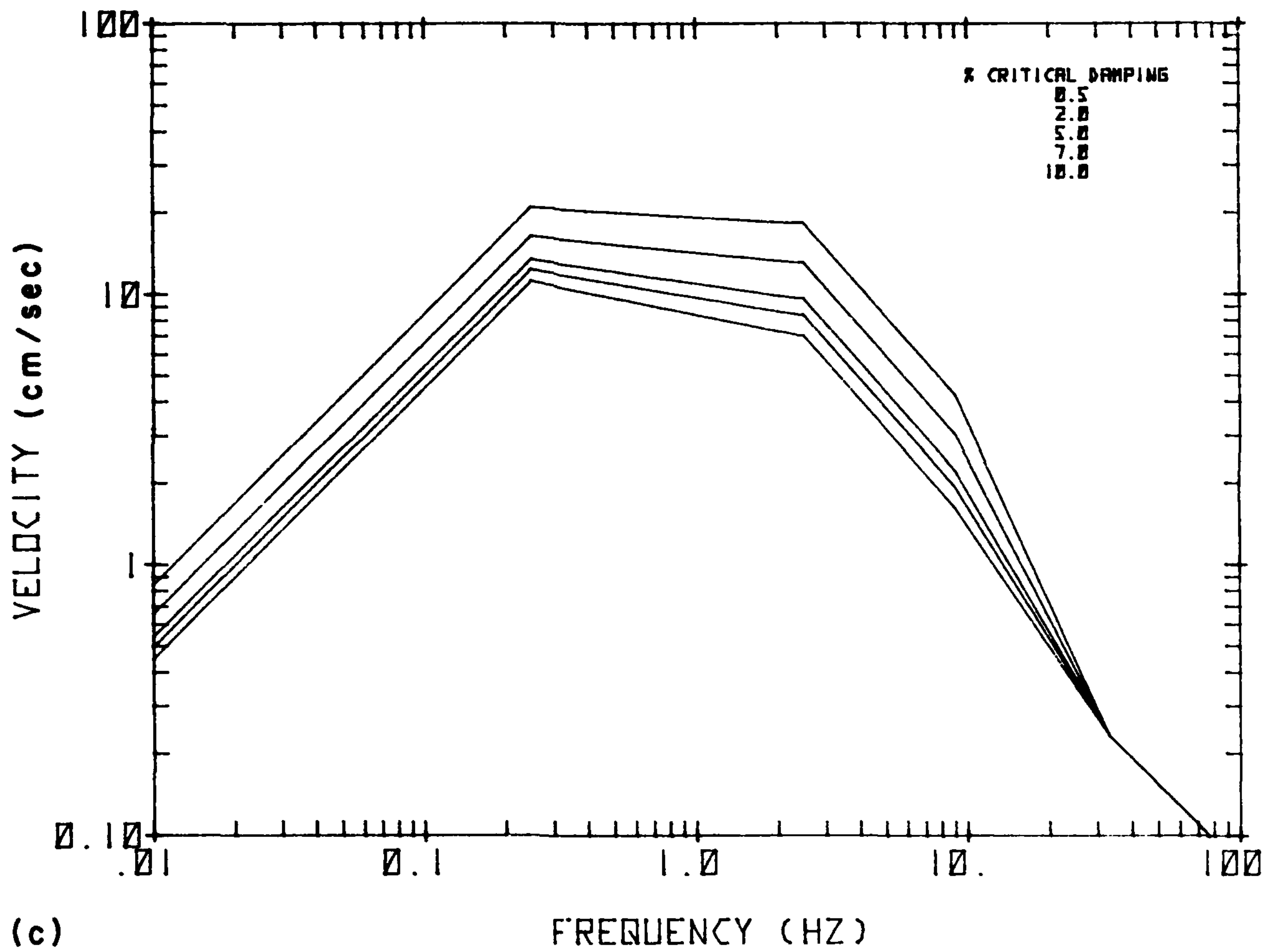


Figure 7c. 90 Percent Confidence Level Spectra for Clovis, 10-Year Lifetime

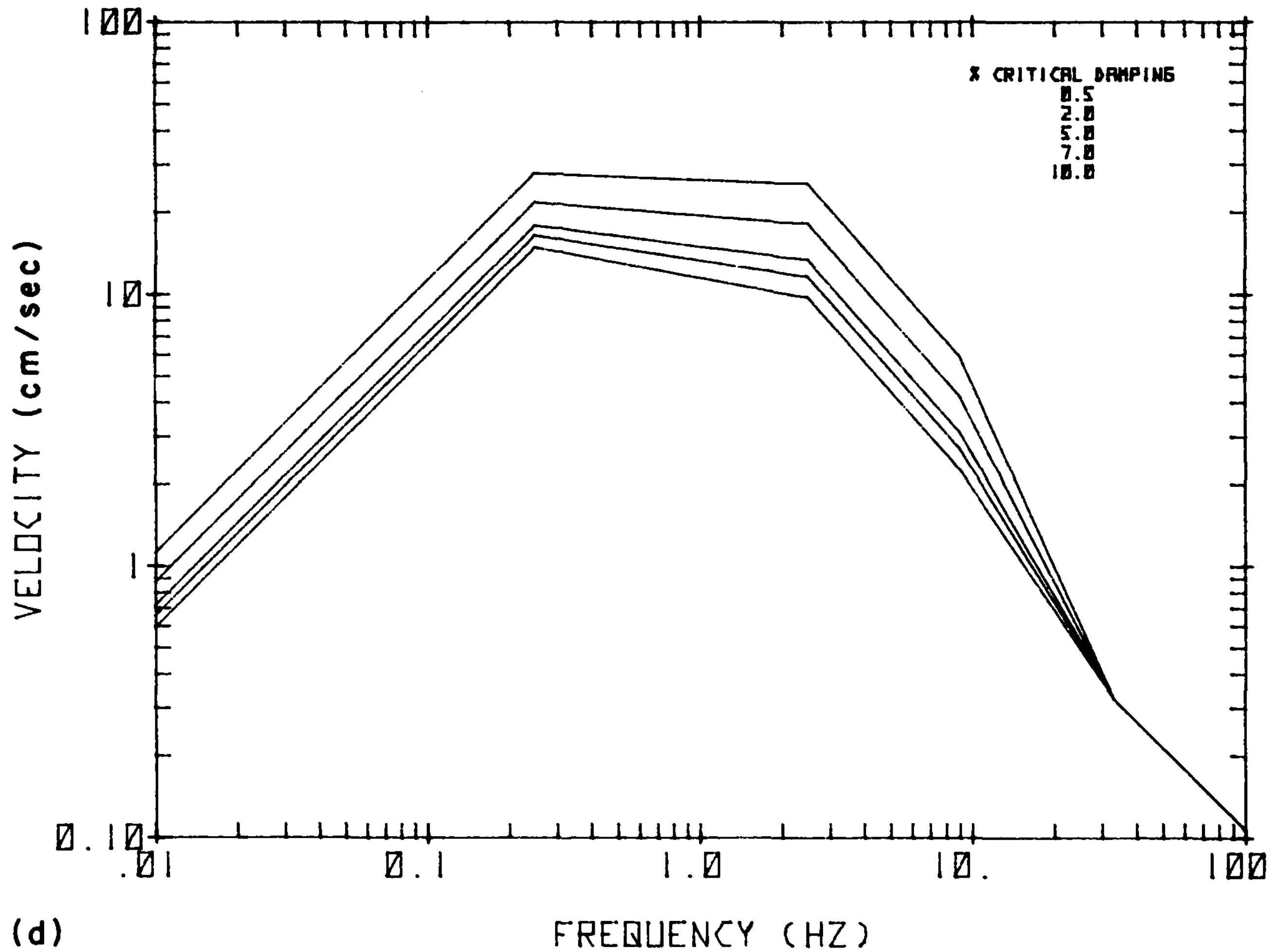


Figure 7d. 90 Percent Confidence Level Spectra for Clovis, 20-Year Lifetime

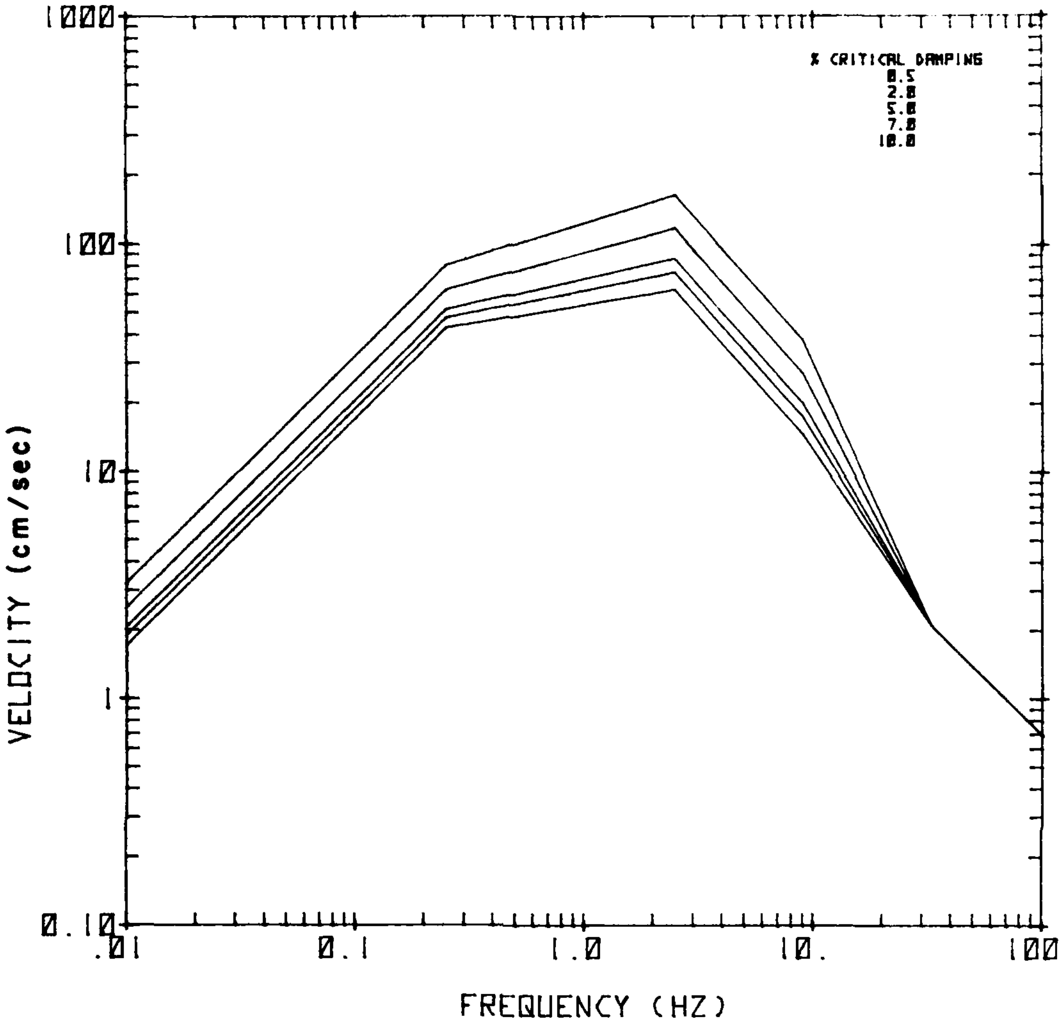


Figure 8. Standardized Response Spectra for Maximum Credible Event for Albuquerque and Roswell

Although Clovis was inside the RGR zone boundary for the probabilistic assessment, it is quite far away from the RGR, the nearest source of high activity. For this site, a magnitude 6.5 at 15 km is modeled for the deterministic spectrum (276 gals, 27 cm/sec, and 10 cm) and presented in Figure 9. This is not the usual definition for a deterministic spectrum, because no fault known to be capable of generating such an event is modeled to be within 15 km of the site.

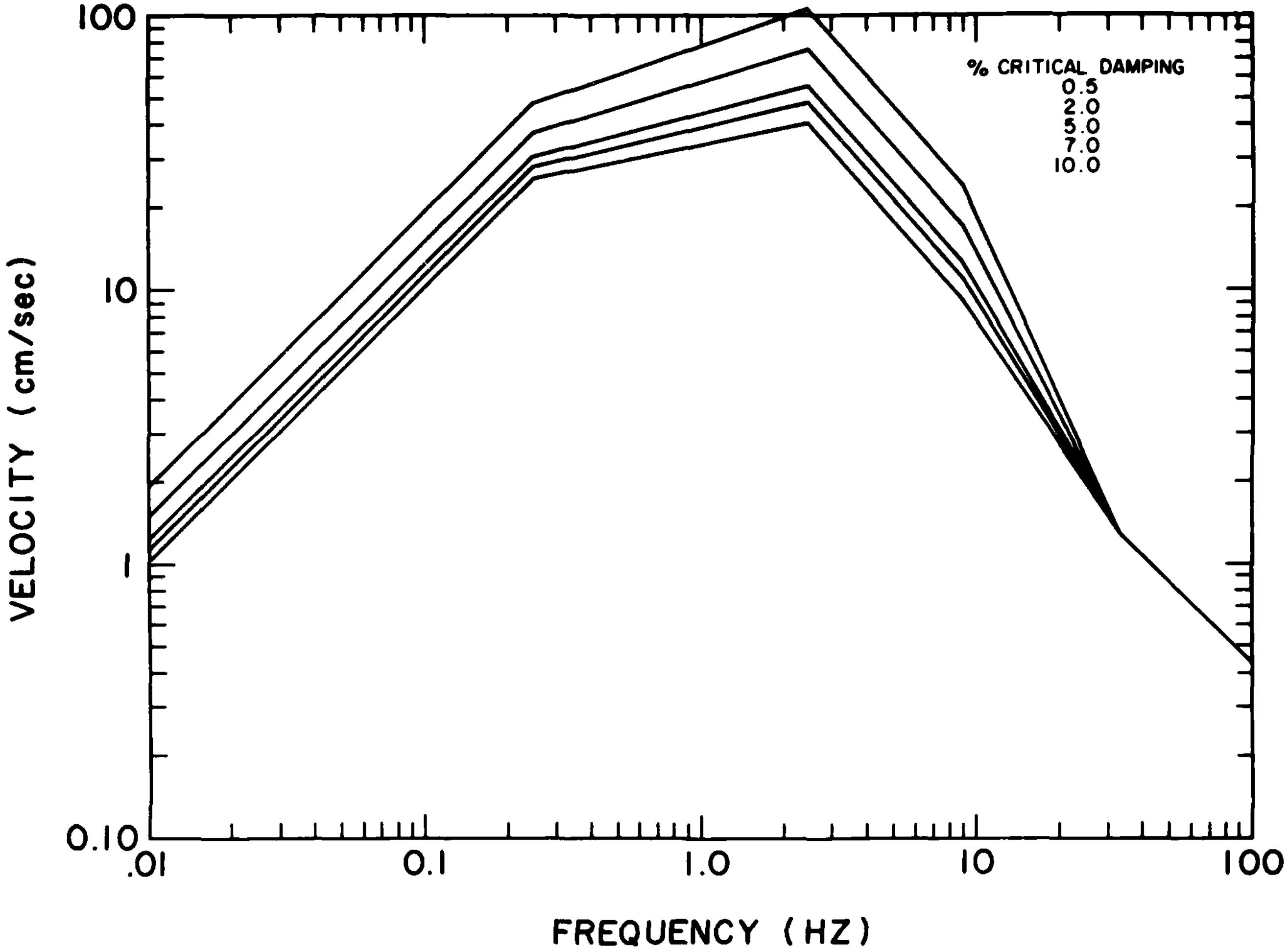


Figure 9. Standardized Response Spectra fo: Maximum Credible Event for Clovis

4.4 Discussion of Hazard for Sites in New Mexico

Since the pattern of seismicity in the area is essentially linear, the model for New Mexico resulted in the level of hazard being a function of east-west distance from the RGR. Even at that a rather wide zone for the RGR was chosen (the entire width of the state) because the pattern of the epicenters is diffuse and subdivision of this zone into finer detail lacks statistical significance. With further study of the area by local networks it may be possible to pin down activity concentrations to mapped geological features, which would make a new model appropriate. To date such correspondence has not been found. If such a new model should emerge, it would likely lead to reduced hazard values in general for regions off the RGR immediate area (± 10 km), such as Clovis, but could conceivably raise the relative hazard at areas (hot spots) along the zone. This raised relative hazard should not exceed the values presented for the Albuquerque and Roswell sites for either the probabilistic estimate or the deterministic spectra presented in this report.

5. NEVADA

5.1 Tectonic Structures

Physiographically, most of Nevada occupies the Basin and Range Province (Figure 10). Some of the northern part of the state lies within the Snake River Plain. The underlying cause for the formation of the basin and range topography is debated; however, sources tend to agree an estimated extension through normal faulting during the past 17 million yr to lie between 50 and 100 km.[7] There are several important structural features in the area (Figure 11). Nevada is quite close to the San Andreas fault zone, which is a major tectonic plate boundary that exhibits strike-slip motion at an average rate of several cm per year. There is a major change in basin-range relief at approximately latitude 37^{o}N; south of this it is hypothesized that Pliocene and Quaternary extension has been smaller than in the north. Such changes in relief are the primary consideration in the zonation scheme of Greensfelder et al[7] shown in Figure 12. In this figure the Basin and Range zone is bounded on the west by Walker Lane and the Death Valley - Furnace Creek fault zone and to the east by the Wasatch Front. Also shown in this figure is the sense of strike-slip motion where applicable. Within

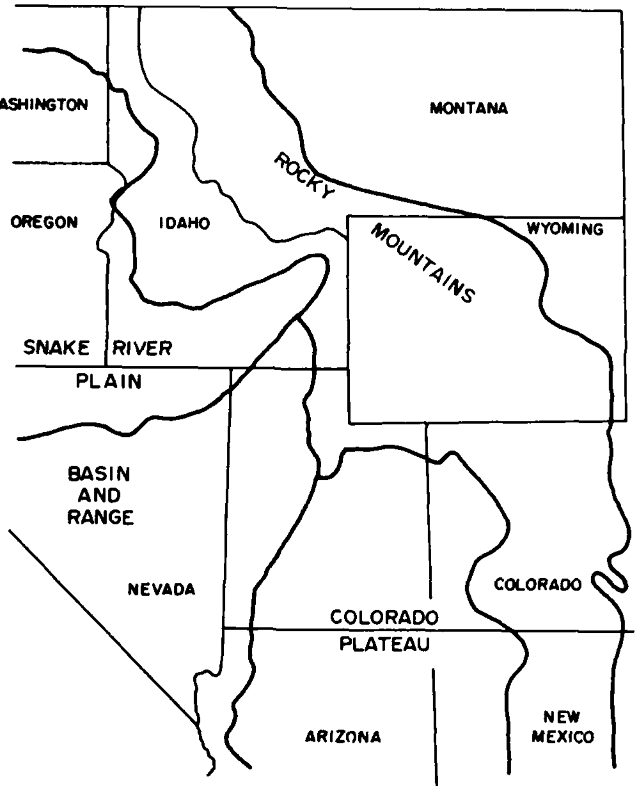


Figure 10. Physiographic Provinces of Western U.S. (Modified from Smith and Sbar[8])

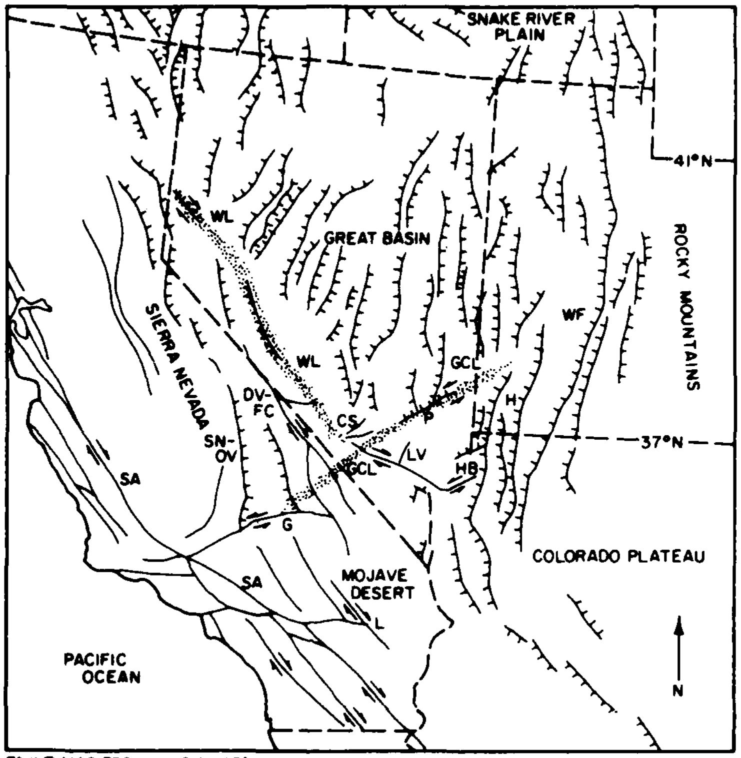
most of the Nevada region, faults considered to be active on the basis of geological evidence are evenly distributed.[23]

5.2 Seismicity

The state of Nevada is among the most seismically active in the United States. In the historical record, which covers approximately 125 yr, nearly 2,000 earthquakes have been catalogued.[24] In the western part of the state, where most of the major historical events occurred, three of these were labeled as intensity X. This intensity denotes destruction of masonry and frame structures along with foundations, cracks in the ground, and possibly landslides.

23. Ryall, A. (1977) Earthquake hazard in the Nevada region, Bull. Seismol. Soc. Am. 67:517-538.

24. Von Hake, C.A. (1974) Earthquake history of Nevada, Earthquake Information Bulletin, 6(No. 6).



FAULT MAP FROM KING (1967) WITH MODIFICATIONS AFTER STEWART (1978).

MAJOR BASIN AND RANGE FAULT
HACHURES ON DOWN-THROWN SIDE

STRIKE-SLIP FAULT-ARROWS INDICATE RELATIVE MOVEMENT

GARLOCK-CALIENTE LINEAMENT AND WALKER LANE OBSERVED ON ERTS-I SATELLITE IMAGERY, SCALE 1:5,000,000 (USDA SOIL CONSERVATION SERVICE, 1974)

NOTE

CS=CANE SPRING FAULT AND RELATED FAULTS
DV-FC=DEATH VALLEY-FURNACE CREEK FAULT ZONE
G=GARLOCK FAULT
HB=HAMBLIN BAY FAULT
H=HURRICANE FAULT
L=LUDLOW FAULT
LV=LAS VEGAS SHEAR ZONE
P=PAHRANAGAT SHEAR ZONE
SA=SAN ANDREAS FAULT
SN-OV=SIERRA NEVADA-OWENS VALLEY FRONTAL FAULT
WF=WASATCH FRONTAL FAULTS
WL=WALKER LANE (STIPPLED)
GCL=GARLOCK-CALIENTE LINEAMENT (STIPPLED)

SCALE
0 100 200 MILES
0 100 200 300 400km

Figure 11. Structural Features of Western U.S. (Greensfelder et al[7])

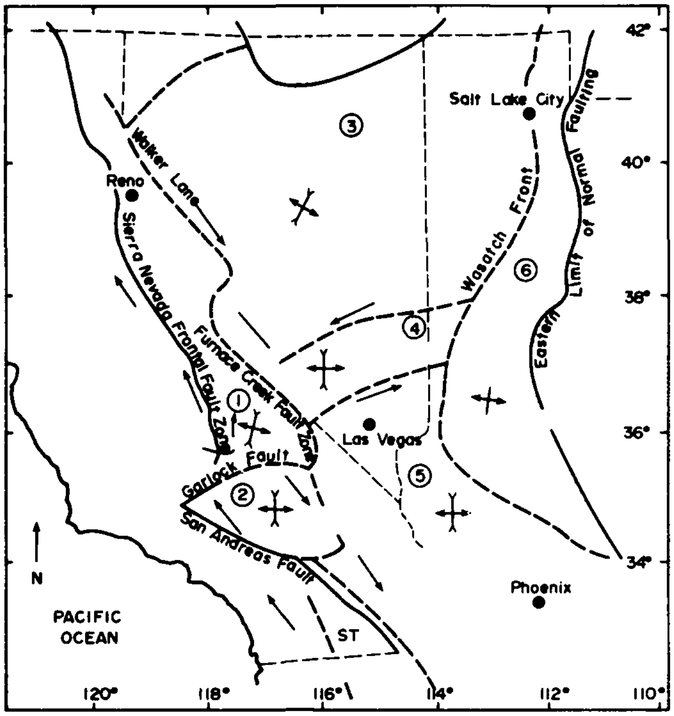


Figure 12. Zonation Scheme of Western U.S. (Greensfelder et al[7])

There have been numerous studies of Great Basin seismicity. A study by Ryall and VanWormer[25] summarizes some of the proposed recurrence estimates (see Table 7). Since about 1840 five great earthquakes (magnitudes greater than or equal to 7) have occurred in the western Basin and Range Province (Figure 13). They are the 1845 Stillwater, 26 March 1872, Owens Valley, California (M ≈ 8), 2 October 1915, Pleasant Valley (M = 7.6), 20 December 1932, Cedar Mountains (M = 7.3), 16 December 1954, Dixie Valley and Fairview Peak (M's = 6.8, 7.3).[23] These historical data yield a short return period for very large events (less than 30 yr).

In contrast, the lower Snake River Plain to the north exhibits much lower seismic activity. Southern Idaho and Oregon do not share the high hazard regime with their neighboring states to the north and east (Washington and Utah). The largest concentration of activity in historic times (since approximately 1884 in Idaho), below 45° latitude, occurred at about 115° and west (see Figure 14) in

25. Ryall, A., and VanWormer, J.D. (1980) Estimation of maximum magnitude and recommended seismic zone changes in the western Great Basin, Bull. Seismol. Soc. Am. 70:1573-1581.

Table 7. Rerupture Times for Faults in the Great Basin (Ryall and VanWormer[25])

Reference	Area	Recurrence time for $M_L >$ 7.0/yr/1,000 km	Rerupture time (yr)
Wallace[26]	North-central Nevada	3.4×10^5	29,000
	Stillwater Front	1.6×10^4	6,300
	White Mountains	2.7×10^4	3,700
Pease[27]	Northern Sierra Nevada	$(2 - 5) \times 10^4$	2,000 - 5,000
	Western Great Basin	$(1.0 - 1.4) \times 10^4$	7,000 - 10,000

From instrumental data for 1932-1969 and 1970-1974

the 1960's in Idaho. In Oregon, near 120°, a series of earthquakes near the border with California began in November 1968 and continued through June of the same year.[28] Even so, the size of the events in both Idaho and Oregon was in the range of intensity VI to VII, much smaller than events in southwestern Nevada.

5.3 Nevada Hazard

5.3.1 PROBABILISTIC CALCULATION

In Battis[1] two zonation schemes were used to model the seismic hazard for the Utah sites: uniform seismicity and subplate margin models. This analysis for Nevada utilizes the former model with the addition of two more zones, California and the Snake River Plain (SRP). The uniform seismicity model is chosen because it represents a more conservative estimate of the hazard for the Basin and Range. Figure 15a is a sketch of the boundaries of the zones. The relevant parameters are tabulated in Table 8. The attenuation relationships

26. Wallace, R.E. (1978) Patterns of Faulting and Seismic Gaps in Great Basin Province, U.S. Geological Survey, Open File 78-945, pp. 857-868.

27. Pease, R.C. (1979) Scarp Degradation and Fault History Near Carson, Nevada, M.S. Thesis, University of Nevada, Reno, 95 pp.

28. Von Hake, C.A. (1976) Earthquake history of Oregon, Earthquake Information Bulletin, 8(No. 3).

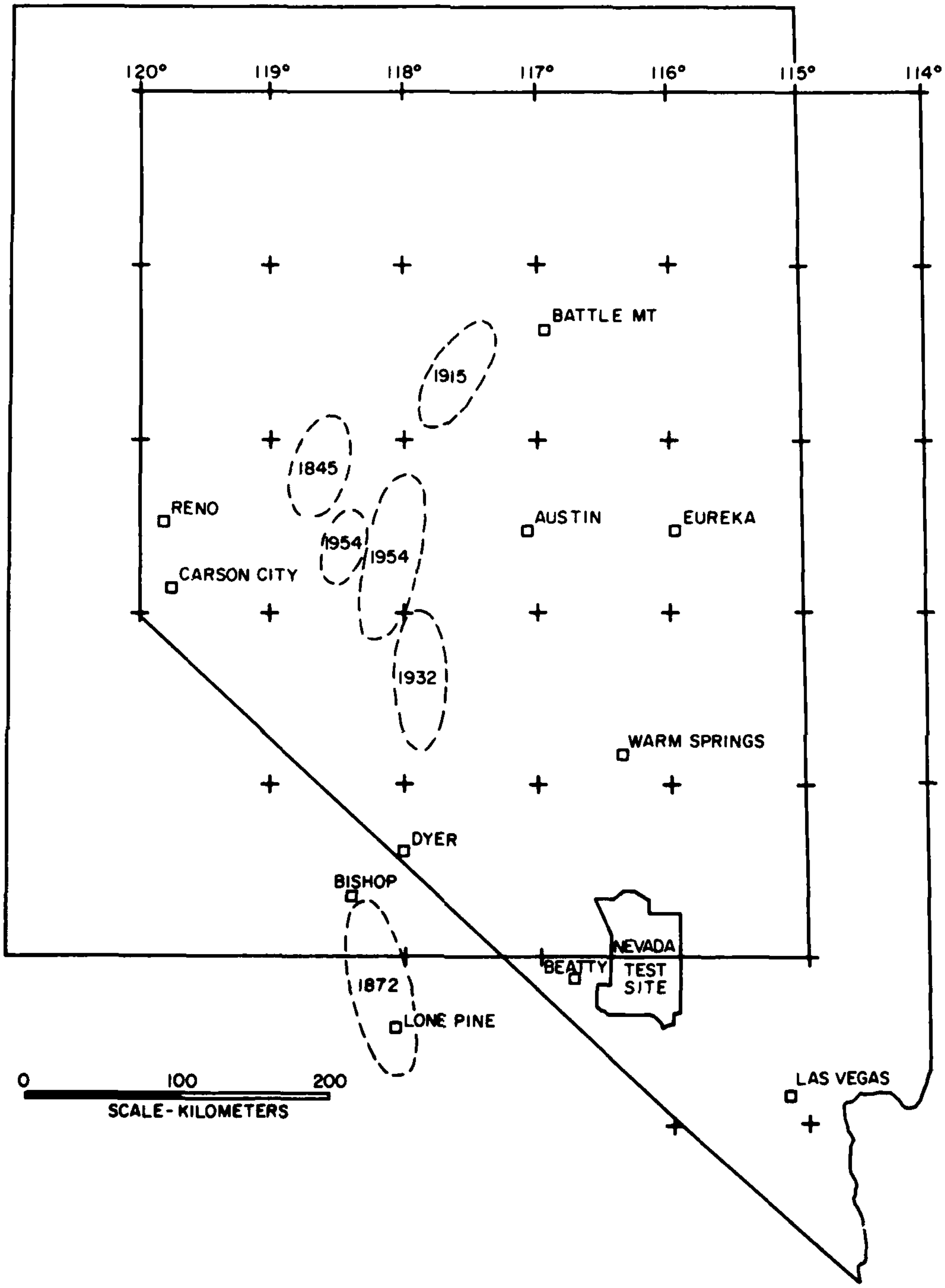


Figure 13. Historical Seismicity of Nevada (Ryall[23])

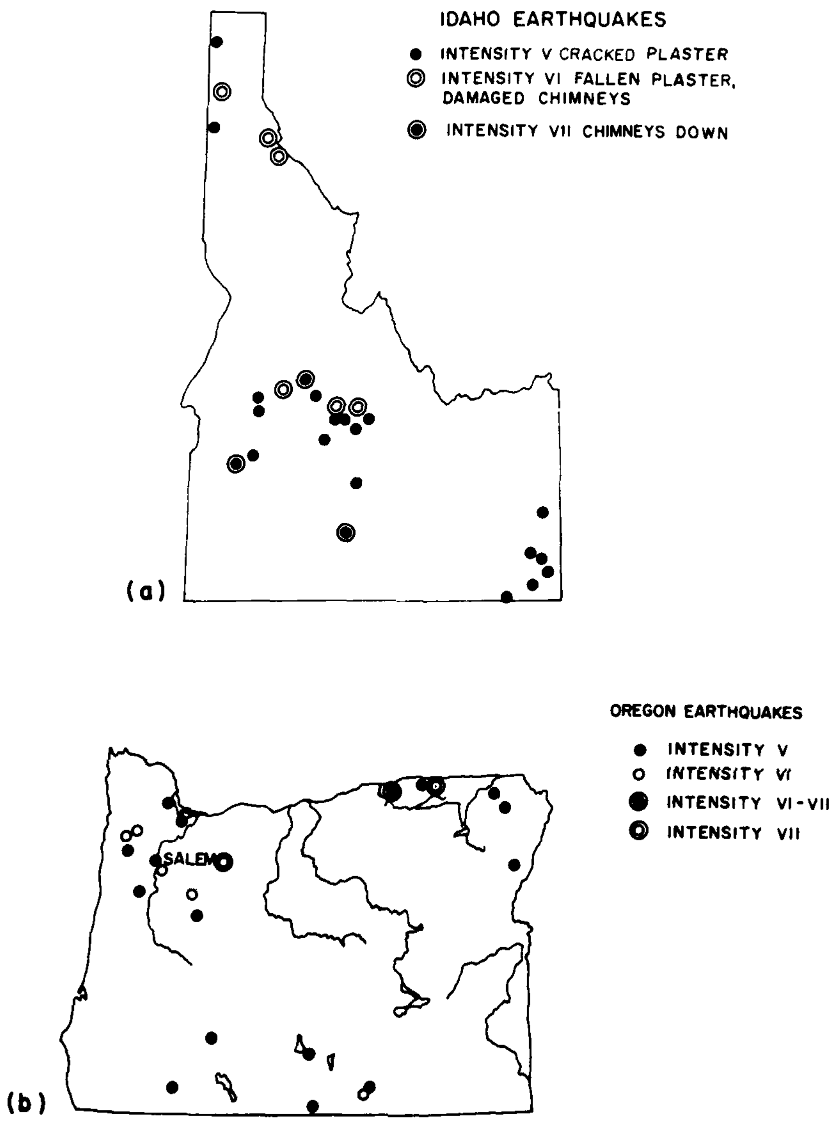


Figure 14. Historical Seismicity of (a) Idaho and (b) Oregon (Von Hake[28,29])

29. Von Hake, C.A. (1972) Earthquake history of Idaho, Earthquake Information Bulletin, 4(No. 2).

used in the program EQRISK[30] are from Battis[1] (Table 4a). Magnitude conversions used in compiling magnitude-frequency curves for the Snake River Plain and California zones are from Brazee[19] (Table 9) for the western U.S.

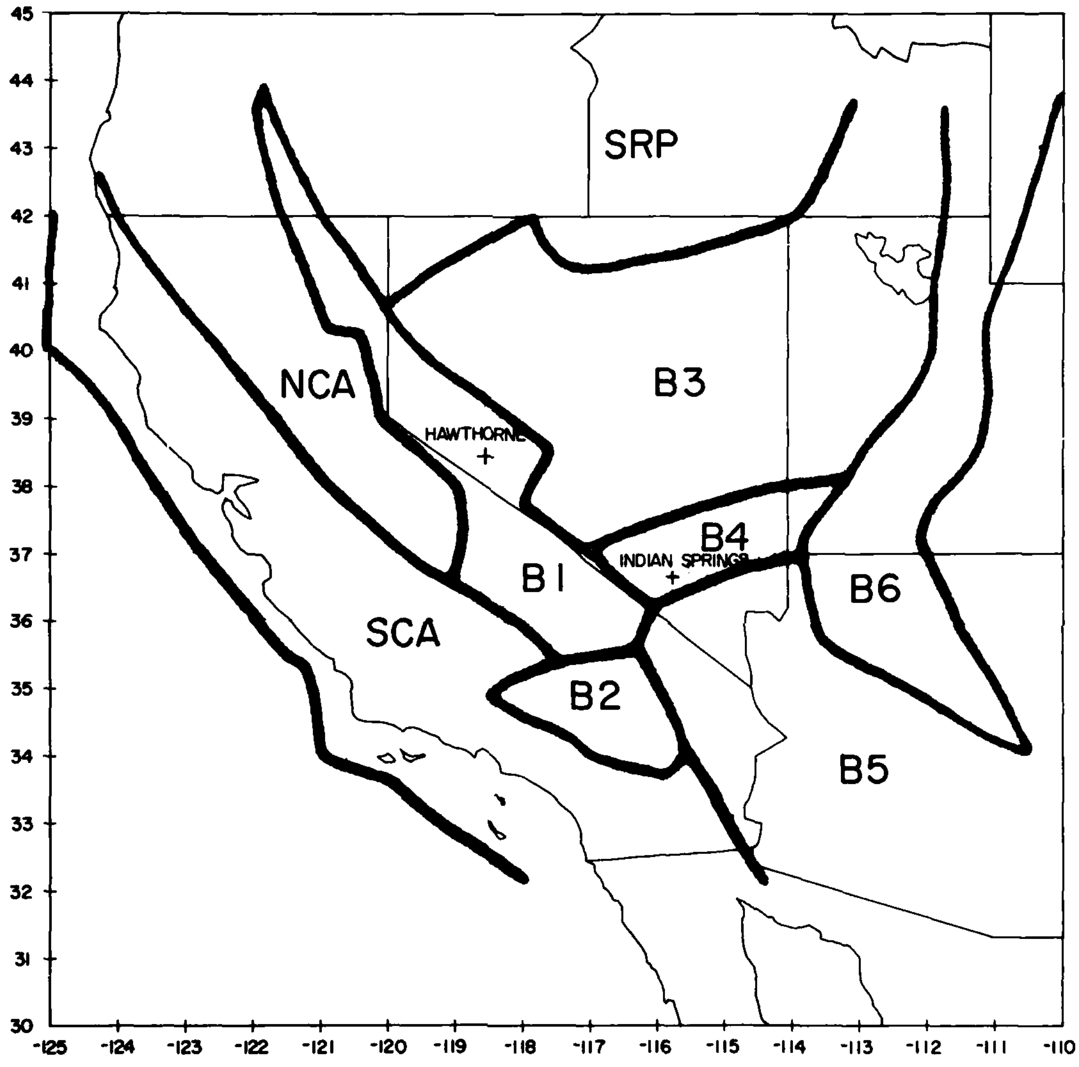


Figure 15a. Zonation Scheme for Nevada Sites

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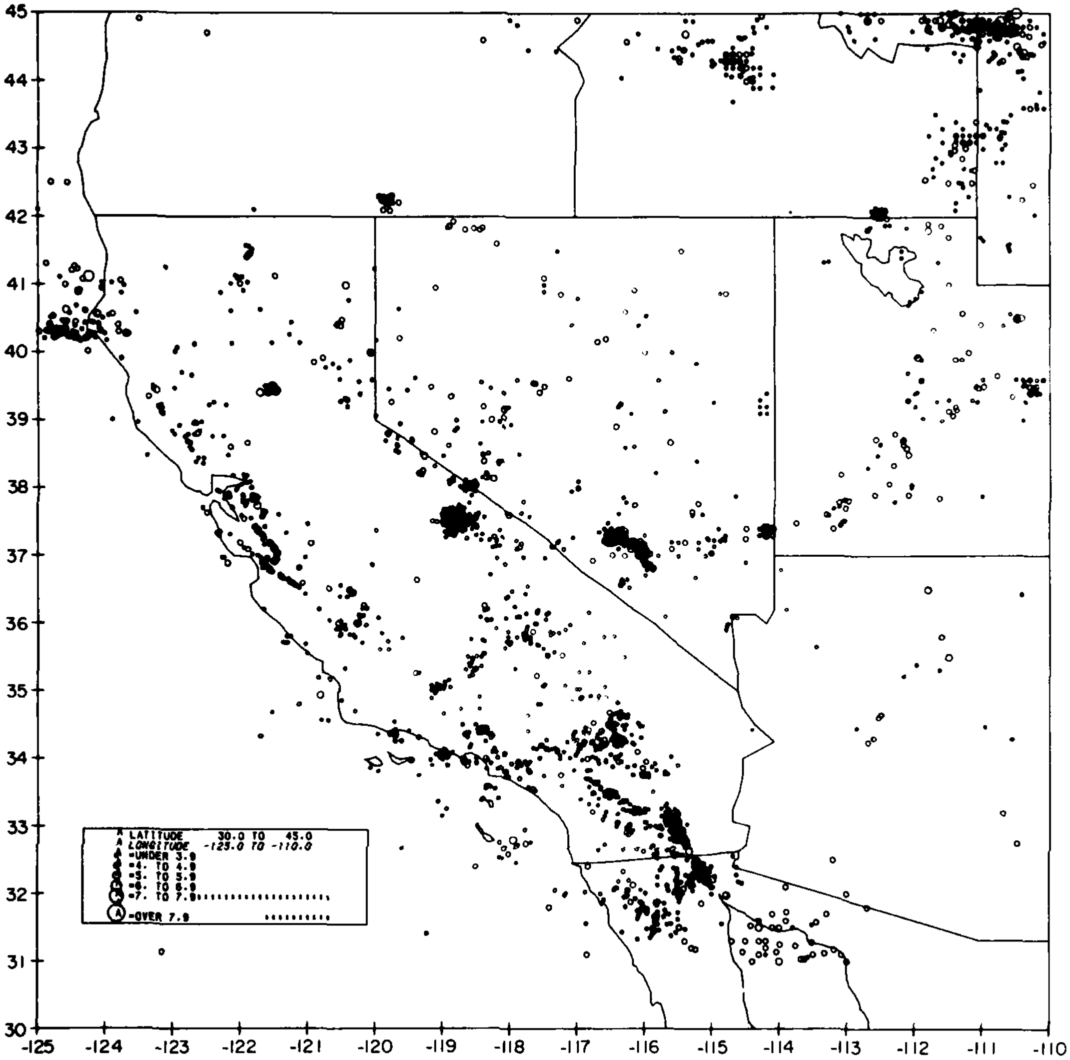
30. McGuire, R.K. (1974) Seismic Structural Response Risk Analysis Incorporating Peak Response Regressions on Earthquakes Magnitude and Distance, Dept. Civil Eng. Research Report No. R47-51, MIT, Cambridge, Mass.



(b)

Figure 15b. Western U.S. Earthquakes Greater Than Magnitude 4.0 From Various Sources on PDE Tape (Approximately 50 yr)

Recurrence parameters for the northeastern California (NCA) zone were computed from a fit between M_L 4.0 and 6.0 (with conversions from m_b) for 10 yr of data from the NOAA tape (several source agencies). The San Andreas seismicity (SCA) zone recurrence utilized 15 yr of data from the same catalog and was fit between M_L 4.0 and 6.0. A maximum cutoff magnitude of M_L = 8.0 has been assigned. The values are well within those published for smaller sections

Table 8. Seismic Hazard Input Parameters - Nevada

Source Zone	Area $\times 10^3$ (km^2)	Log N_c^* = A - B M_L A	B	Min M_L	Max M_L	Return Period of M_L Max (years)
B1	82.9	5.1	1.0	4.0	7.75	447
B2	25.3	3.44	0.91	4.0	7.6	2992
B3	263.7	4.9	0.91	4.0	7.6	104
B4	34.1	4.1	1.0	4.0	7.2	1259
B5	166.6	3.9	1.0	4.0	7.5	3981
B6	133.2	4.8	0.96	4.0	7.77	456
SRP	250.0	4.5	1.0	4.0	7.5	1000
SCA	358.0	5.8	1.04	4.0	8.0	331
NCA	165.1	4.4	0.88	4.0	7.5	158

*Cumulative recurrence per year for entire source zone area.

Table 9. Magnitude Conversions for California and Western Nevada (Brazee[19])

M_L	=	$2.149 + 0.487\ I_o$
m_b	=	$2.886 + 0.365\ I_o$
m_b	=	$1.276 + 0.749\ M_L$
M_s	=	$-1.939 + 1.189\ M_L$

of California.[30,31] The relatively short time period was selected to ensure completeness of reporting. Several sources of data for the western U.S. are plotted in Figure 15b.

Recurrence for the Snake River Plain zone was obtained from the PDE file of the NOAA compilation. Twenty years of data were fit between magnitude (M_L) 4.0 and 6.0. Although a rather high maximum cutoff magnitude is assigned to this zone, the recurrence rate of large earthquakes is small. Significant seismicity in the area in historical terms has been confined mainly to intensity VI's and VII's.[28,29]

31. Battis, J.C. (1978) Geophysical Studies for Missile Basing: Seismic Risk Studies in the Western United States, ALEX(02)-FSR-78-01, Final Report, Contract F44620-76-C-0063, Texas Instruments, Inc.

Results of this seismic hazard model are shown in Tables 10a and b and Figure 16. Hawthorne shows a significantly higher hazard than Indian Springs, although values of ground motion are large for both sites because of the active region they occupy.

Table 10a. Seismic Hazard Results - Peak Ground Motion, Including 90 Percent Confidence Levels for Hawthorne, Nevada

Annual Risk	Return Period (yr)	Accel (cm/sec^2)	Vel (cm/sec)	Disp (cm)
0.5	2	38.0	4.8	2.4
0.2	5	64.0	7.7	4.1
0.1	10	88.0	10.0	5.8
0.05	20	120.0	14.0	8.0
0.02	50	155.9	18.8	11.1
0.01	100	205.9	24.2	14.5
0.005	200	268.0	30.9	18.6
0.002	500	365.0	42.3	25.4
0.001	1,000	420.0	53.1	31.9
0.0001	10,000	1059.1	105.9	62.3
90% confidence level in 10 years		205.9	24.2	14.5
90% confidence level in 20 years		268.0	30.9	18.6

Design response spectra corresponding to the 90 percent confidence level, 10-yr lifetime (100-yr return period) and 20-yr lifetime (200-yr return period), are shown in Figures 17a, b, c, and d, for various damping ratios. They were computed according to the same procedure used in Section 4.3.1.

Battis used zones based on the delineations of Greensfelder et al,[7] who also estimated maximum magnitude earthquakes for the zones from magnitude-fault length studies. His estimate for most of the Great Basin is 7.7, 8.0 in the Salton Trough, and 7.0 in zone 5 (Figure 15a).

Our two sites, Hawthorne and Indian Springs, are approximately 300 km from the mapped location of the San Andreas fault zone. Hawthorne is in region 1 (see map, Figure 15a), whose seismicity parameters are based on geodetic data from Owens Valley and fault displacements for the Death Valley fault

Table 10b. Seismic Hazard Results - Peak Ground Motion, Including 90 Percent Confidence Levels for Indian Springs, Nevada

Annual Risk	Return Period (yr)	Accel (cm/sec^2)	Vel (cm/sec)	Disp (cm)
0.5	2	18.2	2.9	1.8
0.2	5	27.1	4.5	3.0
0.1	10	40.1	6.0	4.0
0.05	20	49.4	8.0	5.4
0.02	50	72.0	10.7	7.6
0.01	100	94.2	13.7	9.9
0.005	200	122.8	17.3	12.6
0.002	500	172.9	23.2	17.02
0.001	1,000	224.2	28.8	21.1
0.0001	10,000	504.6	57.6	44.0
90% confidence level in 10 years		94.2	13.7	9.9
90% confidence level in 20 years		122.8	17.3	12.6

and the Garlock fault system as well as seismicity recorded in the area.[8] Indian Springs lies within region 4, which encompasses the Garlock-Caliente Lineament and its intersection with the Cane Spring fault system and the southern extension of Walker Lane. The Nevada Nuclear Test Site is also included in this zone.

5.3.2 DETERMINISTIC CALCULATION

Deterministic spectra computed for the sites are shown in Figure 18. They were computed based on the same technique used in Section 4.3.2. Because of the even distribution of the Quaternary faults in the area and the high rate of seismic activity, the maximum cutoff magnitude event for the zone was attenuated to a distance of 15 km. These spectra represent the mean values of ground motion (acceleration, velocity, displacement = 522, 51, 19, Indian Springs; 860, 85, 33, Hawthorne; cgs units), and the very high values are at the limit of the calculation.

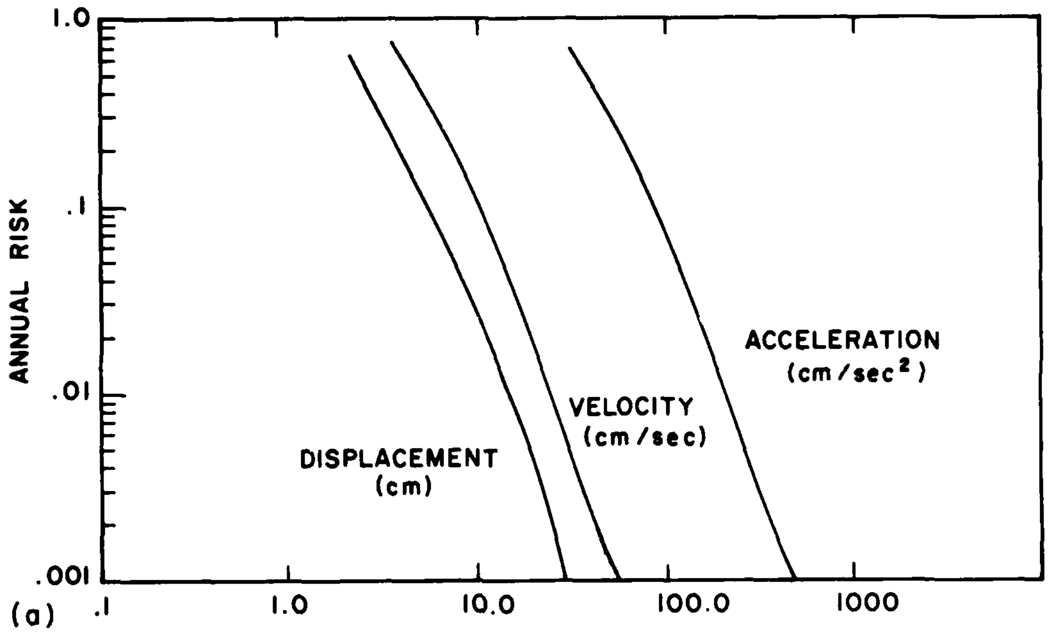


Figure 16a. Annual Seismic Risk for Hawthorne

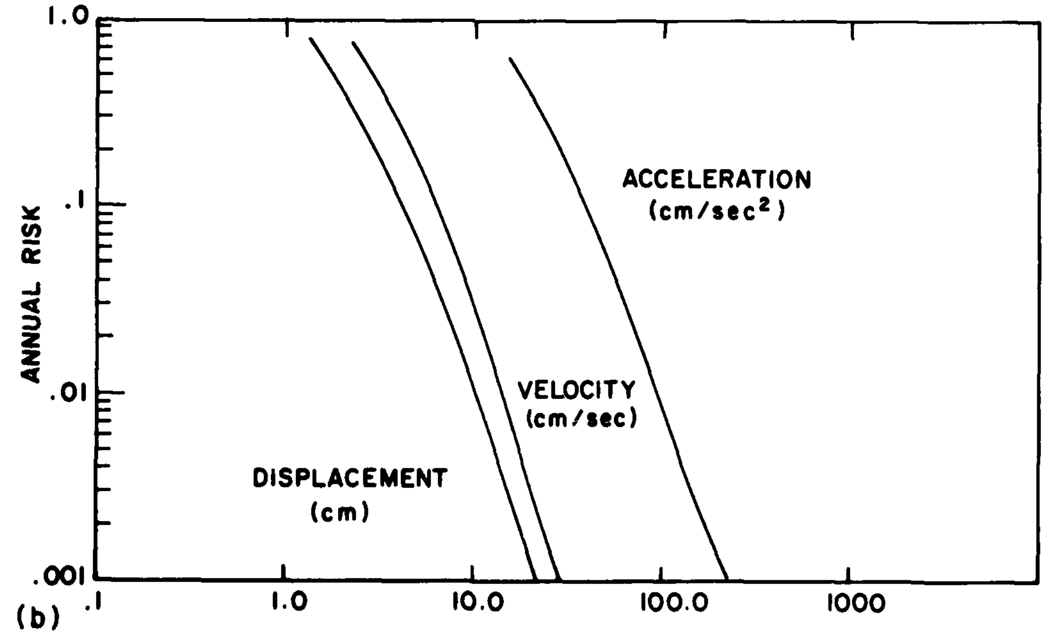


Figure 16b. Annual Seismic Risk for Indian Springs

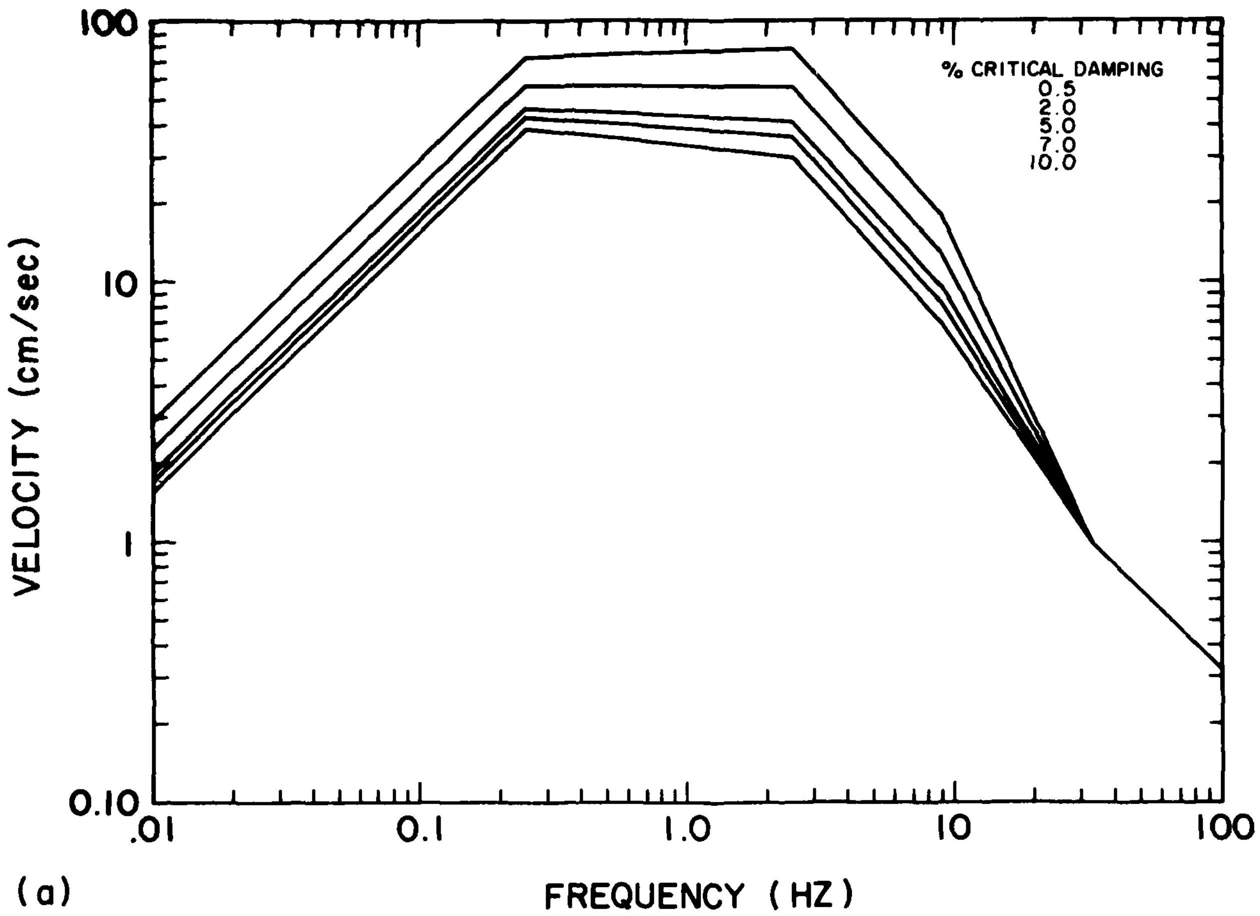


Figure 17a. 90 Percent Confidence Level Spectra for Hawthorne, 10-Year Lifetime

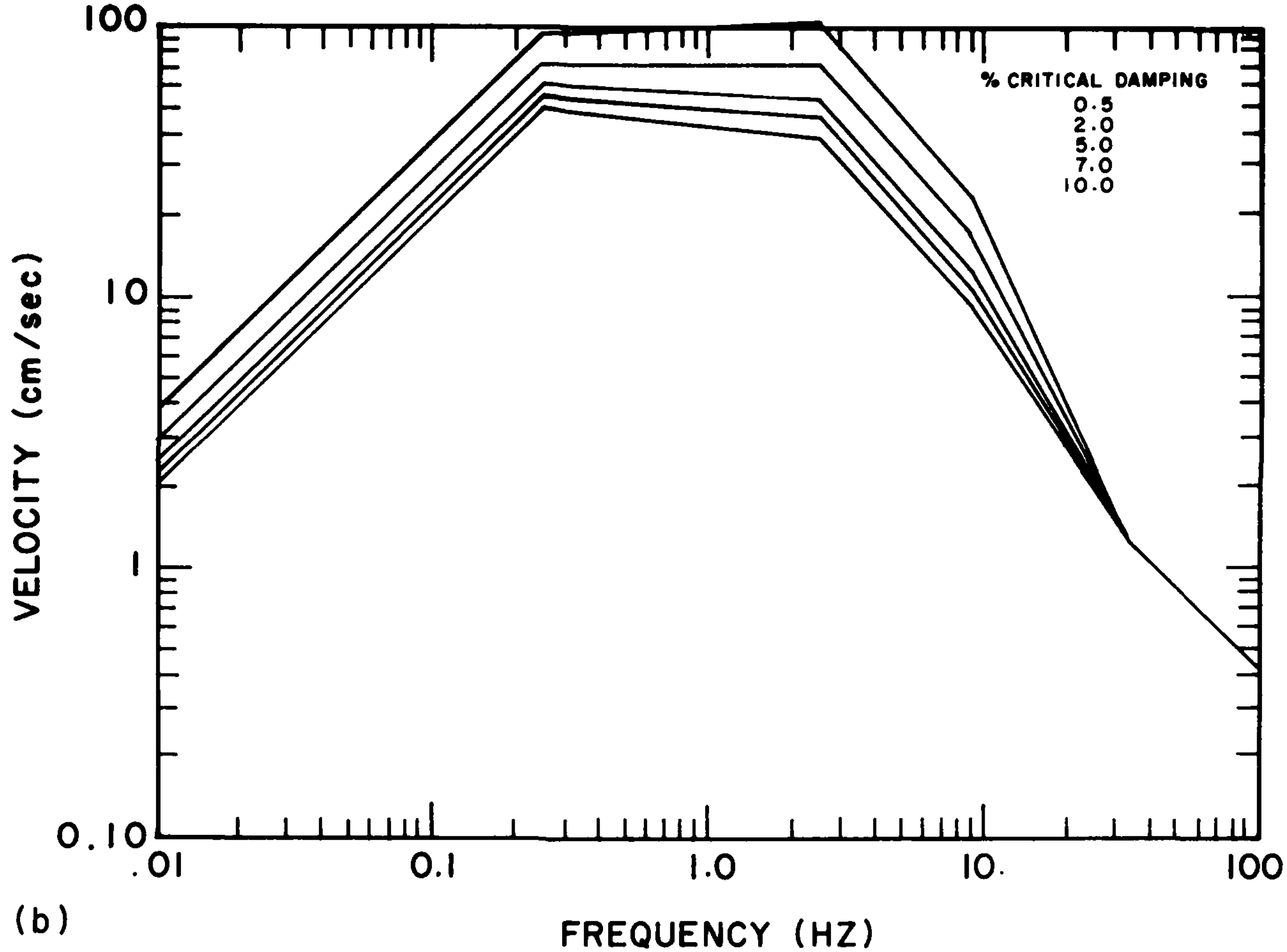


Figure 17b. 90 Percent Confidence Level Spectra for Hawthorne, 20-Year Lifetime

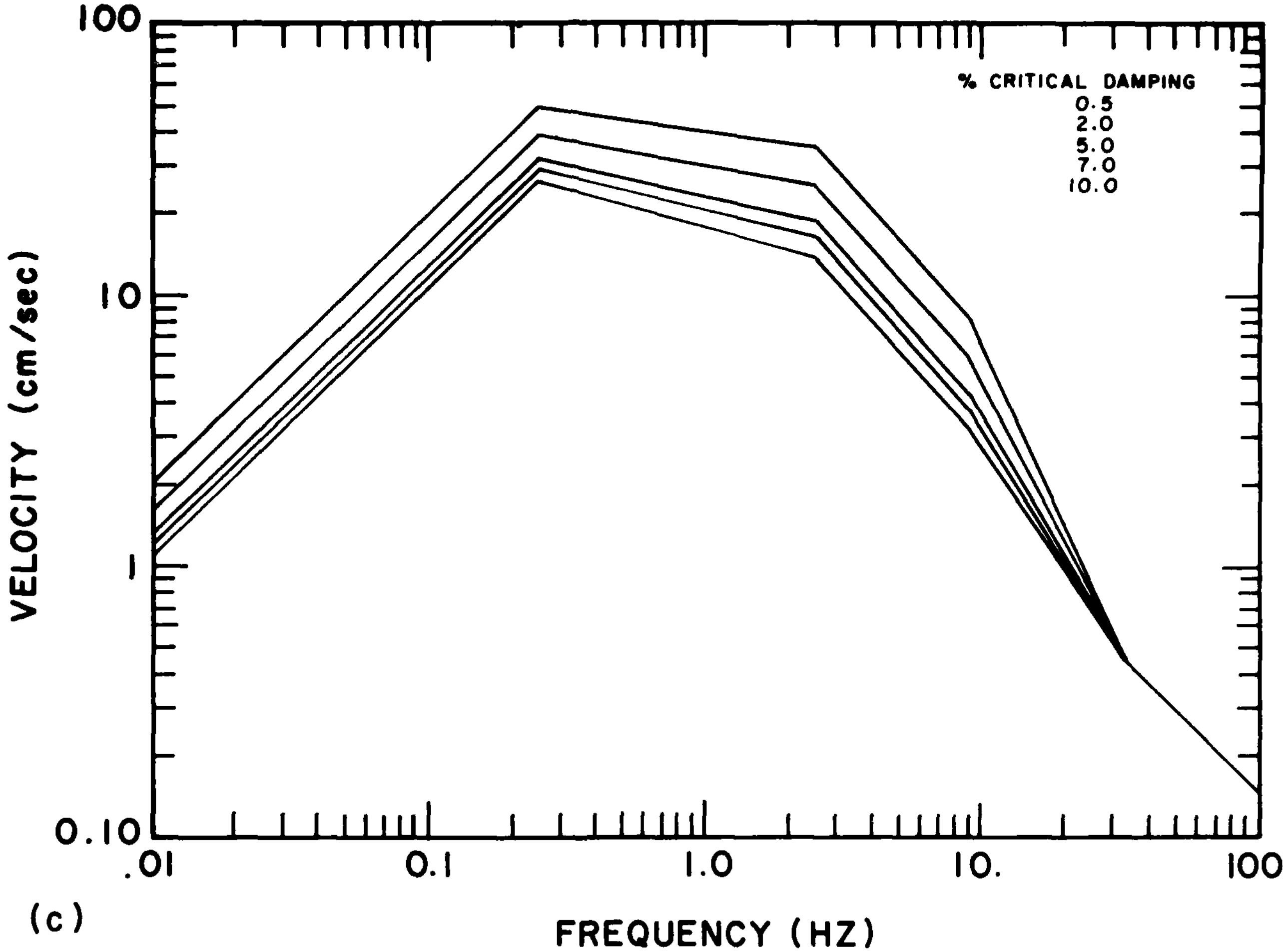


Figure 17c. 90 Percent Confidence Level Spectra for Indian Springs, 10-Year Lifetime

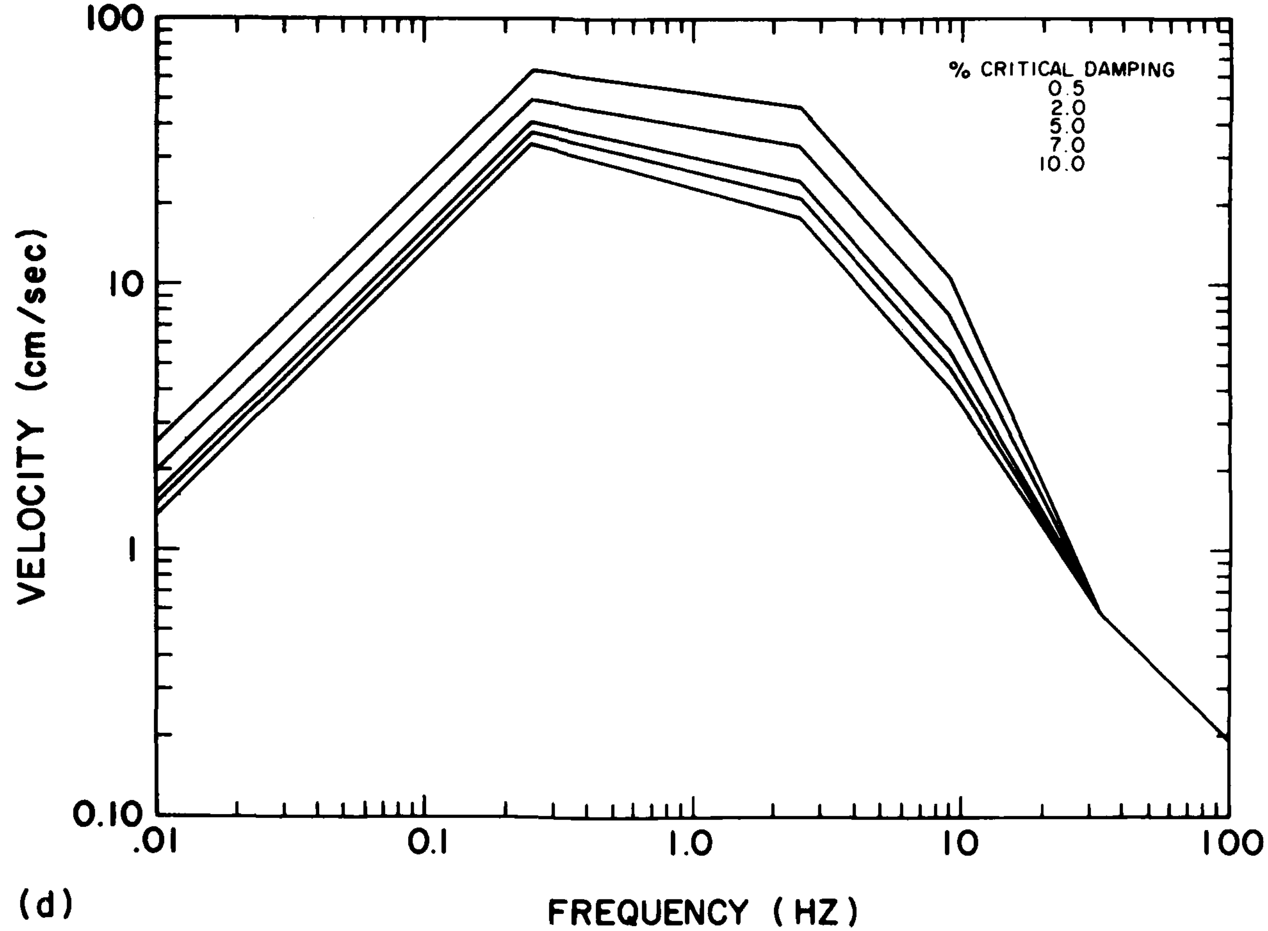


Figure 17d. 90 Percent Confidence Level Spectra for Indian Springs, 20-Year Lifetime

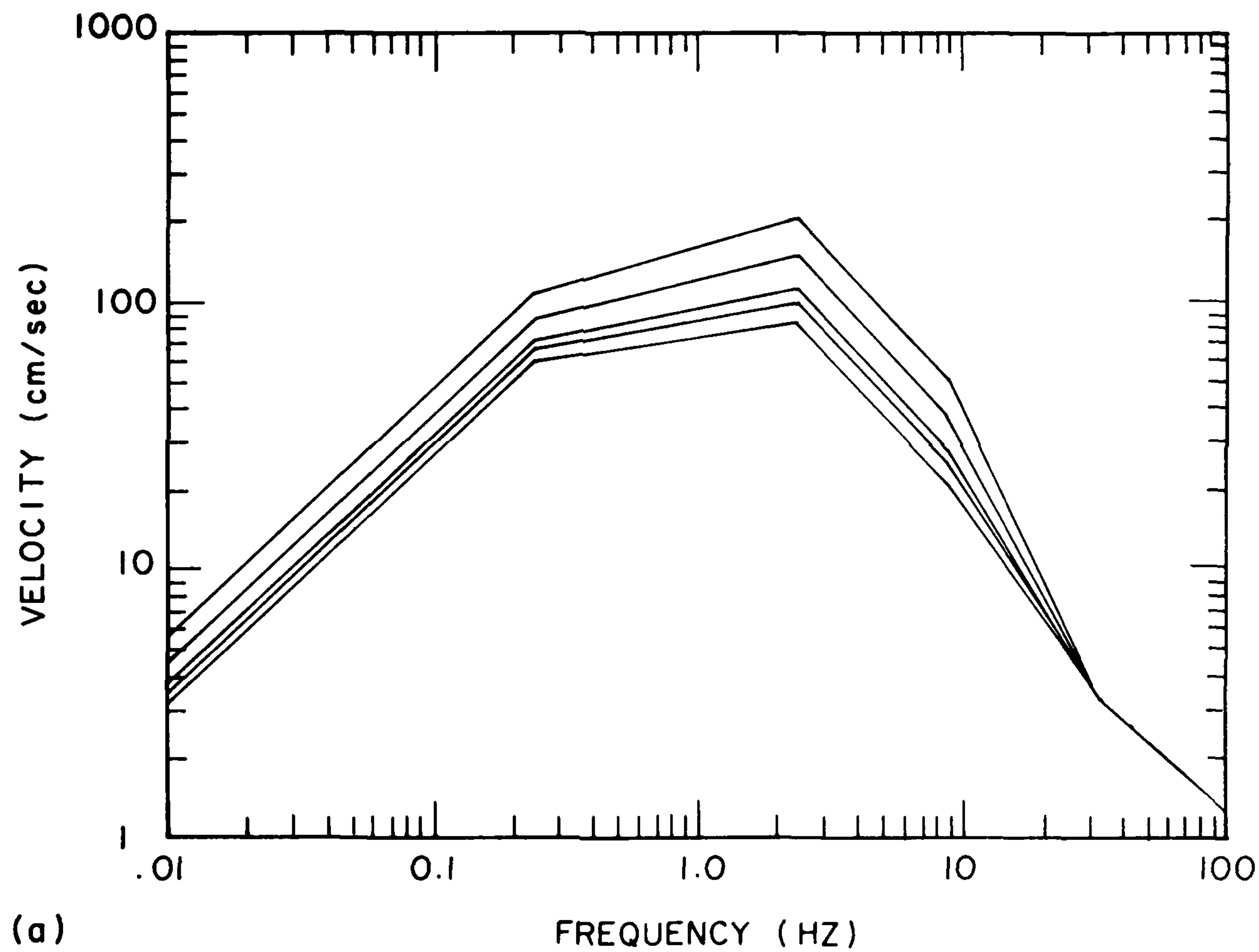


Figure 18a. Standardized Response Spectra for Maximum Credible Event for Hawthorne

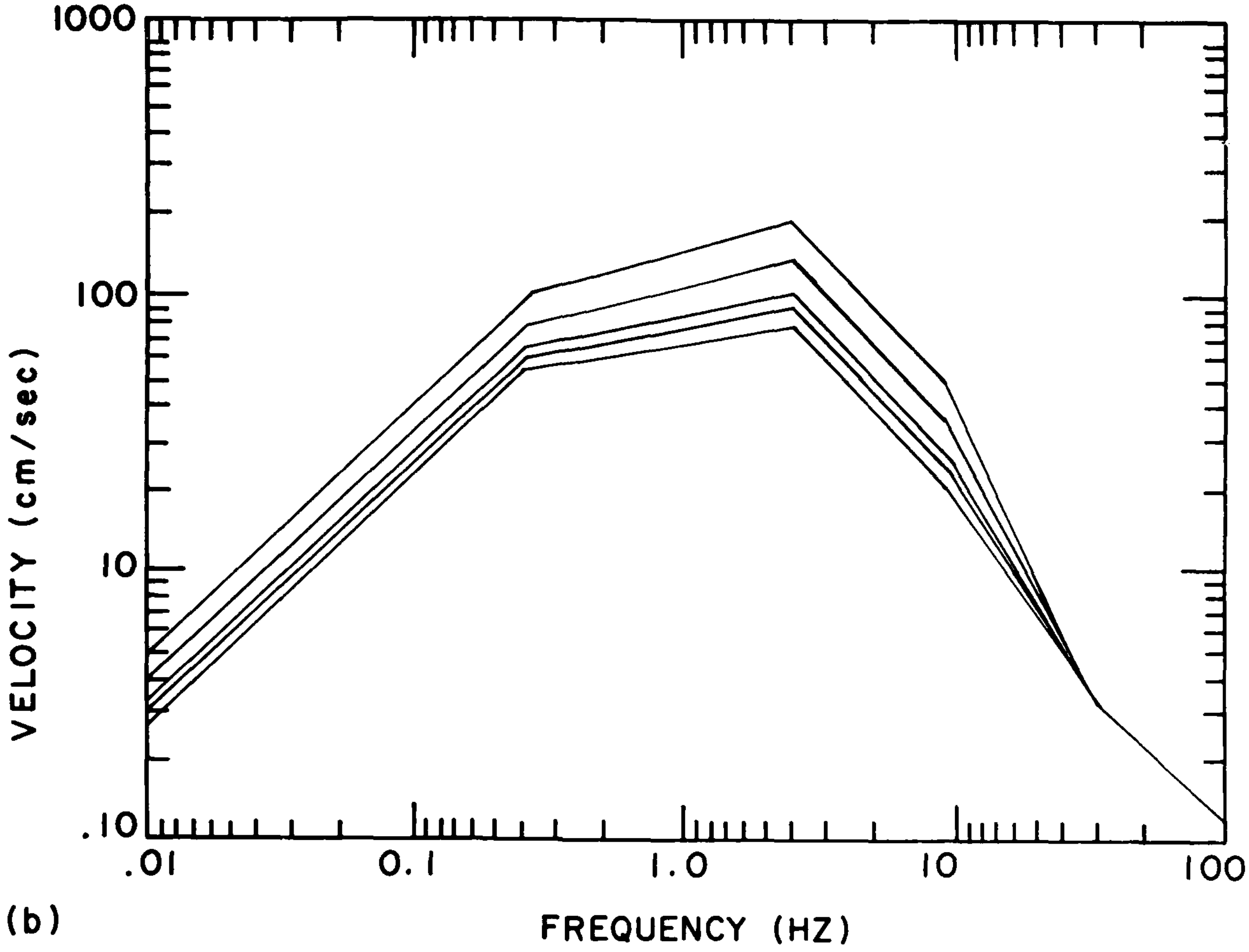


Figure 18b. Standardized Response Spectra for Maximum Credible Event for Indian Springs

5.4 Discussion of Hazard for Sites in Nevada

The two sites examined in this section exhibit very high seismic hazard values from the probabilistic analysis and the deterministic estimate. Hawthorne's values are greater in both cases. This can be understood in terms of its location in zone 1, an area of very high activity. Indian Springs, however, is located in zone 4, a less active region that borders quieter zones (3 and 5) to the north and south. The spectra presented should be used with the knowledge that they do not represent the predicted ground motion for any one earthquake. Even in the deterministic case, the standardized spectral shape is, at best, an approximation, better suited to an earthquake more distant than the 15 km used here.

6. DISCUSSION

This report has followed Battis's[1] Utah hazard report in an attempt to define quantitatively the ground motion at selected sites in two tectonically diverse locations. While the calculated return periods of earthquakes of a given magnitude may incorporate large errors and the annual risk values may be biased by many factors, the strength in the methods employed here lies in the relative values. We may say with certainty that Clovis is at lower risk than Albuquerque or Roswell and that the risk at any one of those sites is substantially less than the risk at Hawthorne or Indian Springs. The risk at Indian Springs is definitely less than that at Hawthorne. Probabilistically speaking, this does not ensure that a magnitude 7.5 will not occur tomorrow at Clovis, nor guarantee that a magnitude 7.5 will occur at Hawthorne within the next 500 yr.

The hazard computed for the Nevada sites was based on well-determined parameters because so much data could be obtained in the active western U.S. area. For the New Mexico sites, more assumptions had to be incorporated into the analysis. Patterns of seismicity are not yet well-defined. Separation of seismicity according to causative mechanism (volcanic or deep-seated rifting) has not been accomplished. As a consequence, the hazard values for these sites may be overly conservative. Since there are local networks now in operation, this situation should soon be corrected. The deterministic values especially may change as the structures that have a correspondence to earthquake occurrence are identified.

Values of predicted risk of ground motion can be modified at a site by the type of geological foundation that a structure of interest has. For example, an alluvial basin is likely to amplify ground motion towards the longer periods relative to a bedrock site. Progress can be made toward quantification of the amplification effects once a particular site's foundation condition has been studied in detail.

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