DPST-78-424

PARAMETRIC STUDY OF THE EFFECT OF SOUTHEASTERN EARTHQUAKES ON THE SRP SITE

by

D. E. STEPHENSON
and
I. W. MARINE

November 20, 1978

Savannah River Laboratory
Aiken, South Carolina

This document was prepared in conjunction with work accomplished under Contract No. DE-DE-AC09-76SR00001with the U.S. Department of Energy.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Appendix A to 10 CFR 100 provides guidelines to be followed by an applicant to NRC for determining the seismic design of nuclear facilities. Following their guidelines has led to seismic designs of 0.10 to 0.25 g (g = the acceleration of gravity) for nuclear facilities in the South Carolina and Georgia area; the seismic design for SRP is 0.20 g.

The U. S. Army Corp of Engineers with the help of the U. S. Geological Survey, has independently developed a method of determining seismic design. Using this method the Corps developed a seismic design of 0.4 - 0.5 g for the Richard B. Russell Dam on the Savannah River. This seismic design has been criticized as being too low; 0.85 g or perhaps as high as 1.0 to 1.5 g has been suggested as being appropriate.

Thus, from essentially the same geologic and seismologic data different results are possible. The development of seismic design is thus not clearly demonstrable but is an evaluation that is arrived at by consensus and by regulatory process.

The major part of this document is a parametric study that determines the design accelerations that would be developed for SRP depending on: (1) three different assumptions on the location of the earthquake: (a) at its historic position, (b) at the edge of its seismotectonic province, and (c) at SRP; (2) six different attenuation relationships; and (3) eight different relationships between intensity and acceleration. The earthquakes used are the Charleston earthquake of 1886 (MM = X), the Union County earthquake of 1913 (MM = VII), the Wilmington, North Carolina, earthquake of 1958 (MM = VI), and a hypothesized earthquake on the Belair fault northwest of Augusta, Georgia. Depending on the assumptions and relationships used, the intensity at the SRP site may range from VI to X and accelerations from 0.03 g to 2.8 g. This is a parametric study and no recommendation is given as to which specific set of assumptions and relationships is most reasonable or which should be used in seismic design.

A probabilistic seismic hazard analysis, using the different assumptions on the location of the earthquakes, two selected attenuation relationships and three selected recurrence relations, was made for SRP using the method of McGuire (1976). The annual probability was found to be dependent on the seismic source area used and very dependent on the attenuation relationship used to calculate the probability. The annual probability varied by one or two orders of magnitude for a given intensity as a function of the attenuation relationships used.

INTRODUCTION

In safety analyses of both existing facilities and proposed facilities the effects of earthquakes must be considered. The evaluation of safety relative to earthquakes is a difficult and much argued subject throughout the nation. An additional uncertainty is present when evaluating the effects of earthquakes in the southeastern U. S. because the temporal and spacial occurrence of these earthquakes is poorly understood. In general, it is agreed that different areas differ in their seismic potential and that this should be recognized in seismic design. Yet the long time scale of earthquake recurrence in some areas leads to some uncertainty in using the historic record to assess the area's seismic potential. In addition, there are temporal changes in the seismic potential of some areas, and the probability that this will occur in the future is poorly understood.

Two opposing philosophies lead to different conclusions on the seismicity of an area: (1) where it's happened before it can happen again, and (2) there's always a first time. Most seismic evaluations apply philosophy (1) and attempt to base the evaluation of future seismicity on the record of the past, either historical seismicity or the geologic record of past earth movements. The science of seismology is presently devoting much effort to the study of past records in an attempt to predict the future. Most studies in the U. S. use data from California or the western U. S. as they are much more plentiful than data from the eastern U. S. However, because this is a developing science, there are many different relationships and assumptions in use. Thus, a single seismological question may have many different answers with numerous adherents, making it difficult to give a single definitive answer that will be enduring.

One should not, therefore, anticipate that a single seismic analysis will be accepted by all or forever. As the science develops, certain relationships that were acceptable may no longer be acceptable and certain assumptions may loose favor. If the acceptability were based on clearly defined fact, the matter would be easily disposed of. But acceptability in today's climate is arrived at by discussion. The rules governing some of these discussions also tend to change with time.

Designing for large seismic forces raises the cost of both existing and proposed facilities. But becoming a party to a discussion of the seismic potential of an area also raises the cost in terms of effort as well as delay. In the construction of modern nuclear facilities, many utilities have taken the position that the seismic discussion raises the cost of the facility more than the seismic design will, and thus they agree to designs that they may believe are unjustified. Sometimes the acceptance of a higher seismic design has merely raised the level of the discussion so that the utility finds it has accepted a higher seismic design than it thinks is justified and yet has not escaped being a party to an extended seismic discussion. Thus, it is a difficult decision to make as to when to accept a higher seismic design than one thinks is justified and when to draw the line and defend with great vigor one's seismic analysis. It is to assist in this decision that the following parametric study of the relationships of various seismic parameters was performed. Different assumptions and relationships are used to develop what the seismic effects at SRP would be. No specific assumption or relationship is endorsed or implied. The purpose is to elucidate that with current technology the answers to seismic question depends on the assumptions that one starts with.

DISCUSSION OF APPENDIX A TO 10 CFR 100

The NRC has the responsibility of evaluating the suitability of sites for proposed nuclear facilities with respect to seismic design. To determine the suitability of a site it is necessary to have as complete as possible a description and evaluation of the local and regional geologic, tectonic, and seismic characteristics. Criteria were developed to provide a uniform and systematic method of evaluation and assure that the information necessary for an evaluation is available by seismologists working on nuclear power plants. These criteria were developed with the knowledge that the sciences involved do not now provide precise data on earthquake occurrences, and therefore, all criteria are applied in a rather flexible but conservative manner. These criteria are also constantly being reviewed and revised as necessary when more complete information becomes available.

To assure proper design and function of a nuclear facility, the criteria established for the seismic design include the potential for the occurence of two different earthquakes. The first, or operating basis earthquake (OBE), is the earthquake which produces an intensity of ground motion for which the facility is designed to remain functional and operating. The second, the safe shutdown earthquake (SSE) or design basis earthquake (DBE), is the earthquake for which the facility is designed so that all features important to the public safety remain functional during and after the earthquake, and allow for the safe shutdown of the facility.

The determination of the safe shutdown earthquake is accomplished by a thorough review and evaluation of seismic and geologic data of the region, with particular emphasis on studying the earthquake history and the tectonic structures that might have bearing on the earthquake potential of the area. The largest magnitude or intensity earthquake that has occurred in the region is determined, and where possible is related to a tectonic structure in the region. It is then postulated that this earthquake also could occur anywhere along the tectonic structure, and the vibratory ground motion at the site is determined by assuming the epicenter to be located at the point on the structure closest to the site.

When the location of the earthquake cannot reasonably be related to tectonic structure, it is assumed that the earthquake can occur at any site located within that seismotectonic province. If the largest earthquake in the region occurs in a seismotectonic province in which the site is not located, it is assumed that the event occurs at the point on the boundary of the province closest to the site.

The vibratory ground motion from such an event is then attenuated to the site to determine the maximum value at the site. It may be necessary to evaluate the effects of several earthquakes to determine which produces the largest acceleration at the site, and this event is then designated as the safe shutdown earthquake or design basis earthquake.

The operating basis earthquake acceleration at the site is usually taken as 50 percent of the acceleration of the safe shutdown earthquake; however, it may be necessary to consider the maximum earthquake that has occurred at or near the site if this is larger than 50 percent of the acceleration produced at the site by the safe shutdown earthquake. It is considered that there is a reasonable chance that the operating basis earthquake will occur during the life of the facility.

The ground accelerations estimated for the site, resulting from the two earthquakes, are based on instrumental records derived from strong motion seismographs, when possible. However, because of the rather limited number of strong motion recorders outside California, the accelerations are generally estimated based on intensity values assigned to the earthquakes. Although intensity is a subjective measure in terms of an arbitrarily-defined scale, it has been correlated with surface accelerations. However, there is a good deal of scatter in these data and such correlations should be used with caution and conservatism. It is assumed that the intensities occurred or were estimated to occur on bedrock or well consolidated material. When the facility is located on material other than competent rock such as alluvium, the selected accelerations must be multiplied by a soil amplification factor to determine the final design accelerations.

DISCUSSION OF CORPS OF ENGINEERS DESIGN CRITERIA

In 1975, the U. S. Geological Survey developed under contract to the U. S. Army, Corps of Engineers (USACE or CE), Construction Engineering Research Laboratory, "Guidelines for Developing Design Earthquake Response Spectra." Also the USACE-Waterways Experimental Station has been developing seismic criteria as part of their studies "Methodologies for Selecting Design Earthquakes" and "Earthquake Resistance of Earth and Rock-Fill Dams." In general, the CE criteria follow the guidelines and procedures of the NRC. They list the following as the method for developing the design earthquake:

1) Study the seismic history of the area to determine the location and intensity of all felt earthquakes within a wide radius of the site (320 km - 200 miles). Using these data, establish a recurrence relationship for the area.

2) Evaluate the location and characteristics of the faults and other tectonic structures in the region to determine their potential for generating earthquakes. This establishes the causative fault or structure. The conservative approach used by the NRC may be followed, i.e., moving the earthquake location to the site of concern or to the nearest edge of the tectonic structure.

3) Determine the attenuation function for the area.

4) Using the information obtained from the previous studies, make an estimate of the maximum vibratory ground motion at the site based on an acceptable level of risk. The ground motion is determined by moving the earthquakes along the causative fault or tectonic structure to the point closest to the site and applying the attenuation relationship. If the earthquake is located in the same seismotectonic province as the site, it is moved to the site; if located in a different seismotectonic province, it is moved to the point on the province boundary closest to the site and the ground motion is attenuated to the site. The method of determining intensity and ground motion is found in the Waterways Experiment Station report.

5) Using the values of peak ground motion at the site, develop the response spectra for the site.

6) Determine the local soil amplification effects at the site by a laboratory testing program.

7) Revise the response spectra if laboratory testing results indicate that soil amplification occurs.

DISCUSSION OF CORPS OF ENGINEERS REPORT ON R. B. RUSSELL DAM

In March of 1977 the Savannah District, U. S. Army Corps of Engineers (USACE or CE) issued their report entitled, "Geological and Seismological Evaluation of Earthquake Hazards at the Richard B. Russell Project." The report presents the results of the extensive geologic and seismic studies performed by the Corps and their consultants to determine the seismic hazards which would be associated with the construction of the dam. In conducting the investigation, the Corps followed the procedures set out in their documents for assessing earthquake hazards in the U. S. and generally those contained in Appendix A to 10 CFR 100.

The CE performed an extensive review of the geology and tectonic history on the region around the proposed dam and detailed field studies in the vicinity of the site to determine if any active faults were present. They found no evidence of any active faults (faults showing recent movement), and concluded that all faults investigated were old and inactive.

The historic seismicity of the region was reviewed and used as the basis for determining the maximum earthquake expected to affect the site. The CE considered five seismotectonic zones, as developed from the historic seismic activity, within which an earthquake occurrence could affect the site. These five seismotectonic zones are the Blue Ridge, Piedmont, Coastal Plain, Charleston-Summerville, and New Madrid (located in Southeastern Missouri). It was concluded on the basis of the geologic studies that it was not possible to correlate, and thereby restrict, the earthquakes in any of the zones to identifiable faults or tectonic structure. Charleston-Summerville and New Madrid were considered unique zones confined to limited areas because of their high concentration of seismic activity not seen elsewhere in the South-Central and Southeastern Coastal Plain. Since none of the other earthquakes could be related to geologic structures, it was assumed that they could occur anywhere within their respective seismotectonic zone.

A note of importance related to the method used by the CE above is that at the present time the U. S. G. S. is conducting a detailed geological and seismological investigation in the Charleston-Summerville area in an attempt to determine the cause of the large 1886 earthquake. Similar studies by others are being conducted in the New Madrid area. These studies may better restrict these earthquake zones.

The maximum historic earthquake in each seismotectonic zone was moved within its respective zone to a point on the boundary nearest the site, and the ground motions attenuated with distance to the proposed dam site. In the Piedmont seismotectonic province, in which the proposed dam is located, it is assumed that the maximum earthquake within that zone could occur at the site. The largest historic event in the Piedmont seismotectonic zone is the January 1, 1913, Union County, South Carolina, earthquake of intensity VII[1] as reported in Earthquake History of the U. S. (Coffman and von Hake, 1973). Using a relationship between intensity and magnitude, it was calculated that the Union County event had a magnitude of 5.5. One of the members of the CE's board of consultants also calculated, using the theory of stress drop on faults, the maximum magnitude of reservoir induced seismicity for the proposed project to be 5.6. Therefore, the design basis earthquake for the Russell Dam was established as a magnitude of 5.5 or intensity VII.

Using the MM VII earthquake at the site the CE then determined the peak ground motions that could occur. This was accomplished by using relationships developed by the U. S. Army Corps of Engineers-Waterways Experiment Station for assessing earthquake hazards for peak ground motions on bedrock. The horizontal acceleration so determined was 0.4 - 0.5 g in the near field, with the vertical component taken to be two-thirds the horizontal; peak particle velocities of 30-45 cm/sec; and displacements up to 20 cm for an earthquake of 5 seconds duration. The relationships used to determine these values were developed from measured acceleration data for various intensity levels; however, all the data were from California. The largest accelerations recorded for a intensity VII earthquake fall between 0.4 - 0.5 g level (two data points). Apparently the CE used these values in an attempt at conservatism since the mean value was about 0.2 g and the two data points were greater than one standard deviation away from the mean. The CE then compared their values with those developed by other investigators and showed good agreement. This was not unexpected since almost all data available for the U. S. are from California, and are used by everyone in developing ground motion relationships. This is not to say that the relationships are incorrect, but to point out the limited amount of data available, and that in general our knowledge is influenced by California experiences.

---

[1]All intensities are in the Modified Mercalli (MM) scale as given in Richter (1958). Where a single intensity is associated with a given earthquake, it is the maximum intensity for that earthquake, i.e., the intensity at the epicenter.

The probability of earthquake recurrence at the dam site was calculated by one of the members of the board of consultants. He performed a probabilistic analysis using one of the techniques used by seismologists for recurrence calculations. A 0.01 annual risk (100-year return period) for a peak ground acceleration of about 0.07-0.08 g was obtained (see Figure 1), and a 0.0014 annual risk for 0.2 g acceleration (700-year return period). Using this analysis, the CE determined the operating basis earthquake for design purposes of non-critical items as one that would result in a peak acceleration of 0.075 g at the site. The value of 0.4 to 0.5 g was determined as the design basis earthquake, and critical structures that could affect safety were designed to this value.

CRITICISM OF THE CORPS OF ENGINEERS SEISMIC ANALYSIS OF THE RICHARD B. RUSSELL DAM

The Corps of Engineers study for the Richard Russell Dam has come under some criticism recently by several geologists who participated in a meeting in February 1978 sponsored by Friends of the Savannah River. A critical review was written by Robert R. Curry of the University of Montana. Curry's analysis of the Corps of Engineers report has four principal points of disagreement.

1) The upstream dams are designed to a much smaller peak acceleration than the Richard B. Russell and therefore a small earthquake, say under Hartwell Dam, might cause the failure of that dam which would then cause sequential failures of Richard Russell and Clark Hill. His point is that the Corps of Engineers has not done a sequential failure analysis as is required for nuclear plants. Thus, he believes that the Corps has not properly informed the residents of Augusta of the hazards of building the Richard Russell Dam. Of course, the problem is that even without the Richard Russell Dam the same hazard presently exists, so it raises the question as to whether all dams on the Savannah River should be upgraded to meet a higher acceleration.

2) The method of estimating the design acceleration and its return period for probability of recurrence is statistically in error and does not have an adequate factor of safety. He states, referring to the Corps of Engineers report, "It is not correct statistically to presume that an event of 0.01 annual probability (a "100-year event") will have only one chance out of one hundred of occurring within the 100-year dam design lifetime. In fact, an event with a 100-year return period as discussed in Appendix 1 of the Report has a 64 percent chance of occurring one or more times during any given 100-year period. The implication in the design earthquake report is that the maximum design earthquake of intensity VII with a return period of 2,000 to 2,200 years would mean that there is an acceptable risk that such an event would not occur within a 100-year period. In fact, there is a 5% chance of its occurrence within a 100-year period. Such a risk is totally unacceptable."

3) Dr. Curry apparently also objects to the downgrading of the 1913 Union County Earthquake from an intensity VIII to VII. However, the Corps of Engineers is not responsible for this change; it is based on information obtained from the Earthquake History of the U. S. (1973) and has been accepted by NRC. Dr. Curry also believes that it is not proper to leave the Charleston Earthquake at Charleston but believes it should be moved to the dam site.

He also believes that the fact that there are few strong motion recorders in this area may be responsible for the low accelerations that are postulated. He states that with more strong motion recorders the peak acceleration would become 0.85 g. He also states that if the Union County Earthquake were to be left at an intensity VIII, the safe upper limit of acceleration would be nearly 1.0 g. He reported that in Mexico, an earthquake of magnitude 5.0 produced an acceleration of 0.5 g 36 km from the source. If this acceleration were scaled back to the epicenter, it would provide a value of acceleration of 1.3 g. One of the problems with Dr. Curry's analysis is that he never mentions duration in his statements about maximum acceleration. In many cases, a single peak in acceleration may not be damaging.

4) He believes the intensities for induced seismicity caused directly by the impoundment of water by the dam are inadequately treated. In this point, he simply says that he agrees with Dr. David Snow's analysis (which was done for the Corps) and believes that it should not have been dismissed by the Corps of Engineers.

A FEW OTHER CASE HISTORIES

The nature of public hearings now held in conjunction with the development of certain projects is such that the prospective owner and operator must prove that there is no undue hazard to the public or the environment, whereas the intervenors need only demonstrate that there is a reasonable doubt. In this situation geology and seismology often become points of contention. Because of the deductive nature of conclusions associated with these sciences, it is difficult to prove some conclusions beyond a reasonable doubt, even to other geologists and seismologists, since experience and background will strongly influence their conclusions and none have exactly the same training and experience. Therefore, even though a seemingly complete and thorough investigation is conducted for the proposed project, it is not necessarily going to be accepted without questions and possibly disagreements.

Once the design basis or safe shutdown earthquake has been established for a proposed facility and becomes a part of the public record, it is subject to review. In the case of nuclear facilities, the first review is by the NRC and their consultants, usually the U. S. G. S. It is also reviewed by the Advisory Committee on Reactor Safety (ACRS) and their consultants and the intervenors and their consultants. Data or interpretation by any of these groups can result in the design basis earthquake being changed (usually increased). It is, therefore, very important that all geologic and seismic factors be investigated that may affect the selection of the SSE, and that information obtained and judgements or methods used in interpretation be defensible under all conceivable circumstances.

An example of this were the hearings pertaining to the issuance of a construction permit for the V. C. Summer Plant located near Parr, SC, which resulted in the current NRC-sponsored U. S. G. S. investigations in the Charleston-Summerville area.

The applicant had performed an analysis of the geological and seismological characteristics of the region, which included Charleston. However, Charleston was located in a different geologic province (Coastal Plain) than the proposed site (Piedmont). It was the applicant's contention that, because the major portion of the historic and present day seismic activity in South Carolina is confined to the Charleston-Summerville area, the 1886 (I_e = X)[1] event that occurred there should not be moved. The Charleston earthquake was attenuated to the site to determine the intensity (I_s = VII)[1] and to obtain the accelerations expected from the recurrence of this event. The Union County, SC, earthquake (I_e = VII) was also considered as possibly occurring at the site since the distance from Union County to the site is about 27 km, and the confidence limit on location of the epicenter of historic felt earthquakes is about ±25 km. Based upon an intensity VII at the site an acceleration of 0.12 g on bedrock was determined as the SSE. The Regulatory Staff considered this as not conservative enough and they finally agreed on a value of 0.15 g for the SSE at the Summer Plant.

It was the opinion of some of the ACRS consultants that this did not provide enough conservatism and that the value should be 0.20 g. The Regulatory Staff's consultants, the U. S. G. S. and, at that time, NOAA, presented data to the ACRS and their borad of consultants in support of the applicant's SSE acceleration at the site of 0.15 g. Several of the ACRS board of consultants felt that the Charleston earthquake of 1886 should be moved at least halfway to the Summer site and the ground motion calculated (a g value of about 0.2 - 0.3 was determined), however one of the consultants "thought the Charleston earthquakes could be moved anyplace on the eastern face of the Appalachian mountains and as far north as New Jersey." It was also suggested that if the cause of the Charleston earthquake is not understood, maybe all East coast nuclear plants should be built to withstand the 1886 event. It should also be pointed out that some of the board of consultants to ACRS agreed with the applicant and Regulatory Staff.

It was finally established that, consistent with other plants approved by the Commission (Barnwell, Robinson, etc.), the proposed value of 0.15 g horizontal ground motion would be accepted in this case. This decision was not setting a precedent and other facilities in the region would probably

---

[1] I_e = intensity at the epicenter
I_s = intensity at the site or point of interest.

have to be designed for 0.20 g accelerations. Table 1 lists the design ground motion for a number of nuclear and non-nuclear facilities in the Southeast. Also, because of the lack of information on the Charleston earthquake, the ACRS and its board of consultants recommended to the Commission that an intensive study be undertaken to understand the cause of the Charleston event. The Advisory Committee on Reactor Safety by letter to the Commission chairman in January, 1977, recommended a minimum design of 0.2 g for all new reactors in the East.

The V. C. Summer Plant hearings occurred in 1972; and five years later the CE used the same earthquake (Union County, SC) as the design basis earthquake for the proposed Russell Dam and developed a peak horizontal acceleration of 0.4 - 0.5 g. Yet to some this is not a conservative enough value, and 0.8 - 1.0 g should have been used as the design basis acceleration. The Tran-Alaska Pipeline, in a highly seismic area, was designed for 0.12 g in the M = 5.5 [1] (I_e=VII) earthquake region of the route (Newmark and Hall, 1973).

The question of the 1886 Charleston earthquake has not yet been resolved. Until it is, the idea of moving this event is still possible.

During 1975 and 1976 a number of detailed geologic and seismologic investigations were conducted in New York State near the Indian Point Nuclear Generating Station, and extensive hearings were held before the Atomic Safety and Licensing Appeal Board concerning the seismicity of the area. Seismologists such as Richter, Trifunac, Sykes, and others were involved in these hearings. Even though the hearings have concluded, the discussions have not ended. Aggarwal and Sykes (1978) published a paper, taking the discussion to the public, showing that a risk of 5 to 11 percent existed that shaking will exceed that of the SSE (0.15 g) at least once during the 40-year life of the facility. They also take exception to the applicability of Appendix A to 10 CFR 100 in the eastern U. S. It is informative to present their arguments.

Aggarwal and Sykes (1978) wrote:

> "The Indian Point seismic hearings before NRC brought out a number of problems about the applicability of the existing federal regulations to sites in the East. By these regulations a capable fault is defined on the basis of either (i) demonstrated fault movement younger than 500,000 years or (ii) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault. There is no evidence for surface breakage in any earthquake in the central or eastern United States, with the possible exception of questionable ground breakage during the New Madrid, Missouri, earthquakes of 1811-1812. Yet we know that a number of large and damaging shocks have occurred in these areas. The Ramapo fault is typical of many eastern sites in that almost all of the rocks in the region, with the exception of scattered postglacial deposits less than 15,000 years old, are older than 150×10^6 years. Hence, it is very difficult to tell if earth movements are as old as 150×10^6 years or if they happened in the past 0.5×10^6 years. Thus surface breakage is not a good indicator of either "capability" or seismic risk for many eastern sites.

[1] M = magnitude on the Richter scale.

"The hearings demonstrated that the word "macroseismicity", which is not defined in the regulations, is rarely used or defined by seismologists. Various scientific witnesses differed to a large extent in their concept of macroseismicity. For much of the East, instrumental data of sufficient precision to demonstrate a relation to specific faults are very limited in time. Hence, it is not surprising that no fault in the central or eastern United States has as yet been declared legally capable.

"In the absence of capable faults the concept of "tectonic provinces" is used in deriving the intensity of the design earthquake from the historic record of shocks. The intensity at the site is calculated by moving historic shocks in the same province to the site and shocks in adjacent provinces to the closest point within those provinces (if the shocks cannot reasonably be correlated with a tectonic structure). Although this procedure may appear conservative in terms of design safety, it is so only if reasonably large tectonic provinces are used. At the Indian Point hearings it was clear that the scientific witnesses had greatly varying opinions about the size, designation and concept of tectonic provinces. These ambiguities can result in a number of small provinces being invoked to keep critical historic shocks at a distance such that their intensities at the site are much lower than those near the epicenter. In the case of Indian Point, this leads to a design earthquake of intensity VII or VIII depending on the designation of tectonic provinces.

"The rate of seismic activity along the Ramapo fault and in the East in general is clearly less than that for major faults in, say, California or Japan. Although the federal siting regulations put the question of the capability of a fault as a yes-no decision, the present rate of movement along faults obviously varies by many orders of magnitude. We believe recognition must be given to the fact that some faults are more "capable" than others. Until this is done, the public may well equate the designation of capability with size and rate of occurrence of earthquakes like those along, say, the San Andreas fault in California. In the context of siting nuclear power plants and other critical facilities, we believe that the rate of activity must be judged in comparison to the design earthquake of the plant. The rate of activity along the Ramapo fault is such that it probably only warrants concern for critical facilities such as nuclear power plants and hospitals for which integrity must be ensured at a high level of confidence."

PARAMETRIC INVESTIGATION FOR THE SRP SITE

Intensity and Acceleration Determinations

An examination of the earthquake history of the Southeastern United States (1754-1975) in the region of the site was performed by Tarr (1977). The locations of both felt earthquakes and those instrumentally recorded are plotted in Figure 2. The seismotectonic provinces of the Southeastern U. S. as defined by Hadley and Devine (1974) are shown in Figure 3. Using these data it was determined that three historic earthquakes were of great interest to the SRP site, and would be used in a parametric study. The earthquakes considered were the largest in the region— the 1886 Charleston earthquake of intensity

X (magnitude $M \sim 7.0$); the 1913 Union County, SC, event of intensity VII ($M \sim 5.0$-5.5) – the largest in the Piedmont; and the Wilmington, NC, quakes of 1884 and 1958 with an intensity VI ($M \sim 4$-4.5) – the largest in the Coastal Plain Province excluding the Charleston-Summerville area. It was concluded that it would also be useful to investigate the effects of a postulated earthquake occurring on the Belair Fault near Augusta, GA. It should be pointed out that the current regulatory position is that a recurrence of a Charleston earthquake is confined to the historic epicentral area between Charleston and Summerville, SC, and that the Belair Fault is not considered capable; however, because of the lack of sufficient data both these positions are considered possibly subjected to change.

In performing this parametric study, the various procedures outlined in Appendix A to 10 CFR 100 were evaluated to determine the effects on the site of the following different hypotheses:

1) The earthquakes were assumed to be associated with a geologic structure, such as a fault, in the area of maximum intensity, and so fixed to the historic epicentral region. The epicentral intensity was then attenuated to the SRP site.

2) The earthquakes were moved to the point on the boundary of the seismotectonic province in which they occur nearest the site, or to the site if in the same province. The intensities were then attenuated to the site. (The Charleston earthquake was confined to a region extending northwest as far as Bowman, SC.)

3) It was assumed that no knowledge of the causative mechanism underlying the earthquake process was available, and thus, the seismic event could occur anywhere in the Southeastern U. S.

There are numerous attenuation relationships found in the literature. They are of the general form:

$$I_s[S,R] = C_1 S + C_2 + C_3(R+r_o) + C_4(R+r_o)$$

where I_s is the intensity at the site of interest and C_1, C_2, C_3, C_4, and r_o are constants, S is the size of the earthquake in intensity, magnitude or acceleration and R is the epicentral distance in km. For comparison six attenuation relationships were used to determine the site intensity. These are listed below:

1) $I_s(R) = I_e + 3.7 - 0.0052(R) - 2.88 \log R$

developed from the Charleston 1886 event by Bollinger (1977);

2) $I_s(R) = I_e + 3.1 - 1.34 \ln R$

from McGuire (1977) for the Eastern U. S.;

3) $I_s(R) = I_e + 3.278 - 0.0029R - 0.989 \ln R$

developed for the Central and Eastern U. S. by Howell and Schultz (1975);

4) $I_s(R) = I_e + 3.7 - 0.0011(R) - 2.7(\log R)$

developed by Gupta and Nuttli (1975) for the Central U. S.;

5) $I_s = I_e + 0.15 - 3.17 \log R$

developed for California by Neumann (1954); and

6) graphical relationships of attenuation for the Eastern U. S. developed by Brazee using historical data (1976) shown in Figure 4.

Since most of the historic data on earthquakes in the Eastern U. S. are in terms of intensity, and design is in terms of acceleration at the site, it is a necessary requirement that accurate acceleration/intensity relationships exist. Measured accelerations and assigned intensities were first related in the early 1900's. As the number of strong motion seismographs increased in active earthquake zones, empirical correlations of this sort were developed by over 40 investigators. For this study it was decided to use only those that are more common and appear often in the literature, such as those shown in Figures 5 and 6. The general form of the equations of these lines (through the mean values) is

$$\log \alpha_h = m_1 I_s + m_2$$

where m_1 and m_2 are constants, and α_h is the horizontal acceleration. Figures 7, 8, and 9 show the data from which some of the relationships were developed; the large amount of scatter in the data is evident. Figures 7 and 8 are in terms of the near field and far field accelerations, where the near field is defined in Table 2.

Using the possible earthquakes identified and the attenuation and acceleration/intensity relationships chosen, the alternate hypotheses for the occurence of the seismic sources were examined. Specific details are presented in Table 3. The magnitude and intensity of the postulated event occurring on the Belair Fault were determined from relationships developed using California data on rupture length vs. magnitude. It was assumed that slip would occur along the entire 21 km length of the fault. Table 4 shows the values of magnitude obtained using five different relationships.

To be conservative the Richter magnitude value of $M \sim 7.0$ was used to calculate the intensity using Richter's (1958) relationship

$$I_e = \frac{3}{2} (M-1)$$

which gives an epicentral intensity IX.

By applying the attenuation relationships to an earthquake of the given intensity in the source regions presented in Table 3, the site intensities were determined. These results are presented in Table 5. When the earthquake occurs at the site no attenuation was assumed.

By choosing the appropriate intensity level at the site the corresponding horizontal acceleration can be determined for a design basis. Various values of acceleration for intensity levels from IV to X are presented in Table 6. The data used in developing the different relationship were from California except for that of Ambraseys (1974) and Murphy and O'Brien (1977) who used worldwide data. Neumann (1954) and the Corps of Engineers (1975 and 1977) developed relations for both the near field (NF) and the far field (FF). In Neumann's relation, the near field was 25 km and the far field was 160 km. In the Corps of Engineers study the near field varied with the size of the earthquake as shown in Table 2. The same data base was used by the Corps and by Trifunac and Brady (1975). For the Corps data, where available, values of one and two standard deviations are given, as well as the maximum recorded value. Also given in Table 6 is the strong motion acceleration recorded at the Citadel College in Charleston during the November 22, 1974, earthquake of VI intensity and a magnitude of $M = 4.7$.

A single peak acceleration value alone is not an effective measure of the damaging potential of an earthquake. Only when the estimated mean value of the peak acceleration is combined with other parameters, such as the size of the earthquake in energy or magnitude, the duration, and the frequency distribution can a reasonable description of the ground motion be obtained.

Recurrence Rate Determinations

One of the primary uses of seismicity data is to establish the earthquake recurrence rate.

It was demonstrated by Richter (1958) in California and elsewhere in many parts of the world by Evernden (1970) that earthquake recurrence generally follows an empirical linear relationship

$$\log N_M = a - bM$$

where N_M is the number of earthquakes occurring in a given time period within the region of interest with magnitudes equal to or greater than M; the constant a is the seismicity index of the region and is dependent upon the size of the region considered and the length of the time period involved; and the constant b is the severity index and is generally in the range of 0.8-1.0 for most areas of the world when magnitudes are used in the equations.

A consistent assumption is then made that the intensity level in a region is proportional to the number of events in the same way:

$$\log N_I = a - bI_e$$

Where N_I is the number of earthquakes occurring in a given time period within the region being investigated with intensity greater than or equal to I_e. In the U. S. the values of b generally range from 0.35 - 0.65 where intensity is used in the equation. The linear relation usually holds within the range of intensities IV-VIII. This is because the record of higher intensities is complete for a longer period of time than small events (I_e = I-III); the larger events are more apt to be felt over large areas and reported. It is also a possibility that at the very large intensities the number of events are less, causing the curve to bend downward.

McGuire (1977) has stated:

> "As few as five or ten earthquake observations are adequate to define the occurrence rate in an area, for the purpose of deriving risk-associated design intensities. The seismic history of the Eastern U. S. is not, however, adequate to define accurately the

> maximum possible intensity in chosen source areas... The "b" value describing the relative frequency of small and large events cannot be determined unequivocally because of different possible interpretationsof seismic history and different methods of numerical analysis. It is evident, however, that variations in "b" values from area to area in the Eastern U. S. can be attributed to statistical variations resulting from small numbers of events available to make the determinations. Thus, it is reasonable for the purpose of calculating design intensities to adopt a single value of "b" for the Eastern U. S."

In Table 7 an example of various values for the recurrence equations obtained from the Eastern U. S. region and areas within the region is given.

From Table 7 the effect of the size of the region being investigated on the "b" value can be seen. Once a recurrence equation for an area has been determined, the earthquake recurrence ratio can be calculated. Because of the lack of data on seismic sources in the Eastern U. S., there is reason to accept McGuire's suggestion and use one value for the entire region. The plots of several of these curves are shown in Figure 10.

For the Eastern and Southern U. S. the "b" value is between 0.5-0.6; however, if the Charleston earthquakes are considered and the region of investigation decreased to a more specific area around Charleston, these events dominate and tend to lower the "b" value because of the paucity of smaller events.

In the study for R. B. Russell Dam, the CE (1977) and their consultants chose to use a value of 0.36 which appeared to be low, and they state that the catalog of seismic events used, with an incomplete recording of intensity V and less events in the Piedmont, may explain the low value.

Risk Analysis

To perform a probabilistic seismic hazard analysis of any given site, it is necessary to define the seismicity of the region surrounding the site. It is necessary to determine the source of seismic activity and the rate of occurrence of events for each source or source area, to estimate the relative frequency of different size events and to decide on the applicable attenuation relationship for the region and the maximum possible size of events for each source.

As can be seen from the preceding discussions, there are large uncertainties in the seismic sources in the Eastern U. S., "b" values, attenuation relationships, and maximum possible size of events. For this reason there are uncertainties in any risk assessment and different values of risk will be obtained, dependent upon the parameters chosen for the analysis.

To illustrate this, Table 8 shows the results of a risk evaluation for two nuclear power plants in the Southeast. The risks were calculated independently by seven experts in the field of seismology as part of a study sponsored by the NSF program, Research Applied to National Needs, and reported by Okrent (1975). Using the same basic data taken from the PSAR's and FSAR's each individual determined the seismic hazard associated with each site. The results of the study show that, based on the judgements used, there were differences between the risks obtained from the seven experts.

Risk analysis was performed for the SRP site using the method of McGuire (1976) to compare results using the different source areas discussed in the preceding sections. These source areas are shown in Figures 11, 12, and 13. These seismic source cases represent the condition in which a large Charleston 1886-type seismic event can occur anywhere in the Southeast, where the seismic sources are limited to certain seismotectonic regions and where the seismic source is confined to the historical epicentral area. The Coastal Plain activity up to and including a Wilmington, NC - type event was considered as background seismicity. The probabilities were calculated using two different attenuation relationships and three "b" values for earthquakes of intensity V-X. The results were determined as the probability of exceeding an intensity level.

Using the attenuation relationship of McGuire (1977) and Howell and Schultz (1975) and a "b" value of 0.50, a significant difference in the seismic risk at the site was obtained for all three seismic source configurations. The results are shown in Figure 14. The results also indicate very clearly that only when the earthquakes are assumed to occur anywhere in the Southeast is there a large difference in the risk for various cases. The difference between confining the seismic source to the historic epicentral area or to the seismotectonic zone is much less than the uncertainties in the method. All cases were repeated with two other "b" values used; however, the effect of the different "b" values was nowhere as significant as the attenuation relationship. The lower "b" values increase the frequency of the larger earthquakes with respect to the smaller and a small increase in the risk value for the higher intensities was noted, but again, the increases were small in comparison to the change caused by the attenuation relationship. The "b" value of 0.5 used in the calculational results shown in Figure 14 is a fair average value for the Southeastern U. S.

The calculation of the risk for any time period may be obtained from the annual risk given by these calculations. Assuming that the risks in successive years are independent, the risk for the life expectancy of a facility may be obtained using the relationship

$$R_n = 1 - (1-R_A)^n$$

which calculates the risk R_n in n years where R_A is annual risk.

As pointed out by Apostolakis† (1978) probabilities are measures of the degree of belief. As shown in this section, they are a function of the relationships in which the person calculating the probability places his belief. Consequently, it is difficult to talk about true values of probability as related to seismic risk.

CONCLUSIONS

This parametric study has shown that by following the criteria of Appendix A to 10 CFR 100 it is possible to arrive at several different conclusions regarding the seismic intensity at a given site and, therefore, the design ground motions and risk. These conclusions are a function of an individual investigator's experience and judgement concerning the seismic activity and the causes thereof, the attenuation relationships for the area, the recurrence of seismic events in the area and the intensity-acceleration relationships.

As shown in Table 3, there are three possible source areas in the Eastern U. S. for each earthquake, since there are not enough data to relate the historic events with any tectonic structure. There are at least six attenuation relationships that various seismologists have proposed for the Eastern U. S. that one can use to attenuate the intensity from the epicentral region to the site. Table 5 shows the effects of these two parameters on the intensity one could determine for the SRP site. A few of the possible site accelerations for different intensities are shown in Table 6, which indicates the range in values that could be determined depending on the individual's judgment. Shown in Figure 10 are a few of the recurrence relations that have been developed for the East; however, each of these is dependent upon the data base chosen by the investigators. Finally, Table 8 and Figure 14 show the effect of the judgments made concerning all the previous parameters on the probability of exceeding a given value at a site.

The analysis of the seismic design and risk for any critical facility does not at this point in time have a correct answer, only believable ones which depend upon the judgment and experience of the individual. It is therefore important that a consistent, conservative, analysis be adapted for SRP based upon realistic evaluations of the existing data base. Because of statistical uncertainties a probabilistic approach will be more meaningful than an empirical deterministic analyses.

REFERENCES

Aggarwal, Y. P. and L. R. Sykes (1978). Earthquakes, Faults, and Nuclear Power Plants in Southern New York and Northern New Jersey, Science, Vol. 200, pp. 425-429, April 28.

Algermissen, S. T. (1969). Seismic risk studies in the United States, *Proc. World Conf. Earthquake Eng., 4th, Santiago, Chile*, 1, 14-27.

Algermissen, S. T. and D. M. Perkins (1976). A probabilistic estimate of maximum ground acceleration in the contiguous United States, *U. S. Geol. Surv. Open-File Rept. 76-416.*

Ambraseys, N. N. (1969). Maximum intensity of ground movements caused by faulting, *Proc. World Conf. Earthquake Eng., 4th, Santiago,* Chile.

Apostolakist, G. (1978). Probability and Risk Assessment: The Subjectivistic Viewpoint and Some Suggestions, Nuclear Safety, Vol. 19, No. 3

Bollinger, G. A. (1977). Reinterpretation of the intensity effects of the 1886 Charleston, South Carolina, earthquake in Geological, Geophysical, and Seismological Studies Related to the Charleston, South Carolina, Earthquake of 1886; A Preliminary Report, D. W. Rankin, Editor, *U. S. Geol. Surv. Profess. Paper 1028.*

Bollinger, G. A. (1975). Seismic Activity in the Southeastern United States in the *Proceedings Earthquake Engineering Conference* ed. by Radziminski and Biedenback University of South Carolina, Columbia, SC, p. 17-48.

Bollinger, G. A. (1972). Historical and Recent Seismic Activity in South Carolina; *Bull. Seism. Soc. Am.*, Vol. 62, No. 3, pp. 851-864.

Bonilla, M. G. and J. M. Buchanan (1970). "Interim Report on Worldwide Historic Surface Faulting," open file, Series No. 16113, *U. S. Geological Survey*, Washington, DC.

Brazee, R. J. (1976). An Analysis of Earthquake Intensities with Respect to Attenuation, Magnitude, and Rate of Recurrence, NOAA TM EDS NASDC-2, U. S. Dept. of Commerce, Boulder, CO.

Coffman, J. L. and C. A. von Hake, ed. (1973). "Earthquake History of the United States," Publication 41-1 revised edition (through 1970), National Oceanic and Atmospheric Administration, U. S. Department of Commerce, Boulder, CO.

Coulter, H. W., H. H. Waldron, and J. F. Devine (1973). "Seismic and Geologic Siting Considerations for Nuclear Facilities," *Proceedings, Fifth World Conference on Earthquake Engineering*, Rome, Paper 302.

Evernden, J. F. (1970). A Study of Regional Seismicity and Associated Problems, *Bull. Seism. Soc. Am.*, Vol. 60, p. 393.

Gupta, I. N. and O. W. Nuttli (1976). Spatial attenuation of intensities for Central U. S. earthquakes, *Bull. Seism. Soc. Am.* 66, 743-751.

Gutenberg, B. and C. F. Richter (1956). "Earthquake Magnitude, Intensity, Energy, and Acceleration (Second Paper)," *Bull. Seism. Soc. Am.*, Vol. 46, pp. 105-145.

Hadley, J. F. and J. F. Devine (1974). Seismotectonic map of the Eastern United States, Geol. Survey, Misc. Field Study, MF-620.

Hays, W. W. et al (1975). Guidelines for Developing Design Earthquakes Response Spectra by U. S. G. S., for U. S. A. Corp of Engineers Construction Engineering Research Laboratory, TR M-114, NTIS.

Hershberger, J., "A Comparison of Earthquake Accelerations with Intensity Ratings," *Bull. Seism. Soc. Am.*, Vol. 46, 1956, pp. 317-320.

Housner, G. W. (1970). "Strong Ground Motion," *Earthquake Engineering*, R. L. Weigel, ed., Chapter 4, Prentice Hall, Englewood Cliffs, pp. 75-91.

Howell, B. F., Jr. and T. R. Schultz (1975). Attenuation of Modified Mercalli intensity with distance from the epicenter, *Bull. Seism. Soc. Am.*, *65*, 651-665.

King, C. Y. and L. Knopoff (1969). A magnitude-energy relation for large earthquakes: *Bull. Seism. Soc. Am.*, Vol. 59, No. 1, p. 269-275, Feb. 1969.

Krinitzsky, E. L. and F. K. Chang (1975). State-of-the-Art for Assessing Earthquake Hazards in the United States; Earthquake Intensity and the Selection of Ground Motions for Seismic Design, Miscellaneous Paper S-73-1, Report 4, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

Long, L. T. (1974). Earthquake sequences and b values in the Southeast United States: *Bull. Seism. Soc. Am.*, Vol. 64, No. 1, pp. 267-273.

McGuire, R. K. (1977). Effects of Uncertainty in Seismicity on Estimates of Seismic Hazard for the East Coast of the United States, *Bull. Seis. Soc. Am.*, 67, pp. 827-848.

McGuire, R. K. (1976). Fortran Computer Program for Seismic Risk Analysis, U. S. Geol. Surv., Open-File report, 76-67 Series.

Murphy, J. R. and L. J. O'Brien (1977). The Correlation of Peak Ground Acceleration Amplitude with Seismic Intensity and Other Physical Parameters, *Bull. Seis. Soc. Am.*, 67, pp. 877-912.

Neumann, F. (1954). *Earthquake Intensity and Related Ground Motion*, University of Washington Press, Seattle.

Newmark, N. M. and W. J. Hall (1973). "Seismic Design Spectra for Trans-Alaska Pipeline," *Proceedings of the Fifth World Conference on Earthquake Engineering*, Rome, Italy, Paper no. 60, (1973).

Okrent, D. (1975). A Survey of Expert Opinion on Low Probability Earthquakes. UCLA-ENG-7515, PB 261 864 NTIS, Springfield, VA.

Richter, C. F. (1958). Elementary Seismology, p. 768, W. H. Freeman and Co., San Francisco.

Tarr, A. C. (1977). Recent Seismicity near Charleston, South Carolina, and its Relationship to the August 31, 1886, Earthquake, in Geological, Geophysical, and Seismological Studies Related to the Charleston, South Carolina Earthquake of 1886, A preliminary report, D. W. Rankin ed. *U. S. Geol. Surv. Profess. Paper 1028*, pp. 43-58.

Tocher, D. (1958). "Earthquake and Ground Breakage," *Bull. Seism. Soc. Am.*, Vol. 48, No. 2, Apr., pp. 147-153.

Trifunac, M. D. and A. G. Brady (1975). "On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion," *Bull. Seism. Soc. Am.*, Vol. 65, pp. 139-162.

U. S. Army Corps of Engineers (1977). Geological and Seismological Evaluation of Earthquake Hazards at the Richard B. Russell Project, Savannah District Corps of Engineers, Savannah, GA.

U. S. Atomic Energy Commission (1971). Appendix A to 10 CFR 100, Seismic and Geologic Siting Criteria, Federal Register V.36, No. 228.

U. S. Atomic Energy Commission, Reactor Site Criteria, Seismic and Geologic Siting Criteria (Amendments) Federal Register, Vol. 38, No. 218, pt. 1, November 13, 1973, p. 2.

TABLE 1. DESIGN GROUND MOTION FOR FACILITIES IN THE AREA

Facility	*Location*	*Peak Horizontal Acceleration (g)*
Nuclear		
SRP	Aiken, SC	0.2
AGNS	Barnwell, SC	0.2
A. W. Vogtle	McBean, GA	0.2
E. I. Hatch	Baxley, GA	0.15
V. C. Summer (seismic category I, dam at reservoir)	Parr, SC	0.15 rock 0.25 soil
Oconee	Oconee, SC	0.10
Catawba	Rock Hill, SC	0.15
Westinghouse Fuel Fabrication	Anderson, SC	0.14
Robinson	Hartsville, SC	0.20
VA Hospitals	Atlanta, GA Augusta, GA Charleston, SC Columbia, SC	0.13 0.18 0.25 0.10
Dams		
R. B. Russell	GA-SC Border	0.4-0.5
Clark Hill	GA-SC Border	UNK
Hartwell	GA-SC Border	UNK

TABLE 2. Limits of the Near Field for Richter Magnitude Earthquakes Between 5.0 and 7.5.

Richter Magnitude	*Maximum Intensity*	*Radius of Near Field (KM)*
5.0	VI	5
5.5	VII	15
6.0	VIII	25
6,5	IX	35
7.0	X	40
7.5	XI	45

After Krinitzsky and Chang (1975)

X (magnitude $M \sim 7.0$); the 1913 Union County, SC, event of intensity VII ($M \sim 5.0$-5.5) – the largest in the Piedmont; and the Wilmington, NC, quakes of 1884 and 1958 with an intensity VI ($M \sim 4$-4.5) – the largest in the Coastal Plain Province excluding the Charleston-Summerville area. It was concluded that it would also be useful to investigate the effects of a postulated earthquake occurring on the Belair Fault near Augusta, GA. It should be pointed out that the current regulatory position is that a recurrence of a Charleston earthquake is confined to the historic epicentral area between Charleston and Summerville, SC, and that the Belair Fault is not considered capable; however, because of the lack of sufficient data both these positions are considered possibly subjected to change.

In performing this parametric study, the various procedures outlined in Appendix A to 10 CFR 100 were evaluated to determine the effects on the site of the following different hypotheses:

1) The earthquakes were assumed to be associated with a geologic structure, such as a fault, in the area of maximum intensity, and so fixed to the historic epicentral region. The epicentral intensity was then attenuated to the SRP site.

2) The earthquakes were moved to the point on the boundary of the seismotectonic province in which they occur nearest the site, or to the site if in the same province. The intensities were then attenuated to the site. (The Charleston earthquake was confined to a region extending northwest as far as Bowman, SC.)

3) It was assumed that no knowledge of the causative mechanism underlying the earthquake process was available, and thus, the seismic event could occur anywhere in the Southeastern U. S.

There are numerous attenuation relationships found in the literature. They are of the general form:

$$I_S[S,R] = C_1 S + C_2 + C_3(R+r_0) + C_4(R+r_0)$$

where I_S is the intensity at the site of interest and C_1, C_2, C_3, C_4, and r_0 are constants, S is the size of the earthquake in intensity, magnitude or acceleration and R is the epicentral distance in km. For comparison six attenuation relationships were used to determine the site intensity. These are listed below:

1) $I_S(R) = I_C + 3.7 - 0.0052(R) - 2.88 \log R$

TABLE 3. Hypotheses Examined.

Historic/Postulated Event	I_e	*Source Area*
Charleston 1886 earthquake	X*	Historic epicentral region At edge of postulated Charleston Block near Bowman, SC At Site
Union County, SC, 1913 earthquake	VII*	Historic epicentral region Boundary of seismotectonic province near Augusta, GA At Site
Wilmington, NC, 1884 and 1958 earthquakes	VI*	Within seisotectonic province, At site
Postulated	IX**	Along Belair Fault near Augusta

* Obtained from Earthquake History of the *U. S. and other sources*

** Calculated

for 21 km (i.e. Bolan fault)

TABLE 4. Magnitude Obtained from Rupture Length

Relationship used	*Magnitude*
Housner (1970)	6.6
Algermissen (1969) based only on San Andreas fault	5.2
King and Knopoff (1969)	7.0
Bonilla and Buchanan (1970)	6.5
Tocher (1958)	7.0

TABLE 5. Intensities [I_s (R)] Determined for the SRP SITE for Four Source Areas (I_e) and Six Attenuation Relationships

	SEISMIC EVENT							
	Charleston I_e=X			*Union County, SC* I_e=VII			*Wilmington NC* I_e=VI	*Belair Fault Augusta, GA* I_e=IX
Source Area	*Historic epicenter [illegible] km*	*Bowman, SC [illegible]*	*At Site*	*Historic epicenter 123 km*	*At edge of Piedmont near Augusta GA, [illegible]*	*At Site*	*At Site*	*Near Augusta 44 km*
ATTENUATION RELATIONSHIP								
Bollinger	VI - VII	VII - VIII	X	III - IV	V - VI	VII	VI	VII - VIII
McGuire	VI - VII	VII - VIII	X	III - IV	V - VI	VII	VI	VII
Howell & Schultz	VII - VIII	VIII - IX	X	V - VI	VI - VII	VII	VI	VIII - IX
Neumann	III - IV	III - IV	X	I	II	VII	VI	III - IV
Gupta & Nuttli	VII - VIII	VIII - IX	X	IV - V	VI - VII	VII	VI	VIII - IX
Brazee	V - VI	VIII - IX	X	IV - V	VI	VII	VI	VIII

TABLE 6. Horizontal Accelerations as a Function of Intensity Using Eight Relationships.

Relationships for Horizontal Acceleration	Ambraseys (1974)	Trifunac & Brady (1975)	Guttenberg & Richter (1942;1958)	Hershberger (1956)	Neumann (1954) FF 125 km	Neumann (1954) NF 25 km	Murphy & O'Brien (1977)	Coulter, Waldron Devine (1973)*	U. S. Army Corps of Engineers (1975 & 1977)† NF	U. S. Army Corps of Engineers (1975 & 1977)† FF	Recorded Charleston, SC Nov. 1974
INTENSITY											
IV	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	1σ=0.23	0.07 MR**0.03 1σ=0.08	
V	0.04	0.03	0.015	0.02	0.01	0.03	0.03	0.03	2σ=0.40 MR=0.03 1σ=0.39	2σ=0.13 MR=0.12 1σ=0.1	
VI	0.10	0.06	0.03	0.05	0.03	0.06	0.06	0.07	2σ=0.67 MR=0.42 1σ=0.45	2σ=0.15 MR=0.18 1σ=0.17	0.01
VII	0.23	0.13	0.07	0.13	0.05	0.13	0.10	0.16	2σ=0.73 MR=0.50 1σ=0.33	2σ=0.21 MR=0.24	
VIII	0.54	0.26	0.15	0.35	0.11	0.27	0.18	0.32	2σ=0.46 MR=0.28	MR=0.24	
IX	1.23	0.53	0.32	0.93	0.22	0.54	0.32	0.73			
X	2.80	1.05	0.69	2.5	0.46	1.12	0.57	1.22	MR=1.24		

* Values taken from curve as mean for average foundation conditions

**MR maximum recorded data

† Mean values are like *Trifunac and Brady's* since data base was the same. Different at high intensity because of separation into near field (NF) and far field (FF). 1 and 2σ is standard deviations.

TABLE 7. RECURRENCE RELATIONSHIPS

Eastern U. S.	
Algemaissen and Perkins (1976)	$\log N_I = 3.02-0.58\ I_e$
McGuire (1977)	$\log N_I = 3.08-0.50\ I_e$ (range of 'b' determined to be .45-.57)
Southeastern U. S.	
Bollinger (1972, 1975)	$\log N_I = 3.01-0.59\ I_e$
Brazee (1976)	$\ln N_I = 0.0668-.5663\ I_e$
South Carolina-Georgia (including Charleston area)	
Stephenson (determined the recurrence relationship for South Carolina and Georgia by using the historic data of the last 100 years to be)	$\log N_I = 1.50-0.42\ I_e$
South Carolina	
Bollinger (1972) exclusive of Charleston-Summerville area	$\log N_I = 0.52-0.31\ I_e$
Long (1973) determined the "b" value in terms of magnitude for McCormick, SC, area to be -1.3 M	
Tarr (1978) exclusive of Charleston-Summerville	$\log N_c = 3.28-0.44\ I_e$
where N_c is the cumulative number and for Charleston-Summerville area	$\log N_c = 2.35-0.25\ I_e$

[illegible] (South Carolina) [illegible]

Expert No.	1	2*	3	4	5	6	7
MM Intensity	**Probability per Year**						
V	10^{-2}		10^{-2}	10^{-2}			10^{-2}
VI	10^{-4}		10^{-3}	3×10^{-2}	5×10^{-3}		10^{-2}
VII	3×10^{-6}		10^{-4}	5×10^{-3}	10^{-3}		10^{-3}
VIII	5×10^{-7}		10^{-6}	5×10^{-3}	10^{-4}	10^{-6}	10^{-4}
IX	10^{-7}			$5\times10^{-?}$	10^{-6}		10^{-7}
X	10[illegible]						10^{-8}
XI	10^{-8}						$<10^{-8}$
XII	10^{-8}						$<10^{-8}$
Peak Horizontal Acceleration	**Probability per Year**						
.05g	10^{-1}		10^{-3}	2×10^{-2}	5×10^{-3}		10^{-2}
.1g	10^{-2}		10^{-5}	4×10^{-3}			10^{-3}
.15g	10^{-3}			10^{-3}	10^{-3}		10^{-3}
.2g	10^{-4}	3×10^{-5}		4×10^{-4}			10^{-4}
.25g	10^{-5}			10^{-4}	10^{-4}	10^{-6}	10^{-4}
.3g	3×10^{-6}			4×10^{-5}			10^{-4}
.4g	4×10^{-7}	2×10^{-5}		8×10^{-7}	10^{-5}		10^{-5}
.5g	10^{-7}				10^{-6}		10^{-5}
.6g	5×10^{-8}	1×10^{-5}					10^{-3}
.8g	10^{-8}	7×10^{-6}					$<10^{-8}$
1.0g	10^{-8}	3×10^{-6}					$<10^{-8}$
>1.1g	10^{-8}						$<10^{-8}$
Dominant Frequency and Duration for 10^{-5}/year Earthquake							
Cycles/sec	3	5	5-8	2-5		1/3-15	
Seconds	10		10-15	15		15-20	

*Probabilities per year are for accelerations greater than the size indicated.

[illegible] (North Carolina) Coastal Plain

Expert No.	1	2*	3	4	5	6	7
MM Intensity	**Probability per Year**						
V	10^{-1}		10^{-2}	2×10^{-2}			10^{-2}
VI	10^{-2}		10^{-4}	10^{-2}	5×10^{-3}		10^{-3}
VII	10^{-3}		10^{-6}	10^{-3}	3×10^{-3}		10^{-3}
VIII	10^{-5}			5×10^{-7}	10^{-3}	10^{-6}	10^{-5}
IX	10^{-7}				10^{-4}		10^{-7}
X	10^{-5}				10^{-5}		10^{-8}
XI	10^{-8}				10^{-6}		$<10^{-8}$
XII	10^{-8}						$<10^{-8}$
Peak Horizontal Acceleration	**Probability per Year**						
.05g	10^{-2}		10^{-4}	8×10^{-3}			10^{-2}
.1g	10^{-3}		10^{-5}	2×10^{-3}			10^{-3}
.15g	10^{-5}		10^{-6}	3×10^{-4}			10^{-5}
.2g	10^{-5}	$<3\times10^{-5}$		6×10^{-5}	2×10^{-3}	10^{-6}	10^{-5}
.25g	3×10^{-6}			6×10^{-6}	10^{-3}		10^{-6}
.3g	10^{-6}			8×10^{-7}	5×10^{-4}		10^{-6}
.4g	4×10^{-7}	$<2\times10^{-5}$					10^{-7}
.5g	10^{-7}				10^{-4}		10^{-7}
.6g	3×10^{-8}	$<10^{-5}$					10^{-7}
.8g	10^{-8}	$<7\times10^{-6}$					10^{-7}
1.0g	10^{-8}	$<3\times10^{-6}$			10^{-5}		10^{-8}
>1.1g	10^{-8}				10^{-6}		10^{-8}
Dominant Frequency and Duration for 10^{-5}/year Earthquake							
Cycles/sec	2		1-2	2-5		1/3-10	
Seconds	10		5	15		20	

*Probabilities per year are for accelerations greater than the size indicated.

TABLE 8. Probabilities Calculated by Seven Experts for Two Nuclear Facilities in the Southeast.

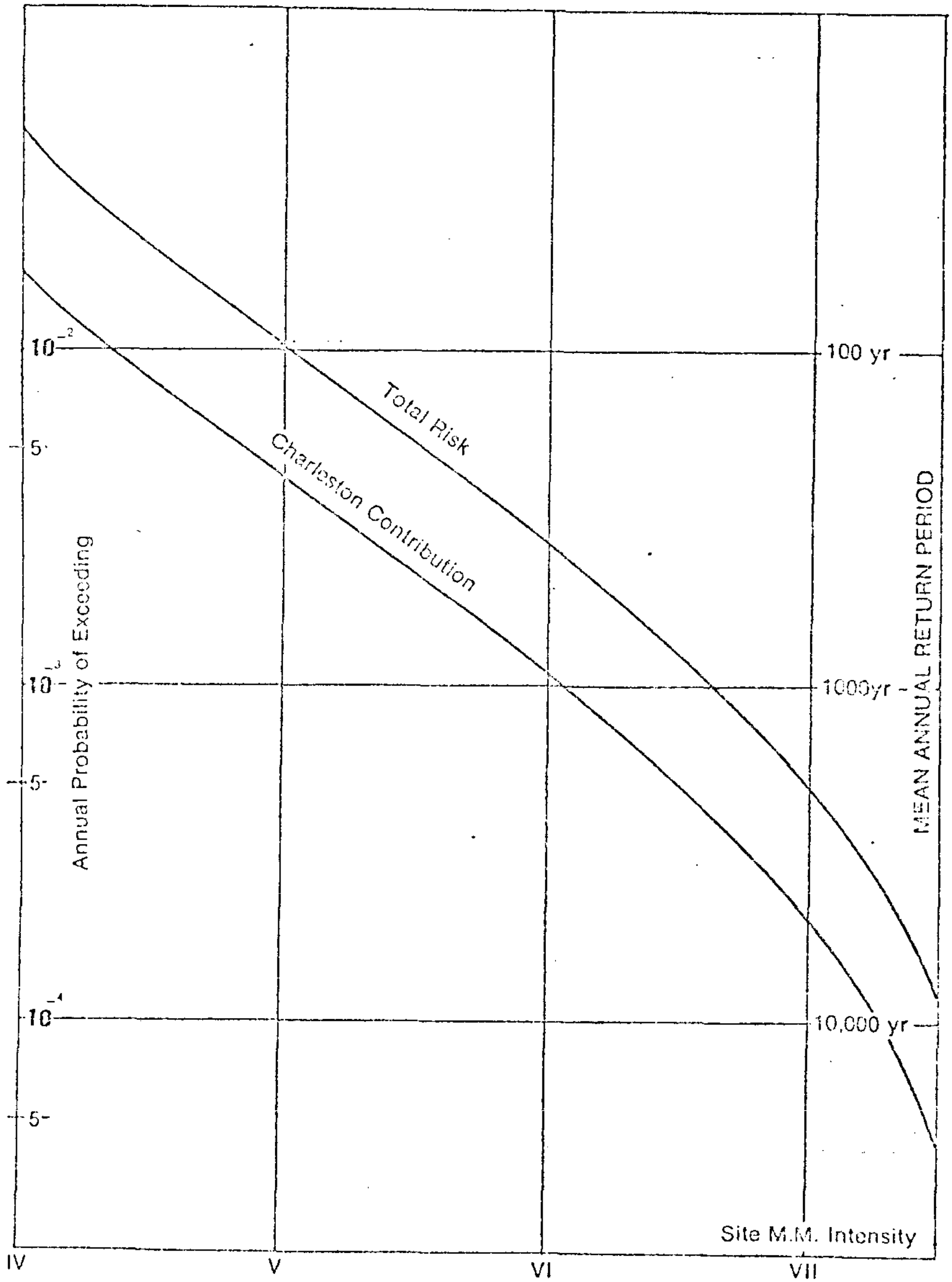

FIGURE 1. INTENSITY VS. ANNUAL RISK FOR THE R. B. RUSSELL DAM (USA Corps of Engineers, 1977)

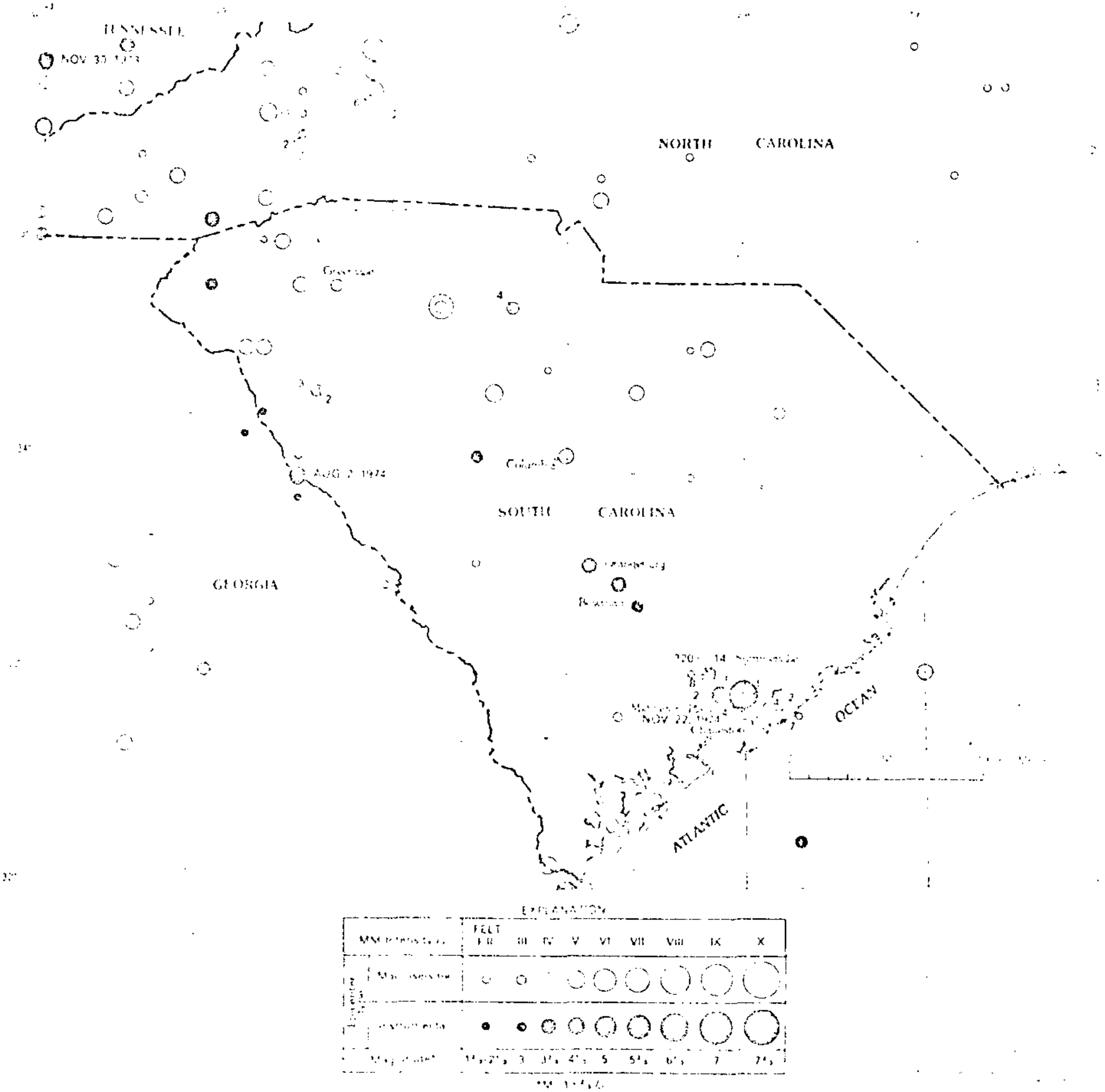

FIGURE 2.—Seismicity in South Carolina and adjoining States, 1754–1975. Earthquakes are indicated by circles of varying sizes, which represent the maximum Modified Mercalli intensities shown in the explanation. Numbers beside the epicenter symbols show the number of events recorded. Earthquakes are from the catalog of Bollinger (1975), supplemented by earthquakes reported by Carver and others (1977) and Bollinger and Visvanathan (1977)(Tarr, 1977)

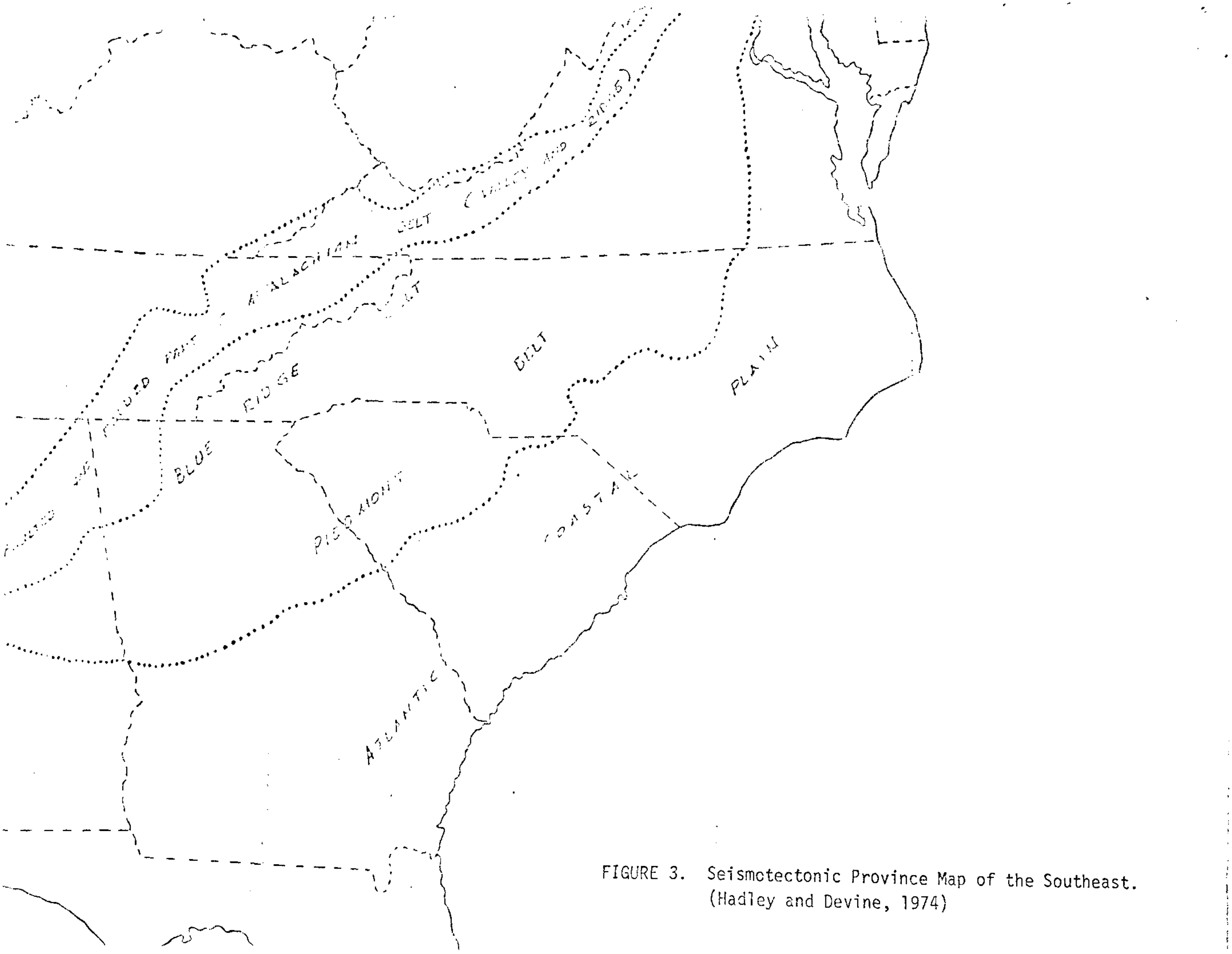

FIGURE 3. Seismotectonic Province Map of the Southeast. (Hadley and Devine, 1974)

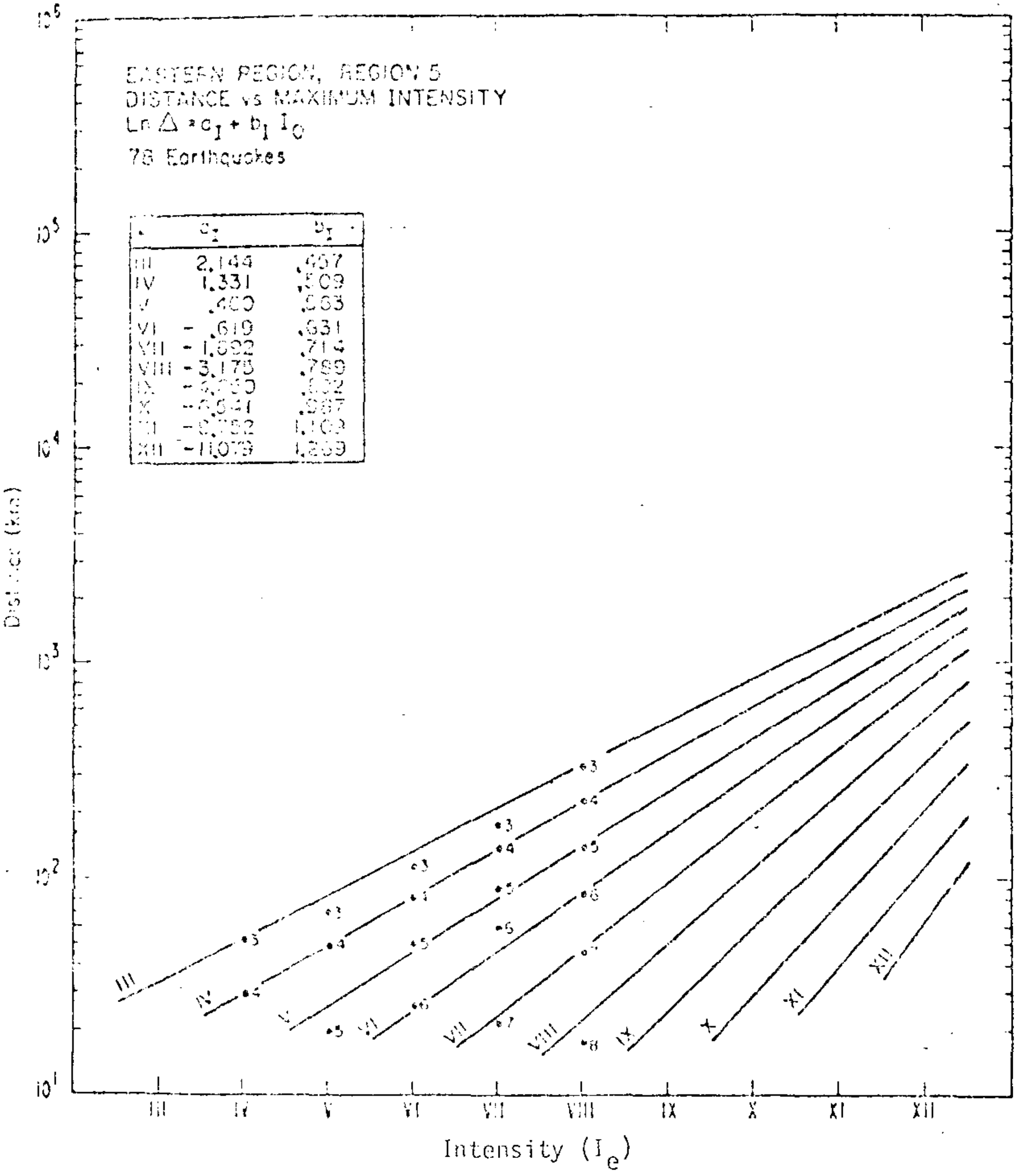

FIGURE 4. Intensity as a function of epicentral intensity and distance for the Eastern region of the U. S. (Brazee, 1976)

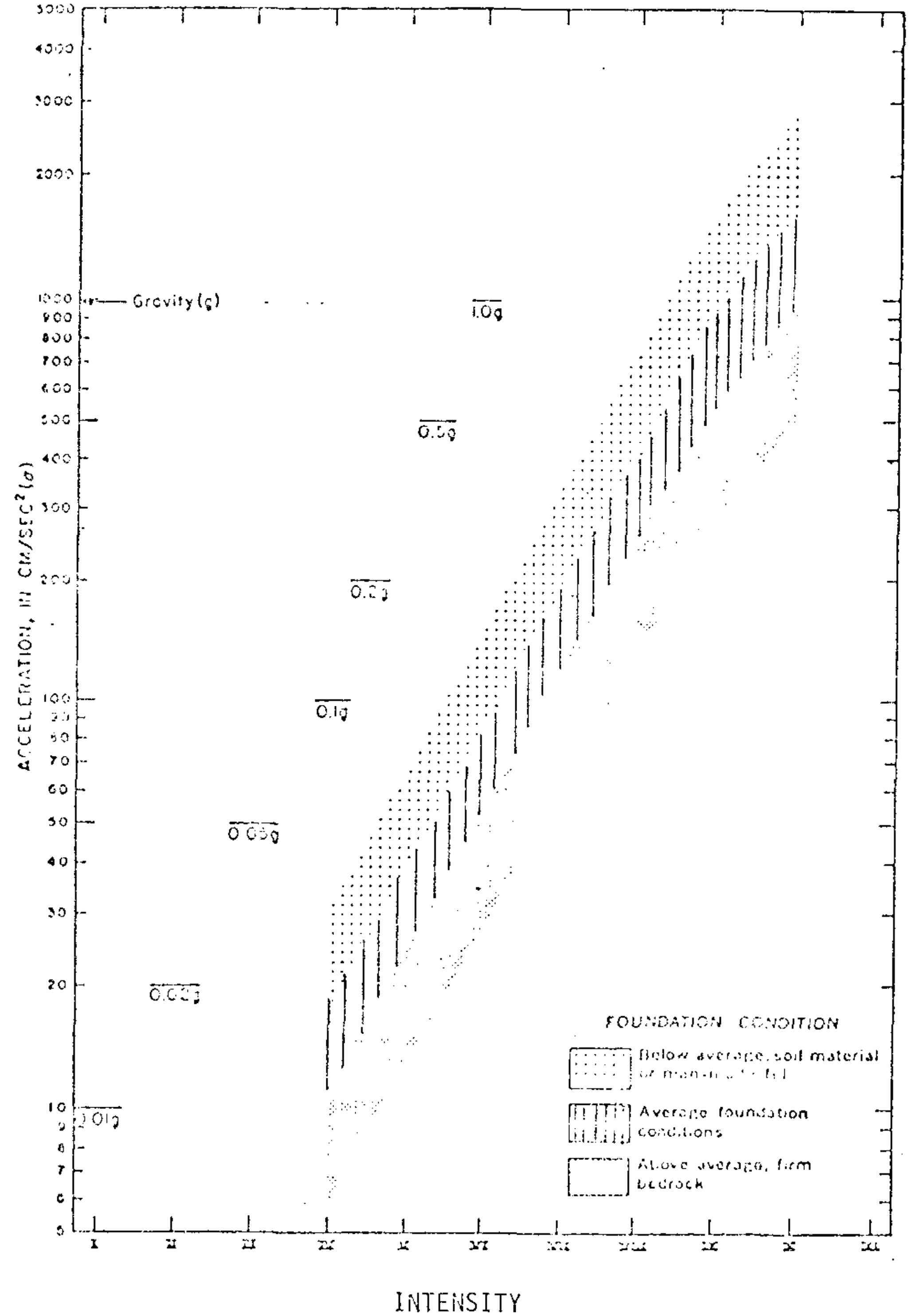

Figure 6. Intensity-acceleration relationships for various types of foundation conditions. (Coulter, Waldron and Devine, 1973)

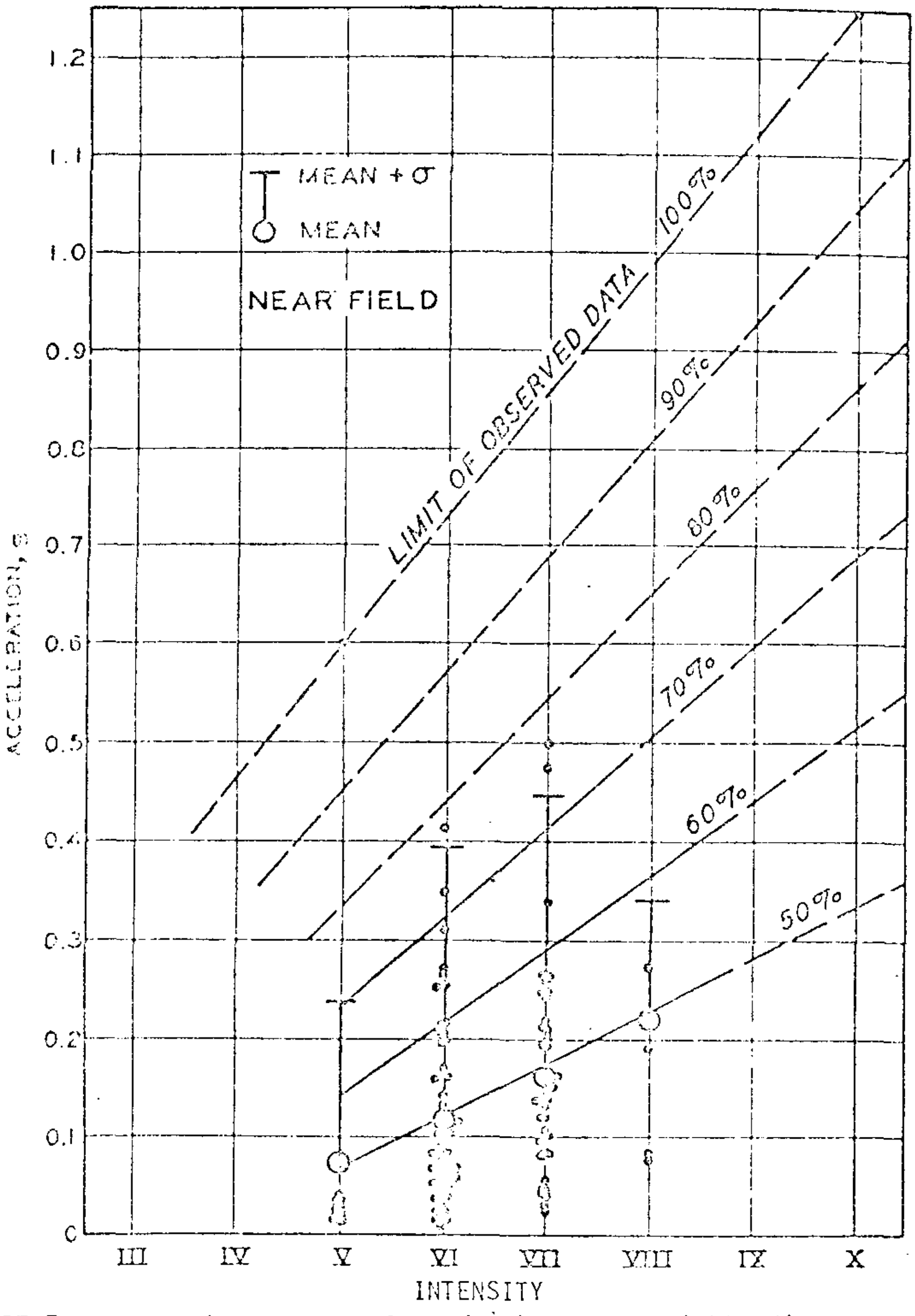

FIGURE 7. Acceleration Versus Intensity in the Near Field. Also Shown in the Mean, Mean plus One Standard Deviation, and 10 percent Increment Between the Projected Mean and the Limit of Observed Data (Krinitzsky and Chang, 1975)

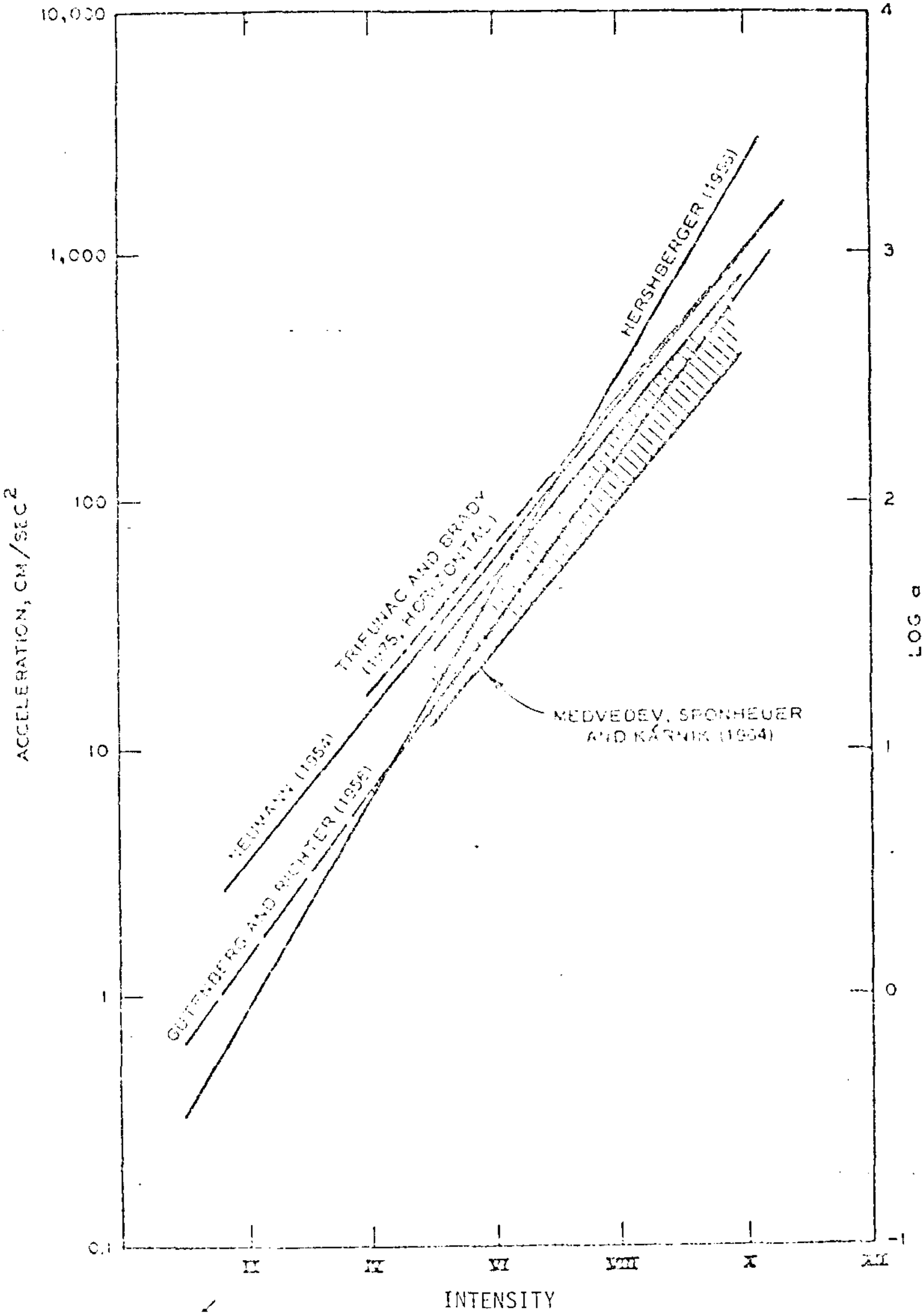

FIGURE 5. Comparison of selected curves for intensity vs. acceleration. (Trifunac and Brady, 1975)

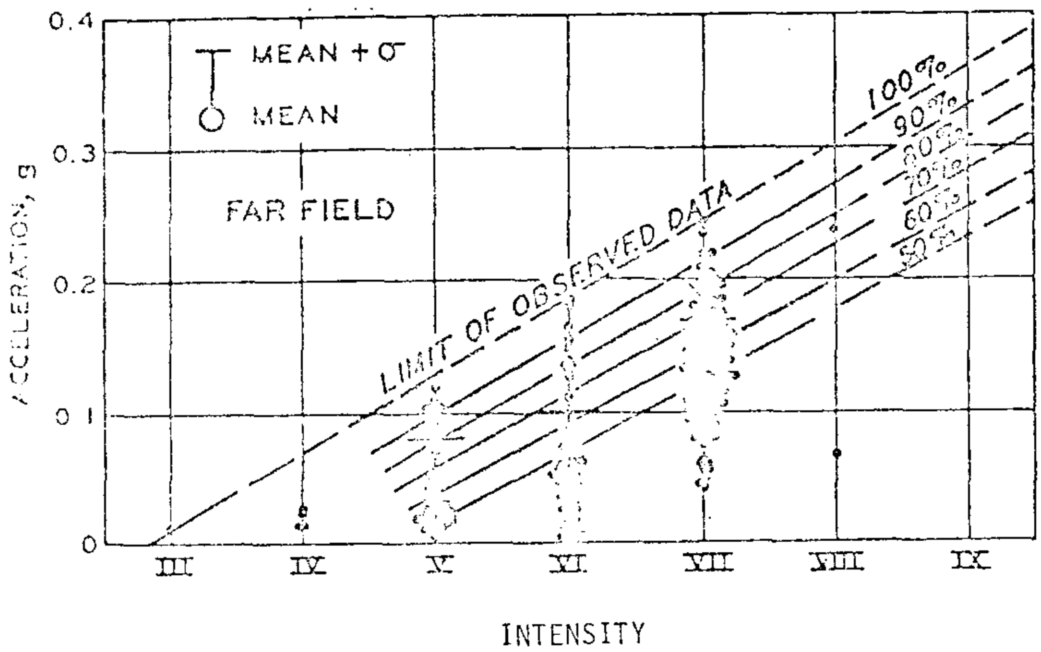

FIGURE 8. Acceleration Versus Intensity in the Far Field. Also Shown is the Mean, Mean plus One Standard Deviation, and 10 percent Increments Between Projected Mean and the Limit of Observed Data (Krinitzsky and Chang, 1975)

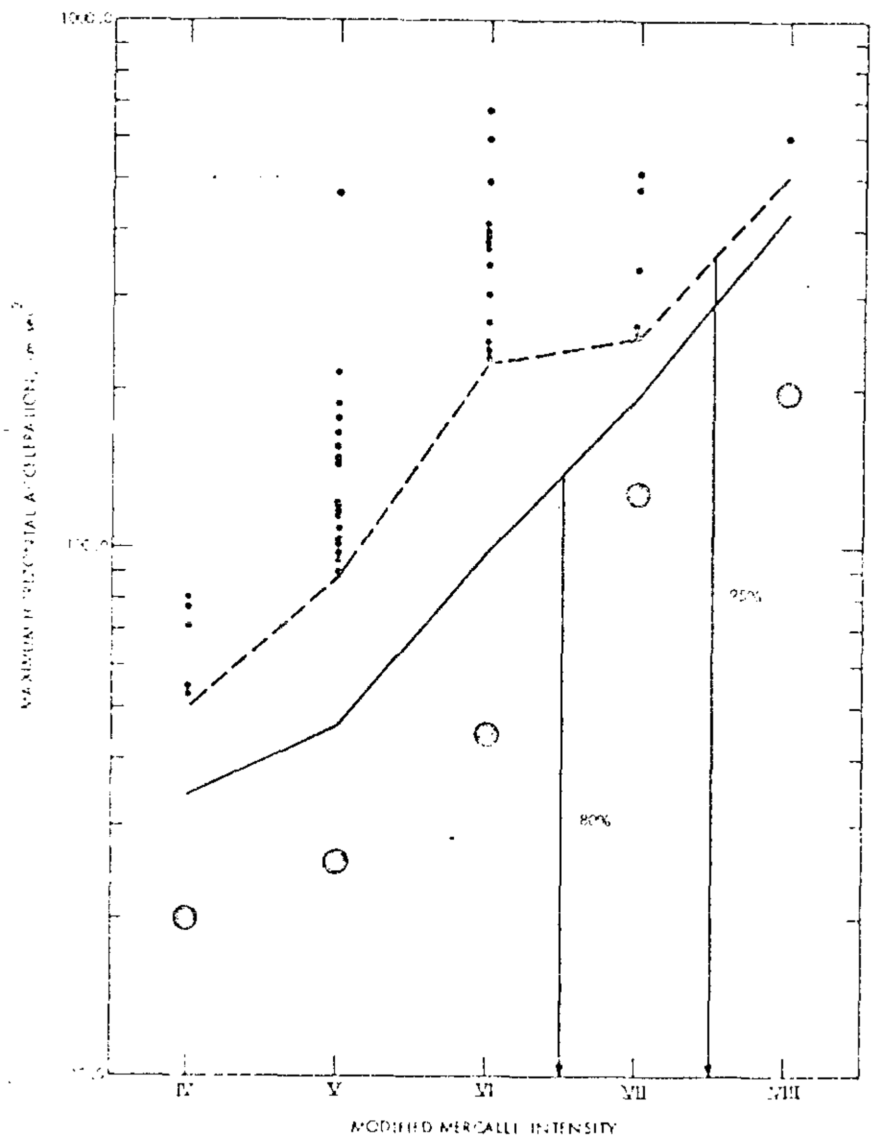

FIGURE 9. Graphic Display of the characteristics of the data sample relating intensity and maximum horizontal acceleration. (Murphy and O'Brien, 1977) Large circles logarithmic mean, solid line upper 80%, dashed line 95%, and small circles observations above 95% bound of the data.

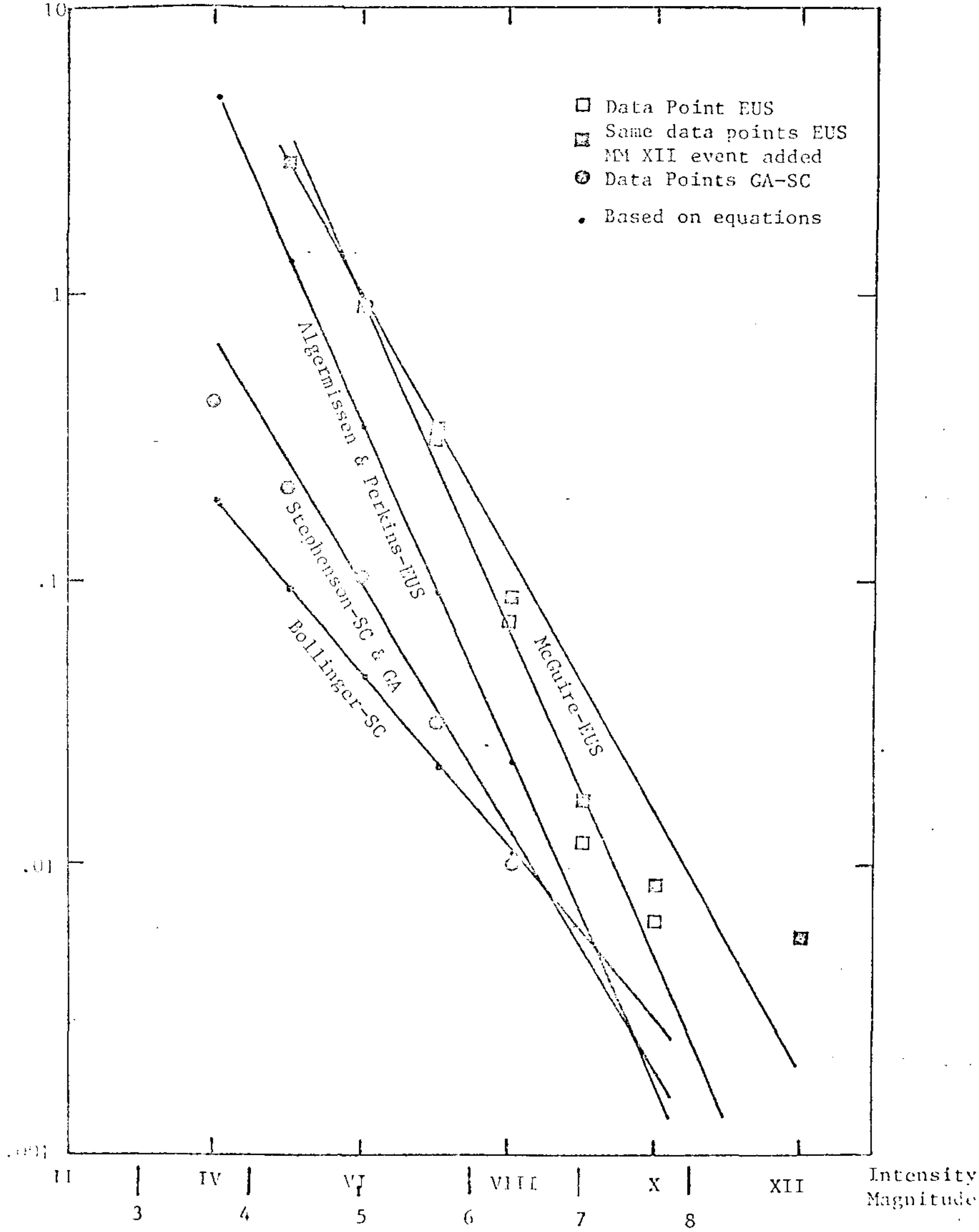

Figure 10. Comparison of selected recurrence curves for the Eastern and Southeastern U. S.

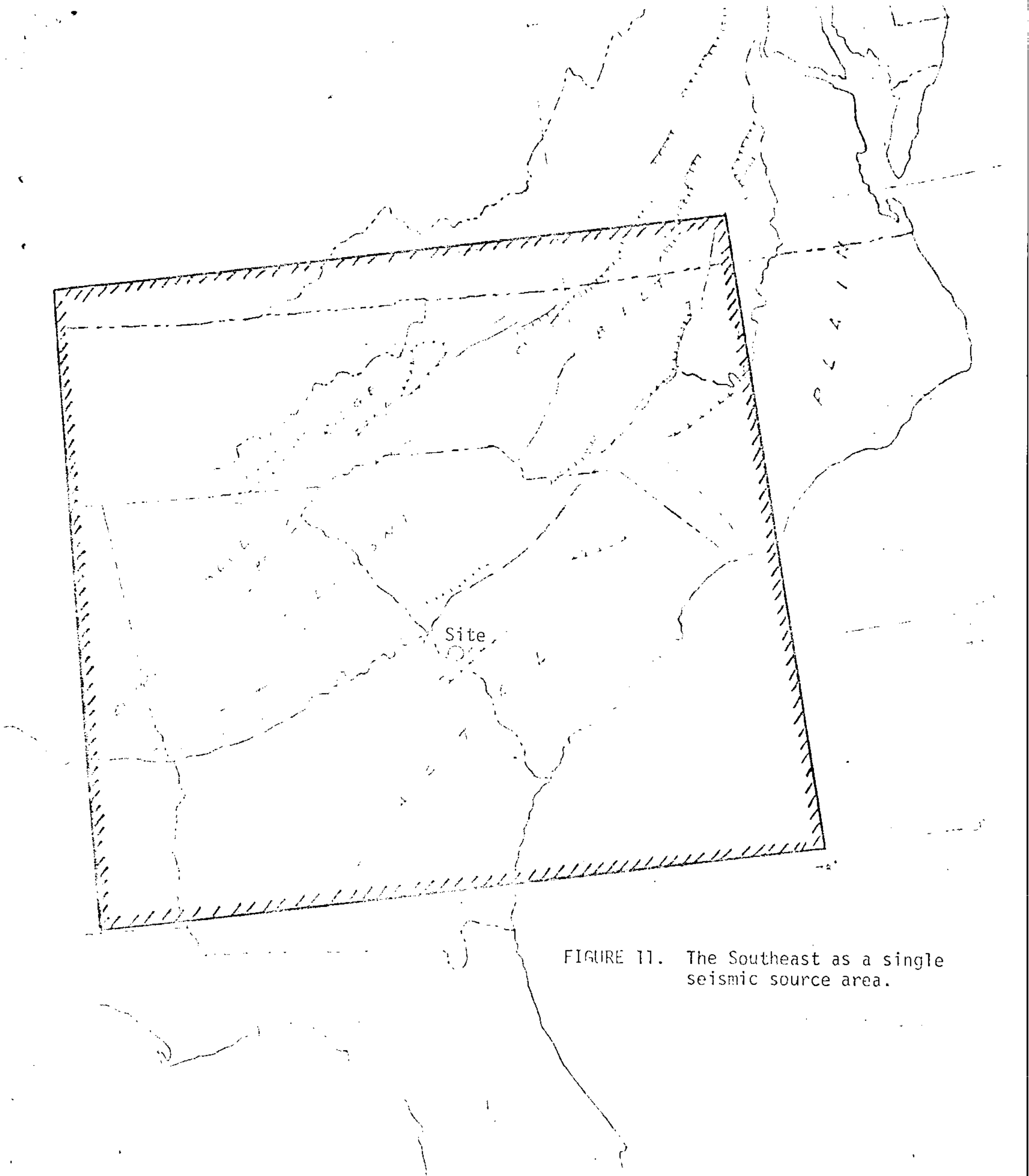

FIGURE 11. The Southeast as a single seismic source area.

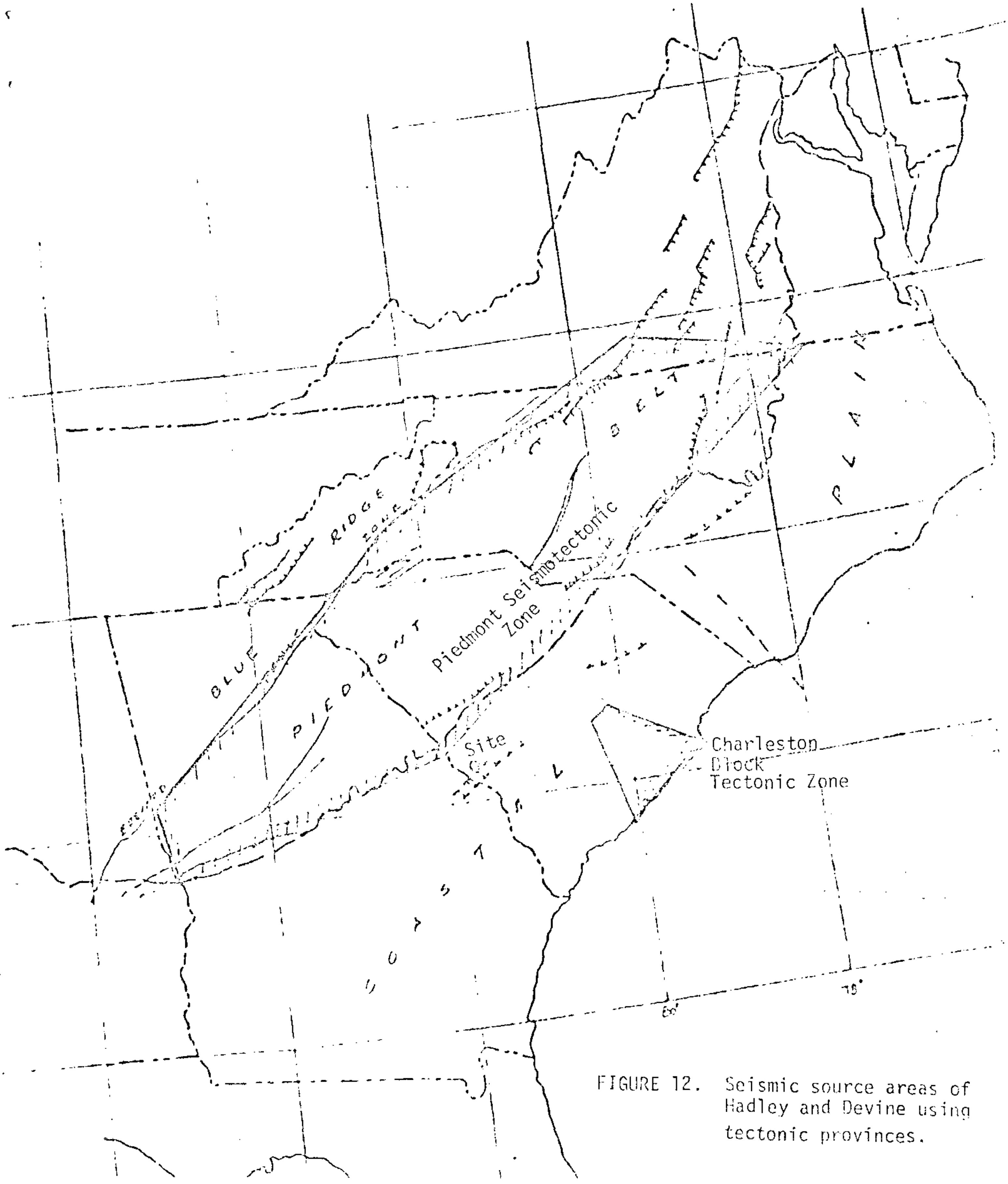

FIGURE 12. Seismic source areas of Hadley and Devine using tectonic provinces.

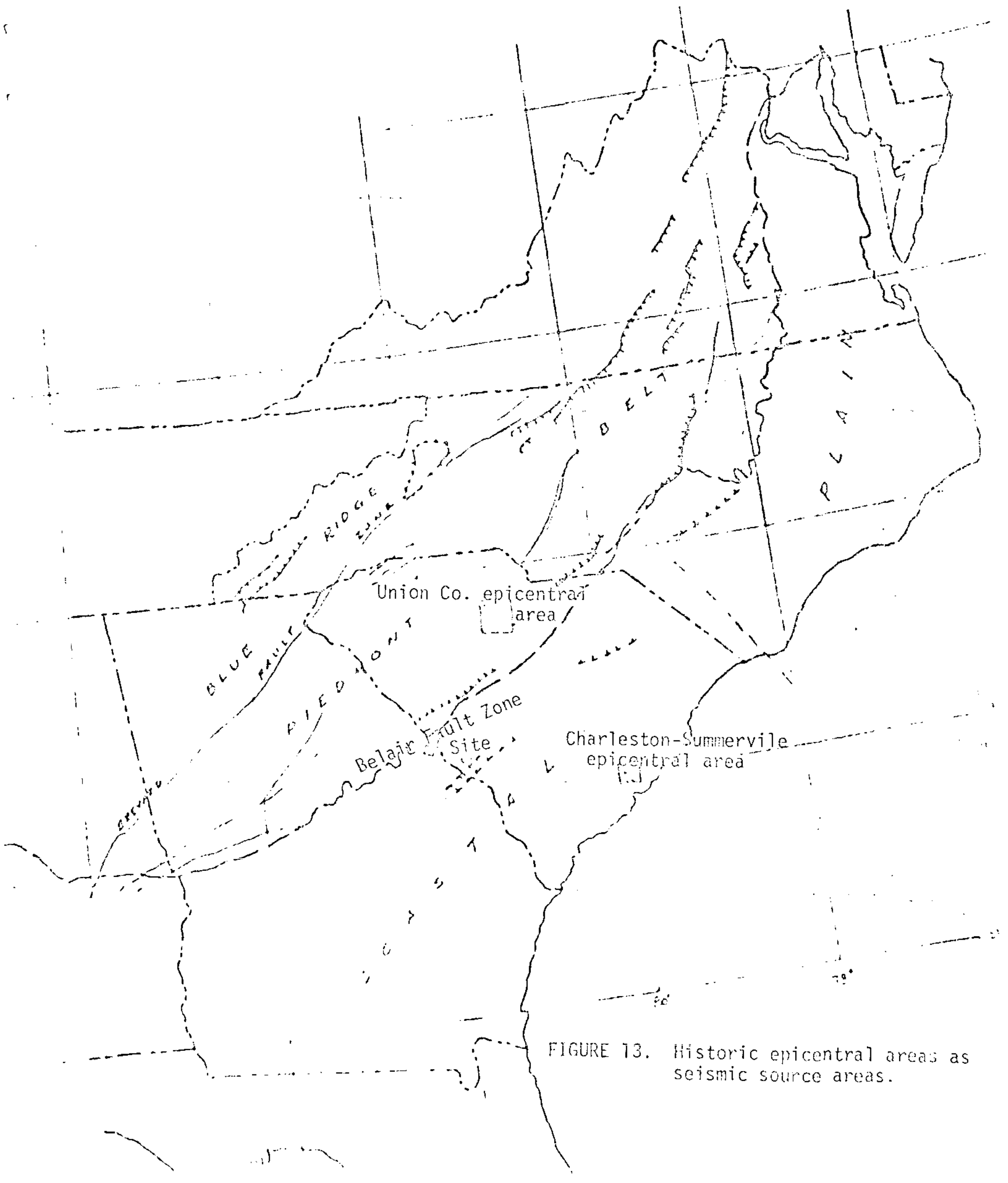

FIGURE 13. Historic epicentral areas as seismic source areas.

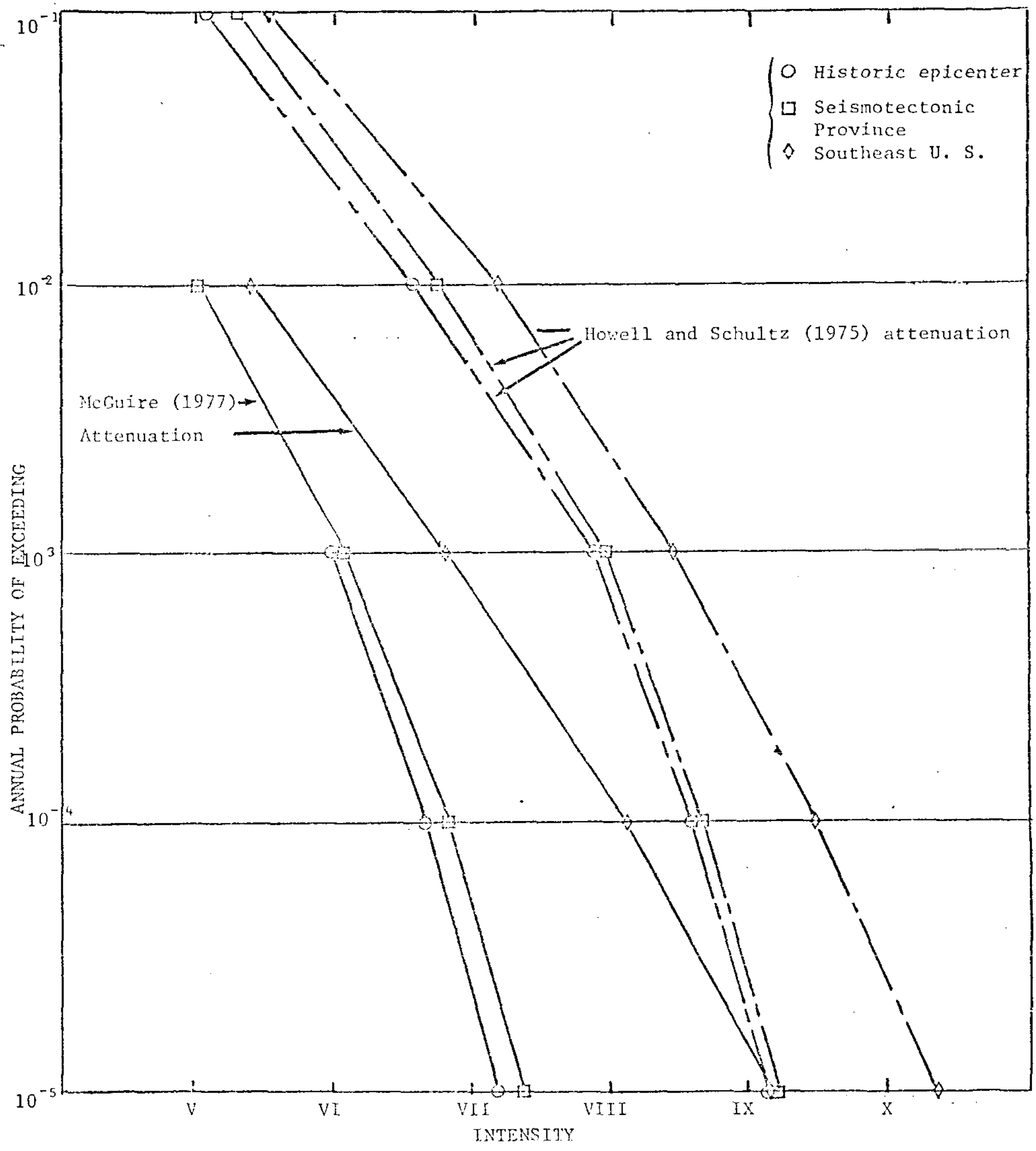

FIGURE 14. Intensity vs. annual probability of exceeding for SRP using attenuation relationships of McGuire and Howell and Schultz.