TENNESSEE VALLEY AUTHORITY

DIVISION OF ENGINEERING DESIGN
CIVIL ENGINEERING BRANCH

JUSTIFICATION OF THE SEISMIC DESIGN CRITERIA

USED FOR THE SEQUOYAH, WATTS BAR, AND

BELLEFONTE NUCLEAR POWER PLANTS.

PHASE I

APRIL, 1978

PDR

TENNESSEE VALLEY AUTHORITY

DIVISION OF ENGINEERING DESIGN
CIVIL ENGINEERING BRANCH

JUSTIFICATION OF THE SEISMIC DESIGN CRITERIA USED FOR THE SEQUOYAH, WATTS BAR, AND BELLEFONTE NUCLEAR POWER PLANTS.

PHASE I

APRIL 1978

PREPARED	J. Jin Kim
SUPERVISED	Frank R Hand
REVIEWED	L. M. Hunt
SUBMITTED	R O Barnett
APPROVED	R. G. Domer

TABLE OF CONTENTS

Section	Title	Page
Introduction		1
1	Modified Mercalli Intensity	3
2	Intensity-Acceleration Relationships	4
3	Relations Between Maximum Historic Earthquake, Peak Acceleration, Epicentral Intensity, and Geology	6
4	Seismic Design Criteria for the Sequoyah, Watts Bar, and Bellefonte Nuclear Power Plants	8
5	Concluding Remarks	11
References		12

Appendices

A, Modified Mercalli Intensity Rating

B, Relations Between Maximum Historic Earthquake, Peak Accelerations, Epicentral Intensity, and Geology

C, Seismic Design Criteria for the Sequoyah, Watts Bar, and Bellefonte Nuclear Power Plants

INTRODUCTION

The purpose of this report is to provide additional information to support the safe shutdown earthquake ground motions used to design the Sequoyah, Watts Bar, and Bellefonte nuclear power plants as requested by a memorandum from the Nuclear Regulatory Commission dated December 27, 1977.

In the eastern United States, a tectonic province approach is used to specify the design earthquake. The three nuclear power plants in question lie within the Southern Appalachian Tectonic Province (SATP). The largest historic earthquake and thus the controlling event in this province is the May 31, 1897, Giles County earthquake. This event will be discussed as it applies to the plant design.

The development of seismic design criteria should include an overview of not only the earthquake motions but also the seismic analysis processes and the structural and mechanical design. These items need to be considered as a unit when assessing the level of earthquake design of a nuclear power plant. When each step is considered as a separate entity and by different groups, an overly conservative earthquake design is the result. In developing seismic design criteria, TVA uses an integrated assessment which includes an evaluation of all the factors which affect the earthquake design. TVA is of the opinion that based on such an integrated assessment, the earthquake design of Sequoyah, Watts Bar, and Bellefonte is conservative and justified. The earthquake ground motion specifications for the above plants are summarized in appendix C and discussed also in the respective Final Safety Analysis Reports. Examination of the response spectra shows that justification of the Sequoyah site would obviate arguments for Watts Bar and Bellefonte since the criteria applied to those are more conservative.

The multiple aspects which were considered in order to define the SSE ground motion specifications are grouped into the following four sections:

1. Modified Mercalli intensity rating.
2. Intensity-acceleration relationships.
3. Relations between maximum historic earthquake, peak acceleration, epicentral intensity, and geology.
4. Seismic design criteria for the Sequoyah, Watts Bar, and Bellefonte nuclear power plants.

In these sections, arguments are presented which demonstrates the criteria utilized for the design of the plants are conservative. Inferences drawn from the material presented in these four sections are contained in a fifth section under the heading Concluding Remarks.

1. <u>Modified Mercalli Intensity Rating</u>

The modified Mercalli intensity scale (MMI) as defined by Richter[1]-Wood & Neumann[2] is generally accepted in the U.S. to describe in numerical form the visible effects of earthquakes. To obtain an overview of the area affected by a particular earthquake, "isoseismal" maps are constructed. Such contouring of seismic intensity areas must be examined thoroughly on its merits for two reasons: The first being that especially for earthquakes which occurred in sparsely populated areas the "resolution" is poor. Secondly, such contours are seldom mapped on geologic maps to show possible relation between ground motion and geologic properties of the underlying rock formation. Similar concerns are expressed by academicians as well as other investigators in the field of seismology. Excerpts of their concerns are included in Appendix A, comprising a more detailed discussion on the subject.

2. Intensity-Acceleration Relationships

NRC's guidelines for earthquake design of nuclear power plants call for design response spectra scaled to the estimated peak acceleration of the largest historic earthquake. Current specifications associate a MM intensity VIII with a peak acceleration of 0.25 g. Considerations leading to the above specifications were a result, to a large extent, of studies undertaken by Trifunac and Brady[4]. Empirical equations developed from this study associate an intensity of MMI VIII with a mean peak horizontal acceleration of approximately 0.25 g. However, remarks made by the authors and interpretations of the data presented infer that the postulated formulae define an upper bound of the expected peak acceleration rather than a mean. For example, the data contained in their report indicate that an MMI VIII produces a mean horizontal peak acceleration of 167 cm/sec^2 (0.17 g) with a standard deviation of 84 cm/sec^2 (0.09 g).

A similar empirical formula propounded by Murphy and O'Brien[5] indicates that an MMI VIII produces a horizontal peak acceleration of 151 cm/sec^2 (0.15 g) with a reported antilog of standard error of estimate of 2.19.

A concise discussion on the more noteworthy of relationships which emanated from diverse intensity correlation studies is contained in a report by Krinitsky & Chang[13]. Figure 1 is a graphic representation of several of these relationships, including those suggested by Trifunac & Brady[4] and Murphy & O'Brien[5]. It appears that, within the realm of the state of the art, the relationships proposed by Murphy & O'Brien have considerable merit and should be judged the most up-to-date estimates of earthquake induced motion. A discussion of the design criteria which are obtained by combining the above formulae with proper constraints is contained in section 4.

3. Relations Between Maximum Historic Earthquake, Peak Acceleration, Epicentral Intensity, and Geology

Although such terms as "bad ground" and "good ground" in relation to earthquake resistant design were coined many years ago, hard data to correlate geologic character of rock foundation to the earthquake induced motions have only begun to appear in the last several years. Nevertheless a general classification relating rock type to ground motion characteristics has been obtained by several investigators. A detailed discussion is contained in appendix B, the main conclusions being that for a given earthquake and disregarding the large dispersion of the data, the peak accelerations are largest on "intermediate" sites, of intermediate value on "hard rock" sites and lowest for "deep alluvium" sites. These conclusions are mostly qualitative in nature except for a study by Mohraz[7] which assigns observed differences in percentages, i.e., maximum acceleration amplification for alluvium sites of 30-foot thickness or less on basement rock is approximately 40 percent greater than that for deep alluvium and approximately 33 percent greater than that for hard rock sites.

Mohraz[7] suggests that better correlation may be obtained if intensity is compared to velocity/acceleration/displacement ratios.

However, the fact remains that until more definite correlations are obtained heavy reliance on historic data will dictate the design criteria. Hence the intensity which was assigned to the Giles County earthquake is of major importance. From the evidence noted in appendix B, TVA concludes that the May 1897 Giles County, VA, earthquake should be assigned an intensity MMI VII or MMI VIII depending on a set of mutually exclusive criteria discussed in section 4.

4. Seismic Design Criteria for the Sequoyah, Watts Bar, and Bellefonte Nuclear Power Plants

The following three criteria constitute the basic premise leading to the justification of design criteria used for the above nuclear power plants.

1. Near-field effects of earthquake induced ground motions are not considered applicable.
2. The Murphy-O'Brien[5] intensity-acceleration relationships are considered the best fit to the available data.
3. The design peak acceleration obtained from (2) is assumed to be referenced to "top of ground." The corresponding peak acceleration for "top of rock" shall be obtained by appropriately modifying "top of ground" values.

The first criterion is consistent with the licensing practice for all eastern U.S. nuclear power plants. The underlying assumption being that the selected nuclear power plant sites are far enough removed from potential earthquake foci to exclude the influence of high frequency ground motion characteristics of near field rock sites. Particularly when the design requirements are referenced to the largest (distant) historic earthquake, as is the case in the SATP, this philosophy appears to be well founded.

The second criterion was adopted after comparison of the relationships proposed by Murphy-O'Brien[5] with those of other investigators.

The third criterion infers that the structures under investigation are anchored to a base which constitutes the top of the solid rock formation underlying the plant site. Material to justify and/or document the preceding arguments and a discussion of the results obtained are contained in appendix C.

If the above criteria are applied to the largest historic earthquake within the tectonic province of the three sites, the following mean horizontal peak accelerations referenced to "top of ground" at the site can be deduced.

a. Assigning an intensity MMI VIII to the Giles County earthquake the Murphy-O'Brien relationship (Figure 2) result in a mean peak acceleration of 0.15 g.

b. Assigning an intensity MMI VII to the Giles County earthquake in accordance with constraints discussed in appendix C, the Trifunac-Brady relationship (Figure 3) result in a mean peak acceleration of 0.13 g.

c. Assigning an intensity MMI VIII to the Giles County earthquake using the Tifunac-Brady relationship and in addition using the Mohraz results to relate this level of acceleration to a "rock" site, the mean peak acceleration referenced to "top of rock" is 0.17 g.

d. Using recommendations by Newmark[10] which recognize that design criteria have to be based on "effective" value of the acceleration the design acceleration would be 0.13 g or less (see appendix C).

Thus, the design criteria which are referenced to a mean peak acceleration of 0.15 g are considered an adequate presentation of the actual conditions which would prevail during an earthquake equal to the maximum historic earthquake.

5. CONCLUDING REMARKS

As indicated at the beginning of this response, TVA feels that an integrated approach to the design of nuclear power plants which includes an evaluation of those factors affecting the conservatism of the final results is the most satisfactory and rational method to arrive at design parameters.

This response deals only with one facet of a complex set of geologic, geophysical, structural, and economic constraints which must be satisfied. The arguments presented to justify the seismic design criteria can be summarized as follows:

1. The MMI of the 1897 Giles County earthquake is a MMI VII-VIII.

2. The intensity rating for the 1897 Giles County earthquake is soil biased, inferring that for the same earthquake the intensity on rock would be less.

3. The Murphy-O'Brien intensity-acceleration relationship is the most appropriate.

4. A typical characteristic of earthquake induced ground motion is that its magnitude decreases with depth.

In this context, TVA is of the opinion that the earthquake design criteria applied are conservative and ensure safe operation of the facilities.

REFERENCES:

1. Richter, C. F., "Elementary Seismology" (1958) Freeman, San Francisco.

2. Wood, H. O. and F. Neumann, "Modified Mercalli Intensity Scale of 1931," Bulletin of the Seismology Society of America, Volume 21, pages 277-283 (1931).

3. Evernden, J. F. and R. R. Hibbard, J. F. Schneider, "Interpretation of Seismic Intensity Data," BSSA, Volume 2, pages 399-422, April 1973.

4. Trifunac, M. D. and A. G. Brady, "On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Motion" BSSA, Volume 65, No. 1, pages 139-162, February 1975.

5. Murphy, J. R. and L. J. O'Brien, "Analysis of a Worldwide Strong Motion Data Sample to Develop an Improved Correlation Between Peak Acceleration, Seismic Intensity and Other Physical Parameters," U.S. Nuclear Regulatory Commission Report NUREG-0402. Prepared by Computer Sciences Corporation, January 1978.

6. Murphy, J. R. and L. J. O'Brien, "The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and Other Physical Parameters." U.S. Nuclear Regulatory Commission Report NUREG-0143 Prepared by Computer Sciences Corporation, March 1977.

7. Mohraz, B. "A Study of Earthquake Response Spectra for Different Geological Conditions," BSSA Volume 66, No. 3, Pages 915-935. June 1976.

8. Law Engineering Testing Company, "Report on Evaluation of Intensity at Giles County, Virginia, Earthquake May 31, 1897." Marietta, Georgia, November 1975.

9. Neumann, F., "Earthquake Intensity and Related Ground Motion" University Press, Seattle, Washington, 1954.

10. Newmark, N. M., "Seismic Design Criteria for Structures and Facilities Trans-Alaska Pipeline System." Proc. U.S. National Conference on Earthquake Engineering - 1975, Pages 94-103. Earthquake Engineering Research Institute, June 1975, Ann Arbor.

11. "Reassessment of the Maximum Intensity of the Earthquake in Giles County, Virginia, on May 31, 1897," Communications Between U.S. Geologic Survey and Energy Research & Development Administration, December 1975-January 1976.

12. Coulter, H. W., H. H. Waldron and J. F. Devine, "Seismic & Geologic Siting Considerations for Nuclear Facilities," Proceedings of the Fifth World Conference on Earthquake Engineering, Volume 2, Pages 2410-2419, Rome 1974.

13. Krinitzky, E. L. and F. K. Chang, "State of the Art for Assessing Earthquake Hazards in the United States." Report 4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, September 1975.

14. Trifunac, M.D., "Preliminary Analysis of the Peaks of Strong Earthquake Ground Motion - Dependence of Peaks on Earthquake Magnitude, Epicentral

Distance and Recording Site Conditions." BSSA, Volume 66, No. 1, Pages 189-219, February 1976.

15. Hays, W. W. et al, "Guidelines for Developing Design Earthquake Response Spectra," U.S. Geological Survey, June 1975.

16. "Report on July 1975, Ferndale Earthquake," Pacific Gas & Electric, San Francisco, California, August 1975.

17. "Soil Structure Interaction Analysis of Humbolt Bay Nuclear Plant," Dames & Moore, Oakland, California, July 18, 1975.

18. Seed, H. B., I. M. Idriss, F. W. Kiefer, "Characteristics of Rock Motions During Earthquakes," Journal of the Soil Mechanics and Foundations Division, ASCE Volume 95, No. SM5, September 1969.

19. Okamoto, S., "Introduction to Earthquake Engineering," John Wiley & Sons, New York, New York, 1973.

APPENDIX A

MODIFIED MERCALLI INTENSITY RATING

Seismologists and engineers have noted that during an earthquake structures founded on soil respond more violently to the earthquake than do structures founded on rock. Many earthquakes recorded in "U.S. Earthquakes" have intensities based on structures founded on soil. The soil intensity concept is also logical when one considers the geographic and topographic setting of the towns reporting an earthquake, particularly if pre-1920 earthquakes are considered. For example, at the time the Giles County earthquake occurred, most towns were established along streams and in valleys (Figure 4). Consequently houses and town buildings are founded on alluvium or residuum of varying thickness. (It has only been in the recent 50 years or so that individuals or communities have found sites so scarce as to justify the costs associated with rock removal.)

In a study on this topic Evernden[3] concludes: "...If no discipline is imposed by correlation of observations with geology, this leads to maps in large part expressing values observed if the entire area were alluvium, the argument being that almost all observations were obtained from alluvial sites." This argument should be equally applicable in the eastern U.S. since settlements occurred in valleys and flat areas where alluvial deposits are common.

To further illustrate the dilemma in assigning intensities to regional areas of ground motion the following excerpts are presented:

Evernden[3] "...The published contours of seismic intensity are grossly deceiving unless properly interpreted. To date, the intensity data are always entered on a base map having no geologic information. Inasmuch as the most sensitive ground condition is alluvium, either in stream or river valleys and because most living sites are on such ground, particularly in remote areas, data from such points predominate in reported intensity values..."

Trifunac & Brady[4] "...The difficulty associated with characterization of earthquake risk by an intensity scale is that, as will be shown in this paper, the subjective and qualitative nature of intensity scale allows only a first order correlation with the measured parameters..."

Ambraseys[5] "...One of the main problems in seismic micro-regionalisation is the classification and mapping of soil deposits according to their properties of modifying bedrock earthquake movement..."

Campbell & Duke[6] "...Because of such factors as soil amplification and instability, earthquake damage and intensity are strongly influenced by local site condition..."

Therefore proper interpretation of intensity ratings of historic earthquakes is a necessary part of the justification of methods and practices used by TVA to arrive at the design criteria in question.

The following comments on the subject are included to corroborate the above statements.

Branner, J. C., Earthquake of August 16, 1906, Valparaiso, Chile, Bulletin of the Seismological Society of America, Vol. 1, No. 2, p. 42, June 1911.

"The city of Valparaiso is built upon loose materials that fill the landward end of the original bay, and extends up the faces of the surrounding hills of massive eruptive rocks on all sides. The map shows that the low flat land made of loose materials and filled with water was the area of high intensity, and the contrast between the high intensity of this low ground and the low intensity of the high ground was still perfectly evident on all sides when I visited Valparaiso in February, 1908."

Borcherdt, Roger D., and James F. Gibbs, Effects of Local Geological Conditions in the San Francisco Bay Region on Ground Motions and the Intensities of the 1906 Earthquake, Bulletin of the Seismological Society of America, Vol. 66, No. 2, p. 467, Abstract, April, 1976.

"Measurements of ground motion generated by nuclear explosions in Nevada have been completed for 99 locations in the San Francisco Bay region, California. The recordings show marked amplitude variations in the frequency band 0.25 to 3.0 Hz that are consistently related to the local geological conditions of the recording site. The average spectral amplifications observed for vertical and horizontal ground motions are, respectively: (1,1) for granite, (1.5, 1.6) for the Franciscan Formation (3.0, 2.7) for the Santa Clara Formation, (3.3, 4.4) for alluvium, and (3.7, 11.3) for bay mud. Spectral amplification curves define predominant ground frequencies in the band 0.25 to 3.0 E for bay mud sites and for some alluvial sites. Amplitude spectra computed from recordings of seismic background noise at 50 sites do not generally define predominant ground frequencies.

"The intensities ascribed to various sites in the San Francisco Bay region for the California earthquake of April 18, 1906, are strongly dependent on distance from the zone of surface faulting and the geological character of the ground. Considering only those sites (approximately one square city block in size) for which there is good evidence for the degree of ascribed intensity, the intensities for 917 sites on Franciscan rocks generally decrease with the logarithm of distance as

"Intensity = 2.69 - 1.90 log (Distance in kilometers). (1)

Branner, J. C., Earthquake of March 20, 1861, Mendoza, Argentina, Bulletin of the Seismological Society of America, Vol. 1, No. 2., p. 41, June 1911.

"One of these areas is on the plains about Uspallata half way between Mendoza and the pass over the Andes. But the Uspallata plain is a flat-floored mountain valley filled to a great depth with loose water-soaked materials, and it seems probable that the high intensity at Uspallata was due to these local favorable conditions.

"The great loss of life at Mendoza is to be attributed to high intensity due to water in the incoherent deep gravels on which the city was built in combination with the character of the buildings."

Staunton, W. F., Earthquake of June 11, 1887, Southern Arizona, Bulletin of the Seismological Society of America, Vol. 8, No. 1, p. 26, March 1918.

"Engineering and Mining Journal of June 11, 1887, covering surface effects in southern Arizona.

"It appears to be well established that the vibrations were of sufficient intensity to constitute a fair working test of what earthquake vibrations might be expected to do to mine workings in their paths. At that time the mines of Bisbee and Tombstone were very extensively opened, and there were many miles of underground workings, including many large cavernous open stopes in the limestone, with little timbering. Notwithstanding these conditions, the actual damage underground was only trifling, while on the surface the shocks were sufficient to cause plaster to fall, to throw down chimneys, and disarrange foundations so as to require the resetting of engines."

Loram, S. H., Earthquake of December 1903, Canutillo, Chile, Bulletin of the Seismological Society of America, Vol. 2, No. 4, p. 244, December 1912.

"The first shock did relatively little damage because the district is thinly populated. Moreover, the houses are only one story high, and constructed either of light plastercovered framework or of adobe with walls a meter thick. Many of the latter, however, were cracked badly enough to render them quite useless. The damage to buildings standing on alluvium was very much greater than the damage to those on rock foundation; of the stone walls there were very few left standing."

"For sites on other geological units, intensity increments, derived from this empirical relation, correlate strongly with the Average Horizontal Spectral Amplifications (AHSA) according to the empirical relation

$$\text{Intensity Increment} = 0.27 + 2.70 \log (\text{AHSA}). \qquad (2)$$

"Average intensity increments predicted for the various geological units are -0.3 for granite, 0.2 for the Franciscan Formation, 0.6 for the Great Valley sequence, 0.8 for the Santa Clara Formation, 1.3 for alluvium, and 2.4 for bay mud. The maximum intensity map predicted on the basis of these data delineates areas in the San Francisco Bay region of potentially high intensity for large earthquakes on either the San Andreas fault or the Hayward fault. The map provides a crude form of seismic zonation for the region and may be useful for certain general types of land-use zonation."

Vickery, Frederick P., Earthquake of April 18, 1906, San Francisco, Bulletin of the Seismological Society of America, Vol. 11, No. 1, p. 81, March, 1921.

"Experience shows that damage done by destructive earthquakes is much greater on alluvial soil than on solid rock....Probably the best example we have is the city of San Francisco itself, which was built variously on solid rock, on sand, on natural alluvium, and on 'made ground.' The description of the destruction done in the city shows that within its limits the character of the foundation was a far more potent factor in determining the damage done than nearness to the fault line. This is not a question of transmission of vibrations, for, on account of the higher elasticity of solid rock, it would transmit vibrations far better than alluvium."

Vickery, Frederick P., Earthquake of April 18, 1906, San Francisco, Bulletin of the Seismological Society of America, Vol. 11, No. 1, p. 82, March, 1921.

"At a later point in the same chapter Mr. Reid states 'that the damage on small marshes may represent an acceleration as much as 12 times as great as on solid rock; on made land, from 4.4 to 11.6 times as great; on loose sand, from 2.4 to 4.4; and on sandstone, from 1 to 2.4. Although it has been well known that the apparent acceleration on soft land is much greater

than on rock, the ratios obtained seem very much greater than had been suspected.'

"In regard to cities situated on alluvium at a considerable distance from the source of the shock, Mr. Reid finds that such cities as Sacramento, San Jose, Willits, and Salinas, as well as the west side of the San Joaquin Valley, suffered from two to sixteen times as intensely as if the ground on which they stood had been solid rock."

Branner, J. C., Earthquake of January 14, 1907, Kingston, Bulletin of the Seismological Society of America, Vol. 1, No. 2, p. 43, June, 1911.

"...The city is built upon an alluvial fan that slopes gently seaward from the base of the high mountains a few miles north of the city. The town known as Port Royal stands upon a long slender spit that rises but little above tide level. I have not been able to obtain a map showing the distribution of intensities at the time of the earthquake of January, 1907, but inquiries made by me in that city in March, 1908, show that it is a matter of common information that the serious damage done by that earthquake was confined to the low ground, apparently of incoherent materials, and near the water."

Reid, Harry Fielding, and Stephen Taber, Earthquake of October 11, 1918, Puerto Rico, Bulletin of the Seismological Society of America, Vol. 11, No. 4, p. 97, December, 1919.

"The apparent intensity was always greater on the alluvial soils than at corresponding points on rock or residual soil, and this effect was most noticeable on alluvial soils where the ground water stood close to the surface."

Reid, Harry Fielding, and Stephen Taber, Earthquake of October 11, 1918, Puerto Rico, Bulletin of the Seismological Society of America, Vol. 11, No. 4, p. 101, December, 1919.

"The destruction of property was greater proportinately in Aguada and Añasco than in any other towns, while between them lies Rincón, which suffered comparatively little. All three of these towns are located close to the west coast of Porto Rico, but

Añasco is about twelve kilometers farther from the origin than the other two. Aguada and Añasco are both built on flat alluvial ground, only seven or eight meters above sea level, and the ground water stands from one to three meters below the surface. The relative immunity of Rincón is to be explained partly by its location on rock and residual soil, and partly by the character of its buildings, most of which are of concrete or of wood and are only one story in height. Such buildings suffered little injury at any place.

"At both Aguada and Añasco several concrete buildings of fair material, having walls fifteen to twenty-three centimeters thick, with little or no reinforcement, were badly cracked and even partly thrown down. Other buildings, one and two stories in height, built of good concrete and well reinforced with steel rods, were uninjured except for a few small cracks. The school houses were of ferroconcrete, and they were practically uninjured. Buildings constructed of mamposteria and of brick were largely demolished...and the walls that remained standing were in most cases so badly cracked as to make their removal necessary. Wood-frame buildings were not damaged except in a few instances where the timbers had been eaten out by insects or had rotted."

Reid, Harry Fielding, and Stephen Taber, Earthquake of October 11, 1918, Puerto Rico, Bulletin of the Seismological Society of America, Vol. 9, No. 4, p. 102, December, 1919.

"...The relatively high intensity at Mayaguez is due to the fact that much of the town is built on alluvial ground, which is in places saturated with water."

Reid, Harry Fielding, and Stephen Taber, Earthquake of October 11, 1918, Puerto Rico, Bulletin of the Seismological Society of America, Vol. 9, No. 4, p. 103, December, 1919.

"Cayey, located in the mountains at an altitude of 380 meters (1247 feet), is built on rock and residual soil. The intensity here was about the same as at San Juan. At Caguas the apparent intensity was a little higher, although it is farther from the origin than San Juan or Cayey. Caguas, however, is built on the alluvial soil of a broad, flat valley floor, and water is encountered at depths of from one and one-half to four meters below the surface.

"At Humacao, near the eastern end of the island, the apparent intensity, between VI and VII, was much higher than at other neighboring towns. Humacao is built on a broad alluvial plain surrounded by steep foot-hills and mountains, which come down close to the town, and the water table is said to stand within one to one and one-half meters of the surface. The Municipal Building and the Catholic Church, both of which are built of mamposteria, were rather badly cracked, and several houses were slightly injured. Yabucoa, only twelve kilometers southwest of Humacao, is located on a low hill, the surface of which is covered with residual soil derived from underlying granite, and the town suffered almost no damage from the earthquake."

Kemnitzer, William, Earthquake of July 24, 1921, Central California, Bulletin of the Seismological Society of America, Vol. 11, Nos. 3 and 4, p. 189, September-December, 1921.

"...At this point, which is on firm rock, the shock was generally felt by everyone; persons asleep were wakened; movable objects were overturned; and milk was thrown from open pans. Practically every person in the region of highest intensity said the tremors were preceded by a distinct rumbling sound, somewhat like that of a fast-moving train.

"More or less equidistant from the epicenter are the towns of Gilroy, Watsonville, Salinas, and Hollister. These towns are built upon alluvium, and, without exception, the intensity of the shock in these places was somewhat higher than at places at equal distances from the epicenter that were on solid rock."

Jaggar, T. A., Earthquake of September 1, 1923, Yokohama, Tokyo, Japan, Bulletin of the Seismological Society of America, Vol. 13, No. 4, p. 134, December, 1923.

"...In Tokyo there were persons in well built low houses in the hilly suburbs who thought the main earthquake no greater than the shock of April, 1922, and who were surprised to learn of a great disaster in the lowlands of the city."

Jaggar, T. A., Earthquake of September 1, 1923, Yokohama, Tokyo, Japan, Bulletin of the Seismological Society of America, Vol. 13, No. 4, p. 141, December, 1923.

"At Akasaka Hill our way lay through a residential section, with small shops bordering each side of the

main street. As we left the burning district behind we observed the damage to buildings was slight compared with damages down in town. Our lane was filled with debris of our neighbor's brick wall."

Jaggar, T. A., Earthquake of September 1, 1923, Yokohama, Tokyo, Japan, Bulletin of the Seismological Society of America, Vol. 13, No. 4, p. 144, December, 1923.

"Construction in general is a matter of building codes and sites, and soft ground is much more dangerous than rocky ground..."

Anderson, Robert, Earthquake of September, 1923, Tokyo, Japan, Bulletin of the Seismological Society of America, Vol. 15, No. 2, p. 100, June, 1925.

"1. The comparative weakness of the earthquake of September 1923, at least in Tokyo, in comparison with the idea that one forms of the magnitude of the catastrophe.

"2. The striking evidence that intensity of the shocks was magnified on low, alluvial, water-soaked ground, and that destructivity was far less on slightly elevated ground."

Anderson, Robert, Earthquake of September, 1923, Tokyo, Japan, Bulletin of the Seismological Society of America, Vol. 15, No. 2, p. 101, June, 1925.

"The great contrast in destructivity of the earthquake in deposits of these two types, not markedly different in origin and character, is probably in the main due to the difference in quantity and depth of the water content, and is an eloquent illustration of the importance of this..."

Nunn, Herbert, Earthquake of June 29, 1925, Santa Barbara, California, Bulletin of the Seismological Society of America, Vol. 15, No. 4, p. 317, December, 1925.

"The nature of the ground beneath the building was also an important factor, as buildings constructed over swampy ground, or on sand, regardless of the type of construction, were damaged more than buildings of similar type constructed over clay, or other solid materials."

Nunn, Herbert, Earthquake of June 29, 1925, Santa Barbara, California, Bulletin of the Seismological Society of America, Vol. 15, No. 4, p. 319, December, 1925.

"1. Unstable ground should be avoided when possible; but if it is necessary to construct on swampy or sandy land, additional precautions should be taken to secure good footings through the use of piling, or reinforced concrete."

Hudgson, Ernest A., Earthquake of February 28, 1925, St. Lawrence Valley, Bulletin of the Seismological Society of America, Vol. 15, No. 2, p. 87, June, 1925.

"The damage in the city of Quebec was confined to the section known as lower town, bordering the St. Lawrence or St. Charles rivers where the depth of soil is considerable. The damage in the rocky section of upper town was nil."

Hudgson, Ernest A., Earthquake of February 28, 1925, St. Lawrence Valley, Bulletin of the Seismological Society of America, Vol. 15, No. 2, pp. 87 and 88, June, 1925.

"...The sheds stand on the filled land sixty-six feet deep and within a hundred feet of the river.

"The sheds were empty at the time of the earthquake. The movement of the earth to the north and west and the shaking caused the fill to settle and a crack about an inch and a half wide opened between the sheds and the edge of the wharf in the then frozen earth. Inside the building a similar crack ran for several hundred feet, parallel to the length and about twenty feet from the north wall...."

Hudgson, Ernest A., Earthquake of February 28, 1925, St. Lawrence Valley, Bulletin of the Seismological Society of America, Vol. 15, No. 2, pp. 89 and 90, June, 1925.

"The chief damage in the area was found in two old stone buildings-one a jail, the other an ancient seigniorial manor. Both are built with thick stone walls; both stand on deep sand slopes; and both are badly cracked.... The church at Malbaie has a massive stone front with stucco side walls. It might be expected that the stone would pull away from the plaster walls. But the building stands on rock and no damage has resulted."

Hudgson, Ernest A., Earthquake of February 28, 1925, St. Lawrence Valley, <u>Bulletin of the Seismological Society of America</u>, Vol. 15, No. 2, p. 90, June, 1925.

"The mountainous nature of the country north of the St. Lawrence is in striking contrast with the deep alluvial soil of the valleys of the south shore. It is believed that the comparative freedom from damage found at Baie St. Paul may be credited to the nature of the terrain and to the fact that the heavy buildings, church, hospital, etc., are comparatively new and are very well built."

Hudgson, Ernest A., Earthquake of February 28, 1925, St. Lawrence Valley, <u>Bulletin of the Seismological Society of America</u>, Vol. 15, No. 2, p. 91, June, 1925.

"Two old stone houses in the district of Rivere Ouelle were badly damaged. They had to be abandoned. Stone houses are not very common in this section. Those that do appear are generally old. In spite of the fact that these two houses on deep soil were completely damaged, other houses, some equally old and within twenty-five miles of this same place were not injured. They stood on rocky ground. Thus the damage here was due to the terrain and type of construction as well as proximity to the epicenter. The frame houses are, in general, without plaster."

Hudgson, Ernest A., Earthquake of February 28, 1925, St. Lawrence Valley, <u>Bulletin of the Seismological Society of America</u>, Vol. 15, No. 2, p. 91, June, 1925.

"Great icicles were common in Quebec city at the time of the earthquake. They were not displaced by it. The keeper of a little notion store in full view of some extra large specimens assured me that they had been there at the time of the earthquake. He said he didn't believe there had been much of an earthquake. It was all newspaper talk. Nothing had fallen in his shop and he hadn't noticed the tremor. He was quite sincere. His store was within a quarter of a mile of the damaged harbor works but was on the solid rock of the cliff."

Abbott, C. D., Earthquake of February 28, 1925, St. Lawrence Valley, <u>Bulletin of the Seismological Society of America</u>, Vol. 16, No. 2, p. 133, June, 1926.

"...The intensity at Quebec must also have been nearly VIII in parts of the 'Lower Town,' while on the rock

formation of 'Upper Town' icicles on buildings were not dislodged. On the tops of the clay ridges at Shawinigan Falls the intensity seems to have been somewhat less than VIII, while in the well-drained valleys nearer rock the damage was inconsequential and indicates an intensity not greater than VI. At Three Rivers the intensity appears to have been about VII."

Abbott, C. D., Earthquake of February 28, 1925, St. Lawrence Valley, Bulletin of the Seismological Society of America, Vol. 16, No. 2, p. 139, June, 1926.

"All noteworthy damage was to structures on the tops of the clay ridges. A peculiarity was the fact that walls of several buildings were shaken. The Shawinigan Water and Power Company's brick buildings, are founded on rock and received no injury."

Abbott, C. D., Earthquake of February 28, 1925, St. Lawrence Valley, Bulletin of the Seismological Society of America, Vol. 16, No. 2, p. 142, June, 1926.

"The Power Houses Nos. 1 and 16 are located less than 300 feet north of the south end of the main plant, at about 160 feet lower elevations, and are understood to be founded on rock. These buildings also have pitched roofs on steel trusses, much like the buildings of the main plant. However, they received no injury, probably because they were on rock."

Abbott, C. D., Earthquake of February 28, 1925, St. Lawrence Valley, Bulletin of the Seismological Society of America, Vol. 16, No. 2, p. 144, June, 1926.

"1. Deep alluvial deposits like those at Three Rivers and high unstable ridges like those at Shawinigan Falls are particularly susceptible to earthquake vibrations. Buildings founded on rock are unlikely to be damaged by an ordinary shock."

Dewell, Henry D., and Bailey Willis, Earthquake of June 29, 1925, Santa Barbara, California, Bulletin of the Seismological Society of America, Vol. 25, No. 4, p. 298, December, 1925.

"(5) The nature of the ground affects the destructive intensity of any given shock. In loose dry ground the initial push may be damped to some extent, but the soil is apt to shake down in the following vibrations. In loose, water-filled ground the initial

shock is transmitted with full force on account of the rigidity of water and the subsequent shaking is of large amplitude because the material offers but little elastic resistance to distortion. The effect of the combined shocks diminishes in dangerous character as the elastic resistance of the foundation material increases, so that a structure built on firm rock is not likely to suffer damage, unless very weak or very near the fault of origin of the earthquake.

"(6) From the preceding it follows that a structure, which is necessarily placed on poor foundation material (or which is located near a fault) should be designed to resist correspondingly violent movements."

Bodle, R. R., Earthquake of August 12, 1925, St. Lawrence Valley, Earthquake Notes, Vol. 1, No. 2, p. 5, October 25, 1929.

"Mr. W. M. Dawley who made a special investigation in the region reports that he was strongly impressed with the narrow limits of material damage which occurred almost entirely on high level ground and over a bed of glacial till, probably about forty or fifty feet thick. A map which he has very kindly furnished is shown below. The dotted line surrounds the area which Mr. Dawley thinks was most severely affected."

Wood, Harry O., Earthquake of March 10, 1933, California, Bulletin of the Seismological Society of America, Vol. 23, No. 2, p. 50-51, April, 1933.

"Inside the area mentioned there are many places where significant damage was not conspicuous-on hilly ground or where underground conditions were not unfavorable and construction not too bad or unsuitable. This was noticeably the case on the compact sedimentary rock of the San Pedro Hills west of Long Beach. In fact a considerable part of the area appeared to be characterized by intensity lower than grade VII of the 1931 scale. Even in the most vigorously shaken areas excellent construction on well-chosen or well-prepared foundations suffered relatively little, even at Compton where the proportion of damaged structures was greatest and the scene of destruction the most spectacular. Many chimneys remained standing in districts where general damage was conspicuous; but in a hurried survey there was no time to ascertain whether these were wholly undamaged.

"Thus it is obvious, as on previous occasions, that much of the spectacular structural damage was due (1) to bad natural ground or grading-made land, or deep water-soaked alluvium or sand; and (2) to bad or unsuitably designed construction-bad foundation structures, little or no provision against the stresses caused by earthquakes, bad or unsuitable materials, bad workmanship, or some combination of these factors. These unfavorable conditions appear to have been more prevalent than usual. Serious structural damage resulted at many places well distributed throughout the area outlined. It was markedly greater in business districts than in the surrounding or adjoining residential districts...."

Wood, Harry O., Earthquake of March 10, 1933, Bulletin of the Seismological Society of America, Vol. 23, No. 2, p. 52, 1933.

"Nevertheless it must be emphasized here that as was so conspicuously the case in San Francisco in 1906, and in practically all other cases also, the localities marked by conspicuous and extensive damage which are situated at several miles' distance from the epicenter, so accurately determined in this instance, are places where the natural ground is bad--made ground or loose alluvium, heavily charged with water in most spectacular effects were seen. Compton, Willowbrook, Lynwood, Southgate, Huntington Park, and near-by points where the damage was very considerable are on ground formerly marshy in part, along Compton Creek and the former courses of the Los Angeles River, with deep deposits of loose, wet alluvium beneath. In places today water extends nearly to the surface. Santa Ana and other places badly damaged near by are on the plain built by the shifting of the Santa Ana River. Bad ground, and unsuitable or bad building, characterized all these places. Now in San Francisco in 1906 it was demonstrated conclusively that the more serious damage was intimately associated with the bad foundation ground. It was strikingly clear that the 'apparent' intensity was greatly less on rock on Telegraph Hill than on made land near the Ferry Building, both about fifteen kilometers (9½ miles) from the known fault source of the shaking. The 'apparent' intensity on rock at the Cliff House and on rock near Colma, four to five kilometers (2 to 3 miles) from the fault, was much less than at the Ferry Building on the made land. Other similar variations were very evident...."

Wood, Harry O., Earthquake of March 10, 1933, Bulletin of the Seismological Society of America, Vol. 23, No. 2, p. 53, 1933.

"Along the shore between Long Beach and Newport Beach, and in a few localities near by a short distance inland, road fills across marshy land, and similar earth construction resting on wet sand or mud, settled, shook apart, or moved laterally, causing considerable damage to the concrete highway surfaces, and to the approaches to highway bridges, which, being better founded, were less affected...."

Callaghan, Eugene, and Vincent P. Gianella, Earthquake of January 30, 1934, Nevada, Bulletin of the Seismological Society of America, Vol. 75, No. 2, pp. 164-165, April 1935.

"This earthquake provided an opportunity to obtain data on the relative perception of shocks on the surface of the ground and underground in the mines. As the principal shock occurred during the noon hour when most of the miners were at the surface, no data on it are available. The miners were all agreed, however, that such shocks as they felt were stronger at the surface than underground. Miners in a tunnel at Marietta reported that they felt obliged to steady themselves during the strong foreshock but were less concerned about the shock and heard less noise than persons at the surface. Miners at Silver Dike scarcely noticed shocks underground that were acutely perceptible to those at the surface. It seems probable that the difference in perception of shocks between the surface and underground may be related to a decrease in amplitude of surface earthquake waves with depth much as the amplitude of water waves decreases from the surface downward."

Engle, H. M., Earthquake of October 1935, Montana, Bulletin of the Seismological Society of America, Vol. 26, No. 2, pp. 102-103, April 1936.

"The mercantile district follows Last Chance Gulch and extends somewhat into the alluvium of the valley to the north. Many of the buildings in the gulch are on rock or close to rock. On the west side of the gulch and against the slope of Mount Helena is a newer residential area; over most of this area structures are on or close to rock....

"...The worst wreckage occurred in structures on the alluvial soil toward the valley: the new High School and the Bryant School were completely shattered, several mercantile buildings were wrecked, and two buildings at Intermountain Union College were seriously damaged...."

Fisher, N. H., Earthquake of January 11, 1941, Gazelle Peninsula, Bulletin of the Seismological Society of America, Vol. 34, No. 1, p. 5, January 1944.

"Perhaps even more informative was the distribution of the intensity of the shock. Here too allowance had to be made for various factors which might affect the apparent intensity, the principal of these being probably the geological structure of the country. Buildings on solid rock or other firm foundation showed much less effect than those on alluvium, on made ground, or on pumice, particularly if the underlying material was not well consolidated...."

Berkey, Charles P., A Geological Study of The Massena-Cornwall Earthquake of September 5, 1944 And Its Bearing on the Proposed St. Lawrence River Project, New York, pp. 7-9, April 10, 1945.

"The accuracy of these limits is complicated by the fact that the effects of the earthquake are much more pronounced in those local areas which are underlain by marine clays and mixed silts than those underlain chiefly by other types of ground. Wherever the marine clays or silty sands occur chiefly in a considerable body there is much more evidence of destructive movement than in adjacent areas underlain by other types of ground, no matter where they are situated.

"Furthermore, because of their manner of origin, there are different patterns of distribution of the different members of the overburden. The larger features take the form of ranges of hills separated by shallow valleys, while the smaller features form irregular patches of elevated and low-lying ground. The major valley-like belts are followed by the streams, all of which exhibit the same pattern with a general trend nearly parallel to the St. Lawrence River itself, while the minor features of patch-like pattern show no uniformity whatever. In all cases, however, the low areas of whatever form are the places where the loose marine silty clays are formed and here the principal destructive effects of the earthquake were registered.

"Thus it happens that even in Cornwall itself, the major destructive effects are distributed along a central zone or strip rather than over the whole city. A belt through the central portion is known to be underlain by marine clays and associated silts and this is the part of the city that was most affected by the earthquake.

"The same principle is recognized over the whole area of disturbance. Although certain cemeteries, for example, are so badly affected that a majority of the monuments show displacement, there are in the immediate vicinity other cemeteries, but on different quality of ground, which show very little destructive effect of any kind. The same observation applies to buildings and the same would be true of larger installations such as engineering works if there had been such works in place.

"The difficulty in drawing the area more definitely is the fact, as already explained, that surface disturbance depends largely on the quality of the overburden,--the looser the material the more easily disturbed it is; and this difference is prominently shown in the different parts of the area under observation. Virtually all badly disturbed or violently shaken or much damaged buildings or other structures are located on either loose silty outwash or silt-clay marine deposits. No buildings or other structures located on heavy glacial till were destroyed or badly damaged.

"The most striking differences of behavior may be observed in neighboring cemeteries. Those located on the loose marine deposits are badly wrecked within the area indicated, whereas those located on comparatively compact till have suffered little damage. That is true over the whole area and makes it somewhat difficult to compare different parts of the region one with another and to draw boundaries accurately.

"In Cornwall itself, which appears to have been violently shaken, there are three cemeteries located on comparatively loose silty and sandy clays and all three show many dislocated monuments, whereas one cemetery located just on the east margin of the village is virtually not damaged at all. When this discrepancy was noticed and the ground was inspected further, it was found that this cemetery was located on ground of entirely different quality from the others."

Houtz, R. E., The 1953 Suva Earthquake and Tsunami, Bulletin of the Seismological Society of America, Vol. 52, No. 1, p. 5, January 1962.

"Most of the earthquake damage occurred in Suva and was usually caused by the settling of made ground. The effects were most severe where structures were situated partly on bedrock and partly on fill; invariably the damage resulted from differential settlement. Damage resulted to a lesser extent where two types of soil were used under different parts of the structure, for instance, gravel and clay. Buildings situated exclusively on marl bedrock were little damaged, although projecting bedrock intensified the motion by the effect of unrestrained vibration at the extremities of the outcrop. Similarly, structures on ridges suffered more harm than those sited on the same material in flat areas. Greater damage was incurred on alluvium and made ground than on bedrock. The foregoing information was outlined by the Government Architect in an unpublished report."

Shor, George G., Jr., and Ellis Roberts, Earthquake of February 1956, San Miguel, Baja, California, Bulletin of the Seismological Society of America, Vol. 48, No. 2, pp. 112 and 114, April 1958.

"B-2. Rancho Mezquite. Alluviated area, about one mile from granite outcrop, One-room adobe-block house badly damaged, west wall leaning outward away from the rest of the building, chimney fallen, northeast corner of building badly cracked....

"B-2. Ranch 1.7 miles north of Rancho Mezquite turnoff; granite area. No visible damage from outside of adobe-block house.

"...The hills on the northeast side of the valley are granite with small patches of metamorphics. The fault trace lies at the base of these hills, separating granite from alluvium. On the southwest side of the valley are volcanic hills. Three adobe houses on alluvium 100 to 200 yards southwest of the fault trace collapsed completely, the walls falling roughly northwest. Failure was through the mud between the blocks; most of the blocks were intact. Like all the other adobe houses in the area, these had no foundations (blocks laid directly on the soil) and only mud between the blocks. The roofs were light-weight (corrugated steel or thatch) with a minimum of wood bracing. One brush-and-mud shack on alluvium and the other on granite survived with only some mud cracked off."

Poceski, Apostol, Earthquake of July 26, 1963, Skopje, Yougoslavia, Bulletin of the Seismological Society of America, Vol. 59, No. 1, p. 1, February 1969.

"The effects of soil characteristics on the intensities of earthquakes have been often observed. It is well known that the amplitude of ground motion on the surface can be increased several times over that on basement rock. These effects depend on the thickness and softness of the surficial layer; the softer the layer, the greater is the amplification.

"There have been many examples of soft deposits being the main cause of very intensive earthquake damage. The following may be mentioned as recent examples: the 1964 Anchorage earthquake, where the main cause of destruction was landslide and subsidence of ground (Scott, 1965; Steinbrugge, 1965); the 1964 Niigata (Japan) earthquake, where the main cause of destruction was subsidence, sliding and liquefaction of the sandy soil (Japan Nat. Comm., 1965); and the Mexico earthquake of 1957, when soft soil in Mexico City caused a several fold increase in the intensity (Rosenblueth, 1960)."

Wallace, Robert E., Earthquake of August 19, 1966, Eastern Turkey, Bulletin of the Seismological Society of America, Vol. 58, No. 1, p. 12, February 1986.

"Of 14 relatively new buildings of reinforced concrete situated on the old river channel, 12 collapsed and one other was very seriously damaged. In contrast, all 12 buildings of similar construction situated on the bench to the northeast remained standing--some were essentially undamaged and others were only slightly damaged. Many chimneys were not even thrown down. Inasmuch as most of the buildings on the old channel were two stories high, a comparison should be made between the one-story buildings on the two sites. A small one-story building, on the western side of the complex near the middle of the channel was damaged beyond repair and near collapse. On the other hand, some similar one-story buildings on the highest part of the bench were almost unharmed. The conclusion seems to be that there was a decided difference in the shaking on the two sites, but whether the difference was in amplitude, spectrum, or duration could not be determined.

"...it can be noted that, in general, damage was less intense in the higher topographic areas than in the lower part of the city. In the higher areas, many buildings remained standing, and even some of those most susceptible to earthquake damage only partially collapsed."

Lee, Kenneth L., and Joaquin Mongee, Earthquake of October 17, 1966, Peru, Bulletin of the Seismological Society of America, Vol. 58, No. 3, pp.945-946, June 1968.

"In general, both the adobe and the quincha houses on sedimentary soil were damaged to degree 3 to 4. In LaMolina where the soil was soft clay, and on artificial fills along the banks of the Rimac River, the damage was of the order of degree 4 to 5. However, on the slopes of the hills that surround the city of Lima, where the foundations were essentially sound rock, the damage was considerably less: of the order of degree 1 to 2.

"...There was virtually no damage to these types of houses which were built on the hill slopes on sound rock foundations. When founded on sedimentary soils in the Lima area, the damage was of the order of degree 1 to 2. On poor fill material the degree of damage was as high as 3."

Ortiz, Francisco, Earthquake of December 28, 1966, Chile, Bulletin of the Seismological Society of America, Vol. 58, No. 3, p. 857, June 1968.

"Taltal lies at the mouth of Quebrada de Taltal. It is built mostly on poorly consolidated sand and gravel deposits representing valley-floor alluvium and associated stream terrace deposits, which rise to a height of about 10 m above the valley floor. A small part of the town is built on bedrock. A strip of artificial fill has been emplaced along the beach. The trace of the Atacama fault trends across the southern part of town, approximately along Martinez Street.

"The few buildings constructed on bedrock sustained no recorded damage. Otherwise, no clear-cut relation could be established between geology and damage to manmade structures in the town, except that there is a slight indication that damage was greatest in the area underlain by aritificial fill along the ocean front and along the trace of the Atacama fault. A small swale developed in a small hole opened along the trace--presumably due to subsidence of a filled prospect pit."

Guha, S.K., P. D. Gosavi, and S. C. Marwadi, Earthquake of October 29, 1968, Koyna, Fifth World Conference, Vol. 1, p. 493, 1973.

"...From the analyses of seismograms of a few selected local tremors equidistant from each of the four identical electromagnetic seismographs working in the Koyna seismograph net it could be inferred that the recorded amplitude of ground motion is governed by the nature of local foundation material and is amplified about twice and four times on literitic and alluvial foundations respectively when compared to basaltic foundations(1). Nature and extent of damages to structures in the present earthquake have corroborated these observations...."

Gordon, David W., Theron J. Bennett, Robert B. Herrmann, and Albert M. Rogers, The South-Central Illinois Earthquake of November 9, 1968: Macroseismic Studies, Bulletin of the Seismological Society of America, Vol. 60, No. 3, p. 966, June 1970.

"The intensities associated with the November 9 earthquake substantiate the often-observed relation between intensity and ground conditions: relatively high intensity corresponds to topographically low areas underlain by thick, saturated sediments; relatively low intensities are experienced in dry upland areas underlain by bedrock at shallow depth...."

Gordon, David W., Theron J. Bennett, Robert B. Herrmann, and Albert M. Rogers, The South-Central Illinois Earthquake of November 9, 1968: Macroseismic Studies, Bulletin of the Seismological Society of America, Vol. 60, No. 3, p. 964, June, 1970.

"At Braden, a crossroads on bottomland (elevation 460 ft) 7 miles west of Dale, the earthquake cracked plaster and toppled the TV antenna on the roof of the Robert Sturm residence. Extensive china and glassware breakage occurred inside the Sturm home. An older home nearby lost its chimney. During the earthquake, waves with crests moving east to west were observed on Lake Jay, an artificial lake ¼ mile wide adjacent to Braden. No apparent damage was evident at Flannigan School, located in the hills (elevation 560 ft) 1 mile west of Braden, or at the Shell Rural Hill water flood plant (elevation 540 ft) 1 mile northeast of Braden."

Guha, S. K., P. D. Gosavi, and S. C. Marwadi, Earthquake of April 13, 1969, Kothagudem, <u>Fifth World Conference</u>, Vol. 1, 1973.

"...Decrease of intensity at least by one unit in MM Scale (from VI to V or IV) could be observed while crossing over the boundary between less elastic sedimentary formations to highly elastic crystalline rocks...."

Nazarov, A. G., B. K. Karapetian, N. K. Karapetian, V. L. Maatsakanian, S. A. Pirouzian, D. N. Roustanovich, S. A. Shahinian, and L. V. Shansouvarian, Earthquake of 1969, Zanghezour, <u>Fifth World Conference</u>, p. 8, 1973.

"...Cracks in the diluvial layer on the hill-slope in the epicenter of the earthquake are shown in Fig. 1 while Fig. 2 illustrates heavily damaged two-storey hospital building in the town of Kajaran...."

Guha, S. K., P. D. Gosavi, and S. C. Marwadi, Earthquake of March 23, 1973, Broach, <u>Fifth World Conference</u>, Vol. 1, p. 495, 1973.

"...Residential buildings in Broach town situated in localities where the underlying soil was moist and slumpy suffered heavy damages while structures resting on comparatively hard and dry soil in the same area escaped with only moderate to slight damages...."

Ballinger, G. A., C. J. Langer, and S. T. Harding, Eastern Tennessee Earthquakes from October to December, 1973, <u>Bulletin of the Seismological Society of America</u>, Vol. 66, No. 2, p. 525, April, 1976.

"...The intensity VI locations in Alcoa were on filled land, but the northeast-trending VI zone through Maryville is in line with the local surface faults and a local topographic ridge. Focusing by the topography is a possibility here (see, e.g., Boore, 1972; Rogers et al., 1974).

"Main-shock focal mechanism solutions. Seventeen P-wave first motions were obtained for the main shock of November 30, 1973. Sixteen of these readings are within P_n range,..."