Public Service Company of New Hampshire

Seabrook Station

Units 1 and 2

Docket Nos. 50-443 and 50-444

# Testimony Concerning Seismology

by

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for

Public Service Company of New Hampshire

## Contents

## Figures



## Table

Comparison of the Probability of the Occurrence of an Earthquake Intensity on Rock Versus Soil

Damage as measured by the intensities resulting from an earthquake is dependent not only on the size and depth of the earthquake but also on the type of the earth materials where the damage occurred. The greatest damage, and therefore observed intensity, resulting from an earthquake almost invariably occurs on soil. Descriptions of earthquakes throughout history are replete with this fact. A few cases are given in Appendix 1 to this testimony.

Since the Seabrook site consists of very hard bedrock, the resulting intensity from an earthquake at this site would be less than that on the surrounding soil materials such as Hampton Harbor and like areas where relatively thick loose soils exist. The probability of the occurrence of an intensity IX from a given size earthquake would be less likely on the rock at Seabrook than on soil. This is illustrated by two figures. Figure 1 illustrates the increase in intensity over granite of material whose longitudinal wave velocities are less than those of granite. The velocity of the bedrock at Seabrook is very close to the velocity given for granite, 5.5 km/sec. The velocity of the soils material near the site range from about one-third (1/3) of a kilometer per second to about one and one-half (1-1/2) kilometers per second. Figure 1 taken from Barosh (1969) was developed by Medvedev, the Geofian scale (USSR) is used, which is equivalent to the Modified Mercalli Scale at the intensities of interest. Using the factors of one (1) to two (2) shown by this curve for the above given longitudinal velocities, the probability of the occurrence of a given intensity on the rock at Seabrook as compared to soil, is reduced by a factor of four (4) to fifteen (15) as illustrated in Figure 2.

Differences in intensity values between rock and soil, particularly poorer soils, can be significant at intensity values VIII and higher. (See Appendix 1, p. 5, Hodgson 1925 St. Lawrence Earthquake.) These higher intensity values are dependent in part on soils failure (Appendix 2, Modified Mercalli Scale), such as liquifaction, cracking of the ground and on the amplification of ground motion due to the contrast between the velocity of the soil layer and the higher velocity of the underlying rock. The relationship of intensity to the selection of a Safe Shutdown earthquake will be discussed later. However, if one is going to set the design earthquake to a probability level, the geologic materials must be considered; otherwise, the analysis does not account for the degree of conservatism in assuming that the intensity values on soil are the same as on rock. An analysis as related to the St. Lawrence Earthquake of 1925 (Appendix 1, p. 5) would have produced absurd results if rock and soil differences were not considered.

## Linearity and Upper Limit of the Type Curves Shown by Dr. Chinnery

The curve shown by Dr. Chinnery results from plotting the number of earthquakes of a given intensity value or higher for a given area per unit time versus intensity of the earthquake (Figure 3, Chinnery, 1979). It is tempting to extrapolate this curve and thereby to "predict" the number of earthquakes of a given size or higher at a given probability level. There are two questions which should be answered before this can reasonably be done:

1. Is the curve sufficiently linear, particularly at the high intensity end, to allow extrapolation?

2. Is there an "upper-limit" earthquake for the region above which the extrapolation should not be carried?

### Linearity of the Curve

The case for linearity of the curve, particularly for an intra-plate environment such as New England, is unproven. In fact, the evidence which exists for the intra-plate areas chosen by Dr. Chinnery are indicative of non-linearity at the high intensity end of the curve.

The earthquake data for the Mississippi area look quite different depending on the time period used. Dr. Chinnery plots the data for the Mississippi area for the time period 1840 to 1969 (Figure 3). In this curve he chooses to leave out the major earthquakes of that region which occurred in 1811, 1812. If these large events are included (thirty-nine more years of data) in the data set (Figure 4), the linearity projected from the smaller earthquakes does not fit the data points for the larger earthquakes.

The Southern United States area chosen by Dr. Chinnery does not include the 1886 Charleston, South Carolina earthquake which occurred before the time period selected by Dr. Chinnery (1900-1969). Tarr (1977) plots earthquakes in the time period 1754 to 1975 for two areas, an area approximately 20 km (average radius) around Charleston (Figure 5A) and an area slightly larger than South Carolina (Figure 5B). The plots of these earthquakes are shown in Figure 5. These plots indicate a slope dependence by area, the small area including the large earthquake having a "flatter" slope. The flatter slope could indicate that the larger faults which produce larger earthquakes behave differently than the population of small faults which produce smaller earthquakes.

There are three areas for the broad region of eastern United States and eastern Canada which have had the largest historical earthquakes (approximate magnitudes of 7). The New Madrid, Mo. (Mississippi Valley), and Charleston, South Carolina have been cited. The cumulative plot of earthquakes for the third area (approximate 33 km radius), La Malbaie, Province of Quebec, Canada, 90 miles northeast of Quebec City, is shown in Figure 6. The largest earthquake for this area magnitude 7, intensity IX occurred in 1925. Again, the recurrence curve developed for this area is not linear at the high intensity end.

For the three cited cases, Mississippi Valley, Charleston, La Malbaie, the high intensity end of the curve does not follow a linear pattern; it does not have a "stable" slope. There are several possible explanations for this:

> The observation period fortuitously includes the large earthquakes and if we looked at a much longer time period their probability level would be much lower (or their return period much longer). This is the explanation Dr. Chinnery has chosen when he uses the "linearity" of the smaller events.
>
> The points may be fitted by another type curve or there are different slopes for the smaller earthquakes than for the larger earthquakes; for the European area different slopes can be fit to different regions (Karnik, 1969) and, in some regions, two slopes fit the data much better than one.
>
> The curve changes slope with time and/or the earthquakes are not uniformly distributed in time and therefore not predictable at any probability level from the limited time base we have.

Whichever one of these explanations we take, the result is the same: the curve in the historical time period is not linear at the high intensity end. To make it appear linear one must adjust the data set on some judgemental basis. In fact, a number of invesigators have chosen other curves to fit the data such as a quadratic law (Cornell & Mertz, 1973) or by use of extreme value statistics (Yegulalp and Kuo, 1974, Lilwal, 1976).

For the sake of comparison, the Boston-New Hampshire region described by Dr. Chinnery, was independently interpreted using the data base for earthquakes researched and compiled by Weston Geophysical Corporation. This list is basically contained in the Chiburis catalog of historical seismicity in the northeastern U.S. (available from the National Oceanic and Atmospheric Administration, Boulder, Colorado) and the Preliminary Safety Analysis for Pilgrim Unit II of Boston Edison Company. Both linear and quadratic recurrence models were fit through the data as shown on Figure 7. At intensity IX on soil, the linear model predicts an annual recurrence rate approximately two and one half (2-1/2) times that predicted by the quadratic model. This variation is not considered to be important at intensity IX, but would have a significant effect at higher intensities. It should be noted that Figure 7 is taken over the same 30,000 square kilometer area as that selected by Dr. Chinnery. This curve does not represent the probability of the epicentral area occurring at the site. The curve for estimating the probability of an intensity IX (epicentral area IX of 1,000 square kilometers) occurring at the site is shown in Figure 8. This curve, developed using the Chinnery linear relationship, shows an annual probability that is 30 times less than the region as a whole or $2 \times 10^{-5}$ at the site. If we use a factor of 10 to account for a rock site (see Figure 2) then the probability of IX at the site reduces to $2 \times 10^{-6}$ per year.

The summary of these arguments is that a purely probabilistic approach such as Dr. Chinnery's involves numerous assumptions and uncertainties and by using other equally realistic models and compensating for geologic condition, site area, etc. several orders of magnitude difference (lower) in probabilitiy levels can be predicted for the larger intensity earthquakes.

Regional Upper-Limit

The curves which have been discussed do not tell us that there is or is not a regional "upper-limit" earthquake. In any given region the available stress and the nature of existing earthquake structures may be such that only small or intermediate earthquakes will be produced. More than 99% of the world's earthquakes occur in less than 10% of its area which attests to the existence of seismic as well as aseismic areas.

Since geologic processes are continuous over long periods of time, evidence from the geological record can extend our time base by many thousands, even millions of years. There is no recent geologic evidence of large earthquakes in New England. Such things as capable faults (that is tectonic offset of recent geologic materials) have not been found although extensive geologic and geophysical mapping has been conducted for many years over the region.

The geologic evidence in New England is quite different than those areas where frequent and large earthquakes occur and whose geologic record abounds with evidence of recent activity.

It is interesting to look at the geologic record in the Mississippi area for evidence of past large earthquakes. The area around the epicenter of the 1811, 1812 earthquakes, New Madrid, Mo., has a great deal of geological evidence of larger earthquakes. Fuller (1912) has described such evidence; an excerpt from his publication is given in Appendix 3.

## Definition of the SSE at Seabrook

There are several elements with respect to the selection of the SSE which were used in selecting the Seabrook design spectrum: an intensity, its corresponding acceleration, and NRC Regulatory Guide 1.60 Design Response Spectra for Seismic Design of Nuclear Power Plants. This is a procedure generally used for nuclear power plants.

The purpose of this portion of testimony is an attempt to present what the design spectrum used at Seabrook represents with respect to equivalent real earthquakes in terms of intensity and magnitude.

The definition of the Safe Shutdown Earthquake is by a response spectra, 10 C.F.R. Part 100, App. A, Section V(a)(1)(iv). Until recently the amount of existing strong ground motion data was not abundant; hence in licensing nuclear power plants standard response spectral shapes such as NRC Regulatory Guide 1.60 were used. The shape of this regulatory guide spectrum was derived by using earthquakes whose magnitudes and distance from the strong motion recording sites ranged widely. Additionally, the foundation materials underlying the recording stations had large variation but were mostly on soil. The spectral shape is basically site independent and represents a set of conditions which the site could not experience from a single earthquake. This standard shape is traditionally set at some anchor point, generally an acceleration level related to the design earthquake expressed in intensity, 10 C.F.R. Part 100, App. A, Section V(a)(1)(iv) and V(a)(1)(ii). This selection of intensity and resulting acceleration was made without credit for rock or rocklike geologic conditions.

Those elements of the procedure (a selection of a maximum earthquake intensity and the corresponding acceleration to which Regulatory Guide 1.60 is set) which lead to a great deal of conservatism are: (1) assuming that the maximum intensity could occur on good to excellent geologic materials such as the bedrock at Seabrook; (2) setting a conservative spectral shape to an acceleration representative of this intensity.

No single element of the process, the earthquake intensity, the corresponding acceleration value or the spectral shape, describes the resulting earthquake design level, namely the final design spectrum by which the Safe Shutdown Earthquake is described. As a result, even if a probability level could be computed for the intensity value it would only be a partial answer.

Recently a large number of strong motion recordings has become available from earthquakes of various magnitudes at different distances and for a variety of foundation conditions including rock. At the present time, a site specific response spectrum corresponding to the selected magnitude level, its distance from the site, and foundation conditions can be constructed for most sites.

Using developed relationships (Nuttli, Boliinger, Griffiths, 1979) which relate magnitude to intensity, the historical earthquake record can be estimated in terms of magnitude. Magnitude and intensity were related using modern earthquakes which have both well documented magnitude as well as intensity values. Basically, this method depends on the size area affected by the earthquake or the falloff of intensities with distance. The resulting magnitude corresponding to a conservative estimate of the perceptible area of the 1755 Cape Ann earthquake ranges from a magnitude ($m_b$) of 5.6 to 6.

Once the definition of the earthquake by magnitude is established, then the distance from the recording station to the earthquake is selected to approximate the distance from the site of the nuclear plant to the earthquake. In the case of the tectonic province the highest intensity of the earthquake is assumed at the site 10 C.F.R. Part 100, App. A, Section V(a)(1)(ii) with its corresponding ground motion. Since the epicentral intensity, if it is characteristic of an earthquake, occurs over an area, a range of distances for the magnitude occurrence is selected. Because capable faulting is generally not a problem in the eastern United States, the selection of the strong motion records should be such that the effects of capable faulting are eliminated or minimized. This is accomplished through the selection of appropriate distances and, if possible, the most representative earthquakes. Note that these procedures do not depend on the selection of an acceleration value at which to set a design spectral shape.

The last criterion to be satisfied is the match of geologic materials underlying the site to those underlying the strong motion recording station. In the last few years measurements of seismic compressional and shear wave velocities have been made at many of the recording sites so that a direct quantitative comparison can be made to the Seabrook site.

A search of the world-wide data set of strong motion records was made to satisfy the above conditions of magnitude and distance range as well as foundation conditions, as nearly as possible. Table 1 lists the accelerometer stations (rock) and earthquakes selected to satisfy the criteria stated. Figure 9 shows the strong motion records from each horizontal component as output through a family of single degree of freedom oscillators (response spectrum) at a given damping value (5%).

The site specific response spectra mean and 84 percentile probability levels are shown on Figure 10. The 84th percentile probability level is consistent with that suggested by Newmark (1973) for design of nuclear power plants. The 84 percentile of this data set, as shown on Figure 10, is less than the motion represented by the Seabrook design spectrum which is Regulatory Guide 1.60 set to a horizontal acceleration of .25g. The range of magnitudes is 5.3 - 6.2 $m_b$ with a mean value of 5.8. The range of epicentral intensities is VII - XI with a mean epicentral intensity of IX. Significant parameters of the earthquakes are given in Table 1.

This data set embraces moderate to large earthquakes from a magnitude consideration. From an epicentral intensity consideration, the range is from a moderate earthquake of intensity VII to an intensity XI, the higher intensity range representing disasterous earthquakes with significant building damage and loss of life.

This study demonstrates that the SSE (response spectra), as it defines the hypothetical threat at Seabrook, accommodates large earthquakes. Clearly, if one could establish a probability level to obtain a reasonably conservative design value for a nuclear power plant it ought to be done with all of the elements which lead to the design spectrum considered.

## References


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Figures

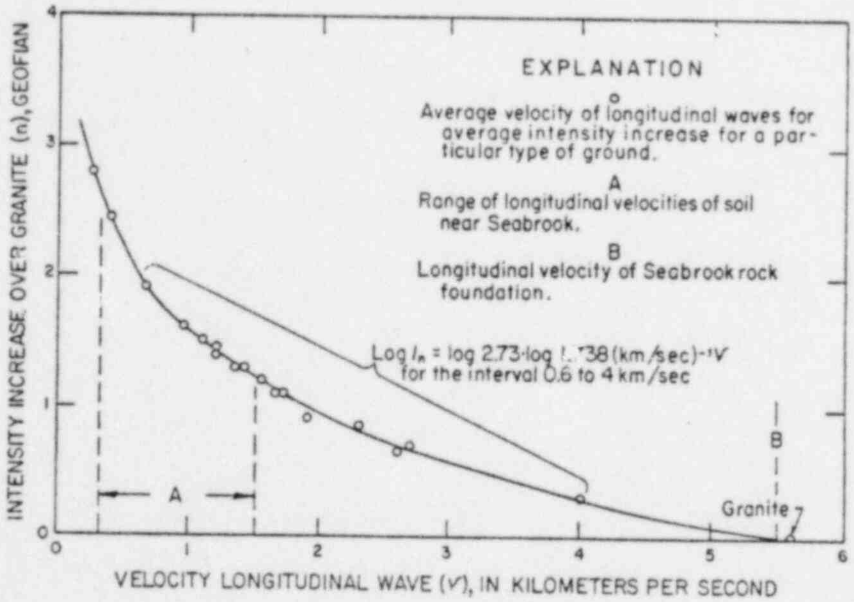



FIGURE 1

Increase of intensity of different types of ground over that of granite as a function of seismic wave velocity. Data from Medvedev (1961, Table 4.2).

Reproduced from Barosh, P. J. (1969)

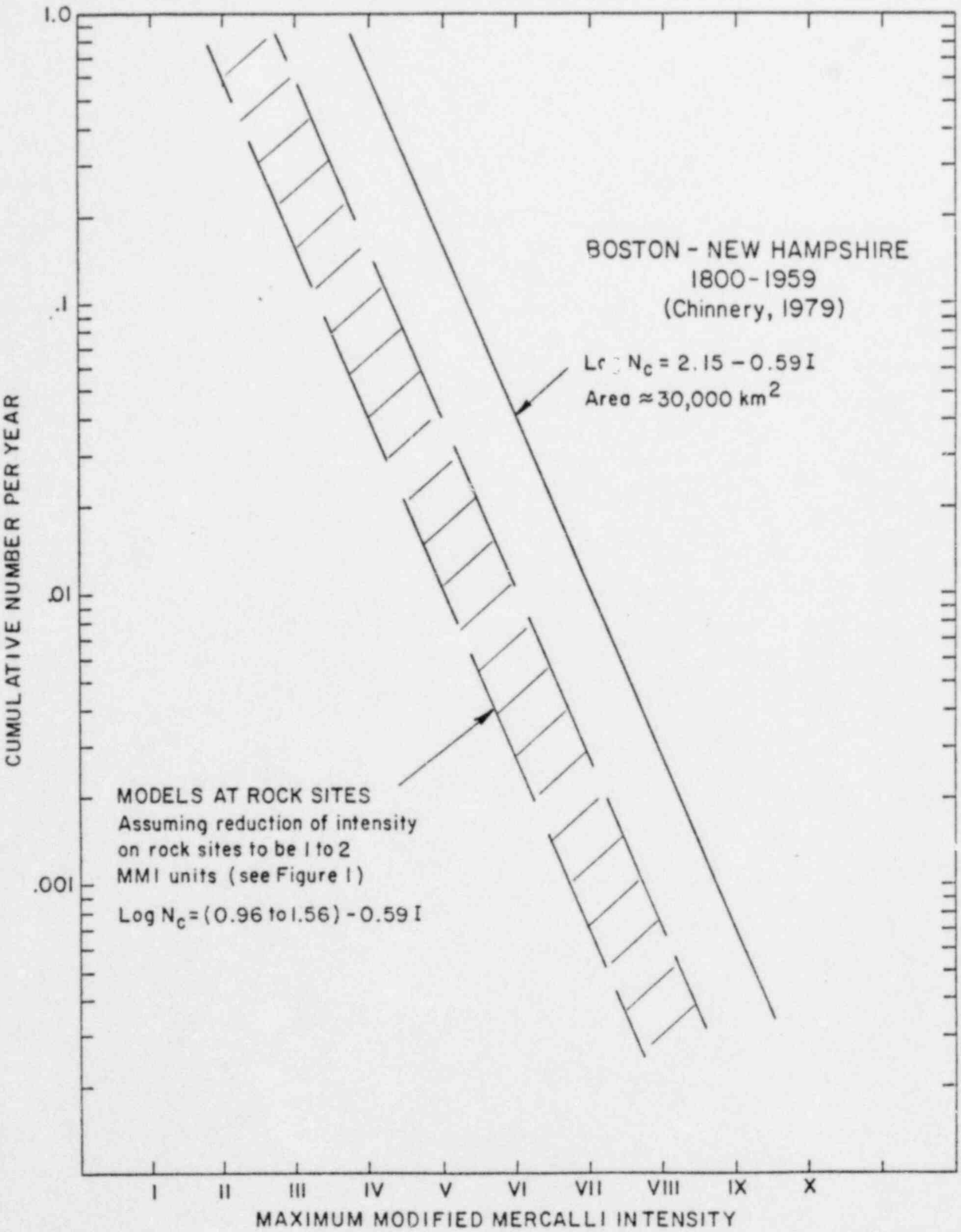
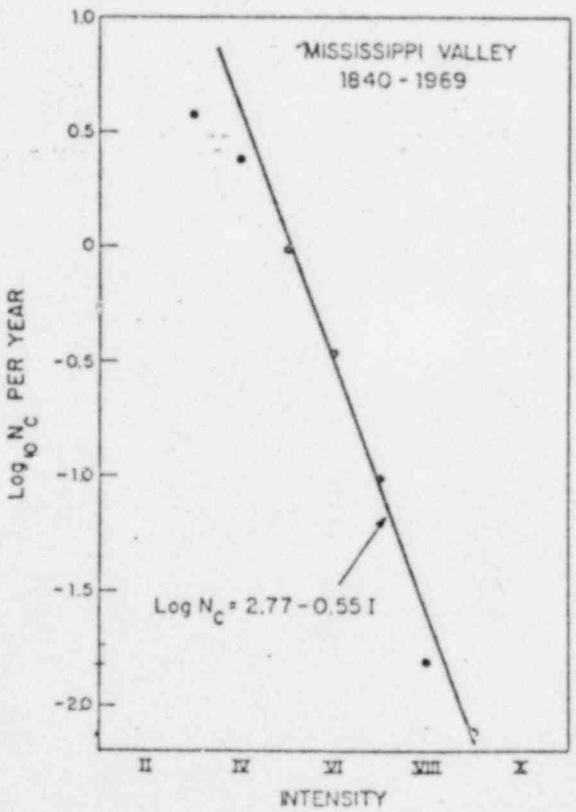



FIGURE 2

Probability of Intensity on Rock for Region of Boston - New Hampshsire.




Cumulative frequency-intensity plot for the data in Table 2.

FIGURE 3

Mississippi Valley 1840 - 1969
(Reproduced from Chinnery, 1979, Fig. 4)

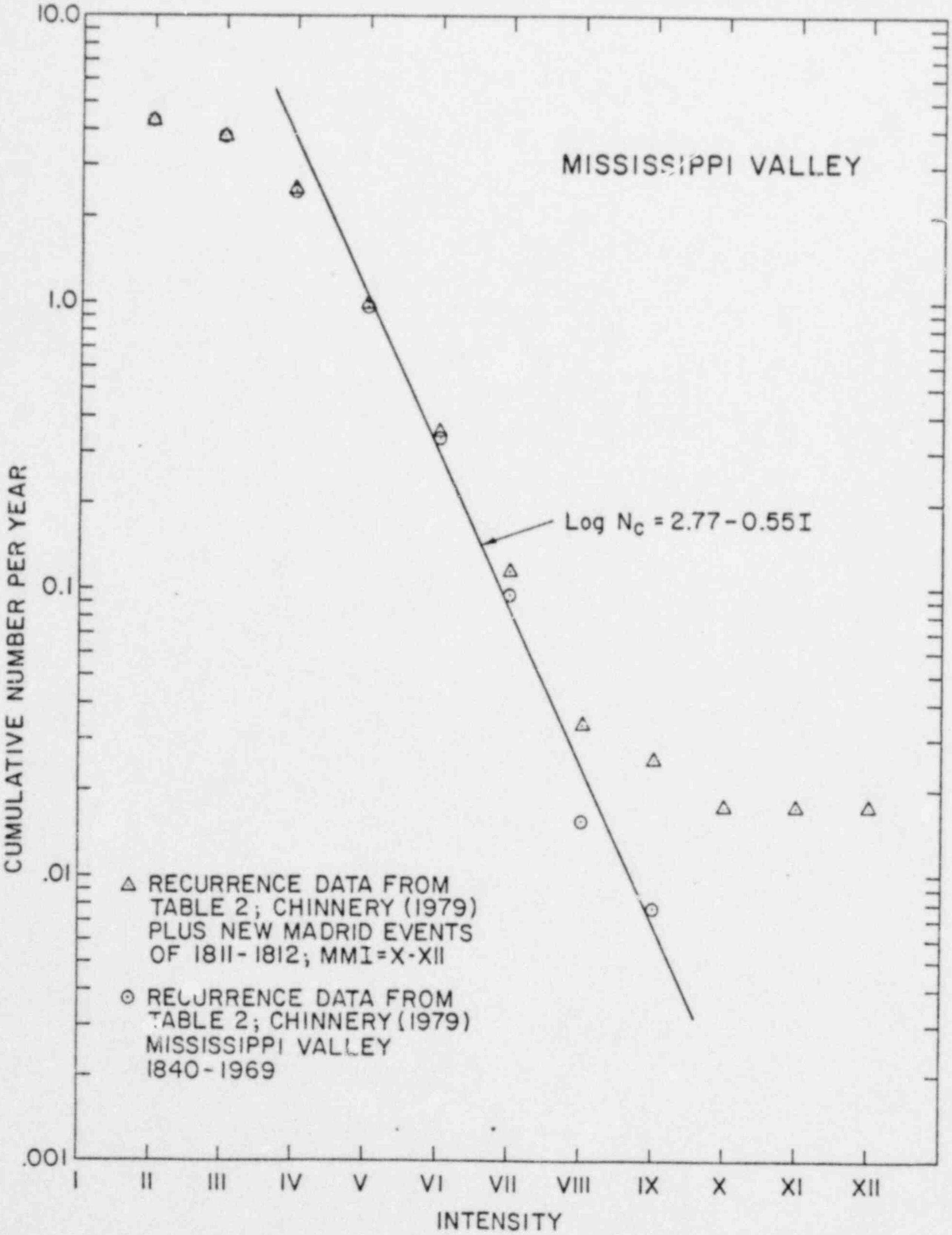



FIGURE 4

Mississippi Valley with all 1811 - 1812 New Madrid Earthquakes included.

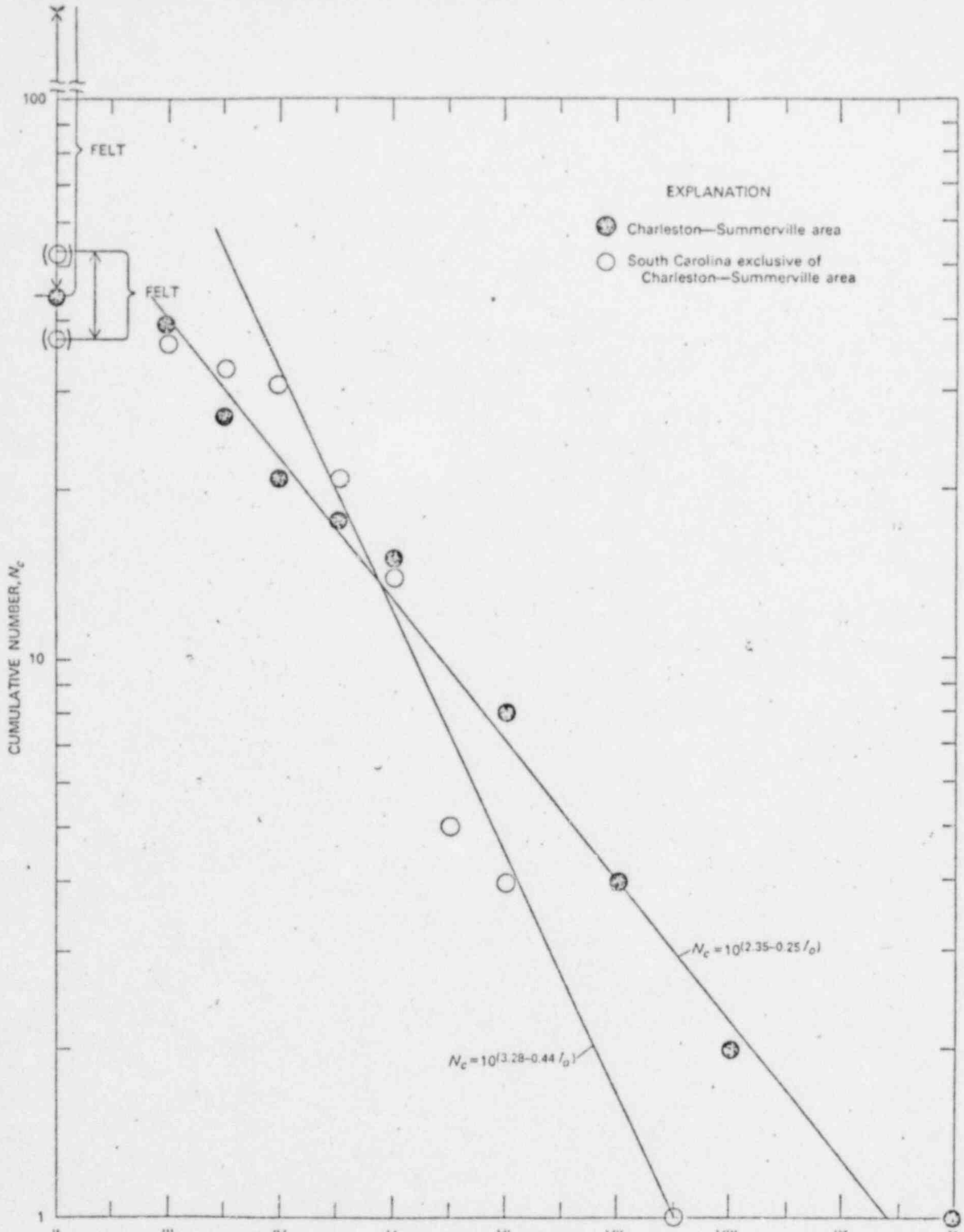



FIGURE 4.—Graph showing the cumulative number ($N_c$) of earthquakes in South Carolina versus maximum Modified Mercalli intensity ($I_o$), 1754–1975. The data, taken from table 1, are separated into two regional sets. Felt earthquakes are added at the intensity-II level. Symbols in parentheses are interpolated points. The Charleston-Summerville data set appears to be complete down to $I_o$=III, and the South Carolina data set appears to be complete down to $I_o$=IV, if the anomalous value of $N_c$ at $I_o$=V–VI is ignored.

FIGURE 5

Charleston, S. C. and South Carolina Earthquakes, 1754 - 1975 (Reproduced from Tarr, 1977).

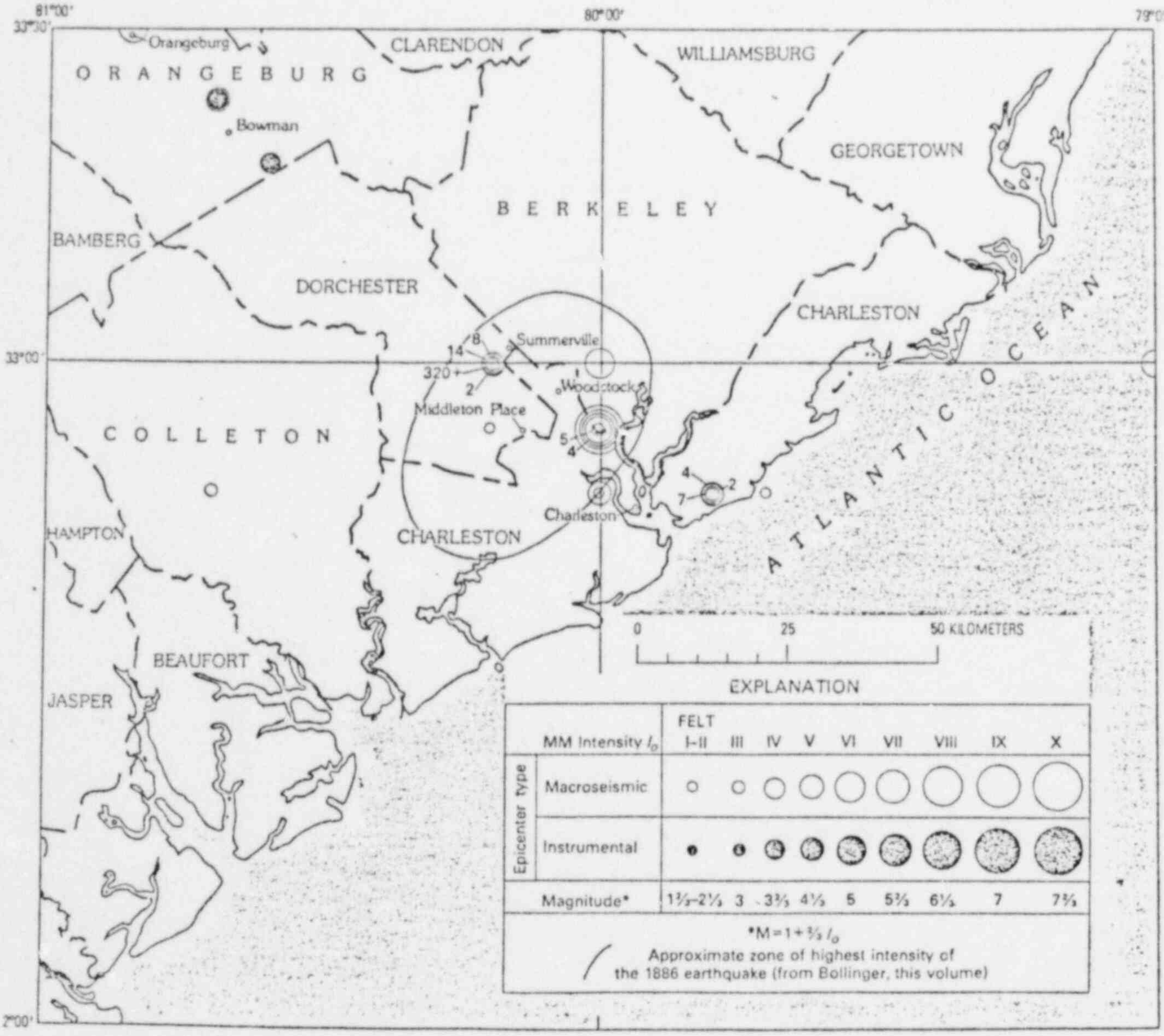



FIGURE 3.—Seismicity in the Charleston, S. C., area, 1754-1972. Data are from the same catalogs as in figure 2. The earthquakes shown are principally but not exclusively, macroseismic epicenters. Numbers beside the epicenter symbols show the number of events recorded.

FIGURE 5A

Seismicity of the Charleston - Summerville, S. C. Area (Reproduced from Tarr, 1977).

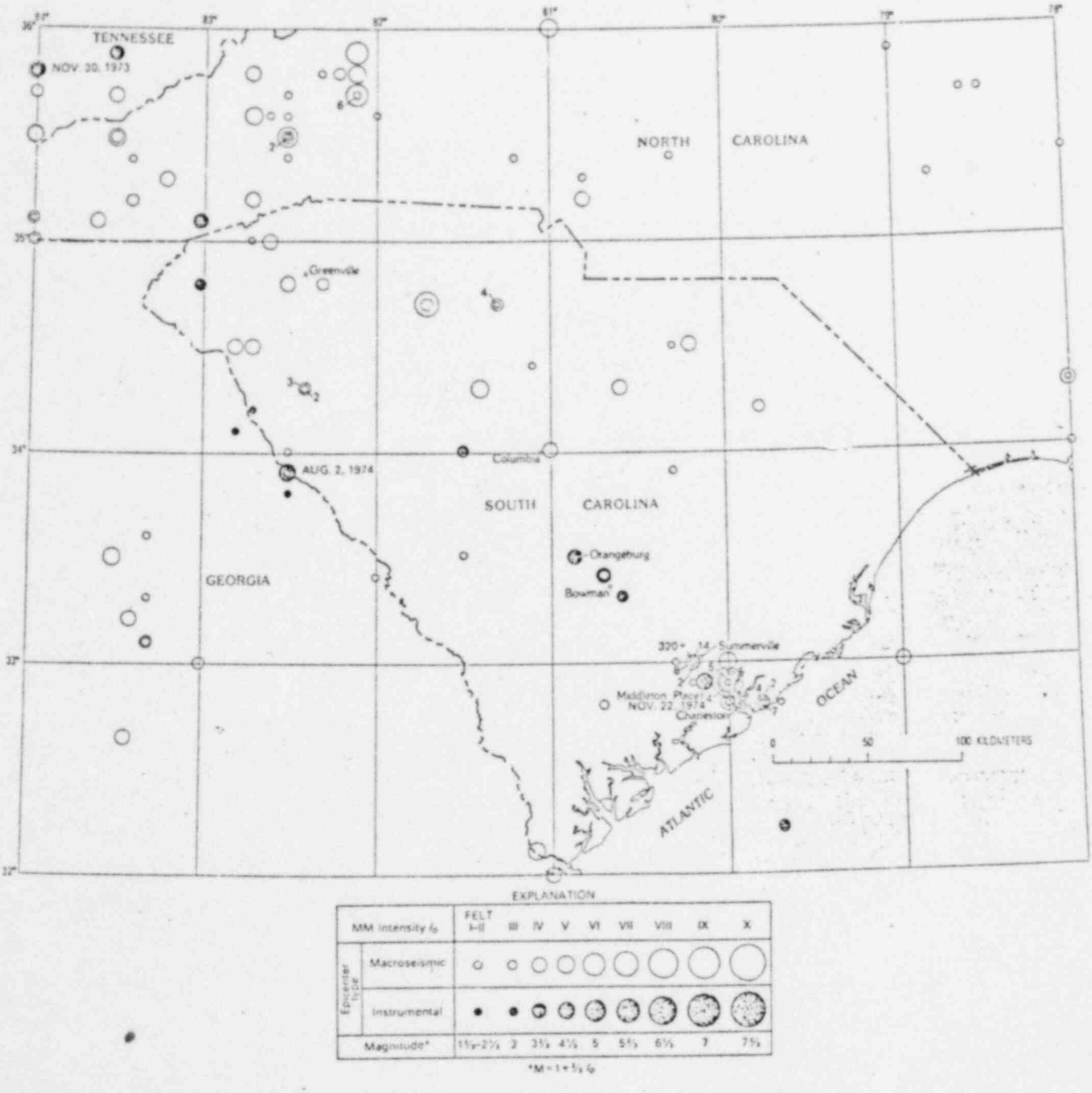



FIGURE 2.—Seismicity in South Carolina and adjoining States, 1754–1975. Earthquakes are indicated by circles of varying sizes, which represent the maximum Modified Mercalli intensities shown in the explanation. Numbers beside the epicenter symbols show the number of events recorded. Earthquakes are from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

FIGURE 5B

Seismicity of the South Carolina Area (Reproduced from Tarr, 1977).

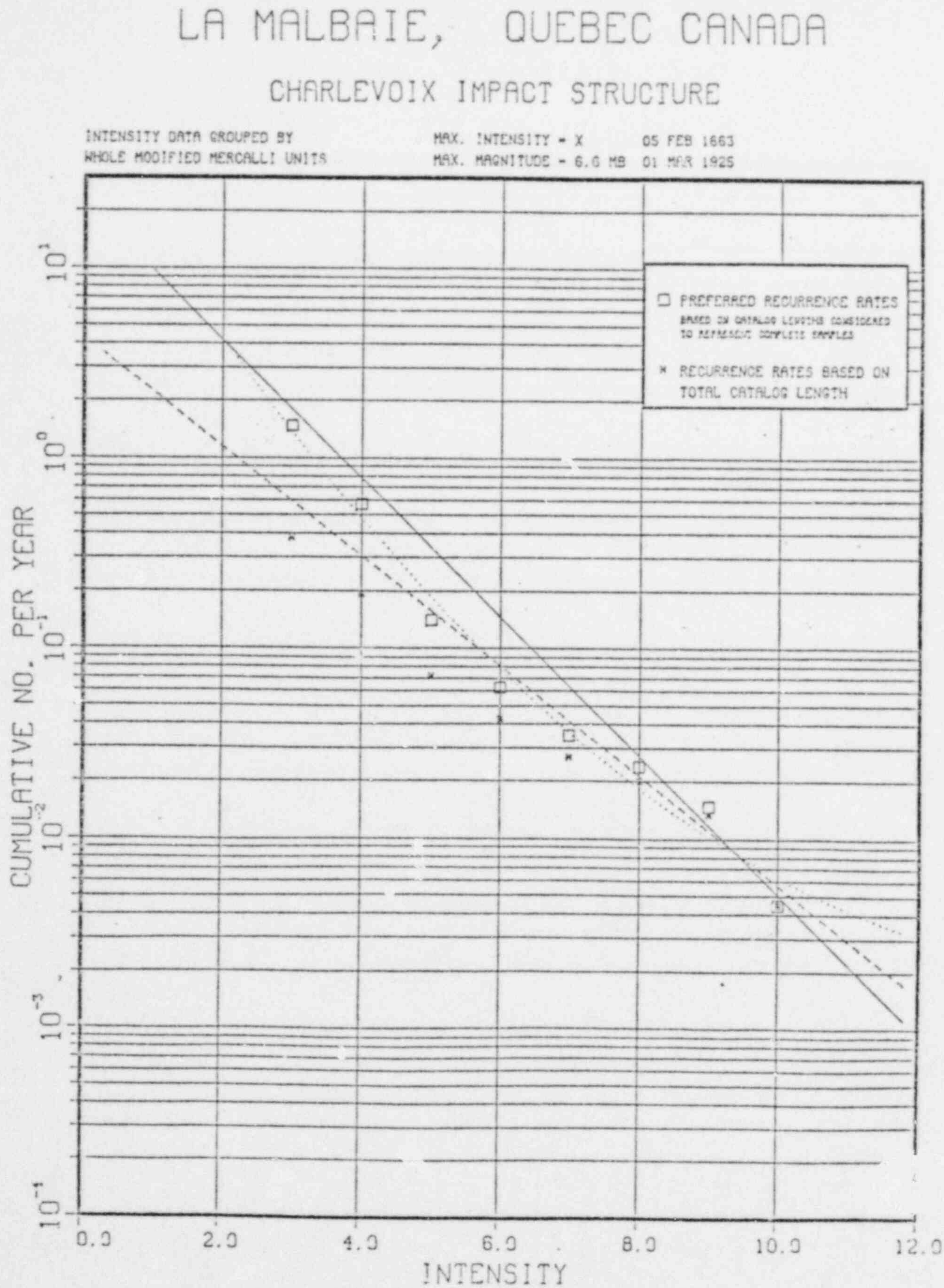



FIGURE 6

La Malbaie, P. Q., Canada Area Earthquakes (1534 - 1978).

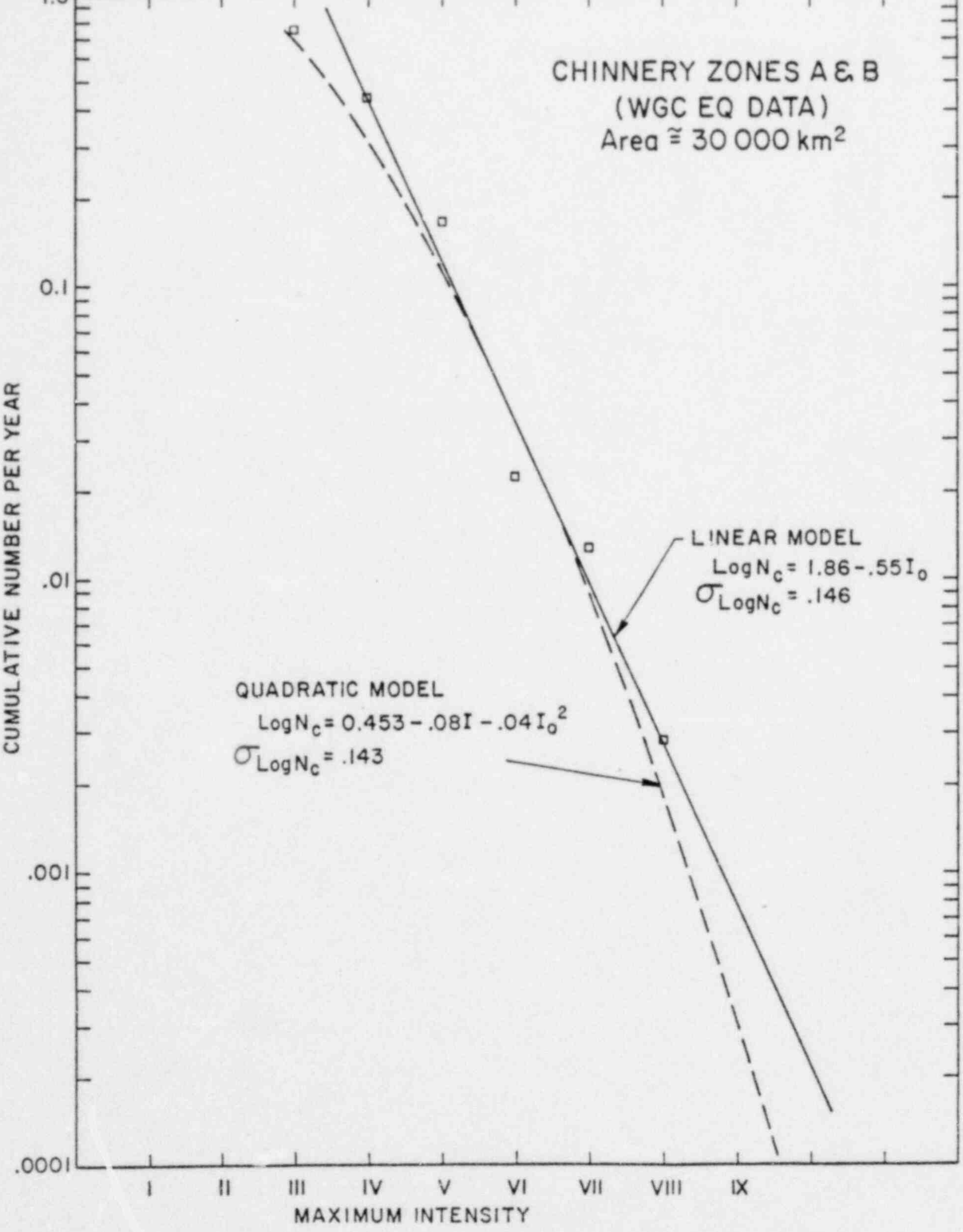



FIGURE 7

Linear and Quadratic Fit to Chinnery (1979) Zones A & B (WGC Earthquake Data Base, 1637 - 1979).

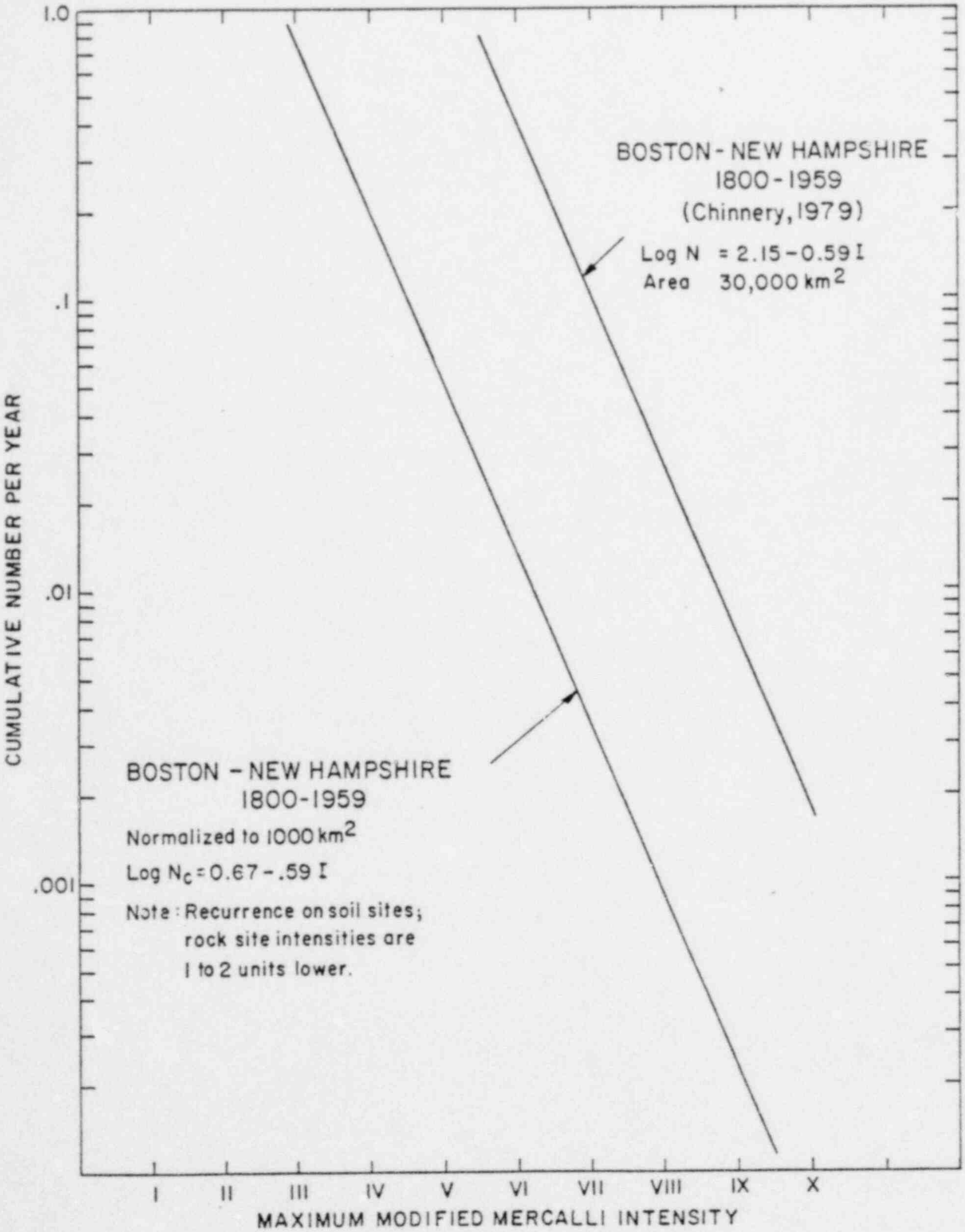



FIGURE 8

Chinnery (1979) Boston - New Hampshire Area Normalized to 1000 $km^2$.

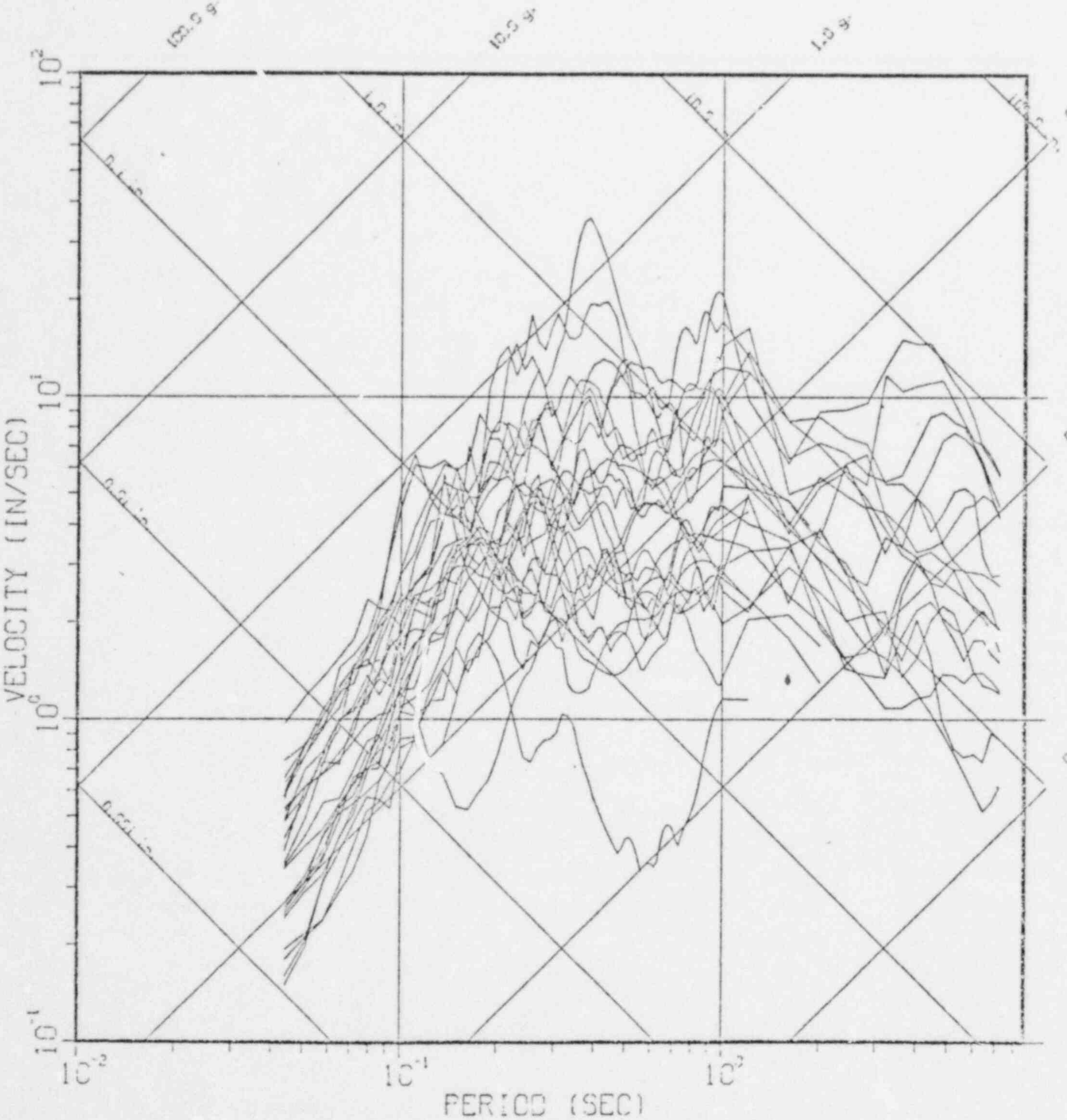



FIGURE 9

Response Spectra for each Component at Strong Motion in Table 1. 5% Damping.

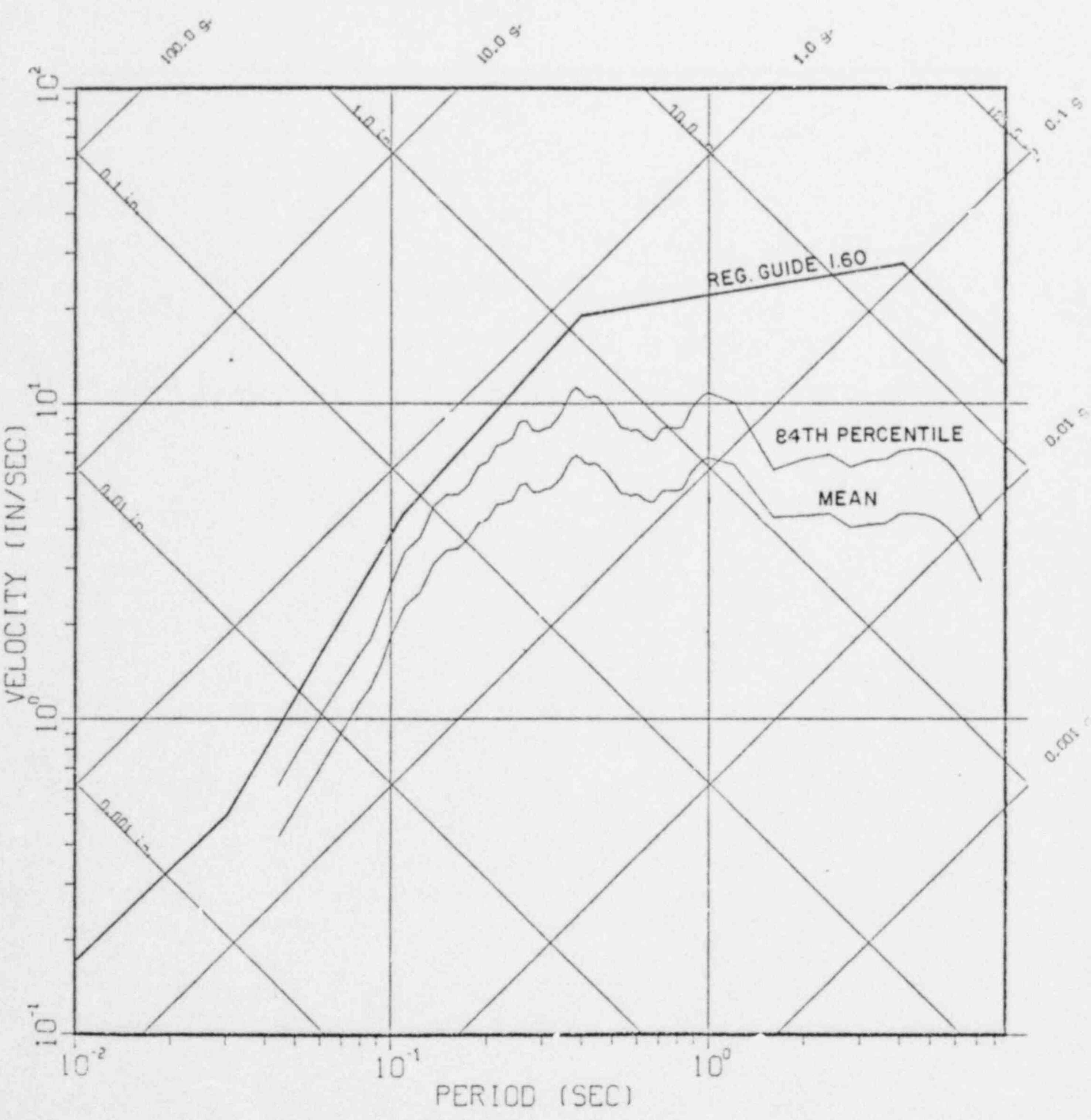



FIGURE 10

Log-Normal Mean and 84th Percentile Response Spectra Compared to 0.25(g) Regulatory Guide 1.60 Seabrook Design Response Spectrum.
5% Damping.

Table

TABLE 1
SELECTED ACCELEROGRAMS FOR
SITE SPECIFIC RESPONSE SPECTRA

SEABROOK NUCLEAR POWER PLANT

| Date | Time(UT) | $m_b$ | $M_L$ | Depth (km) | $I_o$ (MM) | Location | Epic. Dist. (km) | Hypo. Dist. (km) | Peak Acc. (gals) | Comp. | Station |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OCT 31 1935 | 18:37:49 | 5.4 | 6.0 | 8 | VIII | Helena, Montana | 6.6 | 10.4 | 143.5<br>142.5 | NS<br>EW | Caroll College |
| JUN 28 1966 | 04:26:14 | 5.8 | 5.5 | 8.6 | VII | Parkfield, CA | 11. | 35.8 | 264.3<br>340.8 | N65°W<br>S25°W | Temblor No. 2 |
| AUG 01 1975 | 20:20:13 | 5.8 | 5.7 | 15 | IX | Oroville, CA | 12. | 19.2 | 90.6<br>82.5 | N37°E<br>N53°W | Oroville Seismic Station |
| FEB 09 1971 | 14:00:41 | 6.2 | 6.4 | 13 | XI | San Fernando, CA | 32.9 | 35.4 | 213.0<br>198.3 | S08°E<br>S82°W | Santa Felicia Dam |
| FEB 09 1971 | 14:00:41 | 6.2 | 6.4 | 13 | XI | San Fernando, CA | 36.1 | 38.4 | 87.5<br>188.6 | NS<br>EW | CIT Seismological Laboratory |
| FEB 09 1971 | 14:00:41 | 6.2 | 6.4 | 13 | XI | San Fernando, CA | 26.8 | 29.8 | 168.2<br>143.5 | S69°E<br>S21°W | Lake Hughes Array No. 4 |
| FEB 09 1971 | 14:00:41 | 6.2 | 6.4 | 13 | XI | San Fernando, CA | 26.6 | 29.6 | 119.3<br>109.4 | N21°E<br>N69°W | Lake Hughes Array No. 9 |
| FEB 09 1971 | 14:00:41 | 6.2 | 6.4 | 13 | XI | San Fernando, CA | 34.0 | 36.4 | 176.0<br>167.0 | NS<br>EW | Griffith Park Observatory |
| FEB 09 1971 | 14:00:41 | 6.2 | 6.4 | 13 | XI | San Fernando, CA | 32.8 | 35.3 | 64.6<br>97.0 | N56°E<br>N34°W | Fairmont Reservoir |

TABLE 1 SELECTED ACCELEROGRAMS (cont.)

| Date | Time(UT) | $m_b$ | $M_L$ | Depth (km) | $I_o$ (MM) | Location | Epic. Dist. (km) | Hypo. Dist. (km) | Peak Acc. (gals) | Comp. | Station |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SEP 11 1976 | 16:35:00 | 5.3 | 5.9 | 6.0 | IX | Friuli, Italy | 14.0 | 15.2 | 84.9<br>84.2 | NS<br>EW | San Rocco |
| SEP 11 1976 | 16:35:00 | 5.3 | 5.9 | 6.0 | IX | Friuli, Italy | 6.0 | 8.5 | 53.0<br>50.0 | EW<br>NS | Somplago - D |
| SEP 15 1976 | 03:15:19 | 5.7 | 6.1 | 9 | (VIII-IX) | Friuli, Italy | 9.[illegible] | 12.7 | 59.8<br>118.6 | NS<br>EW | San Rocco |
| SEP 15 1976 | 09:21:18 | 5.4 | 6.0 | 11.7 | IX | Friuli, Italy | 20.0 | 23.2 | 124.8<br>230.4 | NS<br>EW | San Rocco |
| RANGE | | 5.3-6.2 | 5.5-6.4 | 6-25 | | | 6-36 | 9-38 | 50-341 | | |
| MEAN | | 5.8 | 6.1 | 10.9 | | | 20.6 | 25.4 | 139.4* | | |
| STANDARD DEVIATION | | .38 | .30 | 3.0 | | | 11.1 | 10.8 | 203.1** | | |

* Lognormal Mean

** 84th percentile of lognormal distribution

# APPENDIX 1

## Excerpts from Earthquake Reports-
## Chronological Order

Loram, S. H., 1912, Notes on an Earthquake at Canutillo, Chile, Bulletin of the Seismological Society of America, Vol. 2, No. 4, p. 244.

"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."

Borcherdt, Roger D., and James F. Gibbs, 1976, 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.

"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 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 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 Franciso 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)

"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

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

"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., 1921, The Apparent Intensity of Earthquake Shock in Alluvial Areas, Bulletin of the Seismological Society of America, Vol. 11, No. 1, p. 81.

"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."

Reid, Harry Fielding, and Stephen Taber, 1919, The Puerto Rico Earthquakes of October-November, 1918, Bulletin of the Seismological Society of America, Vol. 9 , No. 4, p. 97.

"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."

ibid p. 101.

"The destruction of property was greater proportinately in Aguada and Anasco than in any other towns, while between them lies Rincon, which suffered comparatively little. All three of these towns are located close to the west coast of Puerto Rico, but Anasco is about twelve kilometers farther from the origin than the other two. Aguada and Anasco are both built on flat alluvial ground, only seven or eight meters above sea level, and the ground water stands from one or three meters below the surface. The relative immunity of Rincon 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 Anasco 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."

ibid p. 103.

"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."

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

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

Abbott, C. D., 1926, The St. Lawrence Earthquake of February 28, 1925, Bulletin of the Seismological Society of America, Vol. 16, No. 2, p. 133.

"...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 then VI. At Three Pivers the intensity appears to have been about VII."

ibid p. 139.

"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."

ibid p. 142.

"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."

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

"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."

ibid p. 89.

"[grain elevator Quebec City] The whole upper section swayed with the heavy machinery so that practically all of the reinforced concrete columns about the outer walls were cracked at the point where the superstructure met the top of the main building. These were not simple cracks. Some had ground back and forth until great sections of concrete were ground out of the face several feet long, a foot into the wall and a foot to eighteen inches wide on the face. The reinforcing irons, rods about half an inch in diameter, were in some cases worked out through these cracks. No one was in the building at the time. The noise and the swaying would surely have been terrifying.

Less than half a mile from the elevator and shed stands the Chateau Frontenac, the great Canadian Pacific Railway hotel. It is on the rocky cliff supporting the central part of Quebec. Some in this building did not hear the earthquake at all. No one was greatly alarmed by it. The difference between the effects observed at these two spots so close together is due entirely to terrain. The buildings at the harbor are very well constructed. Had they not been they must have been wrecked. They were built where the need required, beside the river. The soft ground was the cause of the damage rather than proximity to the epicenter."

ibid p. 89-90.

"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."

ibid p. 91.

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."

ibid p. 91.

"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."

Dewell, Henry D., and Bailey Willis, 1925, Earthquake Damage to Buildings, Bulletin of the Seismological Society of America, Vol. 15, No. 4, p. 298.

"(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."

Nunn, Herbert, 1925, Municipal Problems of Santa Barbara, Bulletin of the Seismological Society of America, Vol. 15, No. 4, p. 317.

"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."

ibid p. 319.

"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."

Wood, Harry O., 1933, Preliminary Report on the Long Beach Earthquake of March 10, 1933, Bulletin of the Seismological Society of America, Vol. 23, No. 2, p. 50-51.

"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...."

ibid p. 52.

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 nearby 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 nearby 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 (9 1/2 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...."

Engle, H. M., 1936, The Montana Earthquakes of October 1935: Structural Lessons, Bulletin of the Seismological Society of America, Vol. 26, No. 2, p 102-103.

"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., 1944, The Gazelle Peninsula, New Britain Earthquake of January 11, 1941, Bulletin of the Seismological Society of America, Vol. 34, No. 1, p. 5.

"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 principle 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., April 10, 1945, A Geological Study of The Massena-Cornwall Earthquake of September 15, 1944 And Its Bearing on the Proposed St. Lawrence River Project, U.S. Corps of Engineers, New York District, p. 7-9.

"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 principle 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., 1962, The 1953 Suva Earthquake and Tsunami, Bulletin of the Seismological Society of America, Vol. 52, No. 1, p. 5.

"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."

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

"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 liquifaction 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)."

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

"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."

Note: The degree of damage was identified by a number which ranged from 1, light damage to 5, total destruction according to Medvedev, Sponheur and Karnik (1964).

Lemke, Richard W., Ernest Dobrovolny, Leonardo Alvarez S. and Francisco Ortiz O., 1968, Geologic and Related Effects of the Taltal Earthquake, Chile, December 28, 1966, Bulletin of the Seismological Society of America, Vol. 58, No. 3, p 857.

"Taltal lies at the mouth of Quebrad 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 artificial 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."

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

"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...."

Guha, S. K., P. D. Gosavi, and S. C. Marwadi, 1974, Macroseismic Studies of Some Recent Indian Earthquakes, Fifth World Conference on Earthquake Engineering, Rome, Vol. 1, p. 494.

"...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...."

APPENDIX 2

The Modified Mercalli Intensity Scale[1]

[1]Wood, Harry O. and Frank Neumann, 1931, Modified Mercalli Intensity Scale of 1931, Bulletin of the Seismological Society of America, Vol. 21, No. 4.

I Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to III Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars. (VIII- Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse.

Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

APPENDIX 3

# The New Madrid Earthquake[1]

[1]Excerpt from: Fuller, Myron L., 1912, The New Madrid Earthquake, U. S. Geological Survey Bulletin 494, p. 12-13.

APPENDIX 3

pp. 12 & 13 Fuller 1912

Indian traditions - Lyell records that the Indians of the Mississippi Valley had a tradition of a great earthquake which had previously devastated the same region, but he concluded from the absence of old sink holes and of dead trees that no convulsion of similar magnitude could have occurred for many centuries previous to 1811. As shown in the following paragraphs he was mistaken in regard to the absence of such indications of previous shocks, for although it appears to be true that no fallen timber remained, there are many conspicuous and unquestionable geologic evidences of earlier disturbances.

Geologic evidence. - The geologic evidence of shocks long antedating that of 1811 is very conclusive, as has elsewhere been pointed out by the writer. Cracks as large as any of those of the last great disturbance have been seen with trees fully 200 years old grown on their bottoms and slopes (PI. II, A) indicating early shocks of an intensity equal to if not greater than that of the last. Nor is the action apparently altogether recent, for post-Lafayette but pre-Iowan faults (antedating the deposition of the loess), and apparently being either a cause or accompaniment of earthquakes, have been observed by the writer in Crowley Ridge, and Glenn has described sandstone dikes filling old earthquake cracks in the Porters Creek formation of the Eocene Tertiary.

Other geologic evidence leading to the same conclusion is seen in the Tiptonville, Blytheville, and Little River domes and in the occurrence of certain sand sloughs. The Tiptonville dome is known to have antedated, in part at least, the shocks of 1811, as several writers mention that previous to this earthquake the land at New Madrid was never overflowed. This would not have been the case if it had been a part of the undisturbed flood plain. The erosion of the Blytheville and Little River domes since their uplift has been considerable (p. 94) and took place almost entirely before the 1811 shocks. If these domes are classed as earthquake features, as apparently they should be, from the description of the additional uplift of the Tiptonville dome which took place in 1811, it follows that the original disturbance must have long antedated the New Madrid earthquake. South of Lake St. Francis, as described elsewhere (p. 84), several sloughs exist, which have all the characteristics of sunk lands except the dead timber, and are apparently true earthquake features. The absence of dead timber, such as characterizes the areas which sunk in 1811, however, points to a considerably earlier origin.

Note: Lafayette is a term no longer used but the date is Pliocene (1-10 million years ago); Iowan is approximately 22-25,000 years ago.

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

before the

ATOMIC SAFETY AND LICENSING APPEAL BOARD



| | |
|---|---|
| In the Matter of<br><br>PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE, et al.<br><br>(Seabrook Station, Units 1 & 2) | Docket Nos. 50-443<br>50-444 |

CERTIFICATE OF SERVICE

I, Thomas G. Dignan, Jr., one of the attorneys for the permittees herein, hereby certify that on February 17, 1981, I made service of the Resume of Richard J. Holt and the Testimony Concerning Seismology by Richard J. Holt by mailing copies thereof, postage prepaid, first class or airmail, to:

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