INTRODUCTION TO SEISMOLOGICAL CONCEPTS RELATED TO EARTHQUAKE HAZARDS IN THE PACIFIC NORTHWEST

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The objective of this brief discussion is to acquaint you with the general aspects of the earthquake hazards in the Pacific Northwest. We will address the "why," "how big," and "how often" of earthquake occurrence. In addition, some mention will be made of the severity of effects that we may expect in this region. In order to answer the questions concerning "where" and "why," we will call on some general concepts of plate tectonics. Answering the "how big" question will require a discussion of earthquake magnitude and other means of characterizing the "size" of an earthquake. The question of "how often" will cause us to look at some elementary statistics of earthquake distributions and the importance of the historic record. Finally, our discussion of the severity of effects will necessitate the introduction of the idea of how we characterize destructive ground motion and how the severity of motion depends on the local situation.

Whether or not the scientific community is ever able to reliably predict earthquakes, engineering decisions need to be made every day based on our present state of understanding of the earthquake risk. Thus, the principal task of a seismologist interested in reducing the hazards due to earthquake is to develop an understanding of how geologic and seismologic parameters affect motion. This is necessary because we need to predict in advance the nature of ground motion for an earthquake that has not yet occurred and all we have to look at is the geology and the record of past earthquakes.

PLATE TECTONICS AND EARTHQUAKES

The plate tectonic model of planet Earth is the starting place for understanding the "why" and "where" of earthquake occurrence. In the simplest sense, earthquakes are the "noise" or creaking and grinding disturbances that accompany the motion of tectonic plates. In this view, the plates (with associated continents riding along on top of some of them) do not move smoothly at rates of a few centimeters a year; rather, they move spasmodically, with a jump during each large earthquake, such that the average motion viewed over thousands (or millions) of years is several centimeters per year. Of course, the entire plate does not have to lurch forward during a single earthquake, but significant distortion and

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movement could be expected every time a large portion of any its boundaries slips. That earthquakes are associated with the boundaries of these plates can easily be seen by looking at Figure 1, which illustrates the global pattern of earthquake activity. Narrowing our view to the Pacific Northwest, we have the plate configuration illustrated in Figure 2.

Plate Boundaries

A plate has three types of boundary--a spreading ridge boundary, a subducting zone boundary, and a transform fault (or edge) boundary. In the simplest view, the ridge has the smallest earthquake occurrences because the lithosphere is thin and hot (weak) near a ridge and, thus, a large area of potential slip (and, thus, a large volume in which to store strain energy) does not exist. In contrast, the subduction zone boundary appears to be the place where the world's largest earthquakes (great earthquakes) occur. This is because the lithosphere is cooler, thicker, and stronger and because a larger area of potential slip exists (the entire interface between the overriding and underthrusting plates). Transform faults or plate edges appear to be intermediate between these two extremes with a limit on the depth extent of faulting, but with a horizontal extent that can be quite large as in the case of Chile, Turkey, and California. It would appear that large earthquakes, but perhaps not truly great earthquakes, are possible on transform faults. The distinction between "large" and "great" for engineering purposes ultimately may be important because of the size of area affected rather than because of distinction in the severity of ground motion. This is true since in recent years it has become clear that even moderate earthquakes can produce very severe ground motion locally.

Subduction Zones

Looking in more detail at the conditions that affect the potential "size" of earthquakes on subduction zones, we find that the two most important parameters seem to be the age of lithosphere and the rate of plate motion (covergence). A simple model of the downgoing slab, which progressively grows cooler and thicker as it moves out from its source region at the spreading ridge, is that it is sinking vertically under its own weight while also being subjected to relative horizontal convergence as the overriding plate moves over it. All other things being equal, the faster it tends to sink because of negative buoyancy, the less normal stress there will be between the two plates and the more likely it will be able to move smoothly (without a stick-slip type motion) and, thus, the smaller the earthquakes are likely to be. In the limit of a plate that is sinking so fast that it is actually separating (trying to separate) from the overriding plate, it is unlikely that large earthquakes could occur at all. The single most important parameter that seems to control the density of the downgoing plate and, thus its buoyancy, is its age. The older and colder the plate, the more dense it is and the faster it will sink. The other parameter is the plate velocity (covergence rate).

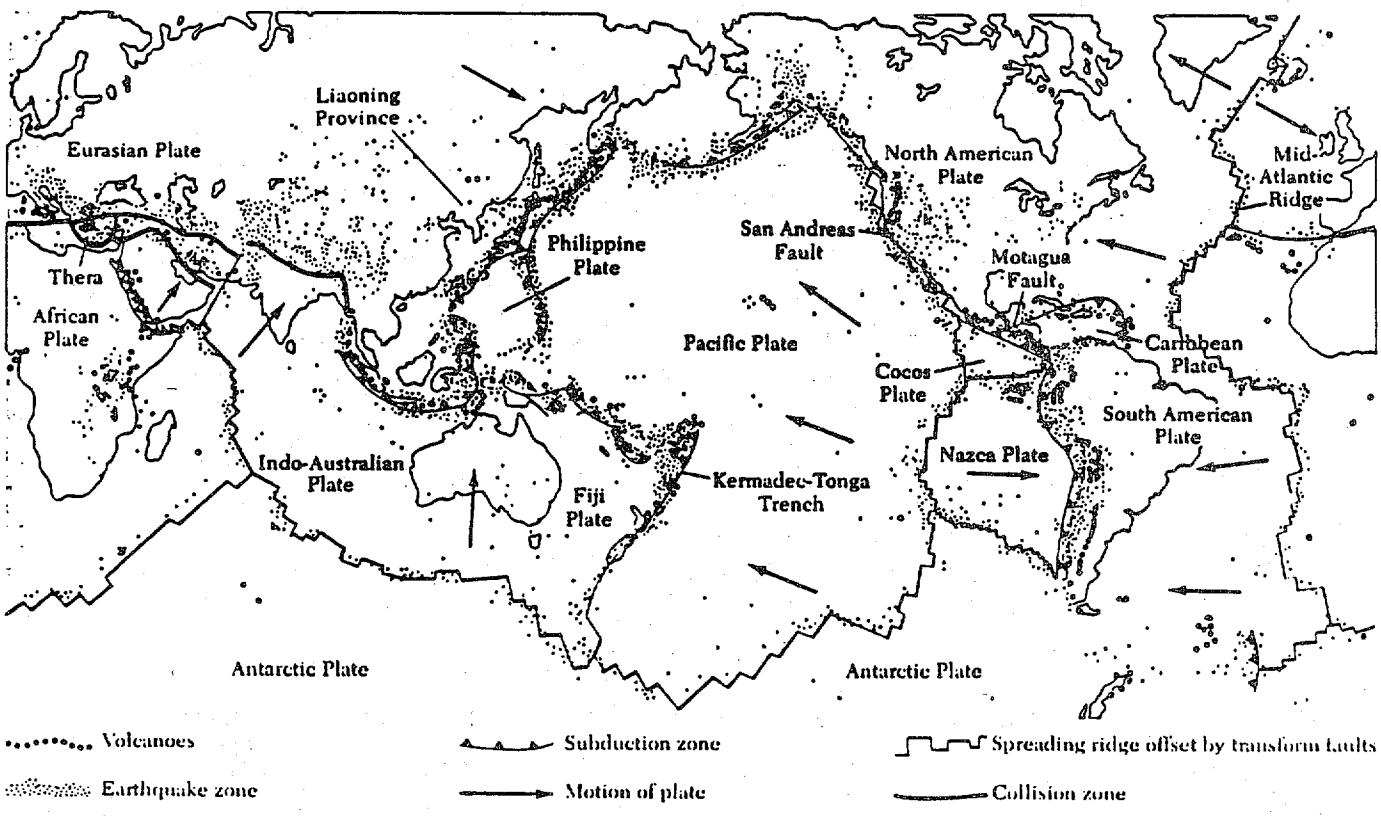

FIGURE 1 World map showing relation between the major tectonics and plates and recent earthquakes and volcanoes. Earthquake epicenters are denoted by the small dots, and the volcanoes by the large dots.

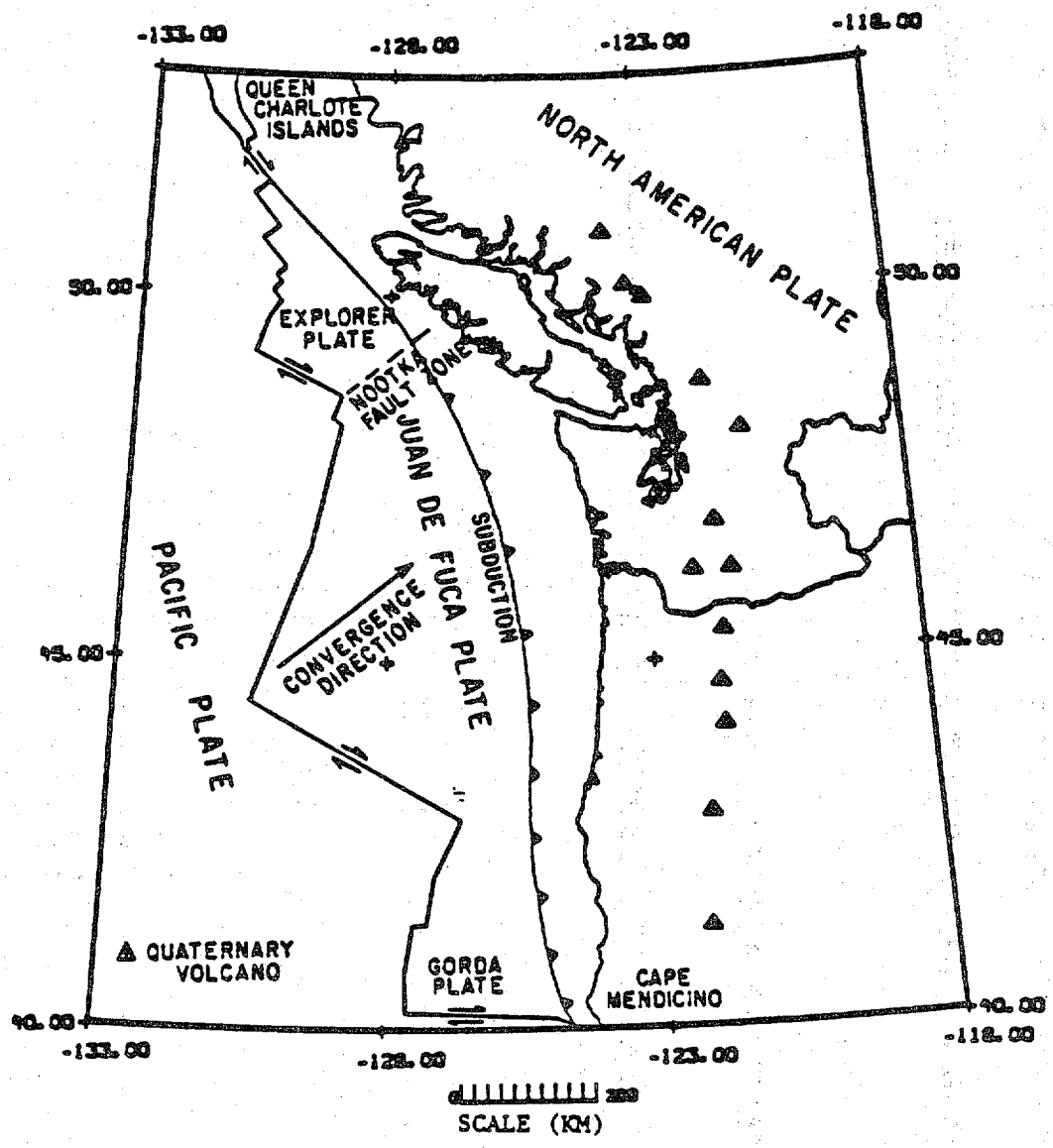

FIGURE 2 Juan de Fuca Plate map.

Here, for a constant sinking rate, the faster the two plates are converging, the more normal stress there will be locking the surface between them. This, in turn, leads to a situation of large stress accumulation and, thus, large earthquakes.

The correlation between lithospheric age and convergence rate shows, for example, that in the Pacific Northwest, where the Juan de Fuca plate has an age of less than 20 million years off the coast of Washington and a convergence rate of about 3.5 cm/yr., the expected value of moment magnitude for the largest possible earthquake is 8.25. The scatter in the data revealed in the multiple regression work by Heaton and Kanamori would cause one to put an uncertainty of about ± 0.4. The remarkable thing about this analysis is that here we have a region where the historic record is less than two centuries and there are no reports of earthquakes larger than around 7.5 and, yet, a model based strictly on geologic data and the plate tectonic hypothesis leads to a prediction of an earthquake as large as 8.5.

Transform Faults

In trying to apply similar kinds of basic physics to transform faults to see what parameters influence the maximum size of earthquakes, we have much less success. It appears to be only the top 20 or so kilometers of crust that can support brittle fracture; therefore, the size of the possible slip area is controlled primarily by the length of the fault. Complexity of the fault, lateral inhomogenieties and bends or kinks, appears to be important in determining how long a section might rupture in a single earthquake event. Thus, the detailed surface geology is critical and no generalizations can be made. Transform faults or plate boundaries are of several varieties depending on which types of plate boundaries the transforms connect. Plate edges between two offset ridges (RR transform) can be easily modeled with a piece of cardboard in which two slots are cut and through which two pieces of paper (appropriately marked with magnetic stripes) can be pulled. Two lessons are learned from this paper model. First, the relative motion on the transform fault connecting the two ridges is opposite to that which would be expected if one thought that the ridges had been offset by a fault that connected them and that they originally had been a throughgoing feature. More important from the standpoint of assessing possible earthquake size, however, is that the ends of the fault, which extend beyond the ridges and are called fracture zones (FZ), have no relative motion and, thus, can be viewed as fossil faults on which there will be no earthquakes generated. Thus, a fracture zone that is a thousand kilometers long can generate a rupture only as long as the segment joining the two actively spreading ridges. Even in the case of the transform fault, the plate tectonic hypothesis provides some important guidance as to the earthquake potential of this feature. My own view is that we have seen only the beginning of the way in which our understanding of the physics (and chemistry) of the earth will affect our assessment of future earthquake hazards.

FAULT AND EARTHQUAKES

Up to this point, we have viewed the only source of earthquakes to be plate boundaries, and our view of plates has been one of a grand scale where there are some 17 major plates comprising the entire surface of the planet. Looking closer, we find that this view is only an approximate one and that the earth is very much more complicated. In some instances the plate boundaries are razor sharp and easy to identify, whereas in others the boundary may be spread out over hundreds of kilometers or greatly obscured by the possible subdivision of the plate into many smaller platelets (the term "microplate" is starting to become popular). When we come to the hard question of estimating the future earthquake activity in a region, it sometimes seems that we have simply substituted one crystal ball for another when we try to invoke ideas of plate tectonic models and the plates themselves are not easily understood. Let us leave the simple plate viewpoint for the moment, recognizing that even if we had a simple plate model at depth, what we would see at surface is likely to be obscured by the local geology (e.g., mountains, sedimentary basins). In examining how the surface rocks may deform or fracture (fault) in response to deeper plate movement, we can use some the ideas of fracture mechanics to relate stresses to resulting fault type and pattern.

Normal Faults

A normal fault is one in which the slip direction is down-dip in such a way that you would expect to develop if the region were stretched and the blocks readjusted accordingly. Typically the dip of normal faults is quite steep, between 45 and 90 degrees. (Remember, dip is measured from the horizontal downward). In terms of earthquake potential, one would not expect a great deal of normal stress pressing the two sides of the fault together since the region is undergoing horizontal tension (being pulled apart). Thus, all other things being equal (which in geology they never are), one would not expect the largest earthquakes to occur on such faults. Substantial earthquakes, however, have been observed on normal faults (e.g., Dixie Valley, Nevada, in 1954 and Hebgen Lake, Montana, in 1959). These faults had vertical displacements of up to 4 or 5 meters over distances of nearly 100 km so they were "big" earthquakes by any measure but they were not "great" earthquakes in the sense of the Alaskan earthquake of 1964. Our 1949 earthquake near Olympia (magnitude 7.1) was apparently on such a fault although it occurred on the deep part of the subducted slab where we cannot directly observe it.

Reverse Faults (and Thrust Faults)

A reverse fault is also a fault on which the slip is in the direction of dip, but in this case it is the upper block (hanging wall) that is pushed up so the sense of motion is opposite to that discussed for the normal fault. Typical dips for reverse faults are 45 degrees or less. When the dip gets to be very shallow, almost horizontal, then the term "thrust" fault is used to describe it. There are numerous examples of nearly horizontal thrust sheets where, over geologic time, the upper

block has slid many miles on top of the lower sheet. One could expect large normal stresses to develop across such faults (since the two sides of the fault are being pushed together) and, thus, very energetic earthquakes. A recent example of a thrust type earthquake was that in the San Fernando region of southern California in 1971. Since the Juan de Fuca plate is being thrust beneath North America, this is the type of faulting that could conceivably occur beneath western Washington. Should this occur, there would likely be quite severe ground motion over the entire region from the Pacific Coast inland to the Cascade Mountains.

Strike Slip Faults

Finally, we have the case of nearly vertical fault surfaces with slip in the horizontal direction. Such faults are called "strike slip" and are classified as to right or left lateral depending on the sense of motion with respect to an observer standing on one side of the fault and looking across it. The famous San Francisco earthquake of 1906 (magnitude 8.25) occurred on the San Andreas fault, which is a right lateral strike slip fault. During that earthquake the fault slipped as much as 17 feet in some places. The recently noted alignment of earthquakes through Mt. St. Helens extending to the northwest is believed to be a strike slip fault based on indirect seismological evidence although geologic data that would confirm slip on this fault has not yet been uncovered.

Earthquake Potential of Mapped Faults

Examination of virtually any geologic map will reveal that there are a multitude of faults on a variety of scales present nearly everywhere. In fact, the density of faulting on maps seems to depend largely on how carefully the area has been mapped by geologists and how good the exposures of bedrock are. Areas like the Puget Sound region may not show many faults, for example, if they are covered by a thick blanket of recent glacial material which makes them inaccessible for geologic mapping. The scale of faulting varies from tiny, millimeter-size features you can see in a rock fragment up to global-size features that are best seen in satellite imagery. Obviously not all these features have the same potential for generating earthquakes. Size or length of faulting is an obvious distinction, but perhaps the most important characteristic is the age of most recent movement.

Age of Most Recent Movement

Most observed faults are very old, representing past periods of deformation under stress conditions that are very different from what we have today. In geology we do our forecasting somewhat like the meterologist does his when he uses the "strategy of persistence"--i.e., the most likely conditions for tommorrow are more of what we have seen today. In that sense, the faults most likely to cause a problem by gener-

ating earthquakes are the ones that have the most recent history of movement. The development of radioactive age dating techniques, particularly those that involve short half life elements like Carbon 14, and can be used to date materials as young as thousands of years, provides the means to distinguish very young and, thus, potentially dangerous faults from those that that are old and no longer active. Investigations are generally made by trenching across the fault trace, or boring through it, with careful mapping of the materials on either sides. The key is to find features that are continuous across the fault and to date these features. For example, an old soil layer that lies uninterrupted across a dip slip fault and has an age of 2,000 years tells us that the fault has not moved in at least 2,000 years. Conversely, if the soil layer were disturbed, it would establish that the fault had moved sometime (exactly when could not be said) in the past 2,000 years.

In western Washington our heavy glacial cover obscures most fault features that might be useful in assessing the record of past earthquakes (and guessing the future ones). Some evidence of ancient fault motion on the Olympic Peninsula was developed a number of years ago by dating trees that were submerged as a possible effect of fault-dammed streams. Some lineaments are visible in air photographs of the Cascade Mountains and in side-looking radar imagery (SLAR), but their significance is not as clearly understood as would be the case in California or Nevada where the overall record of surface geology is much better preserved. In the Mojave Desert of California, fault scarps that moved thousands of years ago are so well preserved they look as if they might have moved yesterday. In contrast, here in the Northwest the rate of growth of vegetation (such as Douglas fir) and the erosion due to heavy rainfall are so great that faults can easily be obscured in a short period of time. In addition, the plate tectonic configuration is basically different in the Pacific Northwest from what it is in California. In California, the boundary between the Pacific and North American plates is a nearly vertical fault plane (or collection of planes) that intersects the surface of the earth producing obvious features (e.g., the San Andreas fault). In contrast, our plate boundary in the Northwest lies beneath us, the gently dipping interface between the Juan de Fuca plate and the North American plate. Its only intersection with the surface where one might look to see its expression is under water several hundred miles offshore.

Definition of Capable Fault

The technology for recovering the history of fault movement has developed remarkably during the past decade driven by society's need to assess the "capability" of faults in connection with large dams and nuclear power plants. There are no firm rules to tell us how old a fault has to be before we can classify it as inactive. It seems to be a sliding scale depending on how high the stakes are. In the case of nuclear power plant siting, a specific criteria has evolved in which a fault that has moved at least once in the past 50,000 years must be considered "capable." Generally, however, if there is no evidence of movement since the last period of glaciation, approximately 10,000 years, it appears unlikely that future movement will occur.

CRUSTAL DEFORMATION

Obviously, with all the plates stretching, squeezing and colliding with one another, there should be some possibly measurable deformation going on between earthquake occurrences. In the earliest days of seismology, an earthquake was attributed to either explosive action or magma movement deep in the earth. It wasn't until the 1891 earthquake at Mino-Owari in Japan that serious consideration was given to sudden fault slip being the cause of an earthquake. The excellent set of geologic and geodetic data that was collected before and after the 1906 San Francisco earthquake, however, really set the stage for the first rational explanation of earthquake sources, the "elastic rebound" theory.

A number of fundamental questions remain to be answered concerning the slow deformation that precedes (and follows) major earthquakes. The tools to measure these effects are available, primarily laser distance measuring devices both land-based and satellite-based, but since the motions are slow, it is going to take quite a few more years before many of the questions are satisfactorily answered. For example, how does the stress increase in the years (possibly centuries) leading up to the earthquake? Is it rather steady, simply building gradually to a point of failure and then starting over again to produce a periodic recurrence of earthquakes? Alternatively, is the stress quiescent most of the time, with rapid periods of buildup just prior to large earthquakes? These two possible scenarios lead to quite different strategies for predicting future earthquakes.

SEISMIC WAVES

We have been using sudden fault slip or rupture as a working model for an earthquake source. The phenomenon that we normally associate with an earthquake, however, is ground-shaking. What's the relation between these two observations? The ground-shaking we notice some distance away from an earthquake (and some time after the faulting occurred back at the hypocenter) is simply the effect of seismic waves that have traveled from the hypocenter to our point of observation. The principal shaking motion that is experienced in an earthquake is due to two broad categories of seismic waves, namely, "body waves" and "surface waves." The term "body wave" means a disturbance that travels directly through a solid medium, choosing a path that is the quickest possible route between source and receiver. There are two general types of body wave, compressional or P waves and shear or S waves. Surface waves travel along the surface of the earth in a manner somewhat analogous to water waves. They also come in two varieties--Love waves that produce strictly horizontal shaking and Rayleigh waves that cause vertical as well as horizontal shaking.

For a number of fundamental reasons, the frequency of both types of surface waves, Love and Rayleigh, is much lower than that for the direct body waves, P and S. As a result, surface waves are of much more concern for long period structures such as bridges and high-rise building than for more conventional structures. Simple consideration of how the wave energy spreads out in a surface wave (two-dimensional or cylindrical

traveling along the surface) compared with body waves (three-dimensional, spherical waves traveling through the medium) tells us that the wave amplitude will die off faster with distance for a body wave than it will for a surface wave. As a result, if a site is near an earthquake, it will most likely be the body waves that do the damage, whereas if the epicenter is a long distance away, it is more likely that the surface waves will present the largest motion.

EARTHQUAKE SIZE

We have now established that earthquakes are the sudden slip or rupture on a fault plane and that the shaking we observe is a result of seismic waves produced by that fault slip. Intuitively, we might expect more intense shaking from a fault that had a relatively large amount of slip. We also might expect more intense shaking if the fault surface on which slip took place was a large one since that would permit constructive interference effects to occur. As a result, the measure of earthquake "size" should somehow include both the amount of slip as well as the size of the fault area.

Now, the observable quantity we have available to measure earthquake size is generally a seismogram. Only very rarely do we have the opportunity to directly measure fault slip and area. Thus, we need a measure of earthquake size that depends on something we can measure on a seismogram, such as the amplitude of some particular seismic wave. In the early development of the magnitude scale, Charles Richter at Caltech simply measured the maximum amplitude on seismograms. To avoid differences in the response of different kinds of instruments, he restricted himself to a particular type, namely, the Wood-Anderson torsion seismograph. This instrument has two attractive attributes for development of a magnitude scale. First, it is a very "broad band" instrument that responds uniformly to vibrations of both very short and very long period. Second, since it is a mechanical-optical device, there are no amplifiers, variable resistors, or, in fact, any knobs at all that can be twiddled to change its sensitivity. Thus, it is nearly "technician proof," and even years after an earthquake has been recorded, one can have confidence in the published sensitivity of the instrument.

Richter Local Magnitude, M_L

Richter noted that the maximum amplitude on seismograms behaved in a organized way. Although there were rapid variations in amplitude and a lot of scatter in data, he found that the maximum amplitude data formed a one-parameter family of curves when the logarithm of the amplitude was plotted versus the logarithm of distance. The free parameter was some kind of arbitrary number which denoted the "size" of the earthquake. He defined that number as the local magnitude and it has been denoted as M_L. There is an arbitrary "starting point" for this scale and he chose it such that a magnitude 0 shock would have an amplitude of 1 mm at a distance of 100 km.

Body Wave Magnitude, m_b

Richter didn't specify which seismic wave he was measuring, he simply chose the largest excursion on the record. Since the instrument was measuring horizontal motion and since he was generally dealing with local (nearby) earthquakes, the maximum always corresponded to the SH wave. Subsequent work using earthquakes from further distances showed that this process was inadequate. As waves travel through the earth they preferentially lose their high frequency constituents and, thus, appear longer in period (lower frequency) the further away you observe them. It was found that dividing the amplitude by the period provided a convenient and useful way to normalize out this effect. It was also necessary to have a scale based on compressional waves as recorded on vertical instruments. The resulting relationship with some empirical corrections added to make it fit reasonably well with the M_L scale looked like:

$$m_b = \log(A/T) + 0.1\Delta + 5.9,$$

where A is the amplitude of ground motion, T is the period of the wave, and Δ the distance.

Surface Wave Magnitude, M_s

It soon became clear that a single number, either M_L for nearby earthquakes or m_b for distant ones, wasn't adequate to describe the "size" of an earthquake. Two earthquakes of the same magnitude might produce remarkably different damage effects, and they certainly could write remarkably different looking seismograms. One of the big differences was in the amount of surface waves generated, and this observation soon led to the development of yet another magnitude scale. It utilized the amplitude of Rayleigh waves at a period of 20 seconds. Because of some waveguide effects in the earth, this period usually corresponds to the maximum part of the train of Rayleigh waves and is thus easy to identify. The resulting expression for surface wave magnitude, again adjusted so that it corresponds as closely as possible with the other magnitude scales, is:

$$M_s = \log A + 1.66\log\Delta + 2.0.$$

Seismic Moment

In addition to these empirical studies, which led to several magnitude scales that were very useful in classifying earthquakes, there were mathematical developments that led to a characterization of the strength of a seismic source. In the differential equations that describe the motion of an elastic medium, there is a source term expressed as a force. We have no way to describe an earthquake as some kind of force system since we are unable to observe forces directly in the earth and it seemed that there was no apparent way to use an earthquake as the source term in the equations of motion. This situation improved after the development of a mathematical representation theorem that showed

how a dislocation (fault slip) model could be expressed as an equivalent force. An important parameter was identified in the resulting equations, the product of rock strength, fault area, and average slip:

$$M = \mu A\bar{u}.$$

It has the dimensions of a "moment," (i.e., force times length) so it was called "seismic moment." Here was a parameter that could be measured from a seismogram and could also be directly related to observations that a geologist could make in the field. It also formed the basis of a calculation of energy or work done during an earthquake, and this, in turn, was used to develop yet another (hopefully the last) magnitude scale, the so-called moment magnitude.

STATISTICS AND RECURRENCE CURVE

One of the first ways of utilizing the magnitude scale was in examining the size distribution of earthquakes. It is immediately clear that there are more small earthquakes than large ones so the question concerns whether the distribution behaves in some organized fashion. The answer, of course, is yes! If we choose a particular area of the earth and record earthquakes over some specific time, then plotting the log of N_M, the cumulative number of earthquakes that exceed magnitude M as a function of magnitude, yields a straight line:

$$\log N_M = a - bM.$$

The intercept "a" is a measure of how active the region is and the slope "b" tells us how many small shocks there are for each large one. We will have only a segment of a straight line because we will run out of data at both ends of the magnitude distribution. There will be some magnitude so small that it will escape detection by our seismic networks, and there will be some upper limit, namely the largest magnitude shock that has occurred during our time of observation. Within this range of magnitudes, the distribution generally does fit a straight line quite well with the slope ranging from 0.5 to 1.2.

An important question concerns how far we can extrapolate such a line to predict the rate of occurrence of earthquakes larger than those that have already been observed. It would be very convenient if one could record and count earthquake statistics in a region for a short period of time, say several months or even several years, and from this data determine both the maximum magnitude that could be expected in the region and its recurrence period. Unfortunately, this procedure doesn't work because without some additional information about the faults, their behavior, and the age of most recent movement, we do not know how to extrapolate the earthquake statistics to large magnitude. To illustrate this, Figure 3 shows the earthquake distribution for the Puget Sound region. Figure 4 shows a map distribution of the earthquakes that have occurred in Washington since 1841. Note that the largest event shown is the 1949 Olympia earthquake and that if this curve is a fair representation of the long-term seismicity, we should expect a repetition of a shock of this size every 130 years on the average. Can we extend the

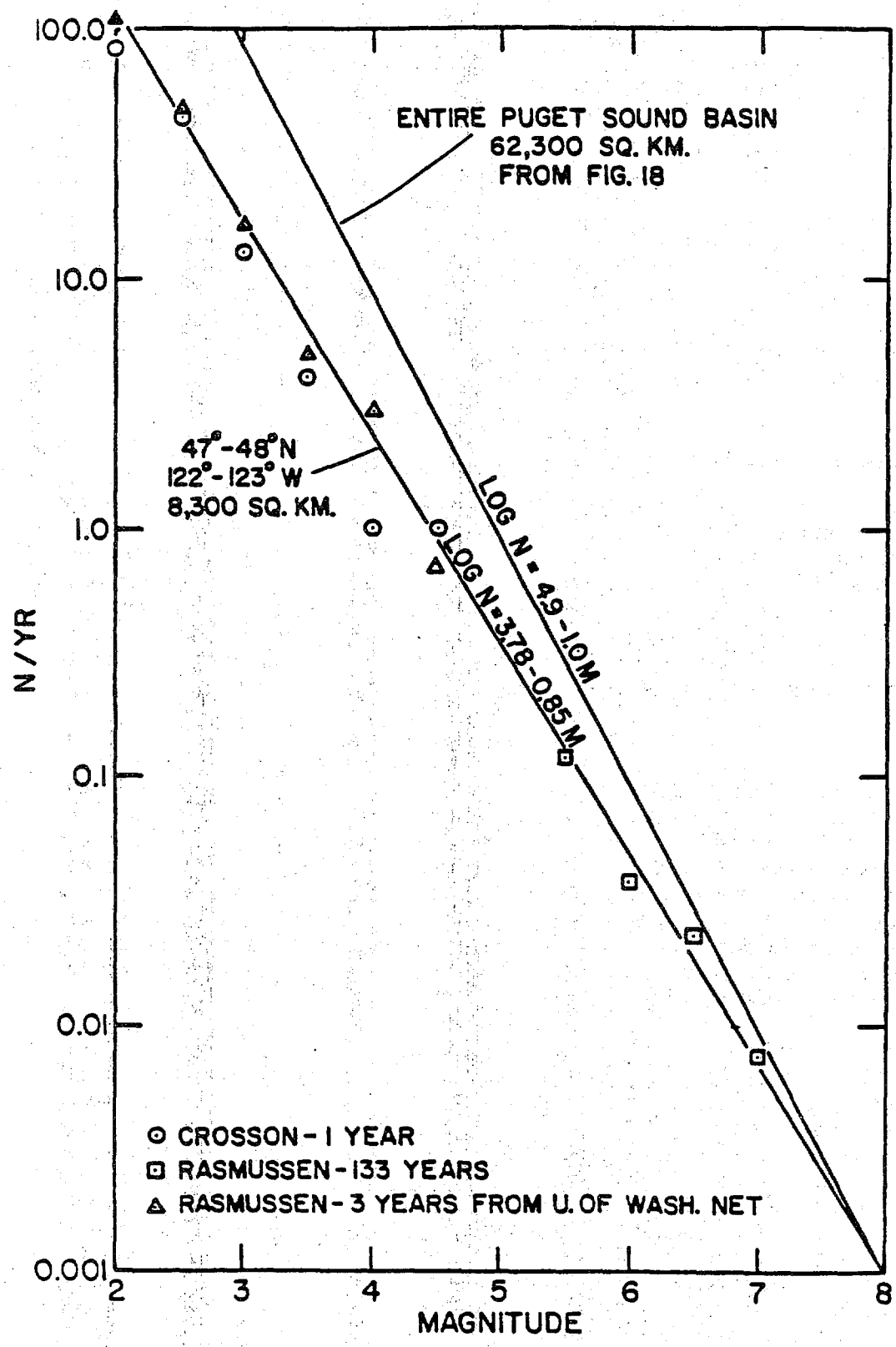

FIGURE 3 Frequency of occurrence vs magnitude for the entire Puget Sound Basis and the one degree area.

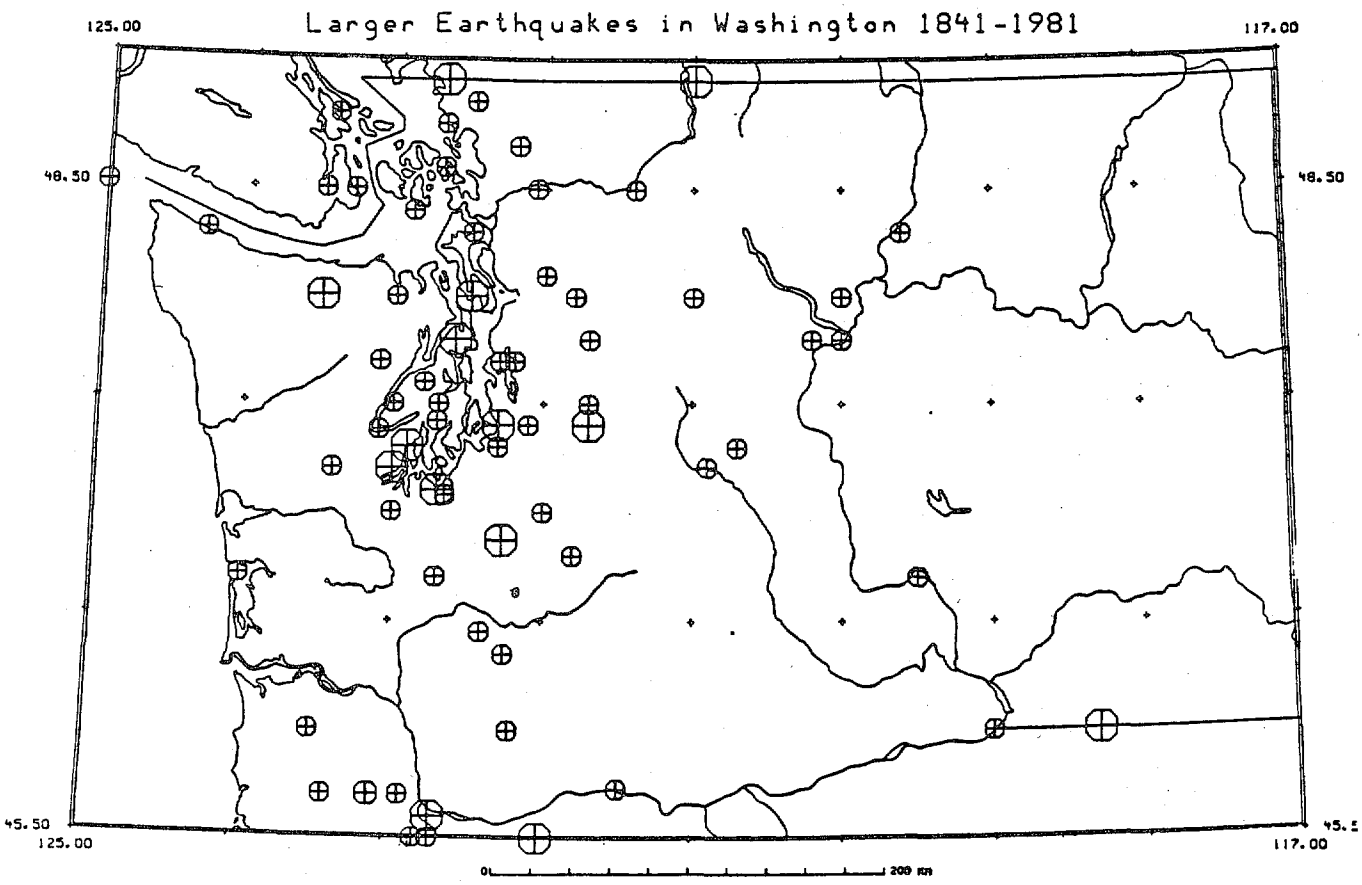

FIGURE 4 Larger earthquakes in Washington, 1841-1981.

curve to larger magnitude? If we do, how often would we "expect" a magnitude 9.0 quake and would this make any geologic sense? The Pacific Northwest is a good illustration of the pitfalls of using such curves because we suffer from a very short historic record, a poorly preserved surface geologic record, and a plate geometry not well suited for producing surface fault scarps. Thus, the critical information needed to intelligently use the meager earthquake statistics is simply not available.

GROUND MOTION

When the ground shakes during a nearby earthquake, we may (it does require some luck) obtain a record (strong motion seismogram) that displays the history of ground-shaking. A considerable amount of information is present in such records, but for our purposes we will mention only a few parameters that can be easily obtained. First, we have the maximum of acceleration, velocity, and displacement. In Figure 5 we illustrate a ground motion recording from the 1949 Olympia earthquake, magnitude 7.1, arguably the largest earthquake to have occurred in historic time. Note that acceleration is measured as a percent of the acceleration of gravity (g) or in units of cm/sec^2 reached a value of 134 cm/sec^2 or 13 percent g for this particular record. Velocity and displacement records are obtained by integrating the original acceleration record once and twice, respectively. Second, we have the duration of strong shaking, which can be defined, for example, as the length of time during which the shaking exceeded some particular value such as 5 percent g. Finally, we have some measure of the frequency content, basically a measure to describe how the energy of shaking is distributed between high and low frequencies. A variety of measures are possible ranging between simply the period of ground during which the maximum motion occurred to a response spectrum which displays the maximum motion that would be encountered by hypothetical buildings (single degree of freedom pendulums) of differing resonant frequency.

Intensity

A completely different way to characterize ground motion is through its damage effects on structures. Earthquake intensity scales are used for this purpose. For the United States, the modified Mercalli scale is the most popular. It characterizes ground motion from I to XII by a series of descriptions ranging from I as barely perceptible through VI where we see the onset of building damage to XII where one has "total destruction." The principal usefulness of such scales is to characterize the "size" of ancient earthquakes for which there are no measurements of actual ground motion. Another useful measure is the area over which the earthquake was felt since this information can often be easily determined from old newspaper reports by simply noting in what localities the shaking was felt.

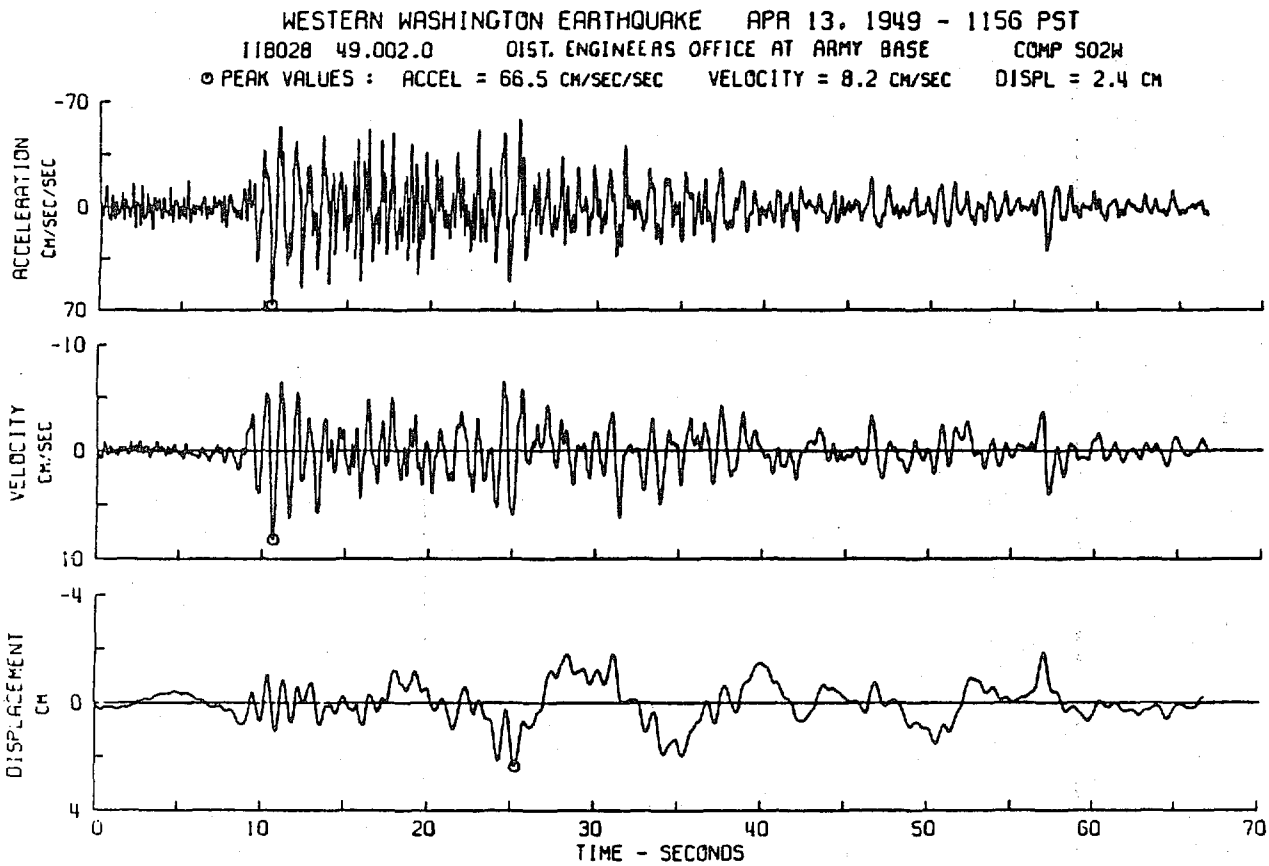

FIGURE 5 Western Washington earthquake, April 13, 1949, 1156 PST IIB028 49.002.0 Dist. Engineers Office at Army Base Comp. S02W Peak Values: Accel. = 66.5 cm/sec/sec Velocity = 8.2 cm/sec Displ. = 2.4 cm.

Attenuation Curves

Obviously, any of these "measures" of ground motion will be more severe for an observation site close to the earthquake than it will be for a more distant location. Attenuation curves are the device we use to display this relation. Any parameter can be used to construct an attenuation curve, even intensity. Typically we display the logarithm of peak horizontal acceleration as a function of distance for one particular size earthquake. The shape of this curve depends critically on a number of seismologic and geologic parameters such as fault type, depth, crustal thickness, and specific dissipation (Q^{-1}). This last parameter is a measure of how much of the elastic energy in a wave is converted to heat as the wave passes through the crust. Thus, each region will have its own distinctive curve. Such a curve, when constructed with locally derived ground motion data, together with a recurrence curve, also locally derived, and a map of the potential earthquake source regions are the basic ingredients that one needs to calculate seismic risk.

CONCLUSIONS

Western Washington lies on top of an active subduction zone. Although the characteristics of this zone are not yet well understood, comparing it with other subduction zones around the world leads us to predict that an earthquake as large as 8.25 on the moment magnitude scale could happen here. The effects of such an earthquake would not be localized to a narrow fault zone such as is the case for the San Andreas fault in California but might be spread widely from the coast inland to the Cascade Mountains and from Vancouver Island to the Columbia River. Although the scientific evidence points toward the possibility of an earthquake of this size, we have not yet been able to determine if such an event is likely to occur once per century or once per millennium. It is this rate of occurrence that will determine if the risk from such a large earthquake is greater than the risk we know for certain exists due to the repetition of smaller historical earthquakes such as those of 1949 and 1965.

MANAGEMENT OF EARTHQUAKE SAFETY PROGRAMS BY STATE AND LOCAL GOVERNMENTS

DELBERT B. WARD

This paper deals with fundamental concepts for management of earthquake hazards and associated earthquake safety programs at state and local levels of government. The focus of the paper is upon recognizing and narrowing a gap which the author believes to exist between earthquake hazards information (essentially research data) and applications of the information (public policies for implementation of hazards reduction methodologies).

BACKGROUND

That natural hazards can be managed for the overall benefit of our society is a notion accepted by most of us. We believe--correctly, I think--that life loss, injuries, and property losses can be reduced through prudent pre-event practices and effective deployment of resources when disasters occur. Emergency management is an institution of government that has evolved over the past two or three decades whose primary purpose is to articulate and carry out a broad array of activities directed to loss prevention and/or loss reduction due to extreme events--both natural and man-made.

Emergency management practices traditionally have separated into several phases, due no doubt to the time-related character of the activities. For this discussion, we refer to four such phrases--preparedness, mitigation, response, and recovery. Other divisions have been used, but the variations have no significance to our purposes here.

Beyond these time-related characteristics that are common to nearly all emergency management activities, the similarities among the risk reduction activities appear to end for the various hazards. Each type of natural hazard-- earthquakes, tornadoes, hurricanes, and floods--derives from a different sort of natural phenomenon, has different physical characteristics that create risks to life safety and property, and, consequently, requires different methods for effective control (management) of the risks.

Mr. Ward is an architect with Structural Facilities, Inc., Salt Lake City, Utah. He presented this paper at the FEMA Earthquake Education Curriculum Workshop held at the National Emergency Training Center, Emmitsburg, Maryland, June 27-29, 1984.

If the reader accepts that there are physical distinctions between the several types of natural hazard named above, then it is useful to examine briefly the implications of these distinctions with respect to the time-related emergency management activities of preparedness, mitigation, response, and recovery. Although management concepts for the hazards may be similar in some cases, the specific risk-reduction activities are quite different for each type of hazard. Moreover, the importance (priority) of the types of action with respect to the end goal of risk reduction seems to be different for each type of hazard.

For example, for a variety of reasons control of losses due to a hurricane requires different emphasis upon preparedness and recovery actions than does control of losses due to an earthquake. In the case of hurricanes, preparedness actions based upon pre-event warning are possible; mitigation is largely a matter of siting considerations; and response activities can be coordinated to occur even during the event. On the assumption that life safety is the paramount objective, preparedness based upon pre-event warning is emphasized.

Riverine flooding, too, requires a different emphasis for effective loss control. Once again, preparedness actions can be based upon pre-event warning, but effective loss control requires that emphasis be placed upon mitigation actions.

Earthquake events, in contrast, say, to hurricanes happen without warning and are of very short duration--a few minutes at most and hardly enough time to do anything more than duck. Current technology does not allow short-term prediction of the events, although regions of greater earthquake potential and even long-term (several years to several decades) speculations about impending events are within current technical state--of-the-art capabilities. Moreover, we presently do not know how to control (eliminate or soften the occurrences) of the earthquake events. Accordingly, emergency management methods presently are limited to (1) reducing the effects of the earthquake upon buildings and people--mitigation--and/or (2) providing recovery services--picking up the pieces, so to speak--after the events.

Either of the above types of emergency management actions will help to reduce earthquake losses to some extent, but mitigation assuredly can be the most effective of the two types of actions. Mitigation can eliminate losses in some cases and certainly can reduce losses in most cases whereas recovery actions can only attempt to contain the extent of losses and restore essential lost facilities and services.

These differences among the hazards lead to differences in management methods that must be acknowledged and met. This entails, first, recognizing the characteristics of each type of hazard and their consequent effects upon us. The appropriate kinds of management activities and the relative effectiveness of each activity then can be tailored to the type of hazard. We now take the specific case of earthquake safety for elaboration upon this point.

The argument developed above aims essentially at making a strong case for mitigation as the most effective means available to us today to reduce earthquake losses. If this argument is accepted, than we are left with the task of defining mitigation for earthquake safety and, consequently, with describing the implication that a mitigation approach has with respect to emergency management methods.

Mitigation of earthquake risk is accomplished almost entirely through control of the "built environment." Earthquakes themselves rarely if ever kill or injure people directly. Rather, they displace buildings, building components and other elements of the build environment such as highway structures, dams, water and electric systems, etc., which in turn may jeopordize life safety and cause great social and economic inconvenience. By controlling the quality of the things we build and by selecting construction sites less likely to feel hazardous earthquake effects, it is possible to achieve reduced life loss, reduced injuries, and reduced property losses. None of the other emergency management phases accomplish this to any degree even though the phases are necessary parts of a comprehensive comprehensive emergency operation.

Construction of the built environment is controlled by construction regulations, codes, zoning ordinances, siting evaluations, and good design practices. Most of these controls already are a part of every community's governance mechanisms. It is through actions that impact upon these processes of control that earthquake mitigation must be accomplished.

The control procedures indicated in the paragraph above are implemented through organizations which have not been dealt with to any great extent by traditional emergency management agencies in the past. Even when emergency management agencies have worked with these existing infrastructures, such as land-use regulatory agencies for flood mitigation efforts, the physical and technical difference between earthquakes and the other hazards allow very little carry-over of learning experiences. It seems clear to this author that effective earthquake hazards mitigation actions will require new liaisons to be forged between emergency management personnel and organizations that control or regulate construction of the built environment.

These new liaisons likely will be somewhat different than the liaison formed in traditional emergency management activities of the past, most notably the civil defense program of the past that dealt with problems not faced by many existing agencies of government. In the case of earthquake mitigation, we find that existing agencies already are in place which have responsibility for controlling the quality of the built environment. It is most likely that these agencies will insist upon preserving their regulatory jurisdictions when earthquake hazards mitigation processes are introduced. Under these circumstances, it is even questionable whether or not the traditional emergency management agency has a role with regard to earthquake hazards mitigation.

Severe flood threat in the State of Utah during the past two years illustrates this point. Having experienced excessive springtime run-off in 1983, with consequent flooding of stream beds and mudslides, Utah coun-

ties and cities undertook hurried public works improvements to mitigate similar future problems. Without exception, these prejects were managed by existing full-time public works administrators and flood control personnel. These personnel are not part of the state's emergency services agencies and work independently of those agencies. Although coordination between the public works agencies and the emergency services agencies occurred, this was primarily with respect to preparedness and recovery actions. Mitigation actions were carried on by the public works agencies.

Mitigation for earthquake safety seems to have silmilar restraints in the sense that there are existing governmental agencies responsible for control of the quality of the built environment. Once public policy has been set for earthquake hazards mitigation, as was the case for mitigation of flooding, the existing agencies having jurisdiction will proceed to carry out the policy mandates, I believe.

One implication of the above observation is that the problem of achieving effective earthquake safety is not so much one of management, but rather is one of persuading a reticent public sector of the need for a sound public policy for earthquake safety. If the public commitment is clear in this regard, the machinery is available in government to carry out the mandate.

THE GAP BETWEEN TECHNOLOGY (RESEARCH) AND APPLICATIONS

Knowledge about the behavior of earthquakes, although far from adequate for the scientific community, is quite adequate today for applying earthquake risk mitigation techniques to the built environment. The literature on earthquake physical characteristics and on techniques for construction of earthquake-resistant facilities--buildings, transportation systems, dams, utilities systems, etc.--is extensive. Sufficient technical information can be assembled to allow preparation of earthquake risk evaluations which, in turn, allow estimates of possible earthquake losses to be prepared. One also can ascertain the types of likely construction failures associated with the losses.

With such information, one can suggest modifications in siting practices and construction methods that are most effective for saving lives and most cost-effective for the community. Indeed, these kinds of data have been assembled in a variety of forms and for a variety earthquake conditions. As well, some of the data are even assembled for different regional earthquake conditions.

Despite this wealth of information, there has not been widespread application of earthquake risk reduction measures in the private or public sectors of this nation. Except in California, public apathy about earthquake risk prevails, and local governments resist adopting public policies that would encourage application of risk reduction. There is a large gap between the available technical information and application of earthquake mitigation measure.

Credit is due to the federal government which has been actively promoting improved earthquake safety practices and encouraging development of emergency management tools to deal with the hazard. However, these efforts have aimed largely at making the federal government a helpful partner with state and local government in such matters. In general, mandated federal requirements for earthquake safety do not exist.

Given this present working arrangement, it should come as no surprise that the federal efforts can be no more effective than the efforts of the other half of the partnership--state and local government. It is at these state and local government levels that earthquake safety has failed to receive the attention that I believe is warranted--the exception again being California. Other states and local governments occasionally give verbal support (motherhood statements) to earthquake safety. Rarely have they set forth public policies to bring about the needed changes.

Yet, control and regulation of construction of the built environment lies almost entirely within the domain of state and local government in this nation. The federal government has not usurped this prerogative. State and local governments zone the land; they adopt building codes; and their personnel design many of the public facilities, such as transportation systems, water supply systems, waste systems, and even some utilities systems. Mitigation of earthquake risk, therefore, apparently must be accomplished through these existing institutions and processes of state and local governments. For them to do so, however, the policymaker must be convinced that the public interests are well served. At this time, they do not appear to be convinced.

Some forward motion in improved earthquake safety practices has occurred through the private sector in ways that generally are independent of government. Recognition of this motion is pertinent to our discussion of the gap between technology and applications because it provides further insight into the reasons why the gap occurs.

Construction practices are influenced, sometimes even controlled, by groups besides governmental regulatory agencies. Two such groups are the design professionals and developers of construction codes and standards. The design professional--the architect or engineer--always has the option of specifying construction of a quality that exceeds the minimum requirements of adopted codes and standards. To some extent this has occurred, although randomly, throughout the nation with respect to earthquake-resistant construction. However, without a clear statutory mandate, designer attentiveness to earthquake hazards mitigation will continue to be random and susceptible to client pressure that the facilities meet only minimum standards of performance.

The national model building code organizations and similar other groups who develop construction codes and standards also have great influence over construction quality. This occurs because the common practice is that state and local governments often adopt these codes as their standards or regulations. Yet, these codes and standards essentially are developed outside of government by mixes of design professionals, building officials acting independently of their agencies, product repre-

sentatives, and trade organizations. Hence, it is possible to achieve improved earthquake safety practices by including appropriate standards in the codes which eventually get adopted by most, but not all, states and local governments. The process for introducing new concepts into codes and standards is long and tedious, but the avenue is available to us.

Although forward motion in earthquake safety practices has occurred through the two types of groups described above, the efforts have been constrained by inadequate knowledge in application. It is one thing to gain appropriate language in the codes and standards; it is quite another thing to interpret and apply the recommendations in actual construction conditions. Broader and better focused training is essential if the design professionals and the standards are to be a primary means for achieving improved earthquake mitigation practices.

CAN EDUCATION NARROW THE GAP?

In this paper, the existence of a gap between our level of technical knowledge about earthquake hazards and a public willingness to apply the available knowledge to loss reduction practices has been emphasized.

In the author's experience with earthquake safety, this lack of public willingness to utilize available knowledge is the major reason for the lack of public policies that are needed to promulgate effective earthquake loss reduction actions. Public apathy toward the problem is manifested by the absence of political commitment by state and local governments to deal with the situation in any significant way.

Although the public generally seems to have knowledge about earthquake hazards and associated risks to life and property, albeit sometimes incomplete and inaccurate, this author's view is that there is adequate knowledge and information for the public to take risk reduction actions if only the will to do so were present.

Several conclusions can be drawn from this observation. One can only speculate as to which, if any, of the conclusions are accurate, and, of course, none of the conclusions may be valid if the underlying premise lacks validity--namely, that a public commitment is missing. Five possible conclusions are listed below and then discussed briefly:

1. The risks posed by earthquakes are not believed to be sufficiently great to warrant doing any more than presently is being done to control losses.

2. Earthquake risks are perceived to be too narrowly limited to just a few population centers (earthquake regions) to justify any public policies aimed at abating the problems.

3. In an economic, cost-benefit sense, earthquake risks are perceived (or actually are) lower than the costs of risk reduction.

4. Potential victims of loss believe that governments (federal, state, and local) will provide the resources to recover any losses. (This conclusion fails to be responsive to the possibility of life loss and injury.)

5. The public simply does not know enough about earthquake risk to give the problem much attention and so does not care.

If Conclusion 1 is accurate, then efforts to broaden the public concern for earthquake safety may be the equivalent of "beating a dead horse." If Conclusion 2 is accurate, then the case can be made for strengthening public information and education programs. If Conclusion 3 is accurate, then some research efforts ought to be shifted to economic analyses to confirm or reject the perceptions. If Conclusion 4 is accurate, then either some changes in governmental assistance policies ought to be made so that individuals and local governments are held accountable for their failure to act prudently or governments should redirect their emergency management functions to preparedness, response, and recovery and abandon mitigation efforts for which the cost is borne by others. If Conclusion 5 is accurate, then intensified efforts in public education seem to be warranted.

This author is not aware of any studies that aim at verifying or rejecting the conclusions suggested above. Until that is done, we can only speculate about which among them may be the more accurate. We therefore cannot direct educational resources to deal with a situation which is inadequately identified.

That the public is not ready at the present time to make policy commitments to earthquake safety is the best that can be said. While those of us who seek improvements in earthquake safety can point to a number of individuals and organizations around the nation who feel the same as we do, it is a sad fact that the numbers of us have not grown significantly in recent years nor have we achieved much in the way of public policy changes.

Enough has been said in the negative. The remaining questions are whether or not education and training can help to change this situation and, if so, what might be the form and focus of this education and training. This author's view is that educational efforts in earthquake safety must continue regardless of public receptivity. To do otherwise would reduce, in effect, the level of present knowledge about earthquake hazards and risk reduction for we would fail even to provide an opportunity for follow-up generations to inform themselves. Old timers eventually are replaced by new faces. It is the natural way of things. We would do a disservice to the younger generations by failing to provide for the transfer of our knowledge.

What kind of education, then, and for whom? Sidestepping for a moment the lack of public commitment to earthquake risk reduction, need for at least three types of education and training can be identified in the comments made in prior portions of this paper: training of emergency management personnel that aims at clarifying the new types of liaisons needed for earthquake risk reduction through mitigation; training for

design professionals and governmental regulatory agency personnel that aims at improving their skills in applying mitigation concepts that may be recommended or mandated in standards and codes; and general public education that aims at advancing the understanding of earthquake risks by the public and their political representatives.

Concurrent with these education and training efforts, it would be helpful to have results from studies of public apathy with respect to earthquake risk--their perceptions, misperceptions, and views--in order to determine whether or not public education is even warranted and, if so, the form it should take to be most effective.

THE NATURE OF THE EARTHQUAKE THREAT IN ST. LOUIS

OTTO W. NUTTLI

Earthquake hazard in the St. Louis area arises from two causes: nearby earthquakes that produce short-duration, high-frequency ground motion and more distant earthquakes that produce relatively long-duration, low-frequency ground motion.

Figure 1 shows my version of the earthquake source zones of the central United States together with my estimates of the surface-wave magnitude of the earthquake with a 1,000-year recurrence time. The source zones closest to the St. Louis area are the St. Francois Mountain uplift to the southwest and the Illinois Basin to the east. The more distant zones are the Wabash Valley fault zone to the southeast and the New Madrid fault zone to the south. On average, St. Louis is 150 to 200 km form the Wabash Valley Zone and 175 to 350 km from the New Madrid Zone.

All four sources zones have produced earthquakes that caused damage in St. Louis. An M_s = 4.4 earthquake in April 1917, which occurred in the St. Francois uplift region about 60 km south of St. Louis, caused modified Mercalli intensity (MMI) V-VI effects in the city. This resulted in bricks being shaken from chimneys, broken windows, cracked plaster, and horses thrown to the pavement.

Two damaging Illinois Basin earthquakes occurred near Centralia, Illinois, about 100 km east of St. Louis. The June 1838 event was of M_s = 5.8 and the October 1857 event of M_s = 5.3. Contemporary newspaper accounts and some current earthquake catalogs mistakenly put their epicenters at St. Louis because of the amount of damage that occurred in the city. The former event caused a number of chimneys to be thrown down in St. Louis, corresponding to a MMI of VII. The latter produced only fallen plaster and cracks in walls and chimneys in the St. Louis metropolitan area, corresponding to a MMI of VI.

A M_s = 5.2 earthquake originated in the Wabash Valley region about 150 km from St. Louis in November 1968. In St. Louis the MMI was only V (cracked plaster, objects thrown off shelves, etc.) but in the eastern part of the metropolitan area the MMI was at least VI (cracks in walls and chimneys and people thrown to ground).

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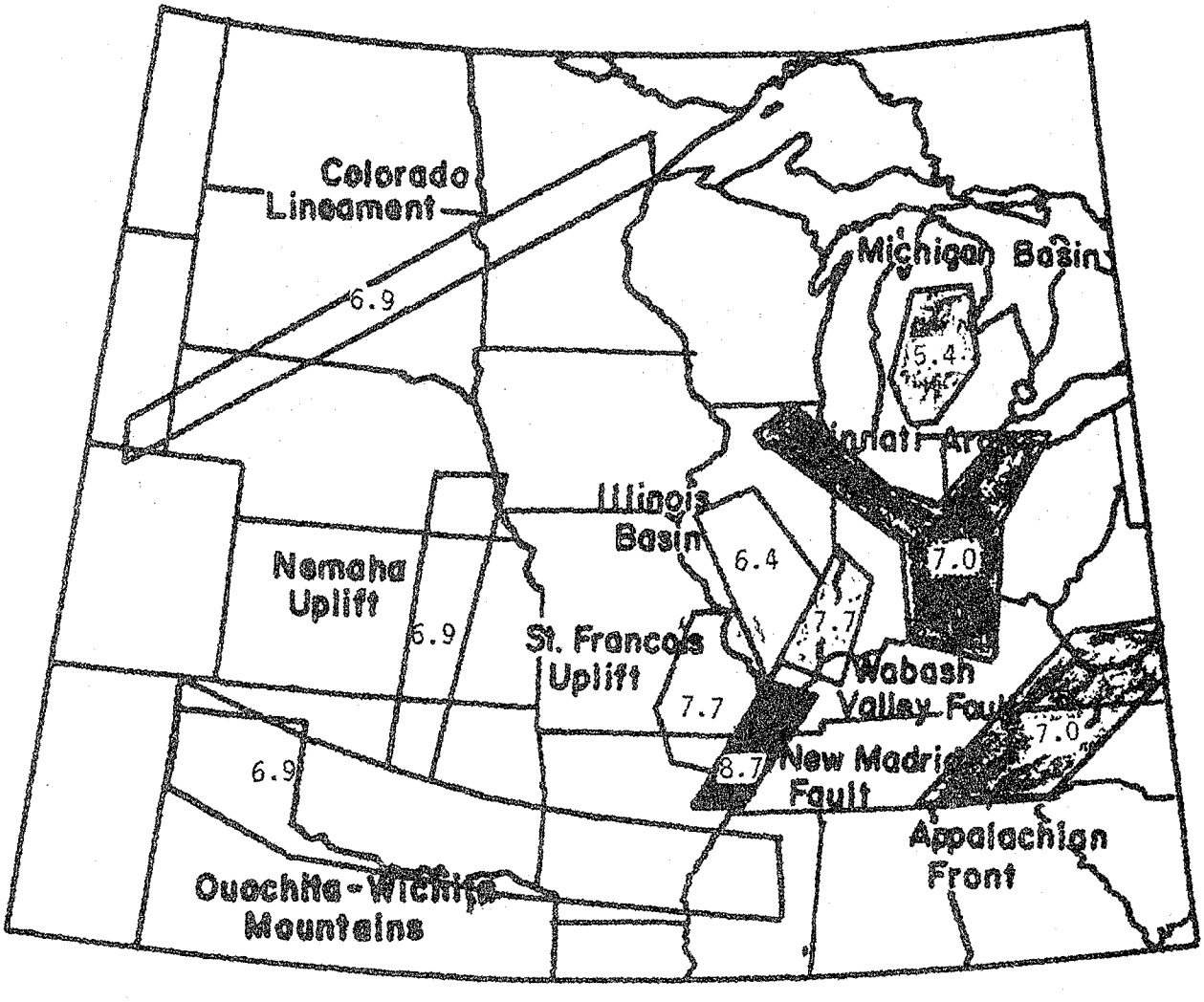

FIGURE 1 Earthquake source zones of the central United States.

The largest earthquake shaking in the St. Louis area since the city's founding in 1764 was caused by earthquakes of the New Madrid fault zone. Earthquakes in December 1811 and January and February of 1812 (M_S values ranging from 8.0 to 8.7) caused chimneys to be thrown down in St. Louis and 2-foot thick stone building foundations to be badly cracked. There were reports of sand catering and soil liquefaction in Cahokia, Illinois, just across river from St. Louis. The four largest earthquakes caused MMIs of VII to IX in St. Louis area. The October 1895 earthquake (M_S about 6.5) occurred near the northern end of the New Madrid fault and caused MMI VI effects at St. Louis. A few chimneys and old building walls were thrown down, suspended objects were thrown from walls, and groceries and other objects were thrown off shelves.

Future earthquake damage in St. Louis can be expected to be more severe than the damage produced by the past earthquakes. In the nineteenth century the population density was low and there were no high-rise structures. There were only 2,000 people living in the metropolitan area in 1811 as opposed to 2,400,000 today. Previously there were no pipelines, bridges, dams, or manufacturing plants with toxic substances to be affected. Futhermore, there was no great dependence on electricity, telephones, highways, and airports, and the economic impact of the disruption of such facilities must be considered.

It is not now possible to make short-term predictions of earthquakes in the Mississippi Valley; however, our knowledge of the earthquake history and the source physics of the New Madrid region permit some generalizations. During the next 50 years MMI VII motion can reasonably be expected in the St. Louis area from earthquake in the St. Francois uplift, the Illinois Basin, or the Wabash Valley region. The shaking will be of relatively short duration (30 seconds or less) and can be expected to cause widespread damage to the walls and chimneys of low-rise structures.

According to my calculations, the maximum earthquake that the New Madrid fault is capable of generating in the near future is one of $M_S = 7.6$. Figure 2 shows the MMI curves for such an earthquake if it were to occur on the central part of fault. The motion at St. Louis again would be of about MMI of VII, but it would be of relatively low frequency (about 5 to 0.1 Hz), of possibly 2 or more minutes duration, and sinusoidal in character. It would not cause structural damage to well designed, high-rise structures, but it would cause large-amplitude displacements at the upper levels and much nonstructural damage (e.g., fallen ceiling panels and light fixtures, moved and overturned furniture, and fallen debris within and outside the buildings). Widespread chimney damage to low-rise structures also should be expected. Sensitive equipment, including computer facilities, could be put out of operation or damaged. The probability of such an $M_S = 7.6$ earthquake occurring on the New Madrid fault is about 25 percent in the next 50 years according to Professor Arch Johnston of Memphis State University. However, he finds the probability of occurrence during the next 50 years of the size of the 1895 event to be about 90 percent. The extent of damage of this smaller earthquake in the St. Louis area will depend upon whether it occurs

near the northern end of the fault as it did in February 1812 and 1895, near the southern end of the fault as in December 1811 and 1843, or in the central portion as in January 1812.

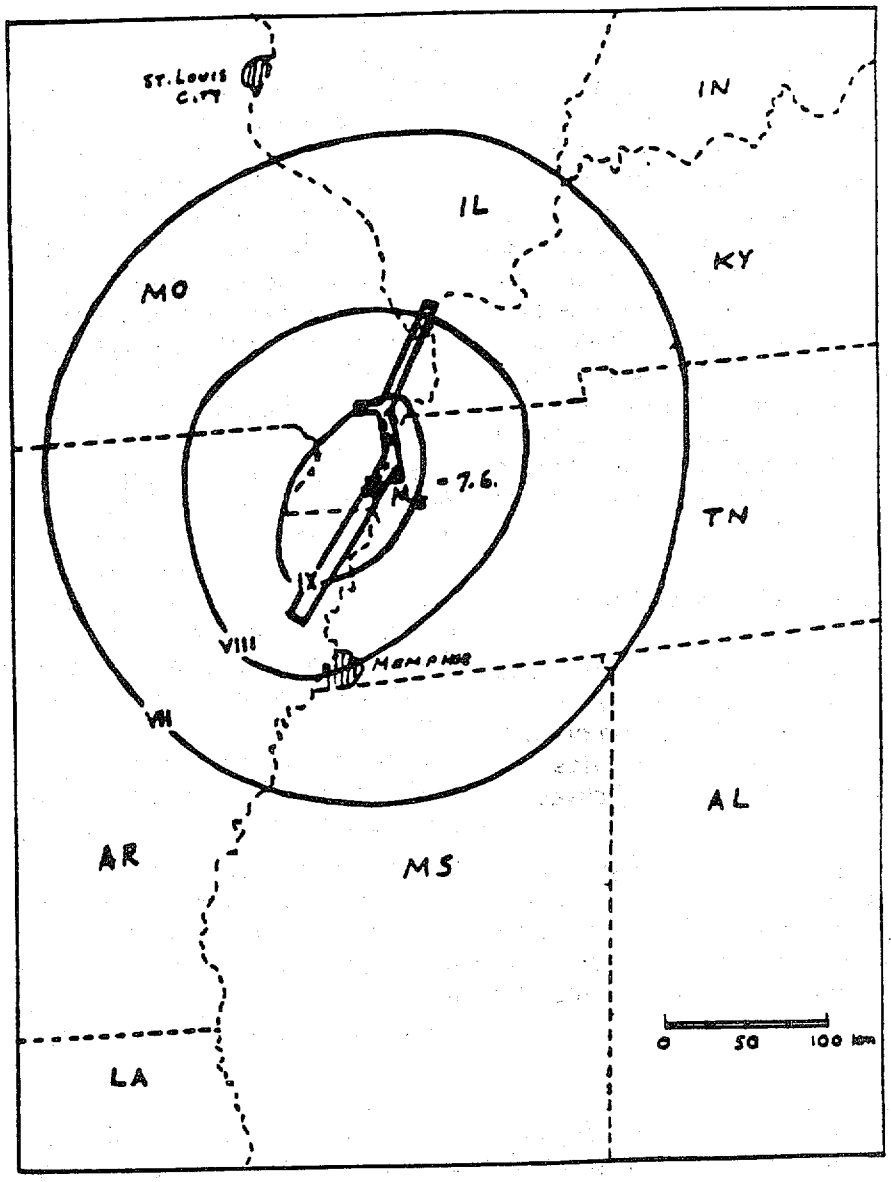

FIGURE 2 MMI curves for earthquakes generated in the New Madrid fault.

APPENDIX A

SUMMARIES OF THE BSSC MEETINGS IN CHARLESTON, MEMPHIS, ST. LOUIS, AND SEATTLE

It was noted that many persons in Charleston believe there will eventually be another serious seismic event but do not have any understanding of what it would do. It also was noted that when adopting improved seismic requirements, one must make sure that the average person does not assume that the use of a building code incorporating seismic considerations will eliminate all damage. It must be emphasized that codes only provide for "minimums" and that their purpose is life safety; seismic code requirements generally are aimed at saving occupants by preventing major structural collapse but are not intended to eliminate property damage.

It was stated that often new construction and even renovation work is done by speculative developers who have no lasting association with the buildings and that buyers therefore must be taught what questions to ask about building seismic safety. Further, many building officials need to be made aware of the seismic hazard, especially since many of them do not have engineering training.

It was explained that prior to 1981, even though the county had adopted the Standard Building Code, which includes seismic provisions for new buildings, enforcement was spotty. Since that time, an ordinance ordering their enforcement has been passed. It was noted, however, that because of the historical nature of much of Charleston, replacement of the existing building stock with new and, hence, seismic-resistant structures will occur quite slowly--that is, while a complete turnover of buildings could be expected to occur in about 100 years in most cities, it will probably take about 300 years in Charleston. It was also noted that some contractors prefer not to work in Charleston or in the county but that is simply because it is cheaper to work in nearby areas where there are no codes at all, not because of the seismic requirements of the city and county. Costs were also discussed to some extent and the need for cost-benefit analyses was mentioned.

Considerable discussion focused on the South Carolina Seismic Safety Consortium headquartered at The Citadel. This organization involves 120 representatives from a variety of professions and interest groups; members come from Virginia, North Carolina, and Georgia as well as South Carolina. It was described as a grass roots but coordinated approach to action. The major activities of the consortium involve digesting available information, data and technology and repackaging it in different forms for various audiences (e.g., building community professionals and homeowners). It was noted that the consortium's work has highlighted the need for technical information, vulnerability analyses, and technology transfer. The consortium believes it has three main audiences

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Currently in force in the city of Charleston is the 1982 Standard Building Code (SBC). Although the SBC incorporate ANSI A58.1-1972 for seismic design if required by local building authorities, at the time of the BSSC trial design effort, the city of Charleston building authority recommended that the more recent ANSI A58.1-1982 be used for its seismic requirements.

to consider when preparing educational information: the general public, the building official, and the architects and engineers. It was further noted that the professional community shares in the responsibility to make the public aware.

With respect to the impact of new or improved seismic provisions on regulatory practices, it was stated that the critical stage is design review. Since inspectors only determine if things are being constructed in accordance with plans and specifications, they would require little if any specialized training. If that is not the case, it is up to the building official to take action. In fact, it was suggested that the building officials ought to take someone found to be in violation of the code to court every now and then just to keep everyone on their toes.

Many questions arose about costs, some focusing on those related to actions providing for more than structural integrity. The tentative nature and form of the cost data presented at this meeting led the participants to conclude that the projections of cost derived from the trial designs probably represented minimums. The participants also indicated that they would like to have cost-benefit data as well as comparative data concerning what seismic protection would cost in comparison with protection from other hazards. Some wondered just how much a building owner would be willing to invest in seismic protection when there do not appear to be any financial incentives like those provided by the insurance industry for fire protection. The subject of whether it is a lessening of property damage or life safety that the insurance industry is trying to stimulate was discussed.

Some believed that the NEHRP Recommended Provisions are designed to address the worst case and frequent problem areas like those in California. It was suggested that in areas like those in the East where earthquakes are possible but not probable, use of the NEHRP Recommended Provisions would tend to overprotect low-density areas and underprotect high-density ones.

A discussion of the model codes led one participant to maintain that the best way to implement the NEHRP Recommended Provisions would be to get them incorporated in the model codes. It was noted that local government probably will not act without strong pressure from somewhere and that consensus by the building community is a necessary first step.

The lack of public awareness of the earthquake threat in Memphis was discussed at length. It was stated that even most Memphis building professionals believe the likelihood of life loss due to earthquake is remote. Since the community has limited resources and wants to attract new industry to provide more jobs and a bigger tax base, it is feared that any increase in building costs would prompt businesses to go somewhere cheaper. It also is feared that many economically marginal buildings simply would not be built at all if higher rents would have to be charged.

It was noted that some Memphis buildings are being designed with seismic protection that not required by the local code and that this shows that at least some people recognize the risk and are willing to pay for protection. It also was stated that lenders sometimes require seismic resistant design and that the expanding use of computers and other sensitive electronic equipment may attract tenants to protected buildings and permit premium rents to be charged. (Such determinations, however, are difficult to make in that one does not know whether it is the seismic protection or just the prestige of a new building that is attracting tenants.)

Currently in force in the city of Memphis and in Shelby County is the Standard Building Code (SBC), 1982, with adopted revisions (which include no seismic requirements) and with seismic design requirements excluded.

There was considerable discussion of the negligence/liability issue. It was explained that since a body of scientific knowledge regarding the earthquake threat is available, earthquakes can no longer be considered "acts of God." When the technical literature shows that there is a risk, a building owner or developer or even a regulatory or other community agency might well be considered negligent if an earthquake occurs and fatalities result, even if there is no building code requirement for seismic protection. The issue might be further complicated if some buildings in a community are designed to be seismic resistant. It was noted that this precedent has not yet been tested in court specifically concerning earthquakes but that it has for other natural phenomena.

Great concern was expressed that enactment of seismic provisions for new buildings would necessitate something being done for some existing buildings, particularly schools and other critical or high-occupancy buildings, and that the cost of such retrofit would be extremely high. It also was noted that problems could arise if the general public became overly sensitive to the earthquake hazard. Information about experiences in other places with similar risks was requested.

Some maintained that the life safety issue is of paramount importance and that studies show that many more people would be injured or killed if an earthquake occurred during the day rather than at night. It was noted, however, that few lives have been lost due to earthquakes in the United States during the past 100 years and that people therefore are unaware of or ignore the potential risk, deeming it to be of little significance to them. In addition, although one can speculate about what the damage would be from specific seismic events, no one knows for sure what will happen and this uncertainty contributes to apathy.

With respect to enforcement of seismic code provisions, it was noted that considerable training of building inspectors and probably additional inspectors would be required. One alternative might be to have the designer provide for the inspection.

Questions arose concerning the existing degree of seismic risk actually present and the probabilities of a major seismic event over time. Questions also focused on the sorts of effects to be expected from various degrees of shaking since the geology of the eastern United States is different from that of the West.

Considerable attention was paid to the architectural or nonstructural damage that might occur and whether the NEHRP Recommended Provisions would eliminate such damage in the future. Similarly, concern was expressed about the possibility of fire damage and whether it might not cause far more damage and deaths than structural collapse. Further, many were concerned about the "interface" area and whether necessary critical facilities would be operational after a seismic event even if they did not collapse.

Another major concern was that providing seismic-resistant structures would increase the average building cost and, therefore, a jurisdiction enforcing seismic provisions would be at a disadvantage relative to neighboring jurisdictions that did not enforce seismic provisions. Any resulting increase in rents was deemed to be of special importance since it might well reduce the market and result in a loss of rental income to the owner, tax revenue, and jobs.

Much discussion was focused on public awareness of seismic risk. It was generally believed that awareness is developing among St. Louis building community professionals and, to a limited extent, among the general public. All seemed to believe that what is needed is awareness without alarm and that the public must be made aware that it is not now protected. Many seemed to think that public officials were not convinced that there is a risk. It also was noted that the adoption of seismic provisions for new construction would raise questions concerning retrofit of existing structures; the retrofit issue poses special problems because of the relatively high costs and great number of buildings thought to be involved. Some maintained that clear cost-benefit data are of major importance, but others felt that the economics are somewhat irrelevant since public safety must be guaranteed whatever the cost.

The question of liability also arose. The discussion reflected the fact that it is difficult to reach agreement on how much one is obligated to do. It was pointed out that most large industrial organizations concern themselves with seismic design because they do not want to experience either a shutdown or life loss but that the speculative developer is concerned only about his market and, hence, would resist anything that would increase costs. Many seemed to believe that public officials need to be made aware that the courts most likely would hold them just as liable as a building designer or owner if an earthquake occurred and lives were lost.

Currently in force in St. Louis is the Building Officials and Code Administrator's (BOCA) Basic Building Code with no enforcement of seismic requirements.

Economic incentives to promote seismic design were deemed to be needed. Many thought that the insurance industry should encourage seismic safety the way it does fire safety. Concern by mortgage bankers also was considered important.

The discussion revealed that because Seattle already has seismic provisions in its code, there probably would be little enthusiasm for changing to incorporate the NEHRP Recommended Provisions. In addition, it was noted that any current concern about seismic regulations in Seattle is related to existing construction and enforcement.

With respect to costs, the participants warned those in communities without seismic provisions about several points: (1) incredibly erroneous statements are made about how much seismic protection increases costs, (2) the speculative developer will resist any increase in costs and will be as shortsighted as the buyer will permit him to be, and (3) sometimes a small design change can cost a lot. One participant asked if there were any data available on life-cycle costs for buildings with seismic protection that might reveal secondary benefits and another wondered whether the structure's useful life would be extended.

The fact that some financial institutions are requiring seismic design and insurance was mentioned. Questions arose about whether the insurance industry really recognizes the benefits of seismic protection and whether seismic protection is acknowledged in company rate structures. If so, it was thought that this would be an economic incentive for owners.

Much of the discussion focused on the importance of awareness and education. It was noted that even government officials, scientists, and building community professionals lack a clear awareness of the problem. It was mentioned that the general knowledge many have of the California earthquake situation presents a problem because people assume there is no risk in their area because there is no obvious active fault zone like the San Andreas.

It was stated that public officials and community decision-makers must understand the problem if they are to be able to respond effectively to their constituents once awareness develops. With respect to the general public, they must be made aware of the seismic hazard, but in ways that suggest that there is something they can do about the it.

In a community with no seismic-resistant building requirements, no one group can hope to stimulate action; all sectors of the community must be involved. It also was maintained that the building professionals in such communities must have the tools they need to provide appropriate seismic designs and that there must be a close relationship with the code enforcement agency. In addition, it was noted that the regulatory agency must have enough trained people to provide for review of designs and to ensure enforcement of any seismic provisions adopted.

Currently in force in Seattle is the Uniform Building Code, 1979, including seismic requirements.

APPENDIX B

GLOSSARY

INTRODUCTION

An important aspect of dealing with community seismic safety involves making sure that everyone "speaks the same language." If the community at large is to gain any real understanding of complex seismic issues, all of the persons involved in seismic safety activities need to understand and use the commonly accepted definitions for important terms.

GENERAL TERMS

The following definitions are from a 1984 U. S. Geological Survey Open-File Report (84-762), A Workshop on "Earthquake Hazards in the Virgin Islands Region", (Reston, Virginia: USGS):

Acceptable Risk - a probability of social or economic consequences due to earthquakes that is low enough (for example in comparison with other natural or manmade risks) to be judged by appropriate authorities to represent a realistic basis for determining design requirements for engineered structures, or for taking certain social or economic actions.

Damage - any economic loss or destruction caused by earthquakes.

Design Earthquake - a specification of the seismic ground motion at a site; used for the earthquake-resistant design of a structure.

Design Event, Design Seismic Event - a specification of one or more earthquake source parameters, and of the location of energy release with respect to the site of interest; used for the earthquake-resistant design of a structure.

Earthquake - a sudden motion or vibration in the earth caused by the abrupt release of energy in the earth's lithosphere. The wave motion may range from violent at some locations to imperceptible at others.

Elements at Risk - population, properties, economic activities, including public services etc., at risk in a given area.

Exceedence Probability - the probability that a specified level of ground motion or specified social or economic consequences of earthquakes, will be exceeded at the site or in a region during a specified exposure time.

Exposure - the potential economic loss to all or certain subset of structures as a result of one or more earthquakes in an area. This term usually refers to the insured value of structures carried by one or more insurers. See "Value at Risk."

Intensity - a qualitative or quantitative measure of the severity of seismic ground motion at a specific site (e.g., Modified Mercalli intensity, Rossi-Forel intensity, Housner Spectral intensity, Arias intensity, peak acceleration, etc.).

Loss - any adverse economic or social consequence caused by one or more earthquakes.

Seismic Event - the abrupt release of energy in the earth's lithosphere, causing an earthquake.

Seismic Hazard - any physical phenomenon (e.g., ground shaking, ground failure) associated with an earthquake that may produce adverse effects on human activities.

Seismic Risk - the probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, at several sites, or in an area, during a specified exposure time.

Seismic Zone - a generally large area within which seismic-design requirements for structures are constant.

Value at Risk - the potential economic loss (whether insured or not) to all or certain subset of structures as a result of one or more earthquakes in an area. See "Exposure."

Vulnerability - the degree of loss to a given element at risk, or set of such elements, resulting from an earthquake of a given magnitude or intensity, which is usually expressed on a scale from 0 (no damage) to 10 (total loss).

The following excerpt from the 1983 National Research Council report, Multiple Hazard Mitigation (Washington, D.C.: National Academy Press), defines several other terms that sometimes cause confusion in discussions of seismic safety:

> ... The level of intensity or severity that is capable of causing damage depends upon the vulnerability of the exposed community; vulnerability is generally a function of the way in which structures are designed, built, and protected, and the vulnerability of a structure or community to a particular natural event is a measure of the damage likely to be sustained should the event occur. The degree to which a community is prone to a particular natural hazard depends on risk, exposure, and vulnerability. When a natural hazard occurrence significantly exceeds the community's capacity to cope with it, or causes a large number of deaths and injuries or significant economic loss, it is called a disaster.
>
> Hazard management includes the full range of organized actions undertaken by public and private organizations in anticipation of and in response to hazards. Hazard management has two primary (but not completely distinct) components: emergency

management, typified by the police, fire, rescue, and welfare work carried on during a disaster; the advance planning and training that are necessary if emergency operations are to be carried out successfully; and the post-disaster recovery period in which damage is repaired; and mitigation, which focuses on planning, engineering design, economic measures, education, and information dissemination, all carried out for the purpose of reducing the long-term losses associated with a particular hazard or set of hazards in a particular location.

MEASURES OF EARTHQUAKE MAGNITUDE AND INTENSITY

The following excerpt from the 1976 thesis, Seismic Design of a High-Rise Building, prepared by Jonathan Barnett and John Canatsoulis in partial fulfillment of the requirements for the degree of Master of Science at the Worcester Polytechnic Institute explains the Richter magnitude scale and the modified Mercalli intensity scale:

> There are two important earthquake parameters of interest to the structural engineer. They are an earthquake's magnitude and its intensity. The intensity is the apparent effect of an earthquake as experienced at a specific location. The magnitude is the amount of energy released by the earthquake.
>
> The magnitude is the easiest of these two parameters to measure, as, unlike the intensity which can vary with location, the magnitude of a particular earthquake is a constant. The most widely used scale to measure magnitude is the Richter magnitude scale. Using this scale, the magnitude, measured in ergs, can be found from the equation $\text{Log } E = 11.4 + 1.5\ M$, where M is the Richter magnitude. This relationship was arrived at by an analysis of the amplitude of the traces of a standard seismograph located 100 kilometers from the epicenter of an earthquake and correlating this information with the radiated energy as determined through measurements of the waves released by the earthquake. The epicenter of an earthquake is the point on the surface of the earth directly over the focus. The focus (or hypocenter) is the point in the earth's crust at which the initial rupture (slippage of masses of rock over a fault) occurs. In use, the Richter scale represents an increase by a factor of 31.6 for each unit increase in the Richter magnitude. Thus, a Richter magnitude of 6 is 31.6 times larger than Richter magnitude 5....
>
> [A] problem with using the Richter magnitude is that it gives little indication of an earthquake's intensity. Two earthquakes of identical Richter magnitude may have widely different maximum intensities. Thus, even though an earthquake may have only one magnitude, it will have many different intensities.
>
> In the United States, intensity is measured according to the modified Mercalli index (MMI). In Europe, the most common

intensity scale is the Rossi-Forel scale while in Russia a modification of the Mercalli scale is used.

The following excerpt from Bruce A. Bolt's 1978 book, Earthquake: A Primer (San Francisco, California: W.H. Freeman and Company), describes the modified Mercalli intensity values (1956 version); masonry definitions from C. F. Richter's 1958 book, Elementary Seismology (San Francisco, California: W. H. Freeman Company), are inserted in brackets:

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frames creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knicknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D [weak materials such as adobe, poor mortar, low standards of workmanship; weak horizontally] cracked. Small bells ring (church and school). Trees, bushes shaken visibly, or heard to rustle.

VII. Difficult to stand. Noticed by drivers. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices also unbraced parapets and architectural ornaments. Some cracks in masonry C [ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners but not reinforced or designed against horizontal forces]. Waves on ponds, water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of cars affected. Damage to masonry C; partial collapse. Some damage to masonry B [good workmanship and mortar; reinforced but not designed in detail to resist lateral forces]; none to masonry A [good workmanship, mortar, and design; reinforced, especially laterally; bound together by using steel, concrete, etc.; designed to resist lateral forces]. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted down, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in the ground. In alluviated areas, sand and mud ejected, earthquake fountains and sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown in the air.

EARTHQUAKE OCCURRENCES

The following maps are included to give the reader some idea of where damaging earthquakes have occurred in the United States.

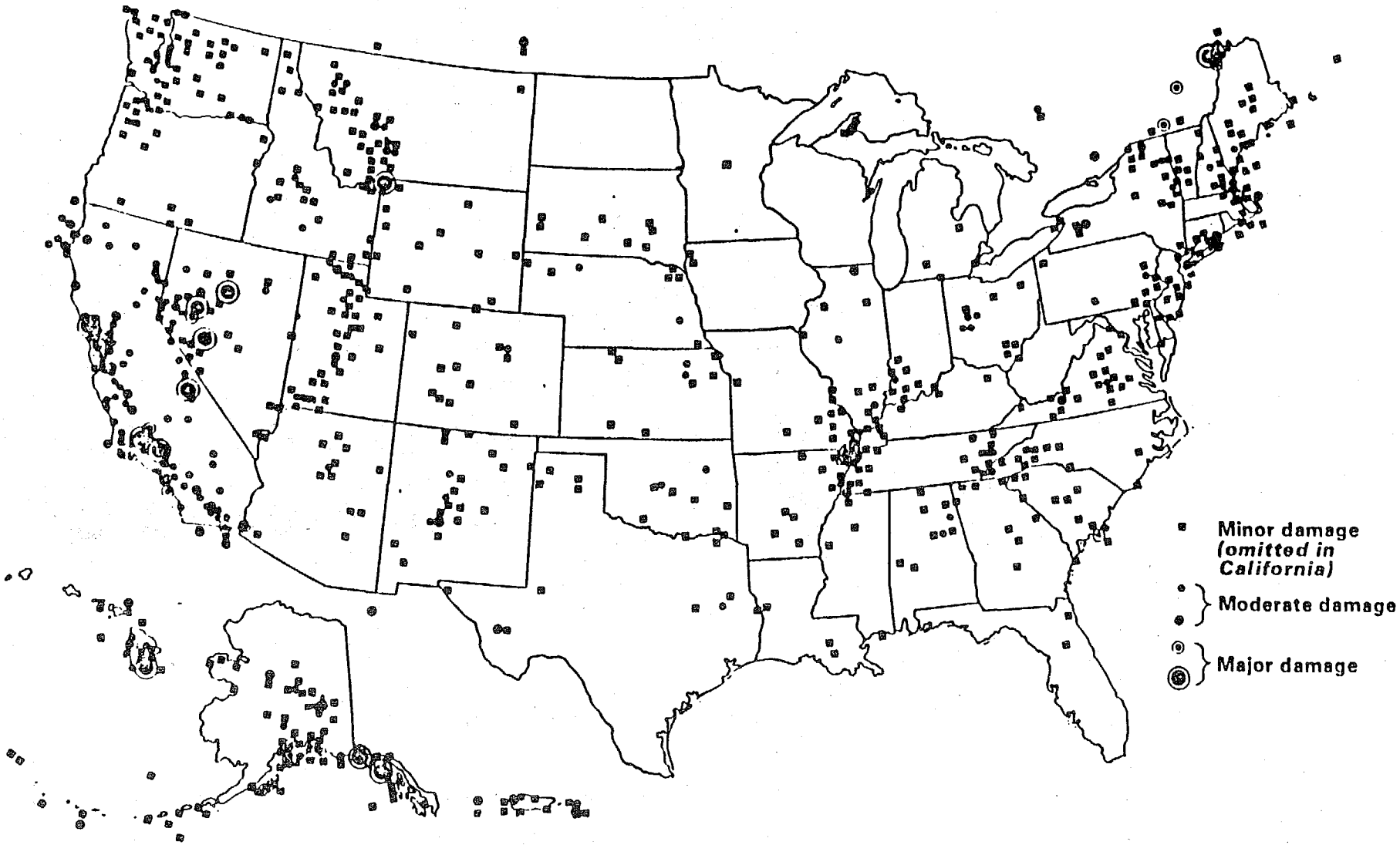

FIGURE 1 Location of damaging earthquakes in the United States. (Reproduced from Christopher Arnold's article "Quake Codes" in the spring 1984 issue of Architectural Technology.)

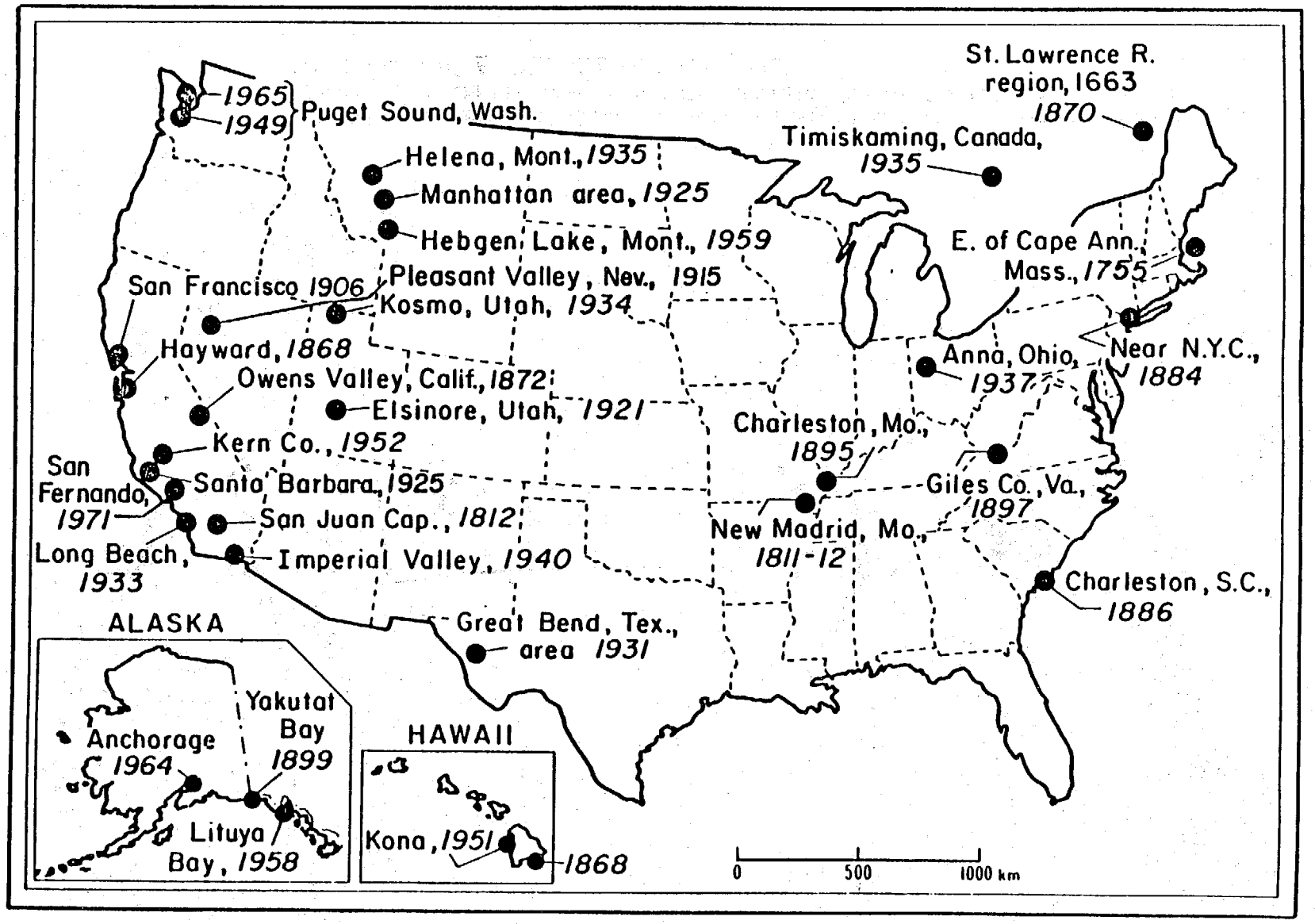

FIGURE 2 Notable damaging historic earthquakes in the United States. (Reproduced from Mary L. Schnell and Darrell G. Herd's 1984 report, National Earthquake Hazards Reduction Program: Overview (FY 1983), Report to Congress, USGS Circular 918, U.S. Geological Survey, Reston, Virginia.)

APPENDIX C

SEISMIC SAFETY INFORMATION SOURCES

INTRODUCTION

This list is designed to identify potential sources of seismic safety information useful at the local level. Although the list is far from exhaustive, it does include many of the associations, organizations, and centers that provide various types of data ranging from relatively general information to specific technical guidance.

Since much information is best obtained at the local level, the reader is urged to contact local academic institutions and the local chapters of the various professional organizations.

ORGANIZATIONS

American Concrete Institute
B.O. Box 19150
Detroit, Michigan 48219
(313)532-2600

American Consulting Engineers Council
1015 15th Street, N.W., Suite 802
Washington, D.C. 20005
(202)347-7474

American Institute of Architects
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202)626-7300

American Institute of Architects Foundation
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202)626-7421

American Institute of Steel Construction
400 North Michigan Avenue
Chicago, Illinois 60611
(312)670-2400

American Insurance Association
85 John Street
New York, New York 10038
(212)669-0400

American Planning Association
1313 East 60th Street
Chicago, Illinois 60637
(312)947-2082

American Plywood Association
7011 South 19th Street
Box 11700
Tacoma, Washington 984411-0700
(206)565-6600

American Society of Civil Engineers
345 East 47th Street
New York, New York 10017-2398
(212)705-7496

American Red Cross, National Office of Disaster Assistance
18th and E Streets, N.W.
Washington, D.C.
(202)857-3718

Applied Technology Council
2471 East Bayshore Road, Suite 512
Palo Alto, California 94303
(415)856-8925

Arizona State University, Office of Hazard Studies
Center for Public Affairs
Tempe, Arizona 85287
(602)965-4518

Arkansas Earthquake Advisory Council
Arkansas Geological Commission
3815 West Roosevelt
Little Rock, Arkansas 72204
(501)663-9714

Associated General Contractors of America
1957 E Street, N.W.
Washington, D.C. 20006
(202)393-2040

Association of Bay Area Governments
Metro Center
P.O. Box 2050
Oakland, California 94606
(415)464-7900

Association of Engineering Geologists
Box 506
Short Hills, New Jersey 07078
(201)379-7470

Association of Major City Building Officials
200 North Spring Street
Los Angeles, California 90012
(213)485-2021

Association of the Wall and Ceiling Industries International
25 K Street, N.E.
Washington, D.C. 20001
(202)783-2924

Bay Area Regional Earthquake Preparedness Project
Metro Center
1018th Street, Suite 152
Oakland, California 94607
(415)540-2713

Bay Area Regional Earthquake Preparedness Project Policy Advisory Board
Assistant Director, Institute of Governmental Studies
University of California
109 Moses Hall
Berkeley, California 94720
(415)642-6722

Battelle Human Affairs Research Centers
4000 N.E. 41st Street
Seattle, Washington 98105
(206)525-3130

Brick Institute of America
11490 Commerce Park Drive, Suite 300
Reston, Virginia 22091
(703)620-0010

Building Officials and Code Administrators, International
4051 West Flossmoor Road
Country Club Hills, Illinois 60477
(312)799-2300

Building Owners and Managers Association, International
1221 Massachusetts Avenue, N.W.
Washington, D.C. 20005
(202)638-2929

Building Seismic Safety Council
1015 15th Street, N.W., Suite 700
Washington, D.C. 20005
(202)347-5710

Business and Industry Council for Earthquake Preparedness
Director of Emergency Planning and Office Administration
Atlantic Richfield Company
515 South Flower Street
Los Angeles, California 90071
(213)486-2535

California Seismic Safety Commission
1900 K Street
Sacrament, California 95814
(916)322-4917

Canadian National Committee on Earthquake Engineering
National Research Council of Canada
Division of Building Research
Ottawa, Ontario K1A 0R6

Central United States Earthquake Consortium
2001 Industrial Park Drive
Box 367
Marion, Illinois 62959
(618)997-5659

Concrete Masonry Association of California and Nevada
83 Scripps Drive, Suite 303
Sacramento, California 95825
(916)920-4414

Concrete Reinforcing Steel Institute
933 North Plum Grove Road
Shaumburg, Illinois 60195
(312)490-1700

Council of American Building Officials
5205 Leesburg Pike, Suite 1201
Falls Church, Virginia 22041
(703)931-4533

Earthquake Education Center
Baptist College
P.O. Box 10087
Charleston, South Carolina 92411
(803)797-4208

Earthquake Engineering Research Institute
2620 Telegraph Avenue
Berkeley, California 94704
(415)848-0972

Federal Emergency Management Agency, Division of Earthquakes and Natural Hazards Programs
500 C Street, S.W.
Washington, D.C. 20472
(202)646-2797

Governor's Earthquake and Safety Technical Advisory Panel
Kentucky Division of Disaster and Emergency
EOC Building, Boone Center
Frankfort, Kentucky 40601
(502)564-8600

Governor's Earthquake Emergency Task Force
California Office of Emergency Services
2800 Meadowview Road
Sacramento, California 95832
(916)427-4285

Illinois Earthquake Advisory Board
Illinois Emergency Services and Disaster Agency
110 East Adams Street
Springfield, Illinois 62706
(217)782-4448

Indiana Earthquake Advisory Panel
Indiana Department of Civil Defense
B-90 State Office Building
100 North Senate
Indianapolis, Indiana 46204
(317)232-3834

Insurance Information Institute
110 Williams Street
New York, New York 10038
(212)669-9200

Interagency Committee on Seismic Safety in Construction
c/o Center for Building Technology
National Bureau of Standards
Gaithersburg, MD 20899
(301)921-3377

International City Management Association
1120 G Street, N.W.
Washington, D.C. 20005
(202)626-4600

International Conference of Building Officials
5360 South Workman Mill Road
Whittier, California 90601
(213)699-0541

Masonry Institute of America
2550 Beverly Boulevard
Los Angeles, California 90057
(213)388-0472

Masonry Institute of Washington
925 116th Street, Suite 209
Bellevue, Washington 98004
(206)453-8820

Metal Building Manufacturers Association
1230 Keith Building
Cleveland, Ohio 44115
(216)241-7333

Mississippi Seismic Advisory Panel
Mississippi Emergency Management Agency
P.O. Box 4501, Fondren Station
Jackson, Mississippi 39216
(601)352-9100

Missouri State Earthquake Safety Advisory Council
P.O. Box 116
Jefferson City, Missouri 65101
(314)751-2321

National Academy of Sciences, Committee on Natural Disasters
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
(202)334-3312

National Association of Home Builders of the U.S.
15th and M Streets, N.W.
Washington, D.C. 20005
(202)822-0200

National Bureau of Standards, Center for Building Technology
Room B168, Building 226
Gaithersburg, Maryland 20899
(301)921-3471

National Concrete Masonry Association
2302 Horse Pen Road
Herndon, Virginia 20072
(703)435-4900

National Conference of States on Buildings Codes and Standards
481 Carlisle Road
Herndon, Virginia 22070
(703)437-0100

National Coordinating Council on Emergency Management
3126 Beltline Boulevard
Columbia, South Carolina 29204
(803)765-9286

National Elevator Industry, Inc.
1 Farm Spring
Farmington, Connecticut 06032
(212)986-1545

National Emergency Managers Association
c/o Director
Colorado Division of Disaster Emergency Services, EOC
Camp George West, Golden, Colorado 80401
(303)273-1624

National Fire Sprinkler Association
5715 West 76th Street
Los Angeles, California 90045
(914)878-4200

National Forest Products Association
1619 Massachusetts Avenue, N.W.
Washington, D.C. 20036
(202)797-5800

National Institute of Building Sciences
1015 15th Street, N.W., Suite 700
Washington, D.C. 20005
(202)347-5710

National Science Foundation, Directorate for Engineering, Fundamental Research for Emerging and Critical Engineering Systems Division
1800 G Street, N.W.
Washington, D.C. 20550
(202)357-7710

Natural Disaster Resource Referral Service
P.O. Box 2208
Arlington, Virginia 22202
(703)920-7176

Natural Hazards Planning Council
Director, Planning Office
P.O. Box 3088
Christiansted, St. Croix, Virgin Islands 00820
(809)773-1082

Natural Hazards Research and Applications Information Center
University of Colorado, IBS 6
Campus Box 482
Boulder, Colorado 80309
(303)492-6818

New England Seismic Advisory Council (proposed)
P.O. Box 1496
400 Worcester Road
Framingham, Massachusetts 01701
(617)875-1318

Oklahoma Masonry Institute
3601 Classen Boulevard, Suite 108
Oklahoma City, Oklahoma 73118
(405)524-8795

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077
(312)966-6200

Prestressed Concrete Institute
201 North Wells Street
Chicago, Illinois 60606
(312)346-4071

Rack Manufacturers Institute
1326 Freeport Road
Pittsburgh, Pennsylvania 15238
(412)782-1624

School Education Safety and Education Project
State Seismologist
Geophysics Department, AD-50
University of Washington
Seattle, Washington 98195
(206)545-7563

Soil and Foundation Engineers Association
P.O. Box 92630
El Taro, California 92630
(714)859-0294

South Carolina Seismic Safety Consortium
Department of Civil Engineering
The Citadel, The Military College of South Carolina
Charleston, South Carolina 29401
(803)792-7677
or
Baptist College
P.O. Box 10087
Charleston, South Carolina 29411
(803)797-4208

Southeastern United States Seismic Safety Consortium
Department of Civil Engineering
The Citadel, The Military College of South Carolina
Charleston, South Carolina 29401
(803)792-7677

Southern Building Code Congress International
900 Montclair Road
Birmingham, Alabama 35213
(205)591-1853

Southern California Earthquake Preparedness Project
6850 Van Nuys Boulevard
Van Nuys, California 91405
(213)787-5103

Southern California Earthquake Preparedness Project Policy Advisory Board
Director of Emergency Planning and Office Administration
Atlantic Richfield Company
515 South Flower Street
Los Angeles, California 90071
(213)486-2535

Steel Plate Fabricators Association, Inc.
2901 Finley Road, Suite 103
Downers Grove, Illinois 60515
(312)232-8750

Structural Engineers Association of Arizona
2415 West Colter
Phoenix, Arizona 85015
(602)249-0963

Structural Engineers Association of California
217 2nd Street
San Francisco, California 94105
(415)974-5147

Structural Engineers Association of Utah
2126 South 1000 South
Salt Lake City, Utah 84106

Structural Engineers Association of Washington
1411 4th Avenue, Suite 1420
Seattle, Washington 98101
(206)624-7045

Technical Advisory Council
Deputy Director, State Emergency Management Office
Public Security Building 22
State Office Building Campus
Albany, New York 12226
(518)454-2156

Tennessee Earthquake Information Center
Memphis State University
Memphis, Tennessee 38152
(901)454-2007

Tennessee Seismic Advisory Panel
Tennessee Emergency Management Agency
Tennessee EOC, 3041 Sidco Drive
Nashville, Tennessee 37204-1502
(615)252-3311

U.S. Geological Survey, Office of Earthquakes, Volcanoes, and Engineering
905 National Center
Reston, Virginia 22092
(703)860-6471

CSM Campus
1711 Illinois Avenue, Mail Stop 966
Golden, Colorado 80401
(303)236-1611

345 Middlefield Road, Building 1, Mail Stop 22
Menlo Park, California
(415)323-8111, Ext. 2312

U.S. Public Health Service, National Institute of Mental Health, Center for Mental Health--Studies of Emergencies
5600 Fishers Lane
Rockville, Maryland 20857
(301)443-1910

U.S. Small Business Administration Disaster Assistance Division
Area 1 (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Puerto Rico, Rhode Island, Vermont, Virgin Islands)
15-01 Broadway
Fair Lawn, New Jersey 07410
(201)794-8195

Area 2 (Alabama, Delaware, District of Columbia, Florida, Georgia, Illinois, Indiana, Kentucky, Maryland, Michigan, Minnesota, Mississippi, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia, Wisconsin)
75 Spring Street, S.W., Suite 822
Atlanta, Georgia 30303
(404)221-5822

Area 3 (Arkansas, Iowa, Kansas, Louisiana, Missouri, Nebraska, New Mexico, Oklahoma, Texas)
2306 Oak Lane, Suite 110
Grand Prairie, Texas 75051
(214)767-7571

Area 4 (Alaska, Arizona, California, Colorado, Guam, Hawaii, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming)
P.O. Box 13795
Sacramento, California 95825
(916)484-4461

University of Delaware, Disaster Research Center
Newark, Delaware 19711
(302)451-2581

Western States Structural Engineers Association
304 Great Western Building
Spokane, Washington 99201

Western States Clay Products Association
9780 South, 5200 West
West Jordan, Utah
(801)561-1471

Western Seismic Safety Council
c/o Hugh Fowler
Washington State Department of Emergency Services
4220 East Martin Way
Olympia, Washington 98504
(206)459-9191

DATA BASES

American Geological Institute
Indexes approximately 5,000 serials on the world's geological literature.
GeoRef
4220 King Street
Alexandria, Virginia 22302
(703)379-2480

Department of Agriculture
Data bases or computerized records maintained by agencies within the department include material on emergency disaster assistance, emergency loan distribution, insurance paid out for crop losses, avalanches, hail, and drought. AGRICOLA is a computerized bibliographic reference service dealing primarily with agriculture.
(301)344-3755

Earthquake Engineering Research Center Library
Extensive library on all aspects of the earthquake problem. Publications available by mail.
University of California
47th and Hoffman Boulevard
Richmond, California 94804
(415)231-9403

Federal Emergency Management Agency, Disaster Management Information System
More than 65 elements of information on presidentially declared disasters are available on magnetic tape.
FEMA/SL-DA
500 C Street, S.W.
Washington, D.C. 20472
(202)382-6423

National Geophysical Data Center
Maintains an earthquake data file, photo files, and a set of data bases of direct interest to Pacific tsunami research and operations
NOAA/EDIS/NGDC
D62
Boulder, Colorado 80303
(303)497-6337

National Technical Information Service
The source for the public sale of government-sponsored research, development, and engineering reports and other analyses prepared

by federal agencies and their contractors and grantees. For general information call (703)487-4604. For information on research in progress call (703)487-4808. For information on the transfer of federal technology having potential commercial or practical applications, call (703)487-4808.

NTIS
5285 Port Royal Road
Springfield, Virginia 22161

Smithsonian Institution

Provides the Scientific Event Alert Network (SEAN) that offers monthly bulletins summarizing short lived events around the world.

SEAN NHB
Smithsonian Institution
Mail Stop 129
Washington, D.C. 20560
(202)357-1511

U.S. Geological Survey

For information on the books, maps, and photographs of the USGS call the Reference Librarian at the:

National Center
(703)860-6671
or
Western Regional Library
(415)323-8111
or
Central Regional Library
(303)234-4133

USGS Circular 777, A Guide to Obtaining Information from the USGS, assists in obtaining USGS products and unpublished information and USGS Circular 817, Scientific and Technical, Spatial, and Bibliographic Data Bases of the U.S. Geological Survey, lists 223 USGS systems. Copies are available free from the:

USGS Branch of Distribution
604 Pickett Street
Alexandria, Virginia 22304.

USGS Earth Resources Observation Systems (EROS) offers a computerized reference service for searches for remote sensing data. Contact:

EROS Data Center
Sioux Falls, South Dakota 57198
(605)594-6151

Geographic Information Systems, Methods, and Equipment for Land Use Planning lists many manual and computer-aided systems, systems design, and data sources for land use planners and managers. It is available as PB 286-643 from:

NTIS
5285 Port Royal Road
Springfield, Virginia 22161

APPENDIX D

SELECTED SEISMIC SAFETY REFERENCES

INTRODUCTION

This list of references focuses on the national arena generally and on the three specific geographic areas examined by the BSSC Committee on Societal Implications: the Mississippi Valley area; the Charleston, South Carolina, area; and the Puget Sound area. It is not intended to be an exhaustive list but rather to serve as the basis for specialized, area-specific research. Not all of the documents cited are widely available but an attempt has been made to identify the authors and/or original publication sites in sufficient detail to permit interested readers to make the necessary contacts. See also the list of information sources in the preceding section.

TOPICS COVERED

The references are presented under the following major headings:

1. Nature and Description of the Seismic Hazard
   a. National
   b. Mississippi Valley Area
   c. Charleston Area
   d. Puget Sound Area
2. Seismic Hazard Mitigation
   a. National
   b. Mississippi Valley Area
   c. Puget Sound Area
3. Seismic Safety Code Development and Implementation
   a. National
   b. Charleston Area
4. Risk Perception and Hazard Awareness
5. Economics
6. Liability
7. Public Policy

NATURE AND DESCRIPTION OF THE SEISMIC HAZARD

National

Algermissen, S. T. 1984 An Introduction to the Seismicity of the United States. Berkeley, California: Earthquake Engineering Reseach Institute.

Algermissen, S. T., Ed. 1972. Conference on Seismic Risk Assessment for Building Standards. Washington, D.C.: U.S. Department of Commerce and U.S. Department of Housing and Urban Development.

Bolt, Bruce A. 1978. Earthquakes: A Primer. San Francisco: California: W. H. Freeman and Company.

Hays, Walter W., Ed. 1981. Evaluation of Regional Seismic Hazard and Risk. USGS Open File Report 81-437. Reston, Virginia: U.S. Geological Survey.

Hays, Walter W. 1981. Facing Geological and Hydrologic Hazards: Earth Science Considerations. USGS Professional Paper 1240-B. Washington, D.C.: U.S. Government Printing Office.

National Oceanic and Atmospheric Administration and U.S. Geological Survey. 1979. Earthquake History of the United States (1971-1976 Supplement). USGS/NOAA Publication 41-1. Washington, D.C.: U.S. Department of Commerce and U.S. Department of Interior.

U.S. Geological Survey. 1978. Proceedings of Conference V, Com municating Earthquake Hazard Information. USGS Open File Report 78-933. Menlo Park, California: U.S. Geological Survey.

Mississippi Valley

Beavers, James E., Ed. 1981. Earthquake and Earthquake Engineering: The Eastern United States. 2 volumes. Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc.

Clifton, Juanita W. 1980. Reelfoot and the New Madrid Quake. Asheville, North Carolina: Victor Publishing Company.

Department of Earth and Atmospheric Science, St. Louis University (Missouri). 1980. The New Madrid Fault Zone: Potential for Disasters, Problems, and Information Needed for Disaster Relief Planning. Unpublished paper.

Department of Earth Sciences, St. Louis University (Missouri). 1980. Earthquake Damage Potential in Missouri. Unpublished paper.

Ferritto, John M. 1979. Seismic Analysis of Memphis. Technical Memorandum 51-79-18. Port Hueneme, California: U.S. Navy, Naval Construction Ballation.

Fuller, Myron Leslie. 1912. The New Madrid Earthquake. Washington, D.C.: U.S. Government Printing Office.

Fuller, M. B. 1912. The New Madrid Earthquake. USGS Bulletin 494. Reprinted by Ramfre Press, Cape Girardeau, Missouri, 1966.

Hamilton, Robert M. 1980. "Quakes Along the Mississippi." Natural History 89 (8):70-74.

Hamilton, R. M., and M. D. Zoback. 1979. Seismic Reflection Profile in the Northern Mo. Embayment. USGS Open File Report 79-1688. Reston, Virginia: U.S. Geological Survey.

Hays, W. W., Ed. 1981. Proceedings of Conference XV, A Workshop on Preparing and Responding to a Damaging Earthquake in the Eastern United States. USGS Open File Report 82-220. Reston, Virginia: U.S. Geological Survey.

Heyl, A. V., and F. A. McKeown. 1978. Preliminary Seismotectonic Map of Central Mississippi Valley and Environs. Miscellaneous Field Studies Map MF 1011. Reston, Virginia: U.S. Geological Survey.

Johnson, Arch C., and Susan J. Nava. 1985. "Earthquake Hazard in the Memphis, Tennessee, Area." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Liu, B. C., C. T. Hsieh, R. Gustafson, et al. 1979. Earthquake Risk and Damage Functions: An Integrated Preparedness and Planning Model Applied to New Madrid. Kansas City, Missouri: Midwest Research Institute. (Available from the National Technical Information Service, Springfield, Virginia.)

M & H Engineering and Memphis State University. 1974. Regional Earthquake Risk Study. Memphis, Tennessee: MATCOG/MCDD.

Nuttli, Otto W. 1985. "Nature of the Earthquake Threat in St. Louis." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Nuttli, Otto W. 1981. Evaluation of Past Studies and Identification of Needed Studies of the Effects of Major Earthquakes Occurring in the New Madrid Fault Zone. St. Louis, Missouri: St. Louis University.

Nuttli, Otto W. 1974. "Magnitude-Recurrence Relation for Central Mississippi Valley Earthquakes." Seismological Society of America Bulletin 64 (4):1189-1207.

Nuttli, Otto W. 1974. "The Mississippi Valley Earthquakes of 1811 and 1812." Earthquake Information Bulletin 6 (2).

Nuttli, Otto W. 1973. "Mississippi Valley Earthquake of 1811-1812: Intensities, Groundmoution, and Magnitudes." Seismological Society of America Bulletin 63:227-248.

Nowak, Andrzej S., and Elizabeth L. Rose Morrison. 1982. Earthquake Hazard Analysis for Commercial Buildings in Memphis. Ann Arbor: University of Michigan.

Parks, W. S., and R. W. Lounsbury. 1976. Summary of Some Current and Possible Future Environmental Problems Related to Geology and Hydrology at Memphis, Tennessee. USGS Water-Resources Investigation 76-4. Reston, Virginia: U.S. Geological Survey. (Available as Report PB-264 513/AS from the National Technical Information Service.)

Penick, James L. 1981. The New Madrid Earthquake. Columbia: University of Missouri Press.

Penick, James L. 1978. The New Madrid Earthquake of 1811 and 1812. Columbia: University of Missouri.

Russ, David. 1981. "Model for Assessing Earthquake Potential and Fault Activity in the New Madrid Seismic Zone." In Earthquakes and Earthquake Engineering, edited by J. Beavers. Ann Arbor, Michigan: Ann Arbor Science.

Street, R. L. 1980. A Compilation of Accounts Describing the Mississippi Valley Earthquake of 1811-1812. Lexington: University of Kentucky.

U.S. Geological Survey. 1983. Proceedings of Conference XVIII, Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area. USGS Open File Report 1983-157. Reston, Virginia: U.S. Geological Survey.

U.S. Geological Survey. 1982. Proceedings of Conference XV, Preparing for and Responding to a Damaging Earthquake in the Eastern United States. USGS Open File Report 82-220. Reston, Virginia: U.S. Geological Survey.

U.S. Geological Survey. 1982. Investigation of the New Madrid, Missouri, Earthquake Region. USGS Professional Paper 1236. Washington, D.C: U.S. Government Printing Office.

Zoback, M. D., et al. 1980. "Recurrent Intraplate Tectonism in the New Madrid Seismic Zone. Science 209 (August).

Charleston Area

Bollinger, G. A. 1985. "Earthquake at Charleston in 1886." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Bollinger, G. A., and Ellen Mathena. 1982. "Seismicity of the Southeastern United States, July 1, 1981-December 31, 1981." Southeastern U.S. Seismic Network Bulletin (9). (Published by the Division of Earth Sciences, Virginia Polytechnic Institute and State University, Blacksburg.)

Lindbergh, Charles, Ed. 1982. Earthquake Hazards and Risk in South Carolina and the Southeastern U.S. Charleston, South Carolina: Seismic Safety Consortium.

Rankin, D. W., Ed. 1977. Studies Related to the Chrleston, South Carolina, Earthquake of 1888--A Preliminary Report. USGS Professional Paper 1028. Reston, Virginia: U.S. Geological Survey.

Reagor, B. G. Seismicity Map of the State of South Carolina. USGS Miscellaneous Field Studies Map MF-1225 (:1,000,000). Reston, Virginia: U.S. Geological Survey.

U.S. Geological Survey. 1977. Studies Related to the Charleston, South Carolina, Earthquake of 1886. USGS Professional Paper 1028. Washington, D.C.: U.S. Government Printing Office.

U.S. Geological Survey. 1983. Proceedings of Conference XX, The 1886 Charleston, South Carolina, Earthquake and Its Implications for Today. USGS Open File Report 83-843. Reston, Virginia: U.S. Geological Survey.

U.S. Geological Survey. 1983. Proceedings of Conference XXIII, Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby Sttes. USGS Open File Report 83-846. Reston, Virginia: U.S. Geological Survey.

Puget Sound Area

Algermissen, S. T., and S. T. Harding. 1965. The Puget Sound Earthquake of April 29, 1965. Washington, D.C.: U.S. Department of Commerce Coast and Geodetic Survey.

Algermissen, S. T., Samuel T. Harding, Karl V. Steinbrugge, and William K. Cloud. N.d. The Puget Sound, Washington, Earthquake of April 29, 1965. Preliminary repor for the U.S. Coast and Geodetic Survey.

Chaney, Eric S. 1978. Geology, Man, and Nuclear Plan Sites on the Skagit. Seattle, Washington: Junior League at Seattle.

Coombs, Howard A. 1974. Report to the Washington State Legislature from the ad hoc Committee on Geologic Hazards. Olympia: Washington State Legislature.

Coombs, H. A., and J. D. Barksdale. 1942. "The Olympia Earthquake of November 13, 1939." Bulletin of the Seismological Society of America 32 (1).

Crosson, R. C. 1972. "Small Earthquake Structure and Tectonics of the Puget Sound Region." Bulletin of the Seismological Society of America 62 (5).

Freeman, Sigmund A., Joseph P. Nicoletti, Joseph B. Tyrrell, and John A. Blume and Associates. 1975. U.S. National Conference on Earthquake Engineering Proceedings, Evaluation of Existing Buildings for Seismic Risk. Oakland, California: Earthquake Engineering Research Institute.

Gower, H. D. 1978. Tectonic Map of the Puget Sound Region, Washington. USGS Open File Report 78-426. Menlo Park, California: U.S. Geological Survey.

Rasmussen, Norman H., R. C. Mallard, and S. W. Smith. 1974. Earthquake Hazard Evaluation of the Puget Sound Region, Washington State. Seattle: University of Washington Press.

Smith, Stewart W. 1985. "Introduction to Seismological Concepts Related to Earthquake Hazards in the Pacific Northwest." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Stepp, C. J. 1971. An Investigation of Earthquake Risk in the Puget Sound Area by Use of the Type I Distribution of Largest Extremes. College Park: Pennsylvania State University.

U.S. Department of Housing and Urban Development, Federal Disaster Assistance Administration. 1978. Federal Earthquake Preparedness Plan for the Puget Sound Area. Seattle, Washington: U.S. Department of Housing and Urban Development, Federal Disaster Assistance Administration.

U.S. Geological Survey. 1975. A Study of Earthquake Losses in the Puget Sound, Washington, Area. USGS Open File Report 75-375. Menlo Park, California: U.S. Geological Survey.

Weaver, Craig S., and Stewart W. Smith. 1982. Regional Tectonic and Earthquake Hazard Implications of a Crustal Fault Zone in Southwestern Washington. Seattle: University of Washington, Geophysics Program.

Yount, James C., and Robert S. Crosson, Eds. 1980. Proceedings of National Earthquake Hazards Reduction Program, Earthquake Hazards of the Puget Sound Region. USGS Open File Report 83-0019. Menlo Park, California: U.S. Geological Survey.

SEISMIC HAZARD MITIGATION

National

Applied Technology Council. 1981. An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings. Palo Alto, California: Applied Technology Council.

Arnold, Christopher, and Richard K. Eisner. 1984. Planning Information for Earthquake Hazard Response and Reduction. San Mateo, California: Building Systems Development, Inc.

Beavers, James E. 1985. "Current Practices in Earthquake Preparedness and Mitigation for Critical Facilities." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Beavers, James E., Ed. 1981. Earthquakes and Earthquake Engineering--Eastern United States. 2 volumes. Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc.

Building Seismic Safety Council. 1984. BSSC Program on Improved Seismic Safety Provisions, Volume 2, NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings, Part 1--Provisions and Part 2--Commentary. Washington, D.C.: Building Seismic Safety Council.

California Seismic Safety Commission. 1979. Hazardous Buildings: Local Programs to Improve Life Safety. Sacramento: California Seismic Safety Commission.

Earthquake Engineering Systems, Inc. 1978. A Rational Approach to Damage Mitigation in Existing Structures Exposed to Earthquakes: Phase I Report. San Francisco, California: Earthquake Engineering Systems, Inc.

Jaffe, Martin, et al. 1981. Reducing Earthquake Risks: A Planner's Guide. Chicago, Illinois: American Planning Association.

Hays, Walter W. "Evaluation of the Earthquake Ground Shaking Hazard for Earthquake Resistant Design." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

National Research Council. 1983. Multiple Hazard Mitigation. Washington, D.C.: National Academy Press.

Nigg, Joanne, and Alvin Mushkatel. 1984. Structural Policy Issues for Seismic Hazard Mitigation. Unpublished paper. (Contact the authors at Arizona State University, Center for Public Affairs, Tempe, Arizona 85287.)

Scott, Stanley. 1982. Third International Earthquake Microzonation Conference Proceedings. 3 volumes. Seattle: University of Washington Department of Civil Engineering, Structural, and Geotechnical Engineering and Mechanics Programs.

Scott, Stanley. 1979. Policies for Seismic Safety: Elements of a State Governmental Program. Berkeley: University of California Institute of Governmental Studies.

Ward, Delbert B. 1985. "Management of Earthquake Safety Programs by State and Local Governments." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Mississippi Valley Area

Drabek, et al. 1983. Earthquake Mitigation Policy: The Experience of Two States. Monograph 37. Boulder: University of Colorado.

Thiel, Charles, Jr., and Ugo Morelli. 1981. "An Approach to Seismic Safety for the Central United States." In Earthquakes and Earthquake Engineering-- Eastern United States, Vol. 2, edited by J. Beavers. Ann Arbor, Michigan: Ann Arbor Science Publishers.

Puget Sound Area

Buck, Richard A. 1978. "The Puget Sound Preparedness Project." In Proceedings of Conference V, Communicating Earthquake Hazard Reduction Information. USGS Open File Report 78-933. Reston, Virginia: U.S. Geological Survey.

Puget Sound Concil of Governments. 1975. Regional Disaster Mitigation Technical Study for the Central Puget Sound Region, Vol. II. Seattle, Washington: Puget Sound Council of Governments.

SEISMIC SAFETY CODE DEVELOPMENT AND IMPLEMENTATION

National

Algermissen, S. T., Ed. 1972. Proceedings of the Conference on Seismic Risk Assessment for Building Standards. Washington D.C.: U.S. Department of Commerce and U.S. Department of Housing and Urban Development.

Algermissen, S. T. 1978. "Earthquake Hazard Studies and Building Codes." In Proceedings of Conference V, Communicating Earthquake Hazard Reduction Information. USGS Open File Report 78-933. Reston, Virginia: U.S. Geological Survey.

Applied Technology Council. 1984. Tentative Provisions for the Development of Seismic Regulations for Buildings. Report ATC 3-06 amended. Palo Alto, California: Applied Technology Council.

Arnold, Christopher, and Robert Reitherman. 1982. Building Configuration and Seismic Design. New York: John Wiley.

Berg, Glen V. 1983. Seismic Design Codes and Procedures. Berkeley, California: Earthquake Engineering Research Institute.

Berlin, G. Lennis. N.d. Earthquake and the Urban Environment. Vol. II. Boca Raton, Florida: CRC Press, Inc.

Biggs and Grace. 1973. Seismic Response of Buildings Designed by Code for Different Earthquake Intensities. ST 358. Cambridge, Massachusetts: MIT Department of Civil Engineering.

Brookshire, David S. and William D. Schulze. 1980. Methods Development for Valuing Hazards Information. Laramie: University of Wyoming.

Building Seismic Safety Council. 1984. BSSC Program on Improved Seismic Safety Provisions, Volume 2, NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings, Part 1--Provisions and Part 2--Commentary. Washington, D.C.: Building Seismic Safety Council.

California Seismic Safety Commission. 1979. Hazardous Buildings: Local Programs to Improve Life Safety. SSC 79-03. Sacramento: California Seismic Safety Commission.

Cooke, Patrick W., and Robert M. Eisenhard. 1977. A Preliminary Examination of Building Regulations Adopted by the States and Major Cities. NBSIR-77-1390. Washington, D.C.: National Bureau of Standards.

Culver, Charles C., et al. 1978. Plan for the Assessment and Implementation of Seismic Design Provisions for Buildings. NBSIR-78--1549. Washington, D.C.: National Bureau of Standards.

D'Appolonia, E., and D. E. Shaw. 1981. "The Impact of Codes and Regulations in Seismic Safety." In Earthquakes and Earthquake Engineering: The Eastern United States, Vol. 1, edited by J. E. Beavers. Ann Arbor, Michigan: Ann Arbor Science Publishers.

De Neufville, Richard. 1975. How Do We Evaluate and Choose Between Alternative Codes for Design and Performance? Report 17 of the Seismic Design Decison Analysis directed by Robert Whitman. Cambridge, Massachusetts: MIT Department of Civil Engineering.

Dillon, Robert M. 1985. "Development of Seismic Safety Codes." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Harris, James. 1978. "Information Flow in the Development of Earthquake Provisions for Building Codes. In Proceedings of Conference V, Communicating Earthquake Hazard Reduction Information, USGS Open File Report 78-933. Reston, Virginia: U.S. Geological Survey.

Hicks, James M., Jr. 1978. Standards Referenced in the National Building Code. NBSIR-78-1490. Washington, D.C.: National Bureau of Standards.

International Conference of Building Officials. 1980. Issues Which Affect the Role of Building Departments in Earthquake Hazard Mitigation. Whittier, California: International Conference of Building Officials.

Krimgold, Frederick. 1977. Seismic Design Decisions for the Commonwealth of Massachusetts State Building Code. Report 32. Cambridge, Massachusetts: MIT Department of Civil Engineering.

Leslie, Stephen K., and J. M. Biggs. 1972. Earthquake Code Evaluation and the Effect of Seismic Design on the Cost of Buildings. Report 20 prepared as part of the Seismic Design Decision Analysis directed by Robert Whitman. Cambridge, Massachusetts: MIT Department of Civil Engineering.

McConnaughey, John S., Jr. 1978. An Economic Analysis of Building Code Impacts: A Suggested Approach. NBSIR-78-1528. Washington, D.C.: National Bureau of Standards.

Mintier, J. Laurence, and Peter Arne Stromberg. 1983. "Seismic Safety at the Local Level: Does Planning Make a Difference?" California Geology 36(7).

National Bureau of Standards. 1978. State Adopted Building Regulations for the Construction of Manufactured Buildings: An Analysis. NBSIR-781503. Washington, D.C.: National Bureau of Standards.

National Technical Information Service. 1982. Seismic Design for Buildings and Building Codes: 1970 to November 1982. Citations from the NTIS Data Base. Springfield, Virginia: National Technical Information Service.

Olson, Richard S., and Nilson, Douglas C. 1981. "Policies and Implementation: Enforcing the Seismic Provisions of Building Regulations." Paper presented at the Annual Meeting of the Western Political Science Association in Denver, Colorado, March. (Contact Olson at Arizona State Universty, Tempe.)

Olson, Richard S., and Nilson, Douglas C. 1983. "California's Hazardous Structure Problem: A Political Perspective." California Geology 36(4).

Slosson, James E., and James P. Krohn. 1977. "Effective Building Codes." California Geology (June).

Smyrl, Elmira S., and Donna Linn Crossland. 1980. Literature Review: The Building Regulatory System. Washington, D.C.: National Bureau of Standards.

Turner, Ralph H., et al. 1981. "Los Angeles Building and Safety Ordinance: A Case Study." In Community Response to Earthquake Threat in Southern California, Vol. 8. Los Angeles: University of California.

Van Zandt, Jack E. 1975. The Historical Development of Building Code Earthquake Provisions. Working Paper. Menlo Park, California: SRI.

Wyllie, Loring A. 1980. "Seismic Strengthening of Old Buildings with Modern Codes." In Proceedings of the First Seminar on U.S./Japan Cooperative Research Program in Earthquake Engineering on Repair and Retrofit of Structures. Ann Arbor: University of Michigan, Department of Civil Engineering.

Wyner, Alan J., and Dean E. Mann. 1983. Seismic Safety Policy in California: Local Governments and Earthquakes. Santa Barbara: University of California.

Zsutty, Theodore C., and Haresh C. Shah. 1985. "The Purpose and Effects of Earthquake Codes." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Charleston Area

Leyendecker, Edgar V. 1983. Seismic Design Requirements in the Southeastern United States. In USGS Open File Report 83-843. Reston, Virginia: U.S. Geological Survey.

Sharpe, Roland. 1983. Earthquake Resistant Design Considerations for the Southeastern United States. In USGS Open File Report 83-843. Reston, Virginia: U.S. Geological Survey.

RISK PERCEPTION AND HAZARD AWARENESS

Saarinen, T. F. 1979. The Relation of Hazard Awareness to Adoption of Approved Mitigation Measures. Unpublished paper. Boulder: University of Colorado (NHRAIC).

Slovic, Paul, Baruch Fischoff, and Sara Lichstein. 1980. "Facts and

Fears: Understanding Perceived Risk." In Societal Risk Assessment: How Safe Is Safe Enough?, edited by Richard Schiving and Walter Albers. New York: Plenum Press.

ECONOMICS

Brookshire, David S., and William D. Schulze. 1980. Methods Development for Valuing Hazard Information. Report prepared for the U.S. Geological Survey. Laramie: University of Wyoming.

Leslie, Stephen K., and J. M. Biggs. 1972. Earthquake Code Evaluation and the Effect of Seismic Design on the Cost of Buildings. Report 20 prepared as part of the Seismic Design Decision Analysis directed by Robert Whitman. Cambridge, Massachusetts: MIT Department of Civil Engineering.

Cohen, L., and R. Noll. 1981. "The Economics of Building Codes to Resist Seismic Shock." Public Policy 29(1):1-30.

Dacy, Douglas C., and Howard Kunreuther. 1969. The Economics of Natural Disasters, Implications for Federal Policy. New York: The Free Press.

Ellson, Richard W., Jerome W. Milliman, and R. Blaine Roberts. 1982. Assessing the Regional Effects of Earthquake Predictions. Unpublished paper. Study supported by National Science Foundation Research Grant PFR 80-19826 and the College of Business Administration at the University of South Carolina.

Ferrito, John M. 1981. "Economic Review of Earthquake Design Levels." ASCE Journal of Structural Engineering (August).

Friesema, H. Paul, James Caporaso, Gerald Goldstein, Robert Lineberry, and McCleary. 1979. Aftermath--Communities After Natural Disasters. Beverly Hills, California: Sage Publications.

Goodisman, Leonard D. 1983. "Disaster Relief Budgeting." Public Budgeting and Finance 3(5):89-102.

Hirschberg, J. G., P. Gordon, and W. J. Petak. 1978. Natural Hazards: Socioeconomic Impact Assessment Model. Redondo Beach, California: J. H. Wiggins Company. (NTIS No. PB294681/AS.)

Jones, Barclay G., and Miha Tomazevic, Editors. 1982. Social and Economic Aspects of Earthquakes: Proceedings of the Third International Conference Held in Bled, Yugoslavia. For copies, contact Barclay Jones, Program in Urban and Regional Studies, Cornell University, Ithaca, New York.

J. H. Wiggins Company. N.d. Building Losses from Natural Disasters: Yesterday, Today, and Tomorrow. Redondo Beach, California: J. H. Wiggins Company.

Kunreuther, Howard, and Elissandra S. Fiore. 1966. The Alaskan Earthquake: A Case Study in the Economics of Disaster. Washington, D.C.: Institute for Defense Analysis.

May, Peter J., and Leonard Goodisman. 1982. Problems in Formulating Disaster Relief After Mount St. Helens. Seattle: University of Washington.

Milliman, Jerome W., and R. Blaine Roberts. 1982. Assessing the Effects of Policies on the Economic Losses of Natural Hazards. Unpublished report. Supported by National Science Foundation Grant PFR 80-19826 and the College of Business Administration, University of South Carolina.

Mukerjee, Tapan. 1971. Economic Analysis of Natural Hazards: A Preliminary Study of Adjustments to Earthquakes and Their Costs. NHRAIC Working Paper 17. Boulder: University of Colorado.

Palm, Risa. 1981. Real Estate and Special Study Zones Disclosure; the Response of California Homebuyers to Earthquake Hazards Information. Monograph 32. Boulder: University of Colorado.

Palm, Risa, et al. 1983. Home Mortgage Lenders, Real Property Appraisers, and Earthquake Hazards. Boulder: University of Colorado.

Petak, W. J., A. A. Atkisson, and P. H. Gleye. Natural Hazards: A Building Loss Mitigation Assessment. Redondo Beach, California: J.H. Wiggins Company.

Rawie, Carol Chapman. 1981. Estimating Economic Impacts of Building Codes. Washington, D.C.: National Bureau of Standards.

Schulze, William D., and David S. Brookshire. 1981. "An Economic Analysis of the Benefits and Costs of Seismic Building Codes." In Earthquakes and Earthquake Engineering: The Eastern United States, Vol. 1, edited by J. Beavers. Ann Arbor, Michigan: Ann Arbor Science Publishers.

Scawthorn, Charles, et al. 1982. "The Influence of Natural Hazards on Urban Housing Loction." Journal of Urban Economics (11):242-251.

Stallings, Robert A. 1983. Making Decisions About Disasters: Policies, politics, and the Costs of Relief. Unpublished manuscript. School of Public Administration, University of Southern California.

Weber, Stephen F. 1985. "Cost Impact of the NEHRP Recommended Provisions on the Design and Construction of Buildings." In BSSC Program on Improved Seismic Safety Provisions, Societal Implications: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Wright, James D., Peter H. Rossi, Sonia R. Wright, and Eleanor Weber-Burdin. 1979. After the Clean-Up, Long-Range Effects of Natural Disasters. Beverly Hills, California: Sage Publications.

LIABILITY

Association of Bay Area Governments. 1979. Attorney's Guide to Earthquake Liability. Berkeley, California: Association of Bay Area Governments.

Association of Bay Area Governments. 1979. Will Local Government Be Liable for Earthquake Losses. Berkeley, California: Association of Bay Area Governments.

Association of Bay Area Governments. 1978. Experiences and Perceptions of Local Governments on Earthquake Hazards. Berkeley, California: Association of Bay Area Governments.

Association of Bay Area Governments. 1978. Legal References on Earthquake Hazards and Local Government Liability. Berkeley, California: Association of Bay Area Governments.

Association of Bay Area Governments. N.d. Earthquake Hazards and Local Government Liability: Executive Summary. Berkeley, California: Association of Bay Are Governments.

Huffman, J. L. 1982. Government Liability for Harm Resulting from Earthquake Prediction and Hazard Mitigation, A Preliminary Report on a Comparative Study. Portland, Oregon: Lewis and Clarke College Law School.

National Association of Attorneys General. 1979. Report of the Special Committee of the National Association of Attorneys Generals on Earthquake Prediction, Warnings, and Public Policy. Washington, D.C.: National Association of Attorneys General.

PUBLIC POLICY

Lambright, W. Henry. N.d. Agenda Setting for Earthquake Preparedness: Lessons from New York State. Unpublished paper. (Contact the author at Syracuse Research Corporation, Merrill Lane, Syracuse, New York 13210-4080.)

Lambright, W. Henry. N.d. Earthquake Preparedness: The Dynamics of Long-Term Policy Innovation. Unpublished paper. (Contact the author at Syracuse Research Corporation, Merrill Lane, Syracuse, New York 13210-4080.)

Lambright, W. Henry. 1982. "Policy Innovation in Earthquake Preparedness: A Longitudinal Study of Three States." Paper prepared for presentation at the Annual Meeting of the American Political Science Association, Denver, Colorado, September 2-5.

Nilson, Douglas. 1984. "How to Gain the Attention and Commitment of Political officials: An Earthquake Primer." In Primer on Improving the State of Earthquake Hazards Mitigation and Preparedness, edited by Paula L. Gori. USGS Open File Report 84-772. Reston, Virginia:

U.S. Geological Survey.

Nilson, Douglas C., and Linda B. Nilson. 1981. "Seismic Safety Planning Strategies: Lessons from California." In Earthquakes and Earthquake Engineering: The Eastern United States, edited by James E. Beavers. Ann Arbor, Michigan: Ann Arbor Science Publishers.

Olson, R. S., and Douglas Nilson. 1980. "Public Policy Analyses and Hazard Research: Natural Complements." Social Science Journal (Fall):1-25.

Petak, William J., Editor. 1985. Public Administration Review 45(January). Special Issue on Emergency Management: A Challenge for Public Administration.

Rubin, Claire B. 1985. "Summary of Recent Research on Local Public Policy and Seismic Safety Mitigation." In BSSC Program on Improved Seismic Safety Provisions, Societal Implictions: Selected Readings. Washington, D.C.: Building Seismic Safety Council.

Wyner, Alan J. 1984. "Earthquake and Public Policy Implementation in California." International Journal of Mass Emergencies and Disasters 2(August).

Wyner, Alan J., and Dean E. Mann. 1983. Seismic Safety Policy in California: Local Governments and Earthquakes. Santa Barbara: University of California, Department of Political Science.

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- PLEASE DESCRIBE YOUR COMMUNITY'S EXPERIENCE WITH RESPECT TO NEW OR IMPROVED SEISMIC DESIGN PROVISIONS. FOR EXAMPLE:

  Who are the key decision-makers most reluctant to incorporate needed new or improved seismic safety provisions in building regulations?

  What appear to be the bases for such reluctance?

  What approaches have been used (or could be used) to overcome this reluctance and what degree of success has been achieved?

  Who seem to be the major proponents, and what appear to be their motivations?

- HAVE YOU FOUND THIS HANDBOOK INFORMATION USEFUL? IF SO, HOW HAS IT HELPED YOU, THE READER, SPECIFICALLY?

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  (WE WOULD WELCOME YOUR FRANK OPINION, BUT ASK THAT REASONS BE PROVIDED SO THAT ANY FUTURE VERSIONS CAN BE MODIFIED APPROPRIATELY.)

- BASED ON YOUR COMMUNITY'S EXPERIENCE, WHAT ADDITIONAL TOPICS WOULD YOU LIKE TO SEE THIS HANDBOOK ADDRESS?

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- WOULD YOU BE INTERESTED IN KNOWING OF THE AVAILABILITY OF OTHER BSSC REPORTS?

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Concrete Reinforcing Steel Institute
Contract Services Administration Trust Fund
Council of American Building Officials
Earthquake Engineering Research Institute
Interagency Committee on Seismic Safety in Construction
International Conference of Building Officials
Masonry Institute of America
Masonry Institute of Washington
Metal Building Manufacturers Association
National Association of Home Builders
National Association of Housing and Redevelopment Officials
National Fire Sprinkler Association
National Concrete Masonry Association
National Elevator Industry, Inc.
National Forest Products Association
National Institute of Building Sciences
Oklahoma Masonry Institute
Portland Cement Association
Prestressed Concrete Institute
Rack Manufacturers Institute
Soil and Foundation Engineers Association
Socotec, U.S.A. Corporation
Southern Building Code Congress International
Steel Plate Fabricators Association, Inc.
Structural Engineers Association of Arizona
Structural Engineers Association of California
Structural Engineers Association of Central California
Structural Engineers Association of Northern California
Structural Engineers Association of San Diego
Structural Engineers Association of Southern California
Structural Engineers Association of Utah
Structural Engineers Association of Washington
The Masonry Society
Unit Masonry Association of San Diego, Inc.
Western States Council Structural Engineers Association
Western States Clay Products Association