UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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| In the Matter of<br><br>PUGET SOUND POWER & LIGHT COMPANY, et al.,<br><br>(Skagit Nuclear Power Project Units 1 and 2) | ) | Docket Nos. 50-522<br>50-523 |

TESTIMONY OF

DR. BRUCE A. BOLT

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# TESTIMONY OF DR. BRUCE A. BOLT

My name is Bruce A. Bolt. I testified previously in this proceeding during July 1975 on the subject of seismology. I further testified in this proceeding in March 1978. At that time, I evaluated the USGS's postulates for the two maximum earthquakes in the region around the Skagit site, which they think should control the SSE.

I am a professor of seismology in the Department of Geology and Geophysics and the director of the seismographic stations at the University of California at Berkeley. Attached hereto is an updated statement of my educational and professional qualifications, including an updated list of publications.

I have been asked by the Applicants to address the subject of correlation between ground acceleration and (a) the magnitude and (b) the intensity of an earthquake. The Board raised this subject in a recent hearing (Tr. 14,202.) In the course of my discussion I will review again my evaluations of the two USGS postulates.

1321 041

## Correlation of Acceleration with Magnitude

One method of assessing acceleration at the Skagit site is to use curves which correlate acceleration with earthquake magnitude. An example of such a curve appears in Figure 1a, which is from Schnabel and Seed (1973). This particular correlation was mentioned by the Board in its request for clarification of methodology. This is applicable to the earthquake postulated by the USGS on the Devil's Mountain Fault.

The Schnabel and Seed correlations in Figure 1a were derived from recorded and computed data from earthquakes in the western United States and Mexico, including the 1971 San Fernando earthquake. Schnabel and Seed plotted the maximum (i.e. peak) acceleration measured on rock against the distance of the recording instrument (a strong motion accelerometer) from the causative fault. As was found by Schnabel and Seed, the plotted points are rather scattered because earthquakes have different mechanisms (e.g. strike slip-movement v. thrust movement) and occur in different geological environments. Nevertheless, for each level of magnitude studied, Schnabel and Seed found that the plotted data points fell within a definable range. They indicated that the range represents the upper and lower bounds within which the peak acceleration values are likely to lie. The ranges for magnitudes of about 5.2, 5.6 and 7.6 are shown by the cross hatched zones in Figure 1b. The curves in Figure 1a show the average peak accelerations at various distances for a number of magnitudes (approximately 5.2, 5.6, 6.6, 7.6 and 8.5).

The Schnabel and Seed curves, which were published in the Bulletin of the Seismological Society of America, have been widely used for engineering design purposes. The curves are used in the following way. If one assumes that an earthquake of a certain magnitude (for example magnitude 5.6) could occur on a fault which is a certain distance (for example 20 miles) from a site, then one enters the set of curves (Figure 1a) and reads off the peak acceleration (in our example, about 0.09g). The ranges from Figure 1b (in our example, 0.03g to 0.14g) indicate the uncertainties involved.

A value within this range on the Schnabel and Seed correlations can be selected to account appropriately for the type of earthquake mechanisms to be expected in the situation under consideration. For example, the earthquake postulated by the USGS for Devil's Mountain Fault would probably arise from a largely strike-slip rupture of the fault; that is, the ground would move horizontally with very little vertical offset. In my opinion, strike-slip earthquakes tend to produce somewhat lower accelerations than do thrust-type mechanisms such as in the 1971 San Fernando earthquake. It would follow that correlations, such as from Schnabel and Seed, that contain data from many different earthquake mechanisms, are conservative for a site which would be shaken mainly by a strike slip mechanism.

Application of a curve correlating peak acceleration with magnitude and distance is not as straightforward as it may seem. It calls for judgment based on the use to which the acceleration values are to be put. A significant limitation to be kept in mind is that even small magnitude earthquakes can cause quite high peaks of acceleration. There are many examples of this. A very recent example is the earthquake of 6 August 1979 on the Calaveras fault in central California. At magnitude 5.9, this earthquake was only moderate in size. It caused very little damage. It was well instrumented in that six strong motion instruments were in the vicinity of the ruptured fault. What was interesting, however, was the recording of a wide range of accelerations, up to 0.4g both horizontally and vertically. Even more extreme examples can be given, such as the peak horizontal accelerations of 0.6g or greater that occurred during the aftershocks to the 1976 Oroville, California earthquake. The lack of correlation between local magnitude and (often high) peak acceleration in these nondamaging earthquakes is clear from Figure 2.

In these cases, the high peak accelerations are generally of very short duration (high frequency) and thus have very little energy associated with them. Consequently, they cause

1321 044

little or no damage to even quite weak structures. It would be quite inappropriate to use these very high peak accelerations that sometimes occur in small or moderate earthquakes to scale the seismic design spectra for a substantial structure such as a power plant or large dam.

Let us now apply the above-described methodology to the postulated maximum earthquake given by the USGS for the Devils Mountain Fault. The highly conservative USGS postulate is a shallow magnitude 7.0 to 7-1/4 earthquake on the Devil's Mountain Fault, 21 kilometers (13 miles) from the site. I performed this exercise in my prior testimony (follows Tr. 8566) for a slightly greater earthquake (magnitude 7.5), using correlations by Schnabel and Seed and by others. Interpolating on Figure 1a (See Figure 3 for interpolated curves drawn for convenience) yields an average peak acceleration of about 0.34g for the 7-1/4 magnitude earthquake, which is the high value on the range specified by the USGS. This value is less than the 0.35g value specified for the safe shutdown earthquake. The acceleration value for magnitude 7.0 is 0.30g according to Schnabel and Seed's curves so that there is room for the formal uncertainty that arises in the drawing of the curve.

In preparing their curves, Schnabel and Seed did not discount any of the instrumentally measured peak accelerations which have high frequencies of little engineering



1321 045

significance. Neither did they discount any of the values for topographic or structural considerations. As well, Schnabel and Seed point out that "in many cases, the effective acceleration of a rock motion may be about 25 to 30 percent less than the actual maximum acceleration of the motion." For the above reasons, there is substantial conservatism in adoption of 0.35g for the SSE value for the Skagit site so far as the Devil's Mountain Fault postulate is concerned.

## Correlation of Acceleration with Intensity

A second method for estimating peak acceleration is to use correlations between peak acceleration and the intensity of the ground shaking. Unlike magnitude, intensity assessments do not depend upon the instrumental measurement of ground motion, but depend on actual observation of the effects of an earthquake. Intensity is an older measure of earthquake size, which was in use long before instruments were available to measure the amplitude of earthquake waves and hence to calculate a magnitude.

Correlations between intensity and acceleration have been widely used in nuclear power siting in the United States, particularly in the eastern United States where the size of earthquakes considered is usually less than in the west and the historical record is longer than in the western states.

1321 046

Intensity, however, is a cruder measure of the size of an earthquake than magnitude. Also, intensity presents problems of application to the modern engineering concepts of the dynamic response of structures as will become clear.

Intensity is assessed through the use of a descriptive scale, such as the Modified Mercalli intensity scale of 1931. At each intensity level on the scale are various indicators of possible earthquake effects on people, vegetation, bodies of water, the ground and buildings. For example, the intensity VIII level on the Modified Mercalli scale (1956 version) discusses the steering of cars being affected, the partial collapse of poor-quality masonry, the fall of stucco, the breaking off of decayed piling, breaking off of tree branches, and cracks in wet ground and on steep slopes. Therefore, each level of the intensity scale contains many different kinds of data.

During an earthquake, there are typically many damage and felt reports within the meizoseismal area, which is the area of the strongest shaking and most significant damage. For example, of 100 reports within a meizoseismal area, 10 might fit indicators for intensity VIII, 80 for intensity VII, and the other 10 might be appropriate for an intensity of VI or less. What intensity should be selected in this example to characterize the earthquake? Should it be the highest

1321 047

intensity reported (VIII in our example) or a value representative of the great majority of the reports in the meizoseismal area (VII in our example). The results of this decision will carry great weight in the correlations that are made between intensity and peak acceleration. The practice in most scientific and engineering correlations is to pick a representative value out of the suite of observations and calculate a measure of scatter such as the standard deviation. In contrast, in most of the past intensity studies, the highest intensity for the meizoseismal region is usually chosen. It is very important to keep this practice in mind when considering the amount of conservatism which is built into correlations between intensity and peak acceleration. In the correlations by (1) Coulter, Waldron and Devine (Figure 4), (2) Neumann (Figure 5) and (3) Trifunac and Brady (Figure 5), considered below, the maximum reported intensity has been correlated against the peak acceleration reported by instruments in the general vicinity (not always the same site).

Another important point to be kept in mind is that intensity reports during an earthquake vary considerably depending upon foundation conditions. Many published intensity maps show that there is less damage to structures founded on rock than to similar ones on soil. One example is the 1965 Puget Sound earthquake in which much higher intensities were found on the lowlands along the Duwamish River than on the surrounding high ground. A second example is provided by the 1906 San Francisco earthquake (magnitude 8-1/4.) Figure 6 shows the well-known comparison by H. O. Wood of intensities and geology on the San Francisco peninsula in the 1906 earthquake. The peninsula is only 2 to 10 miles east of the San Andreas Fault. Intensities varied from VI to X throughout the area. The comparison shows how much the geologic conditions influenced the intensity. Even when intensity X is observed on sand, silt and clay along the shore, the intensity on rock (Franciscan) two miles away is rated only as VI. In fact, contemporary reports from San Francisco indicate that on rocky hills, such as Telegraph Hill, even brick chimneys withstood the shake.

Before turning to correlations between intensity and peak acceleration, it might also be helpful to review the place of peak acceleration in the characterization of ground motion. Two actual ground motion records will be examined for this purpose. The first record, which is shown at the bottom of Figure 7, is of the 1952 earthquake ($M_L = 7.2$) in Kern County, California. This record was made on a strong motion instrument at Taft, 28 miles from the epicenter. As one of the few strong motion records of a really large earthquake, this record is most important. Figure 7 shows that the horizontal shaking continued for a considerable time (over 20 seconds) during

1321 049

which the amplitude of the ground motion varied considerably. The maximum amplitude, which is marked by an arrow on Figure 7, corresponds to a peak single acceleration of about 0.18g. Several other peaks approach this level. Also to be seen from Figure 7 is that the frequency of the motion varied considerably throughout the earthquake. We can see that the ground shaking is quite strong. None of these additional details are included in the simple measure of the peak acceleration. However, the overall energy can be taken into account in describing the response spectra for a proposed structure. Conservatism can be built into this spectra, depending upon the importance of the particular structure being designed.

The second strong motion record (top of Figure 7) is of a much smaller earthquake, a magnitude 4.6 California earthquake near Melendy Ranch in 1972. The shaking lasted no more than about 4 seconds. However, about half way through the earthquake, there was a sharp peak of ground movement, lasting a fraction of a second with an acceleration of about 0.7g. The energy in this motion is very small and would not be sufficient to cause damage to even very weak structures.

It might well be asked that if even small earthquakes can have very large peak acceleration, what is the point of making the correlations that we have discussed? Let me stress again

1321 050

that the judgment of the seismologist or the earthquake engineer who is applying the correlations is very important.

These very small earthquakes should not be included in the correlations between either peak acceleration and magnitude or peak acceleration and intensity when such correlations are applied to the engineering of large structures. What should be taken into account is not only the single highest peak acceleration but also the lesser peak accelerations which indicate that substantial shaking continued at a certain acceleration level for many cycles. This takes us to the idea of effective peak accelerations which has been introduced into earthquake engineering in recent years. The effective peak acceleration can be thought of as the maximum acceleration in earthquakes on rock or firm ground after the high frequencies that do not affect sizable structures have been discounted. The concept of effective peak acceleration makes the scaling value of maximum acceleration much more stable and physically meaningful.

Let us now turn to some of the correlations that have been made between peak acceleration and intensity on the Modified Mercalli scale. The first correlation is from Coulter, Waldron and Devine and is shown in Figure 4. This correlation was developed for use in the evaluation of the suitability of proposed nuclear power plant sites. As can be seen on

1321 051

Figure 4, they have taken into account the foundation conditions where the intensity was assessed and where the acceleration was measured on the strong motion accelerometer. Due to the scatter in the data, a range of values is shown for any given intensity. The curve should only be used to estimate a peak acceleration from a specific intensity. Thus, for intensity VI we can read off a range of accelerations from 0.06g to 0.13g for firm bedrock.

The second correlation is one that I will call the Neumann-Trifunac-Brady Curve. This curve summarizes the work done in 1954 by Frank Neumann, who incidentally was very familiar with intensities and acceleration in the Puget Sound area, and the more recent 1975 work using further data by Trifunac and Brady. I have treated these curves as one since it is very hard to draw them separately on an ordinary piece of graph paper. This curve is shown on Figure 5. Once again, Neumann and Trifunac and Brady plot the peak acceleration against the intensity.

Also shown on Figure 5 are alternative curves, marked Bolt that I published in 1978. These curves depart substantially from the Neumann-Trifunac-Brady curve. First the data are selected differently from that of Neumann and that of Trifunac and Brady with emphasis on the cases with high intensities. Secondly, the intensity values used in deriving the Bolt curves

1321 052

are representative intensity values, not the maximum intensity values used in the other correlations. The representative values were derived by taking the central tendency (actually the modal line) of the histogram (frequency distribution) of felt and damage reports from the meizoseismal area of each earthquake studied. I explained the "central tendency" methodology in my prior testimony.

The Bolt curves also were prepared to illustrate that the correlation approach followed by Trifunac and Brady was unsatisfactory from a statistical point of view. Trifunac and Brady assumed that there could be errors in the measurement of the acceleration, but did not take into account errors of the intensity. Yet, it is in the assessment of intensity that the greatest uncertainty arises. Consequently, in making any formal mathematical correlation between acceleration and intensity, the error in assessment of intensity should be taken into account. Figure 5 shows how much of a difference that consideration makes. The dashed line (marked E) includes consideration of the error in assessment of intensity whereas the solid line (marked EF) does not consider the error. Obviously the result is a very different slope.

1321 053

## Evaluation of USGS's Postulate Regarding 1872 Earthquake

Having reviewed several correlations between intensity and acceleration, I would now like to consider the USGS's other postulated maximum earthquake for the region around the Skagit site. This is "an earthquake similar to the one that occurred December 15, 1872 but having its epicenter sufficiently close to the site that no attenuation effects be considered." Transferring the 1872 event to the plant site is generally agreed to be highly conservative and speculative. (The intensity observed in the Skagit site region in 1872 was, in all published studies, no greater than MM VII.)

If the 1872 earthquake were transferred westward to the Skagit site, the same general pattern of intensities would be produced as were observed during the 1872 event. Another way of viewing this "transfer" is that the intensity map for the 1872 event would be shifted to the west until it overlaid the Skagit site area. Some regions around the site would be marked by intensity IX, some by VIII and others by VII or VI, depending in large part on foundation conditions.

The intensity pattern in the 1872 earthquake was generally that the maximum intensities were assessed at sites on alluvial materials along the edges of rivers and lakes. As previously pointed out, this has been the common experience in other earthquakes. Therefore, under the USGS postulate, ground

1321 054

cracks and ejection of sand and mud (intensity IX) would probably occur in and near the Skagit Valley on unstable slopes or along large river terraces. On the alluvial materials of the floodplain, ground cracking, ejection of sand, and damage to poorly constructed buildings might be found. These would be assessed as intensities of VIII-IX and perhaps even X ("mud shifted horizontally on beaches"). On bedrock, including that at the site, the intensities would be lower, perhaps even much lower. My judgment is that a maximum intensity of VIII or less might be expected at the Skagit bedrock site in the occurrence of the 1872 type event as postulated by the USGS.

Taking this upper value of intensity on the rock Skagit site (intensity VIII), reference can be made to the correlations to estimate a peak acceleration level. From the Coulter, Waldron and Devine correlation in Figure 4, intensity VIII on firm bedrock yields an average of about 0.18g and a range of about 0.14g to 0.26g. Similarly, the Neumann-Trifunac-Brady curve in Figure 5 produces approximately 0.25g. These evaluations, it should be remembered, do not separate soil from rock sites as do the Coulter, Waldron and Devine values and no allowance is made for the scatter of observed intensity values.

1321 055

As I explained in my testimony in this proceeding in March 1978, I evaluated the meizoseismal area of the 1872 earthquake. I determined that the value representative of the majority of the data, or the central tendancy of the data, is about intensity VIII. I had previously assessed this earthquake as VIII+, or a little less than halfway to IX. This, of course, reflects effects on soil. Suppose that even a maximum intensity on the rock site itself midway between VIII and IX is allowed. Then Coulter, Waldron and Devine's curve for rock gives a range of 0.20g to 0.40g with a mean value of 0.28g; the Neumann-Trifunac-Brady curve yields 0.35g and the Bolt curve gives 0.22g.

My conclusion is that the precision of formal estimation of a peak acceleration from the acceleration-intensity method, for the high intensities speculated for Skagit, is lower than that of the acceleration-magnitude method unless special judgment is applied. I concur with the USGS that the postulate on the 1872 earthquake can be accommodated by an SSE of 0.35g.

1321 056

BIOGRAPHY - BRUCE A. BOLT

Born: February 15, 1930

Degrees and Diplomas: B.Sc. (with honors), New England University College of the University of Sydney, 1952; M.Sc., University of Sydney, 1956; Ph.D., University of Sydney, 1959; D.Sc., University of Sydney, 1972; Diploma of Education, Sydney Teachers College, 1953.

Academic and Research Career: Lecturer, Senior Lecturer, 1954-62, Department of Applied Mathematics, University of Sydney.

Research Scientist, 1960, Lamont Geological Observatory, Columbia University, New York.

Visiting Scientist, 1961, Department of Geodesy and Geophysics, Cambridge University, England.

Consultant, 1961, U.K. Atomic Energy Authority, Seismic Research Group.

Professor of Seismology, 1963 - , Department of Geology and Geophysics, University of California, Berkeley.

Director, Seismographic Station, 1963 - , University of California, Berkeley.

Visiting Professor, Michaelmas Term, 1969, Department of Applied Mathematics, University of Sydney.

Acting Chairman, Department of Geology and Geophysics, University of California, Berkeley, Summer 1970.

Visiting Professor, Tokyo and Kyoto Universities, Japan Society for Promotion of Science, Japan, Summer 1972.

Visiting Professor, Department of Applied Mathematics and Theoretical Physics, Cambridge, England, January - June, 1973.

Visiting Lecturer, Academia Sinica, People's Republic of China, July 1973.

Visiting Professor, University of Barcelona, Spain, July - August, 1976.

Visiting Lecturer, Academia Sinica, Republic of China (Taiwan), September 1976.

Lecturer, International Center for Theoretical Physics, Trieste, Italy, November 1977.

Lecturer, University of Tegucigalpa, Honduras, August, 1979.

Overseas Fellow, Churchill College, Cambridge, 1980.

Elected or Appointed Position:

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| University Council (elected by Convocation), New England University | 1957 |
| Council, Royal Society of N.S.W. | 1959 |
| Council, Mathematical Association of N.S.W. | 1959 |
| Executive Committee, International Association of Seismology and Physics of the Earth's Interior, IUGG | 1963 - 67 |
| Committee on Seismology of U.S. National Academy of Sciences | 1965 - 72 |
| Board of Directors, Seismological Society of America | 1965 - 71 and 1973 - 76 |
| Vice President, Seismological Society of America | 1973 - 74 |
| President, Seismological Society of America | 1974 - 75 |
| Editor, "Bulletin of the Seismological Society of America" | 1965 - 71 |
| Associate Editor " " | 1971 - 72 |
| Committee Advisory of ESSA and NOAA, U.S. National Academy of Sciences/National Academy of Engineering (Chairman, Panel on Solid-Earth, Geophysics and Earthquake Engineering and Solid Earth Working Group) | 1966 - 72 |
| Member, Consulting Board for Earthquake Analysis, California Department of Water Resources | 1967 - |
| Earthquake and Wind Forces Committee, Veterans Administration | 1971 - 75 |
| Advisory Committee on Structural Safety, Veterans Administration | 1973 - 75 |
| Governor's Earthquake Council, California | 1972 - 74 |
| Secretary, Working Group 6, Inter-Union Commission on Geodynamics | 1972 - 75 |
| Associate Editor, "Journal of Computational Physics" | 1973 - |
| Geophysical Monograph Board, American Geophysical Union (Chairman, 1976-78) | 1971 - 78 |
| Arthur L. Day Fund Selection Committee, National Academy of Sciences | 1974 - 76 |

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| Task Group 1, Applied Technology Council, ATC-3 Development of Comprehensive Seismic Design Provisions | 1975 - 78 |
| First Vice President, International Associatio. of Seismology and Physics of the Earth's Interior | 1975 - |
| Member, Office of Emergency Services Advisory Panel on Earthquake Prediction | 1975 - |
| Member, Committee on Earthquakes, U.S. Committee on Large Dams | 1975 - 77 |
| Chairman, Panel on National Seismograph Networks, National Academy of Sciences | 1977 - 80 |
| Member, Advisory Committee for Geophysics and Environmental Physics, International Center for Theoretical Physics, Trieste | 1978 - |
| Member, Seismic Safety Commission, California | 1978 - |
| Chairman, Subgroup on Favorable Array Locations, International Workshop on Strong-Motion Earthquake Instrument Arrays | 1978 |

Honors:

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| Fulbright Research Scholar | 1960 |
| Elected Fellow, American Geophysical Union | 1967 |
| H.O. Wood Awards for Research in Seismology by Carnegie Institution of Washington | 1967 and 1972 |
| Research Professor, Miller Institute of the University of California for Basic Research in Science | 1967 - 68 |
| Elected Fellow, Geological Society of America | 1970 |
| Degree of Doctor of Science, University of Sydney | 1972 |
| Elected Fellow, California Academy of Sciences | 1972 |
| Outstanding Immigrant of Year Award International Institute of East Bay | 1977 |
| Elected Member, U.S. National Academy of Engineering | 1978 |

Member:

American Geophysical Union (Fellow)
Australian Mathematical Society
Earthquake Engineering Research Institute (Fellow)
Geological Society of America (Fellow)
Seismological Society of America
Sigma Xi

1321 060

COMPLETE LIST OF PUBLICATIONS - BRUCE A. BOLT

1. "Mathematical Aspects of Automatic Digital Computing Machines", M.Sc. thesis, (University of Sydney), 1955.

2. "The South Australian Earthquake of 1939 March 26", Journal and Proceedings of the Royal Society of New South Wales, 90, 19-28, 1956 (with K.E. Bullen).

3. "The Epicentre of the Adelaide Earthquake of 1954 March 1", ibid., 90, 39-43, 1956.

4. "The Velocity of the Seismic Waves Lg and Rg across Australia", Nature, 180, 495, 1957.

5. "Earth Models with Continuous Density Distribution", Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, 7, 360-368, 1957.

6. "On Taking Means of Density Distribution in the Earth", ibid., 7, 369-371, 1957.

7. "Earth Models with Chemically Homogeneous Cores", ibid., 7, 372-378, 1957.

8. "The Dynamics of a Bowl", Quarterly Journal of Mechanics and Applied Mathematics, 11, 351-363, 1958 (with M.N. Brearley).

9. "Seismic Observations from the 1956 Atomic Explosions in Australia", Geophysical Journal of the Royal Astronomical Society, 1, 135-144, 1958 (with H. Doyle and D. Sutton).

10. "Some Problems on the Structure of the Earth", Ph.D. thesis, (University of Sydney), 1958.

11. "Seismic Travel-Times in Australia", Journal and Proceedings of the Royal Society of New South Wales, 91, 64-71, 1959.

12. "Travel-Times of PKP up to 145°", Geophysical Journal of the Royal Astronomical Society, 2, 190-198, 1959.

13. "The Diffusion of Carbon Dioxide from Coal", Fuel, 38, 333-337, 1959 (with J.A. Innes).

14. "Rayleigh Wave Dispersion for a Single Layer on an Elastic Half Space", Australian Journal of Physics, 13, 498-504, 1960 (with J.C. Butcher).

15. "The Revision of Earthquake Epicentres, Focal Depths and Origin-Times, Using a High-Speed Computer", Geophysical Journal of the Royal Astronomical Society, 3, 433-440, 1960.

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18. "Phase and Group Velocities of Rayleigh Waves in a Spherical Gravitational Earth", Journal of Geophysical Research, 66, 2965-2981, 1961 (with J. Dorman).

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23. "Inside the Earth", The Etruscan, 11, 18-23, 1962.

24. "Transient Analysis of Seismic Core Phases", Geofisica Pura e Applicata, 52, 41-52, 1962 (with M. Landisman, S. Mueller, and M. Ewing).

25. "Revised Torsional Eigenperiods from the 1960 Trieste Data", Geophysical Journal of the Royal Astronomical Society, 7, 510-512, 1963.

26. "Geomagnetic Variations with the Periods of Torsional Oscillations of the Earth", Journal of Geophysical Research, 68, 2685-2693, 1963 (with D. Winch and L. Slaucitajs).

27. "Recent Information on the Earth's Interior from Studies of Mantle Waves and Eigenvibrations", Physics and Chemistry of the Earth, Vol. 5, 57-115, Pergamon Press, Oxford, 1964.

28. "Dispersion of Rayleigh Waves across Australia", Geophysical Journal of the Royal Astronomical Society, 9, 21-35, 1964 (with M. Niazi).

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1321 063

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FIGURE 1a

PER B. SCHNABEL AND H. BOLTON SEED

Bull. Seism. Soc. Am. 63, 1973

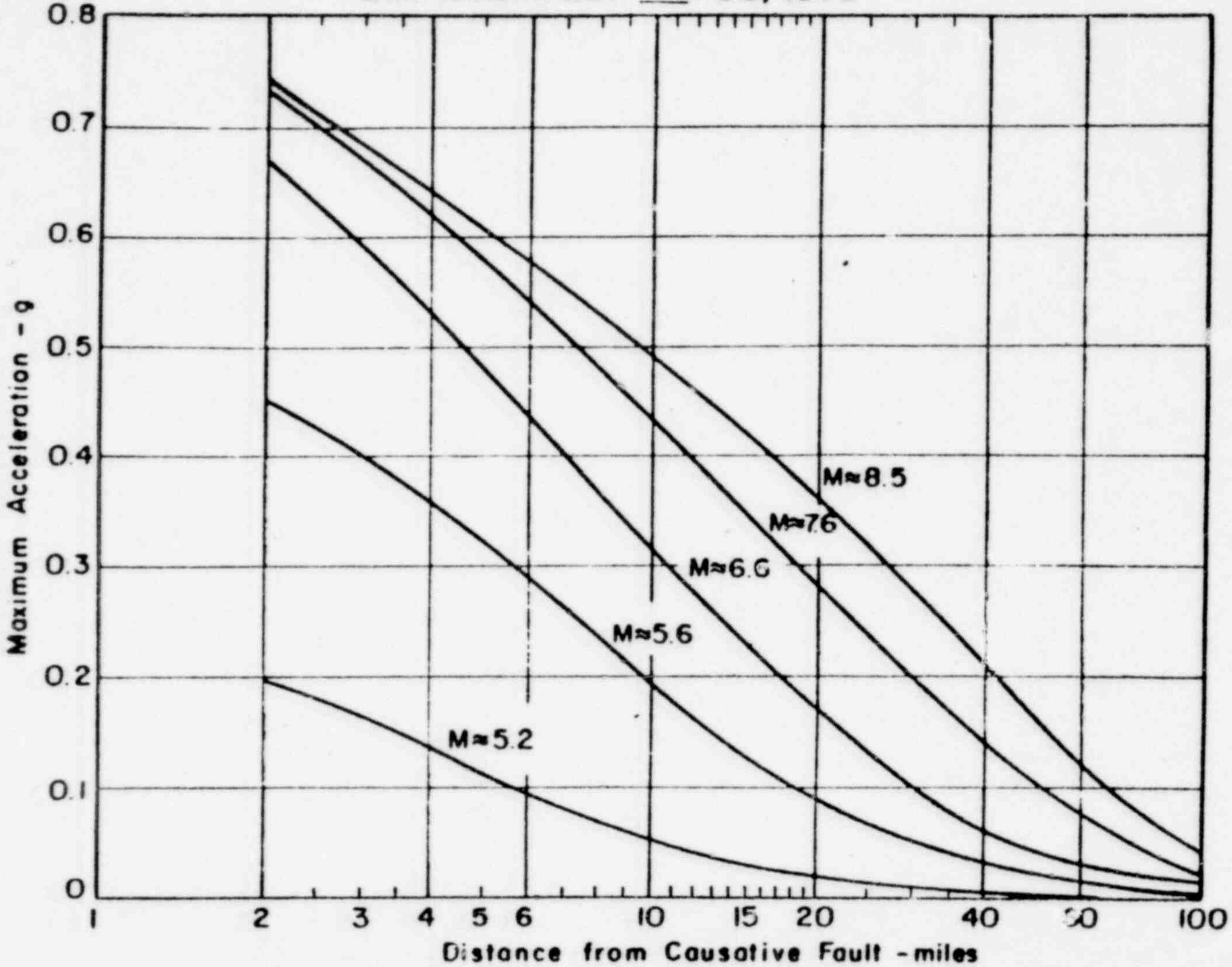



FIG. 5. Average values of maximum accelerations in rock.

1321 071

FIGURE 1b

PER B. SCHNABEL AND H. BOLTON SEED

Bull. Seism. Soc. Am. 63, 1973

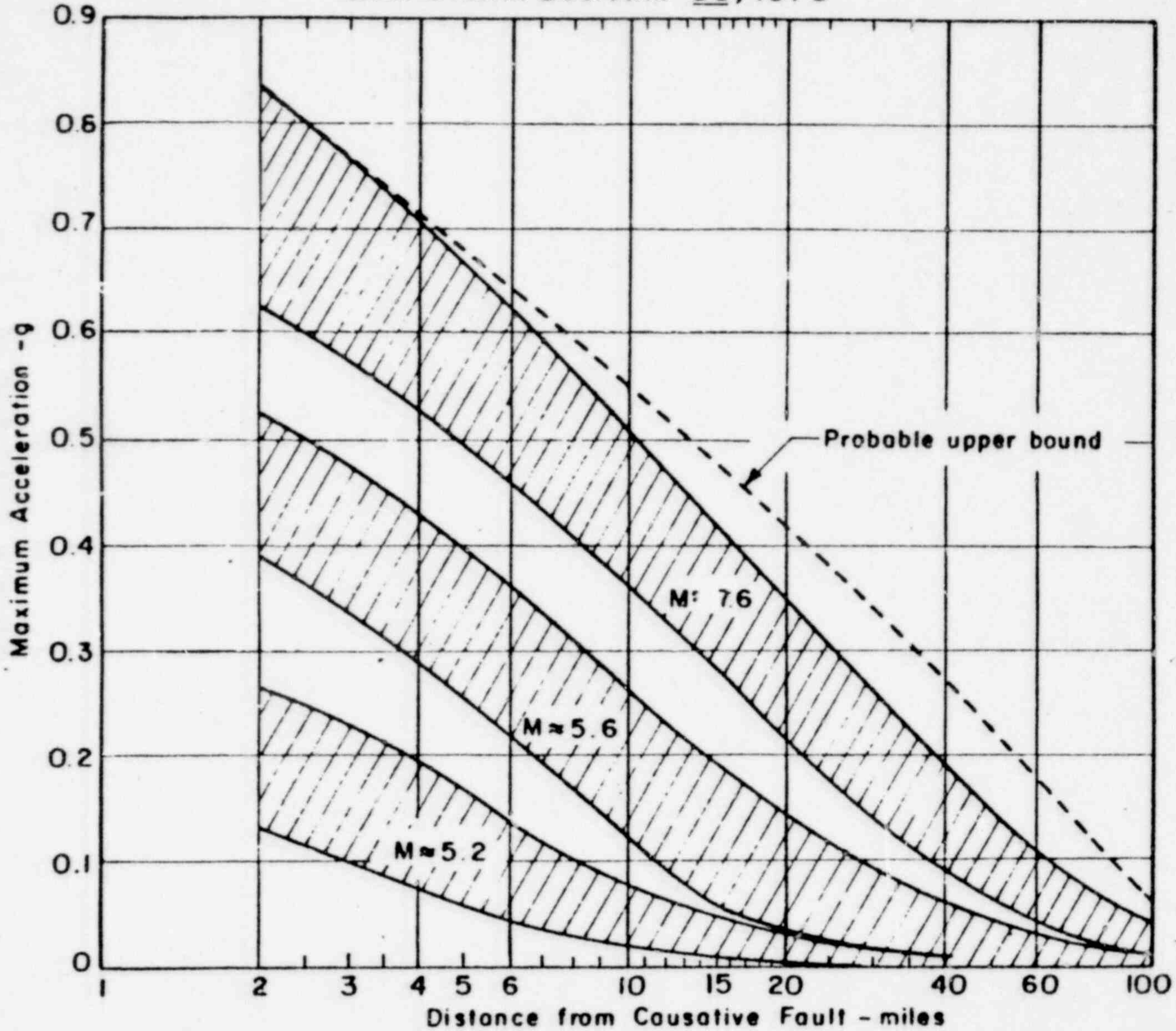
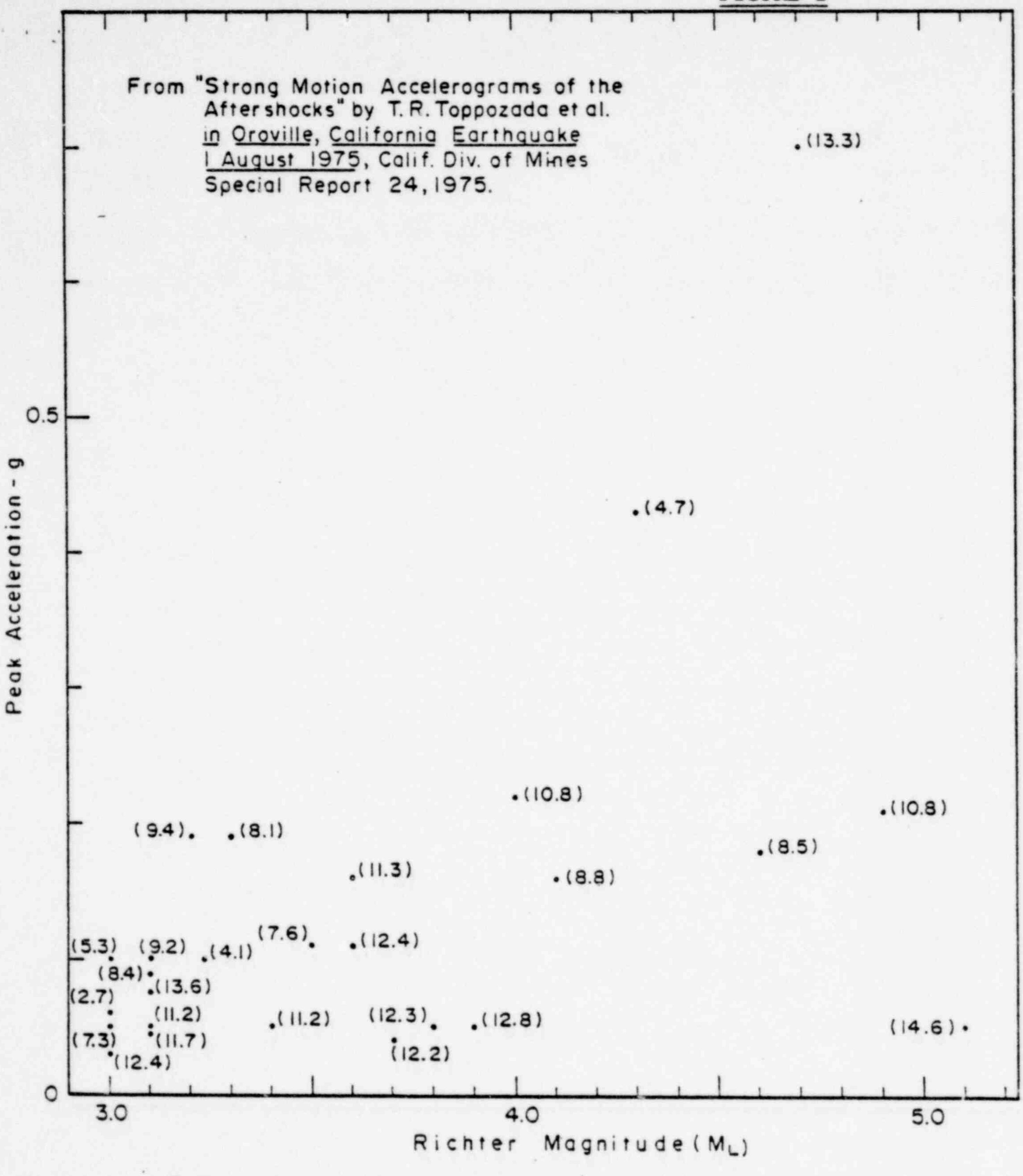



FIG. 6. Ranges of maximum accelerations in rock.

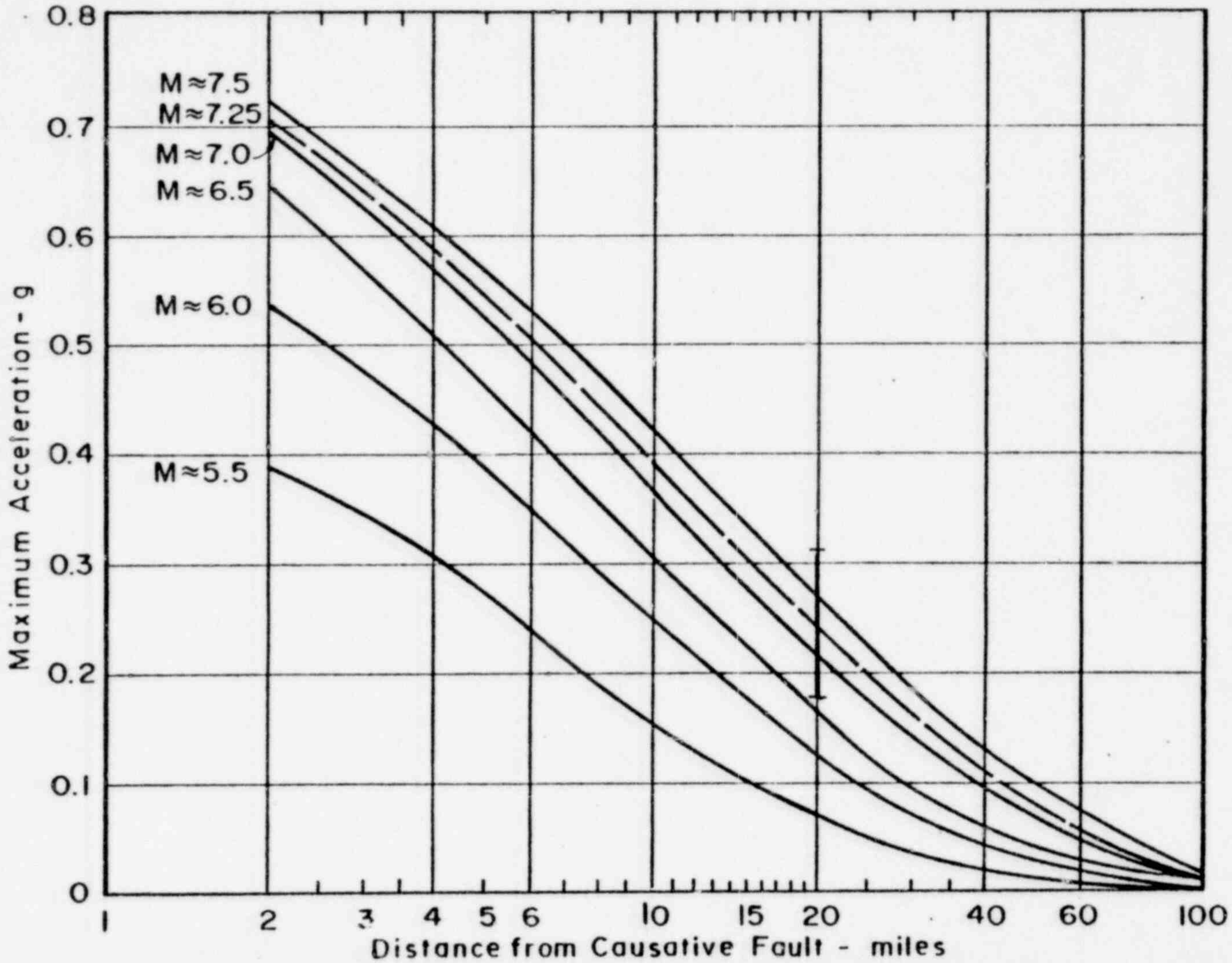
1321 072




Peak accelerations recorded for Oroville aftershocks of $M_L \geq 3.0$. Numbers in parentheses are hypocentral distances in kilometers.

1321 073

FIGURE 3




Average values of maximum accelerations in rock.
Interpolated from Schnabel and Seed curves.

1321 074

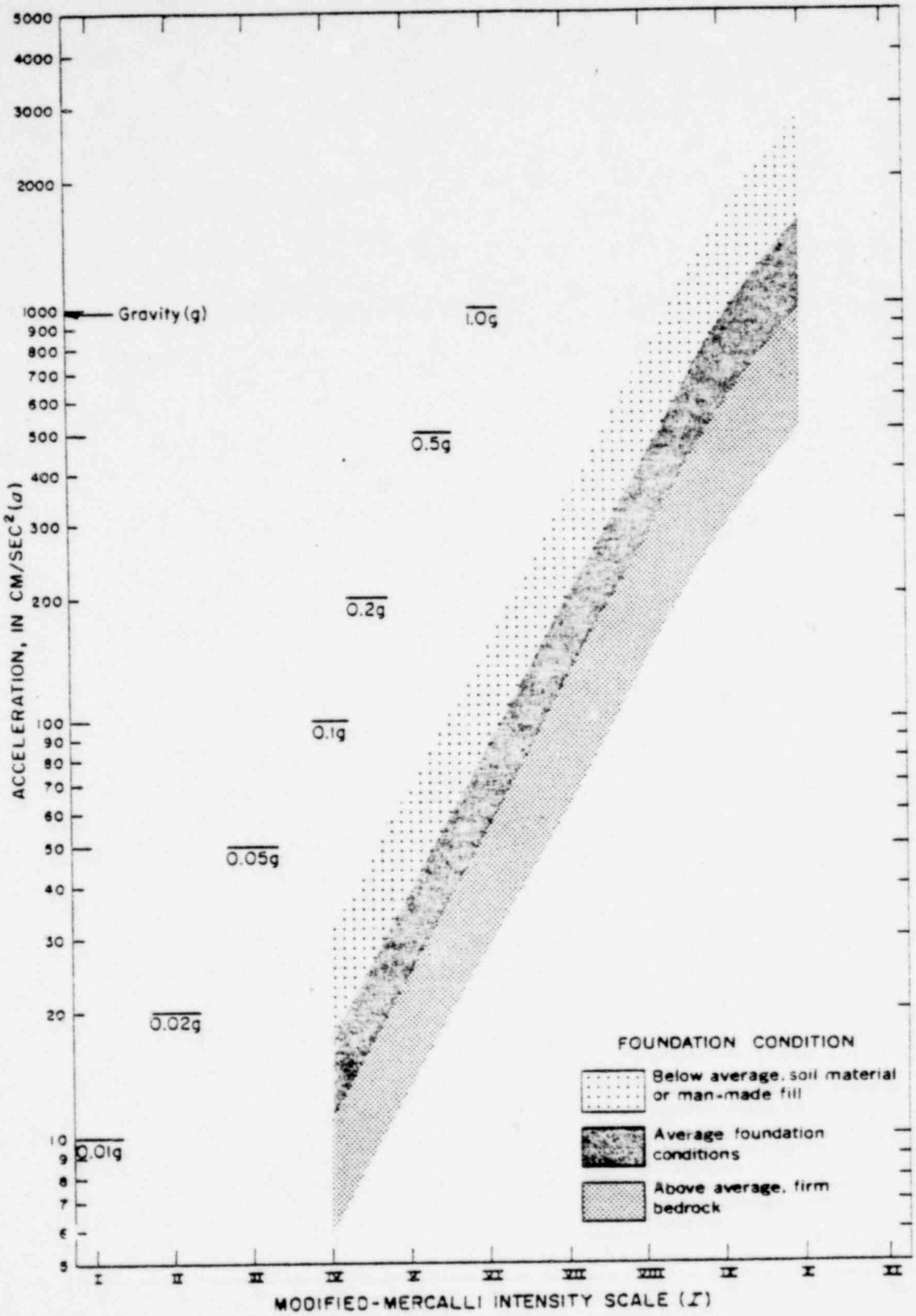
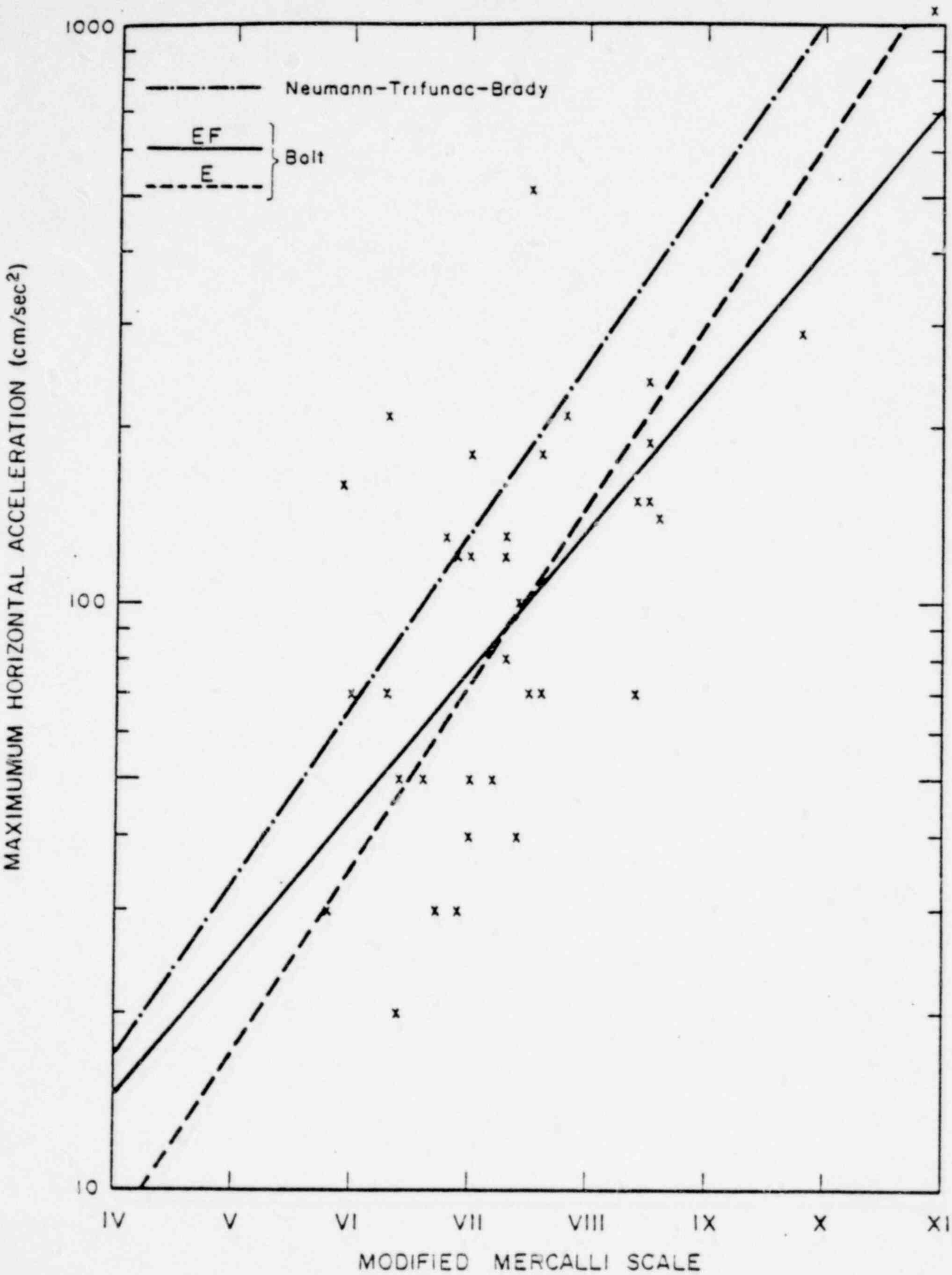



Figure 1.--Acceleration vs. Intensity

From "Seismic and Geologic Siting Considerations for Nuclear Facilities" by H. W. Coulter, H. H. Waldron, and J. F. Devine, Proc. World Conf. Earthquake Engr., 5th, Rome, Italy, 2410-2419, 1973.

FIGURE 5

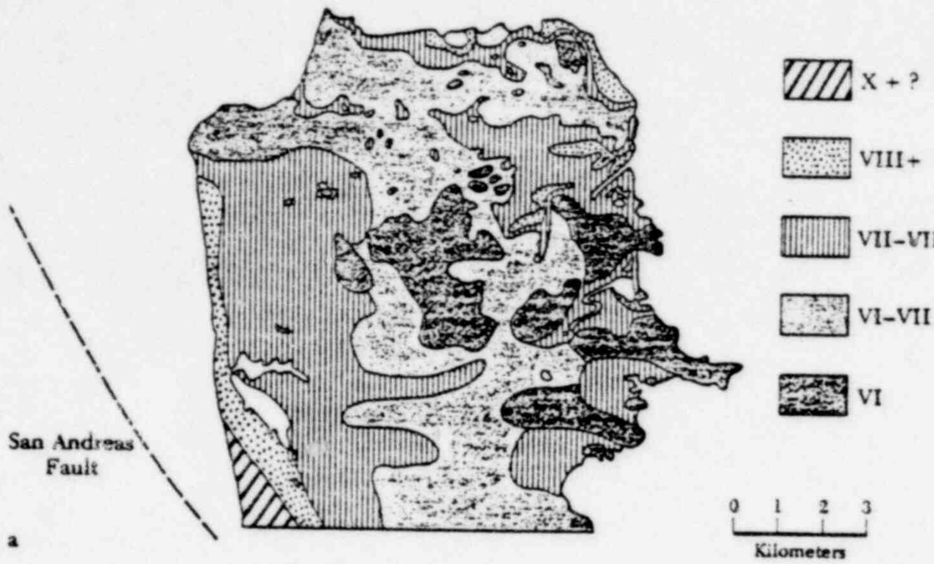



Regression lines and data crosses for present study.

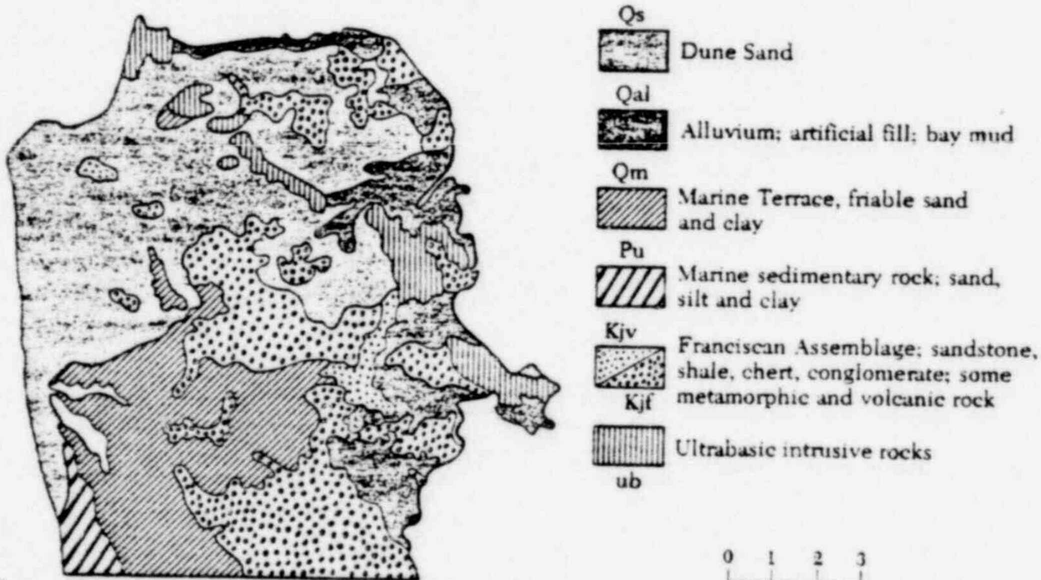
From "Fallacies in Current Ground Motion Prediction" by B. A. Bolt, Proc. Second International Conference on Microzonation, 2, 617-633, 1978.

1321 076

FIGURE 6




a

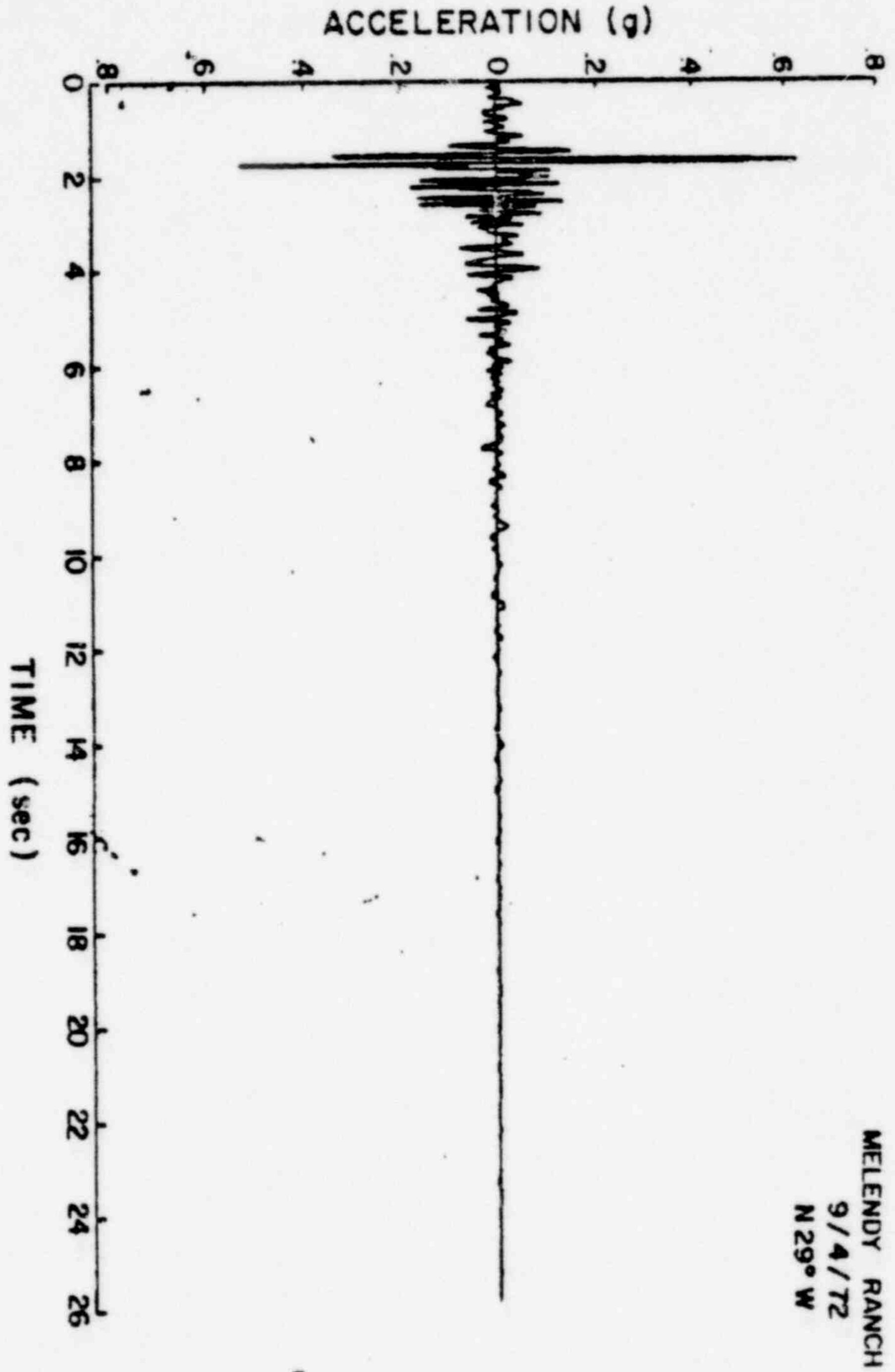


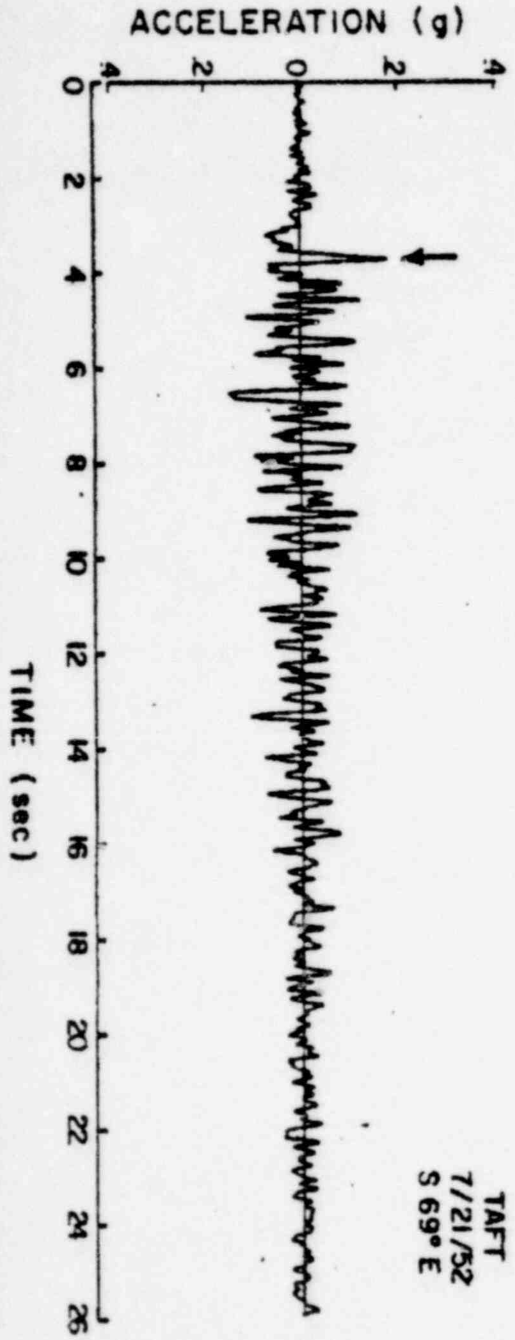

b

(a) Isoseismal lines on the San Francisco peninsula (based on the Modified Mercalli scale) drawn by H. O. Wood after the 1906 San Francisco earthquake. (b) A generalized geological map of San Francisco peninsula. Note the correlation between the geology and the intensity.

From "Earthquakes - A Primer", by B. A. Bolt (W. H. Freeman, 1978).

1321 077


ACCELERATION (g)
.8 .6 .4 .2 0 .2 .4 .6 .8
TIME (sec)
0 2 4 6 8 10 12 14 16 18 20 22 24 26
MELENDY RANCH
9/4/72
N 29° W


ACCELERATION (g)
.4 .2 0 .2 .4
TIME (sec)
0 2 4 6 8 10 12 14 16 18 20 22 24 26
TAFT
7/21/52
S 69° E