EARTHQUAKE

HAZARDS IN TENNESSEE

ENVIRONMENTAL GEOLOGY SERIES NO. 4

COVER PHOTO: Collapsed ground in an earthquake-caused landslide on Nov. 17, 1970 at the Paul Keltner Farm in Lauderdale County, Tennessee. Photo by Richard G. Stearns.

STATE OF TENNESSEE
DEPARTMENT OF CONSERVATION
DIVISION OF GEOLOGY
NASHVILLE, TENNESSEE

EARTHQUAKE HAZARDS IN TENNESSEE

By
Richard G. Stearns and Robert A. Miller

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STATE OF TENNESSEE

RAY BLANTON, Governor

DEPARTMENT OF CONSERVATION

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DIVISION OF GEOLOGY

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EARTHQUAKE HAZARDS IN TENNESSEE

By
Richard G. Stearns[1] and Robert A. Miller[2]

INTRODUCTION

When the word "earthquake" is mentioned, most of us envision violently trembling ground, landslides, buildings being shaken apart, bridges and towers falling, fires erupting, and great loss of life. Our ideas of the event are probably based on the pictures we have seen depicting earthquake damage in Guatemala, Japan, Alaska, and California. Fortunately most earthquakes are not strong enough to cause such damage; most are not even felt by people nearby. Because some are great enough to be dangerous, however, it is important to know as much as possible about their likelihood at any given place and what to do if one occurs.

Few people think of earthquake hazards in Tennessee, yet portions of the state are classified as above average risk areas (See figs. 1 and 2A). The far western part of the state was shaken violently in 1811-12, and significant damage from another such event is possible in all of West Tennessee. All of East Tennessee (Appalachian region) lies within an area where moderate damage is possible. Only Middle Tennessee has an historic record of very few local earthquakes, and even there earthquakes originating in the Mississippi River Valley could cause severe shaking.

It is our purpose in this report to examine some basic facts relative to potential earthquake hazards in our state. Included are a brief history of earthquakes in and near Tennessee, a discussion of their causes, the geologic setting, measurement, and predictability of future events, and an overview of the planning process as it relates to seismic risk and safety measures.

This report is written to assist planners, engineers, educators, and others concerned with land-use planning and decision making, design of structures, public safety, and public information. For more detailed data, a bibliography is included.

ACKNOWLEDGMENTS

This report was prepared under the direction of Robert E. Hershey, State Geologist. The manuscript was reviewed by Stuart W. Maher, Tennessee Division of Geology, and John M. Kellberg, consulting engineering geologist. Editing was done by Pamela S. Jiran, editor, and illustrations were prepared by Pat G. Sheldon, cartographer, both of the Tennessee Division of Geology. Photographs are individually credited.

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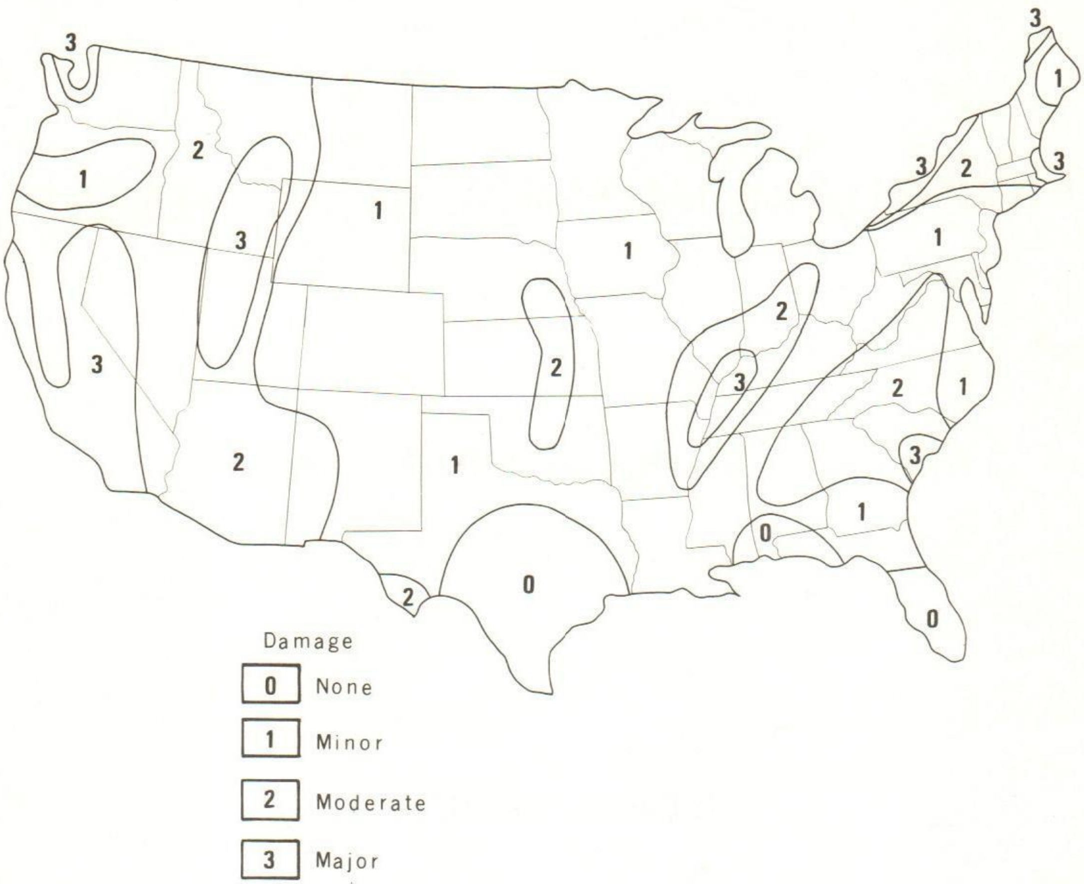


Figure 1. General seismic risk map of the United States. Note that much of Tennessee is in zone 2 or 3, where at least moderate damage is predicted. From Algermissen, Seismic risk studies in the U.S., Fourth world conference on earthquake engineering, January 14, 1969, Santiago, Chile.

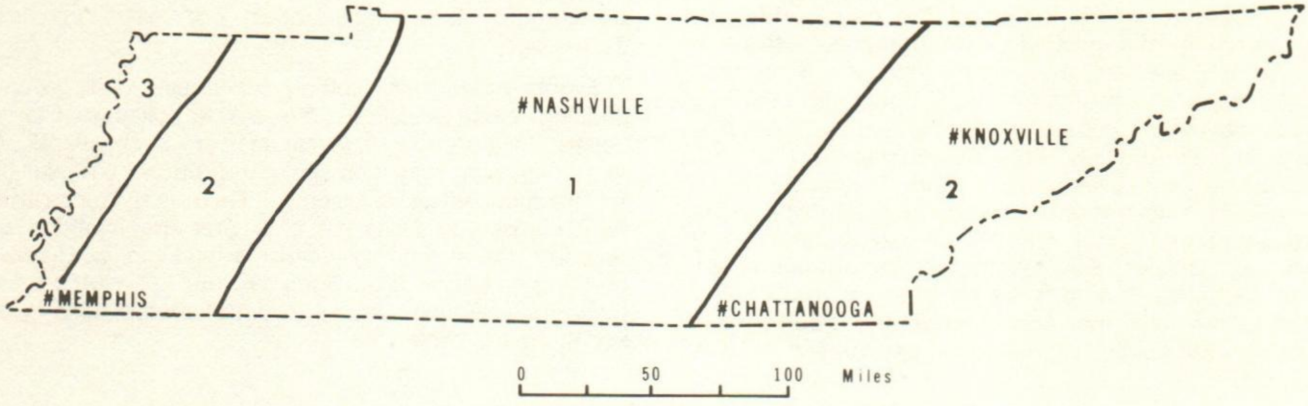
CAUSES OF EARTHQUAKES

Most earthquakes are the result of shock waves created by the sudden release of slowly accumulated stress in rigid bedrock. This release of stress results in the rock's sliding along fractures, called *faults* by geologists. On either side of a fault the rock is offset. The sliding relieves the stress for a time, but continued stress accumulation often leads to recurrent sudden slippage on the fault, and more earthquakes are the result. It is for this reason that geologists are so concerned with accurately mapping fault locations, both old faults no longer active and those along which slippage has occurred in the recent geologic past. By studying the actual history of earthquakes along these faults, it may be possible to predict the likelihood of future earthquakes.

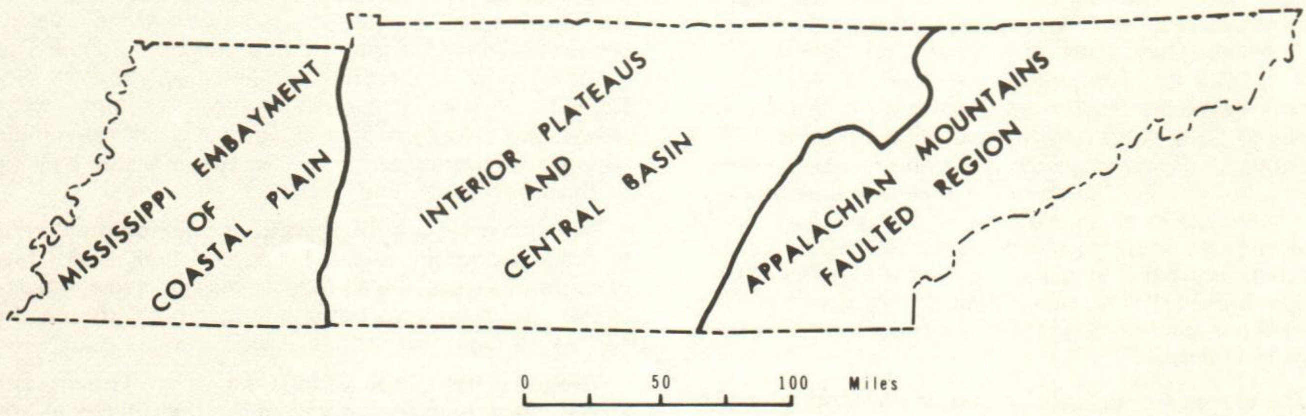
Throughout the world many earthquakes occur along precipitous sea coasts or actively rising mountains at the edges of continental plates. These plates are segments of the outer thin "shell", or crust, of the earth. The crust consists of several of these plates moving slowly apart, or sliding past, over, or under each other. It is along the boundaries of these plates that great amounts of energy are released in earthquakes and volcanic activity. It is not surprising, then, that quakes are so common in California and other places (e.g., Japan) at plate edges along the borders of the Pacific Ocean.

One might ask, "Why should earthquakes occur in and near Tennessee, since we are obviously far from

A-SEISMIC RISK ZONES
(Modified From Fig. 1)



B-MAJOR PHYSIOGRAPHIC REGIONS



Figures 2A and B. Relation of seismic risk zones of Figure 1 to Tennessee's main regions. Note that risk zone 3 is centered in the Mississippi Embayment of the Coastal Plain of West Tennessee with risk zone 2 around it. In East Tennessee risk zone 2 coincides with the Appalachian Mountains.

any coastline or actively rising mountains?" The area of greatest earthquake activity in Tennessee is in the vicinity of the Mississippi River Valley. The river is the approximate axis of the Mississippi Embayment, a northerly extension of the coastal plain sediments found all along the Gulf states (fig. 3A). This is also the line along which many earthquakes have occurred, and along which the crust is sinking. Perhaps it is a *failed rift,* a fracture where the continent once tended to pull apart. In the geologic past, igneous activity is known to have occurred along this axis. This area continues to be a source of energy flow, with relatively small movement compared to the active spreading occurring along such plate boundaries as the Mid-Atlantic rift zone. Evidence of faulting is obscure there, because of burial beneath mud and sand deposits in the Mississippi and other rivers and geologically young formations; nevertheless, faults exist (fig. 3B) and stress relief continues. Buried faults are inferred from lines of small earthquakes that occur frequently, though most are too small to be felt. (Stauder and others, 1976).

In East Tennessee, where fewer and less severe earthquakes occur, there are many faults (fig. 3B) associated with mountain building episodes that ended more than 200 million years ago (toward the end of the Paleozoic Era). These faults are no longer active (fig. 3C), but even after all this time, stress stored up at depth in these rocks is periodically released as minor earthquakes. Geologists believe that potential for devastating earthquakes does not exist in East Tennessee.

Events other than faulting can cause local ground shaking. Large landslides, the sudden collapse of large caverns or eruption of volcanoes[3] are such events. A large explosion may also shake the ground and can be felt for a considerable distance. There is evidence that floods, reservoir filling, or high pressure injection of fluid into the ground may cause a fault to slip, thereby creating an earthquake. Such earthquakes would have occurred eventually, man's activities merely serving to set them off earlier.

RECORDING AND MEASURING EARTHQUAKES

Ground movements from an earthquake are in several distinct forms. The motions are generally classified as *surface waves,* which travel along the earth's surface, and *body waves,* which travel through the earth's interior. Surface waves are generally the most dangerous. They travel outward in all directions from an earthquake area, just as waves do from a pebble thrown into water. They cause the ground to move up and down, back and forth, and from side to side. These waves travel around the earth through rock near the surface. Body waves are of two types — primary and secondary. *Primary waves* are compressional waves (sometimes called "push-pull") that are analogous to sound waves in air or water. *Secondary waves* travel a bit slower; they are shear waves (sometimes called "shake" waves) and cannot pass through liquids or gases. Indeed, it is because they do not penetrate the earth's core that geologists believe the outer part of the core is liquid.

The waves are recorded at stations around the earth with instruments called *seismographs,* which measure ground motion. Although there are several types of these devices, they operate on essentially the same principle. The seismograph is anchored in bedrock with one of its elements, a weight, suspended so that it is free to move (See fig. 4). When the ground shakes the anchored parts move, but the weight does not. Movement of the instrument is recorded on a rotating drum. The actual record is generally made by a light beam emitted from the stationary weight that strikes photographic film on a rotating drum, which moves with the shock waves. This gives an accurate record of the event, the deflection of the line made by the light beam being proportional to actual ground motion. Since the rotation of the drum is calibrated chronologically, the exact time of the ground motion is determined. This graphic record on the drum is called a *seismogram* (See fig. 5). A full installation actually requires three seismographs; one measures vertical earth movement (the one illustrated) and the other two measure shaking in the north-south and east-west directions.

Primary waves are the fastest, and hence they arrive at the seismograph and are recorded first. Secondary waves arrive next, and surface waves last, since they are slower and must also travel a longer path around the earth's surface.

The velocities of the various waves are known, and the lag times between arrivals of the three types at any station tell how far away, but not where, the earthquake was. At least three stations are required to determine the location of the epicenter by plotting the intersection of the individual radial distances. Because these velocities vary according to the rigidity and density of the materials through which they pass, much can be determined about the structure and composition of the earth's interior.

[3]No active volcanoes occur in the eastern United States.

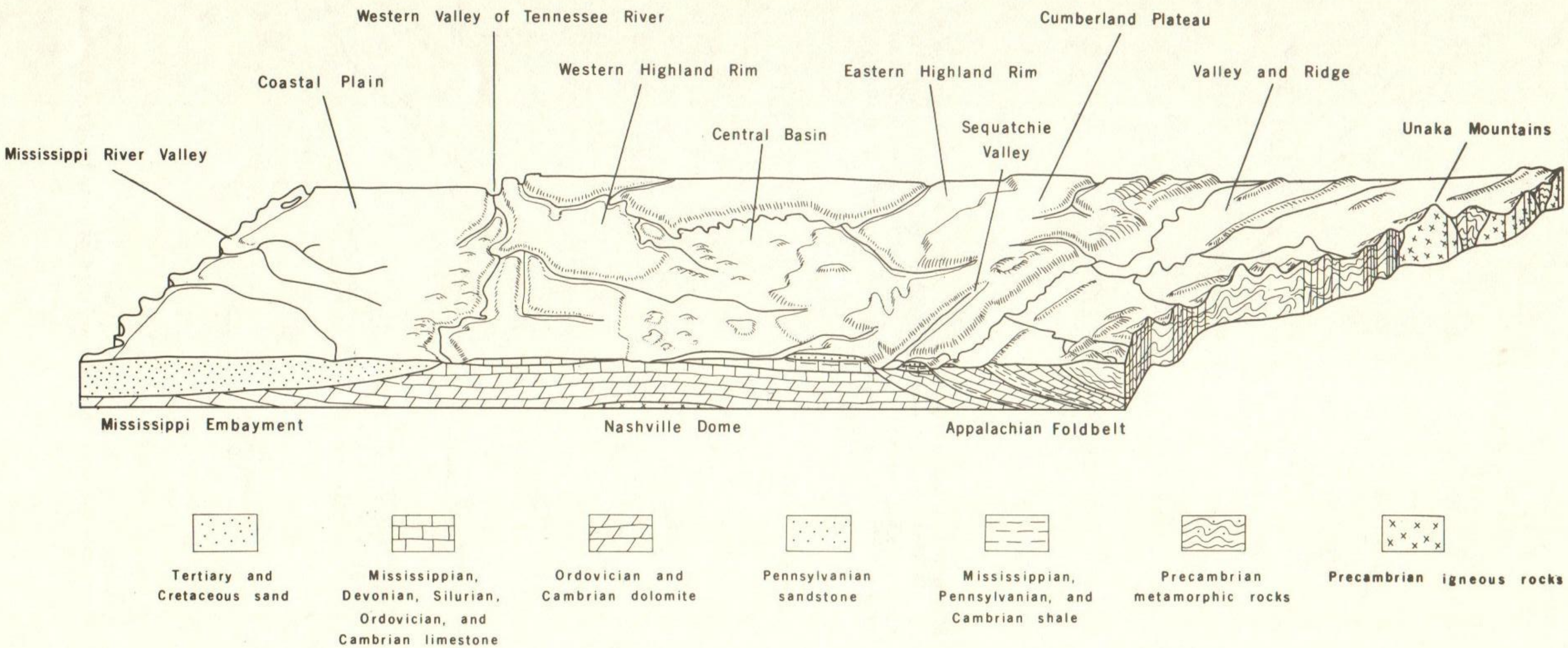


Figure 3A. Relief map of Tennessee showing the relationship of major geologic structures to physiographic units. The obscure, but active, faults of far west Tennessee are not shown here.

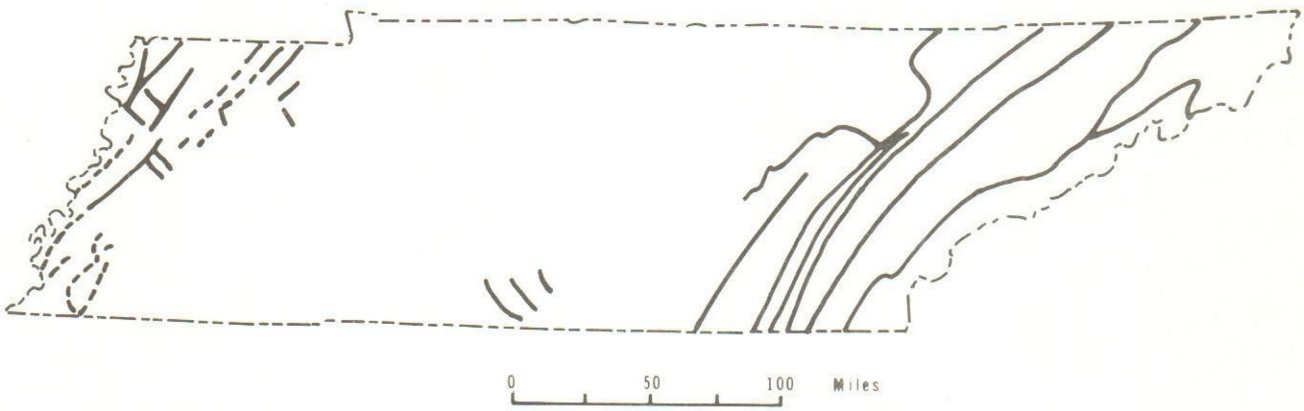


Figure 3B. A generalized fault map of Tennessee. The faults in East Tennessee are inactive, but those in West Tennessee nearest the Mississippi River are perhaps active now. The locations of most major faults in East Tennessee are precisely known, and only a few of the 40 or so major faults there are drawn. In West Tennessee faults are obscure, and those drawn here are only approximately shown.

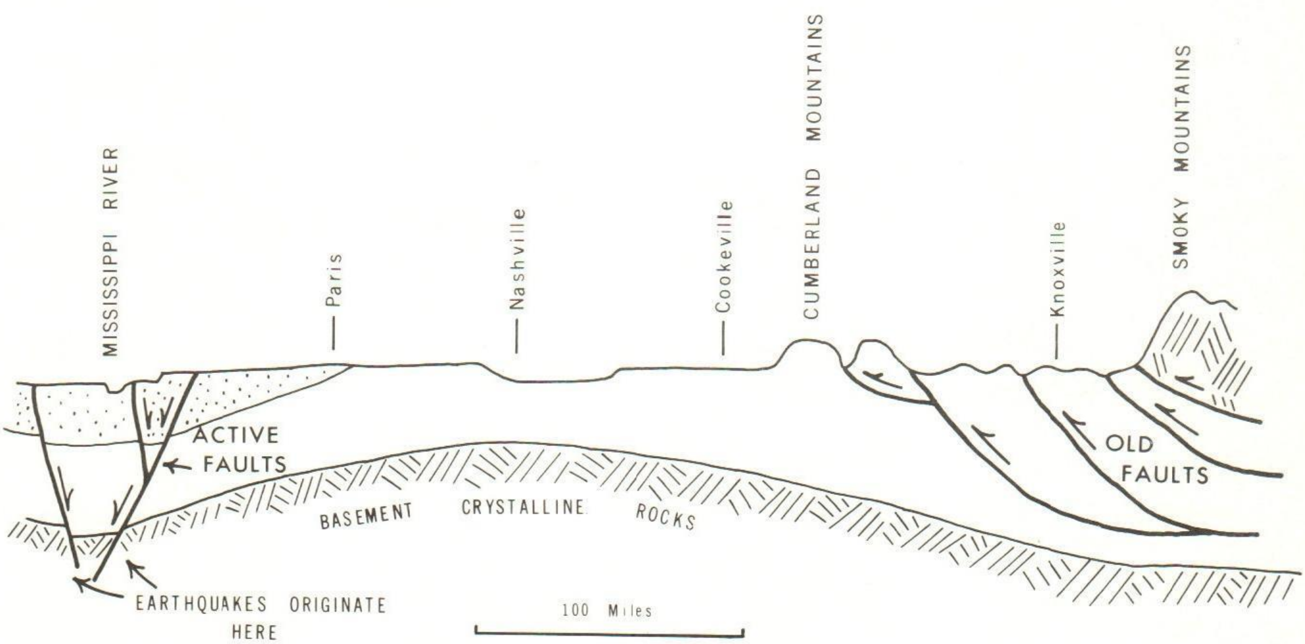


Figure 3C. Sketch profile of Tennessee showing the faults in Tennessee and their relation to earthquakes.

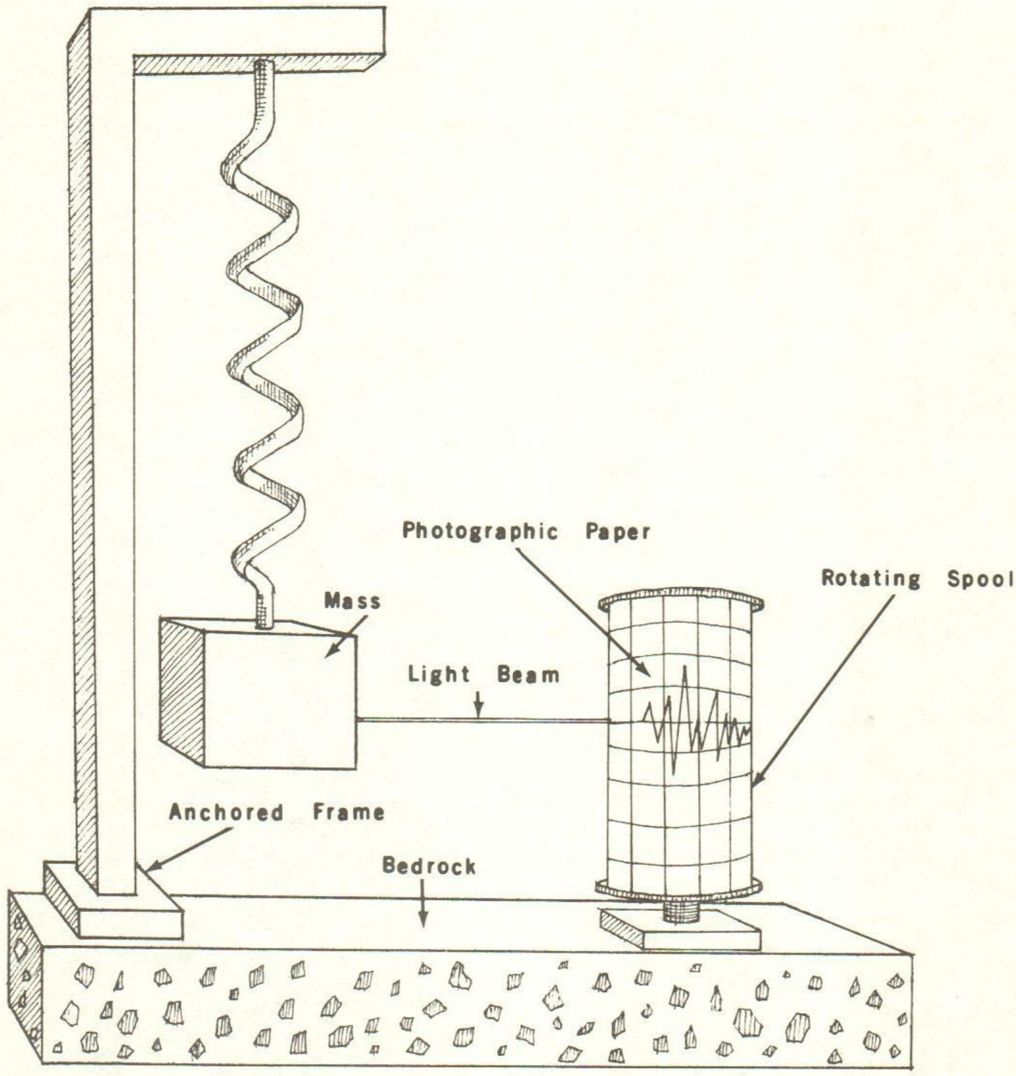


Figure 4. A sketch of a seismograph. When the bedrock goes up and down, drum and hinge are carried with it, but the weight stays (nearly) still by inertia. A light beam or pen marks the drum's up and down motion on the rotating, time-calibrated drum. Redrawn from U.S. Geological Survey.

Many small earthquakes occur where the shaking is only strong enough to reach one seismograph. The recollections of people in the area who note their experiences are helpful in determining the epicenter of these small quakes and in gaining an idea of how much energy was released. The modern seismograph was not developed until the latter part of the 19th century, and all previous historic earthquake information was obtained only by intelligent observations of eyewitnesses. Such records are still extremely useful, and readers are urged to record their experiences, including time, duration and observed effects, during any earthquake.

The *Richter Magnitude*[4] is the measure of earthquake energy interpreted from a seismogram. Magnitude can be calculated rapidly so it is heard immediately on the news. Each quake has a single magnitude that is determined from the amplitude of seismic waves. This scale is a ratio scale, with each number indicating an earthquake having about 30 times as much energy as the next number below it. Therefore, an earthquake of magnitude 7, for example, has nearly a thousand times as much energy as one of 5 (30 X 30). On this scale most earthquakes felt in Tennessee in recent years have been in the 2 to 4 range. Normally an event of magnitude less than 2 will not be felt by people near the epicenter. One of 7 or more is a major earthquake, and devastating effects are likely. The December 16, 1811, New Madrid earthquake is estimated to have been 7.2 (Nuttli, 1973). The largest ever measured was over 8.

[4]Originally defined by C. F. Richter for Southern California earthquakes as the logarithm, to the base 10, of the amplitude in microns of the largest trace deflection that would be observed on a standard torsion seismograph at a distance of 100 kilometers from the epicenter.

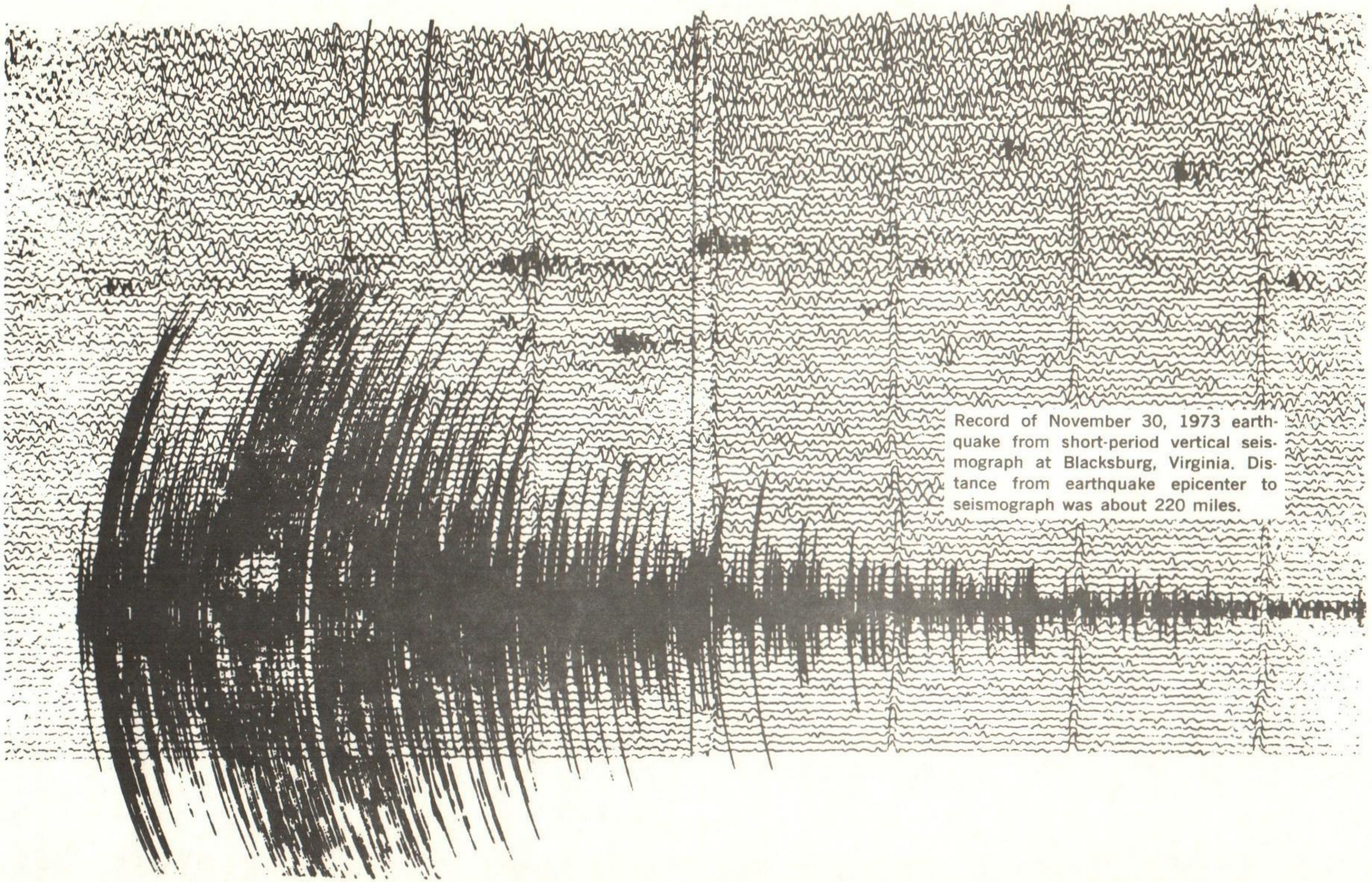


Figure 5. An example of a seismogram. This is the record of an earthquake that had an epicenter near Maryville in East Tennessee, Nov. 30, 1973. Reprinted from U.S. Geological Survey, Earthquake Information Bulletin, v. 6, no. 1, p. 22-23.

The other scale commonly used is the *Modified Mercalli Intensity Scale* (MM). It is more closely related to the things that happen to people and to buildings and other structures. It is too slow for news, however, since it is dependent on the process of collecting personal observations and reports — mostly by examining postcards provided by the government to people in the area. Also, the same experience may be reported differently by different persons, so it has the further defect of being subjective. Even with its defects, it remains the only way to establish a pattern of earthquake effects over large areas. It is also the only practical means of determining anything quantitative about earthquakes that occurred prior to the availability of seismographs.

Each earthquake has a variety of effects. The highest intensities occur near the epicenter, with intensities diminishing outward until the effects fade to where nothing is felt. The resulting pattern is roughly a "bulls eye", but it varies depending on actual shaking, availability and sensitivity of observers, and ground conditions. The following description summarizes the criteria used to assign MM values to a particular place:

MODIFIED MERCALLI INTENSITY SCALE

(From Wood and Neumann, 1931)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not realize it is an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck.

IV. During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

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

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

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

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

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

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

By plotting the various "effect" numbers on a map and drawing lines enclosing equal numbers, distribution of the effects can be shown. By bulges and other configurations the resulting isoseismal map can show where ground was less stable or where seismic waves of greater amplitude were transmitted farther in certain "preferred" directions. This may tell something of the geologic structure of an area, and such data is most important in predicting the significance of future events. See fig. 6 for the isoseismal map of a small earthquake in modern times, and fig. 7 for the much larger area affected by the great New Madrid earthquake of 1811.

The energy from a certain magnitude earthquake will result in very different effects in one type of geologic/hydrologic condition than it will in another. For example, on wet unconsolidated sediment, shaking would be far more evident to people than it would be to those in a building on solid bedrock. This is the reason it is not practical to relate Richter magnitude to Mercalli intensity. With enough observations it may be possible someday to accurately say a given magnitude earthquake will cause a given set of effects at various locales, but such prediction is possible only in a general way at present.

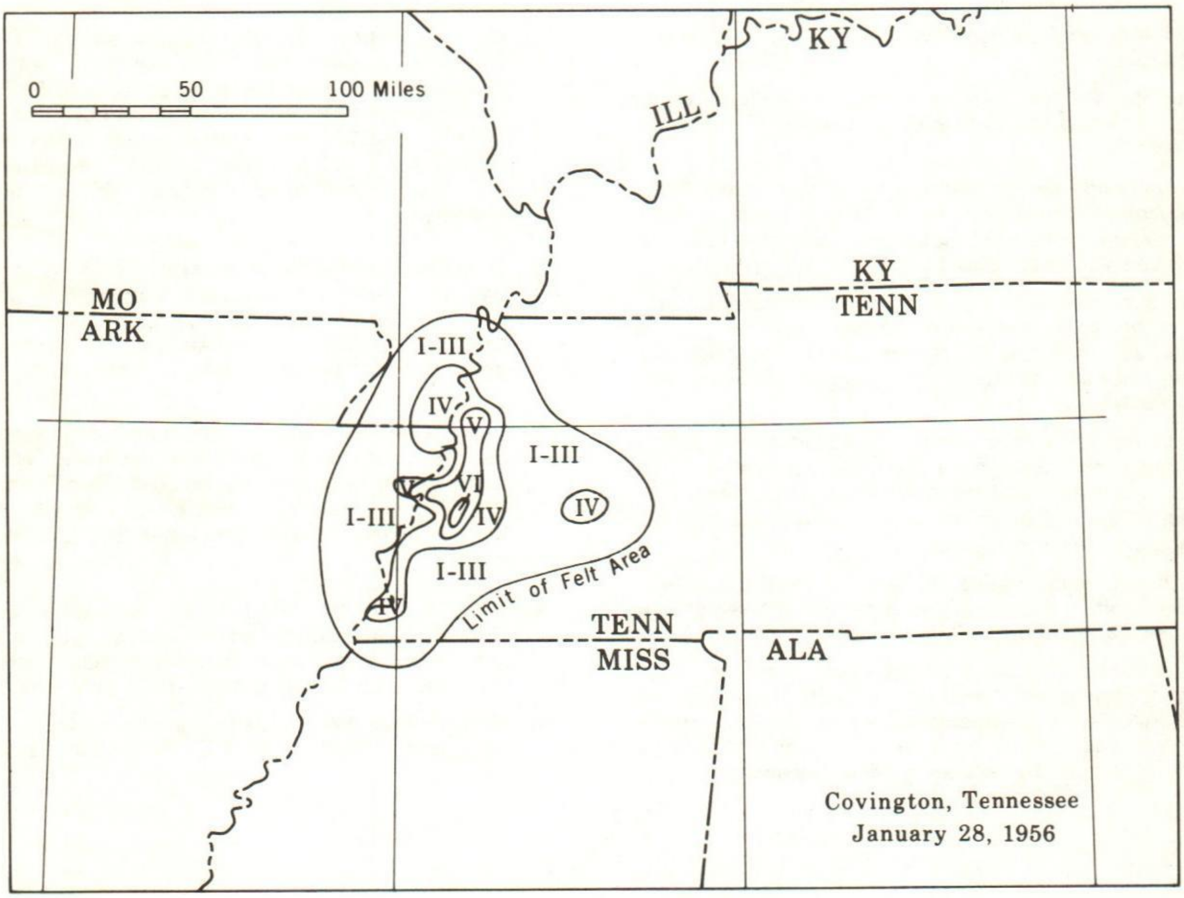


Figure 6. A typical MM (Modified Mercalli) isoseismal map of a moderate, but not damaging, earthquake centered near Covington, Tennessee, Jan. 28, 1956. Note that more intense effects are elongated parallel to the Mississippi River. This may show the trend of a fault that moved to produce the earthquake. Reprinted from Stearns and Wilson, 1972.

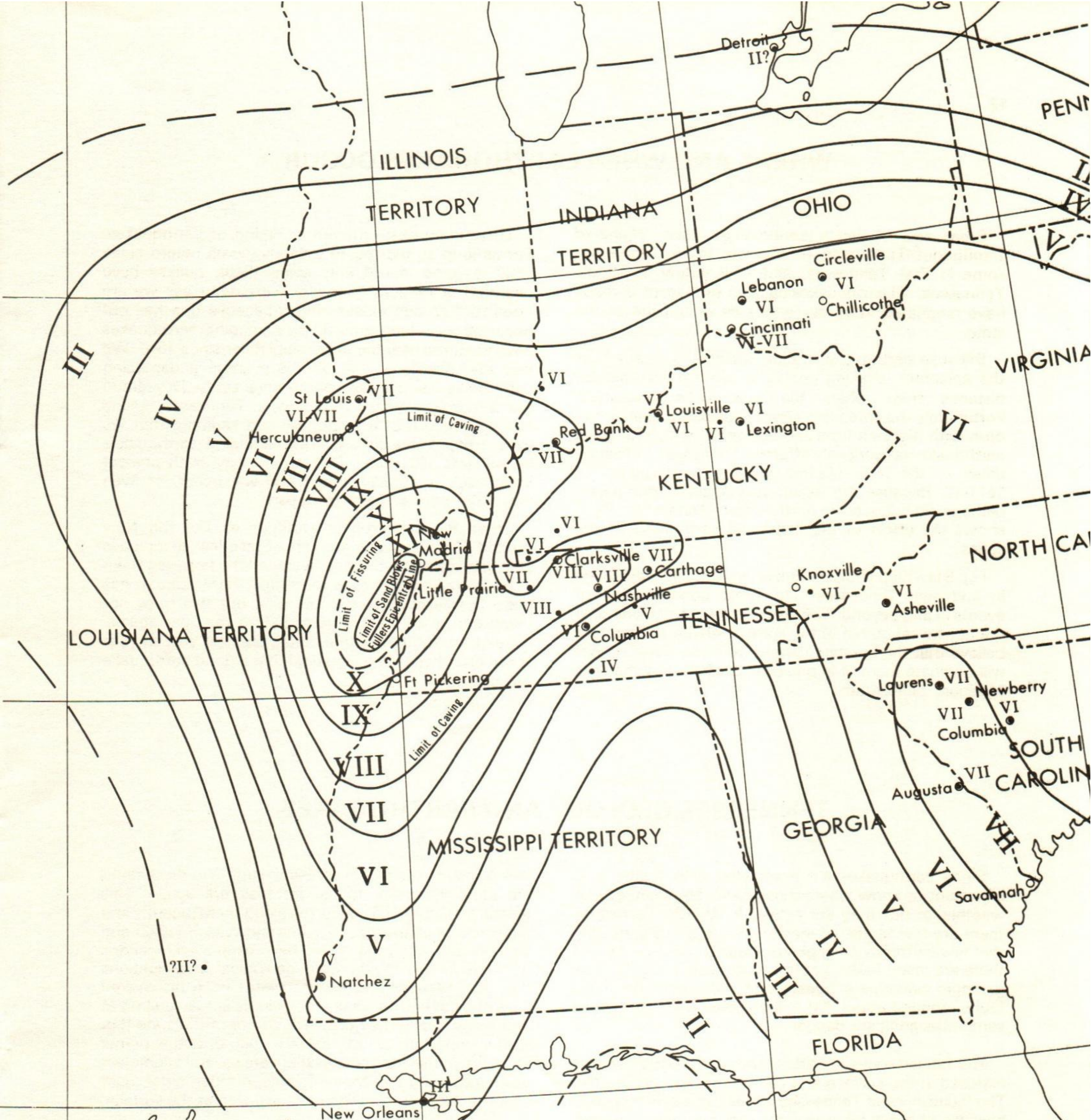


Figure 7. Effects of the New Madrid earthquake of Dec. 16, 1811. The Roman numerals are approximations of the MM scale. If this earthquake were to occur today, much of West Tennessee and some of Middle Tennessee would be damaged. Reprinted from Stearns and Wilson, 1972.

WHERE AND WHEN EARTHQUAKES OCCUR

Small and moderate earthquakes have originated throughout Tennessee — most in West Tennessee, some in East Tennessee, and a very few in Middle Tennessee. All earthquakes causing significant damage have originated in West Tennessee or outside of the state.

Because earthquake motion radiates outward from the epicenter, shaking occurs in areas a considerable distance from where the earthquake originated. Fortunately the spreading effect causes the intensity to drop with distance from the epicenter. Only one great earthquake has seriously affected Tennessee in historic times — the New Madrid series of earthquakes of 1811-12. Because the region was sparsely populated, damage did not occur in northwestern Tennessee. Fig. 7 shows the effect of the first great earthquake of the series.

Fig. 8 is a map showing known earthquake epicenters in and near Tennessee. The great concentration of events in and beyond West Tennessee, particularly near the northwest corner of the state, is obvious. Scientists believe that the greatest danger from any future event will originate there or in adjacent portions of Arkansas, Missouri, or Kentucky.

There is no exact rhythm or timing of earthquakes. For as long as the record extends (some record since 1690; a good record only since 1840), quakes have occurred at random intervals. We cannot say we are "due for" an earthquake simply because one has not occurred for a long time. Eight damaging earthquakes have occurred near the Mississippi River since 1840. We can say, therefore, that on the average a damaging earthquake has occurred about once every 17 years in the Mississippi Valley region near Tennessee. Using this past record as a guide, we can estimate that we expect approximately six more damaging earthquakes in the next 100 years. There is no way, with present knowledge, to predict when one will occur, or even when the next is likely to occur.

Great and catastrophic earthquakes like the New Madrid 1811-12 event are rare. Statistical techniques lead to an estimate that the average time between them in the New Madrid area is more than 1000 years. It has been 165 years since the last one, but this does not mean that it will be 835 years before the next strikes. Instead, we should say that during the next year there is about one chance in a thousand that a great earthquake will occur.

TENNESSEE GEOLOGY AND EARTHQUAKES

Since earthquakes are associated with faults, it is important to know where these faults are located, and whether or not they are active. In Middle Tennessee there are few faults, all inactive, so it is not surprising that few earthquakes originate there. In East Tennessee there are many faults, yet few earthquakes (fig. 3). The geologic evidence suggests that movement on these faults stopped about 200 million years ago, and represents no significant danger.

The faulted rocks in Middle and East Tennessee are exposed at the surface and can be mapped accurately. The faults in West Tennessee are not so easily mapped, because of burial by mud from the many streams and lack of good outcrops in soft sediments. Yet these faults are most important to us, for they are active. This means movement has occurred along them recently and may reoccur at any time. Stearns and Wilson (1972) and Stearns and Zurawski (1976) have estimated locations of faults in this region from geological investigations (fig. 3B); Stauder and his associates have discovered lines of small earthquakes that indicate active faulting at depth in and near the northwest corner of the state (fig. 9). It is important to note that the *foci*, or actual points of origin, of the earthquakes there are several kilometers deep, indicating that they originate in much older, rigid rocks underlying soft sediments exposed at the surface.

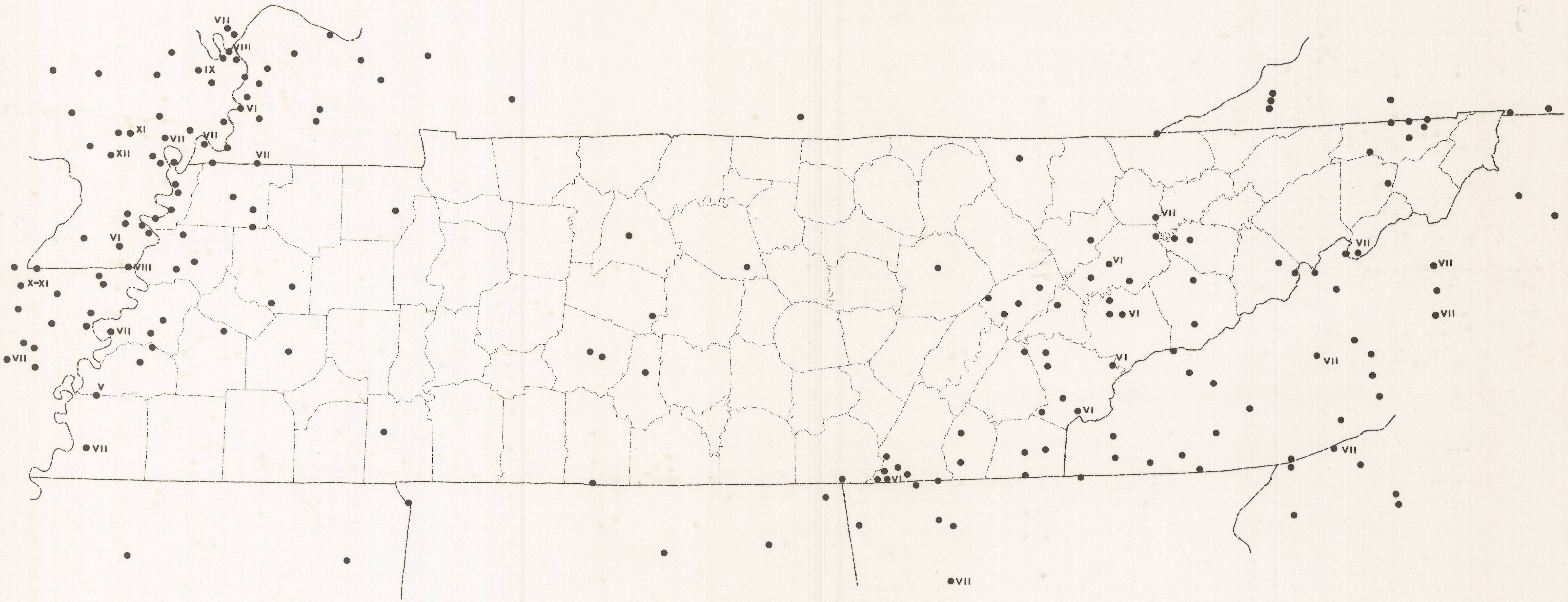


Figure 8. Approximate locations of earthquake epicenters in and near Tennessee. Roman numerals indicate intensity as measured on the Modified Mercalli scale for selected epicenters. Note the concentrations of epicenters in the vicinity of the Mississippi River Valley and in the eastern mountainous region.

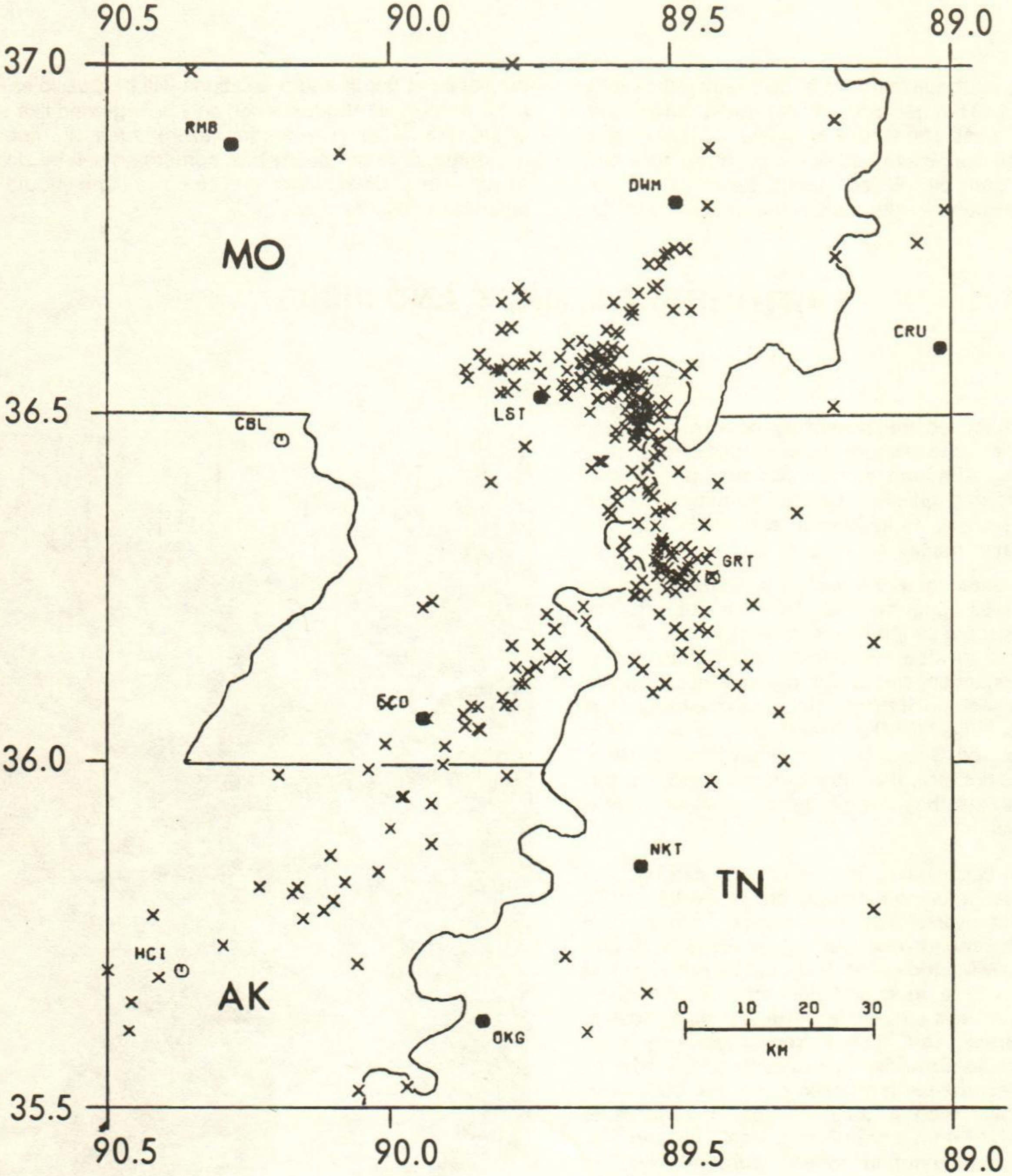


Figure 9. Locations of epicenters of small earthquakes near the northwest corner of Tennessee, recorded from June 1974 to March 1976. The alinements in some places suggest that the faults trend northeast and northwest. The main concentration in Tennessee is in and near Lake County. Reprinted from Stauder and others, 1976, Southeast Missouri Regional Seismic Network Quarterly, Bulletin No. 7.

EARTHQUAKE PREDICTIONS

At present earthquakes cannot be predicted exactly in Tennessee. The geology of the most dangerous areas of far west Tennessee is unlike California and some other places, where bedrock is at the surface and instruments can be placed along faults to aid in prediction. Perhaps in the future instruments can be emplaced at depth and predictions will be possible. For now, though, earthquakes can only be regarded like any other natural or man-made hazard such as floods, accidents, or fires. Meanwhile, something can be done, as will be explained below, and steps can and should be taken to minimize risk.

EARTHQUAKE EFFECTS AND RISKS

Risk is defined as the possibility of loss or injury, thus it is important to examine the effects of earthquakes on that basis. Although some risks are unavoidable, others can be minimized by careful planning. We can examine these risks by looking at two basic types — natural and man-made.

Shaking creates many *natural* risks. Extreme natural danger is well documented by the reports of unfortunate people caught up in an earthquake. These natural effects include the shaking itself, landslides, fissuring, liquefaction, and abrupt changes in land level. For detailed accounts of these effects from earthquakes in Tennessee, Fuller (1912) or Stearns and Wilson (1972) are recommended. Sound (roaring or grinding noise) is not harmful, nor are the odors of escaped pentup swamp gases, but they contribute to panic which is a danger in itself.

In a severe earthquake, ground shaking can become so severe that a person cannot stand. Nuttli (1973) estimated that over a period of several seconds, the relatively soft ground rose and fell more than 16 feet during the New Madrid event. It should be noted at this point that effects in areas underlain by soft, unconsolidated, and wet sediment are much greater than those in solid rock areas. During the New Madrid quakes, landslides cascaded sediments into rivers and, landward from the slides, the earth cracked open and collapsed. Fig. 10A shows such a collapse area in Tennessee, fortunately away from any building. Figs. 10B and 10C show what can happen where collapse involves buildings. Safford (1869) estimated earthquake cracks just north of Dyersburg, Tennessee, to have been over 800 yards long, so such danger is real enough in our state.

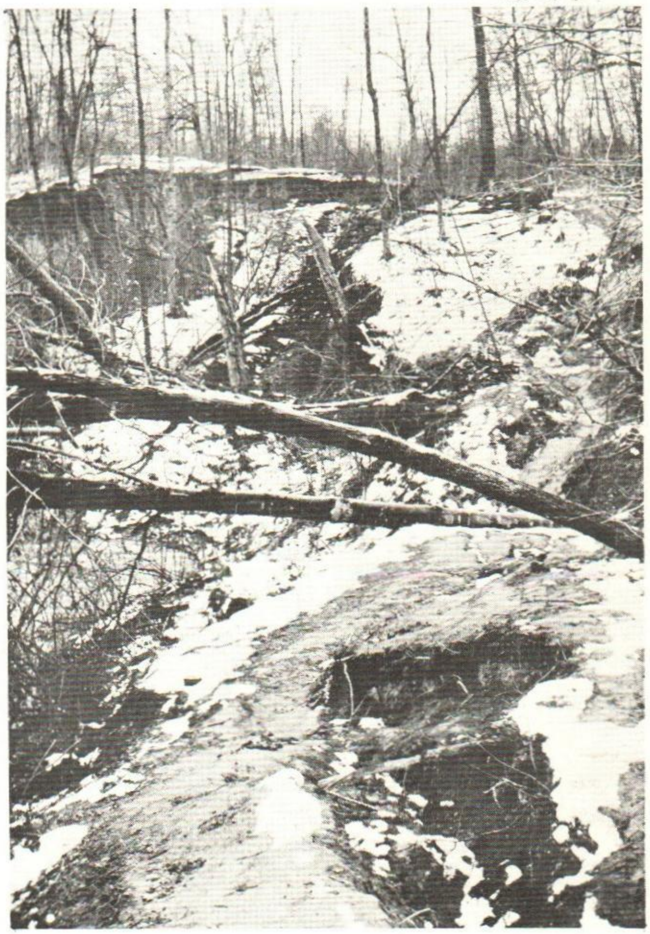


Figure 10A. Collapsed ground in an earthquake-caused landslide on Nov. 17, 1970 at the Paul Keltner Farm in Lauderdale County, Tennessee. Such collapsed ground was common in the West Tennessee area north of Dyersburg during the 1811-12 earthquakes. Any building located over such a collapse would be destroyed. Photo by Richard G. Stearns.

Liquefaction can be a major hazard during an earthquake in areas underlain by soft, water-saturated sediments. This phenomenon is defined as the sudden large decrease of shearing resistance of soil material. It involves a temporary transformation of material into a fluid mass. Buildings resting on such sediment can tip

Figure 10B. Wreckage of a school after a collapse in Anchorage, Alaska, following the March 27, 1964 earthquake. This ground collapse is almost identical to that at the Keltner Slide in Tennessee, but here a school was destroyed. Reprinted from U.S. Geological Survey Professional Paper 542A, p. A55.

and settle or even collapse (See fig. 11). In the New Madrid event liquefied sand squirted out of great cracks on the surface, and this sand, now spreading out by plowing and wind, is still clearly visible in Lake County. These particular features have been called "sand blows". Farmland at the community of New Madrid, Missouri, was buried beneath several feet of sand in 1811-12. See figs. 12A and 12B for recent examples.

Depression of the earth is well exemplified by Reelfoot Lake, in Lake and Obion Counties. Originally mostly a dryland area, the earth suddenly subsided during the New Madrid quakes, and the new low ground subsequently filled with water from creeks and springs.

Man-made structures present special risks during earthquakes, but fortunately steps can be taken to minimize or avoid them — specifically by proper desigh and well-planned location. Buildings with rock facing or overhangs, such as cornices or parapets, are sources of great danger from falling material (See fig. 13A). Masonry veneered structures may crumble from the shaking (fig. 13B).

Figure 10C. Wreckage of a dwelling that was partly on collapsed ground. Such damage is likely from a violent earthquake in Tennessee. Reprinted from U.S. Geological Survey Professional Paper 542A, p. A46.

Figure 11. Spectacular effects of soil liquefaction during the earthquake of 1964, Niigata, Japan. Buildings have tipped and sunk into temporarily liquefied earth. Reprinted from U.S. Geological Survey, Earthquake Information Bulletin, v. 8, no. 1, back cover.

Figure 12A. Sand "blows" similar to those described by eyewitnesses to the New Madrid earthquake of 1811-12. Reprinted from U.S. Geological Survey Circular 690, p. 22.

Tall buildings present their own problems. Since earthquake waves do not fade out in unison, and longer surface waves travel farthest with least attenuation, very tall structures, perhaps considerably distant, may be severely shaken while small (low) structures are unaffected. This is because each structure has a natural fundamental frequency at which it vibrates. The taller (or longer) the structure, the lower that frequency. The long surface waves (low frequency), therefore, produce vibrations in such structures. There is also a "whip" effect which magnifies small sideways movements at ground level into appreciable movements aloft. Consequently people on upper levels of a tall building may be near panic, while those on lower floors may not experience any effect. Fig. 14 is a seismograph record showing that shaking was greater and lasted longer in the upper part of a building.

The possibility of dam failures represents another danger in an earthquake. If one fails, people many miles downstream on low ground would be imperiled (fig. 15). Any structure on a steep slope or adjacent to a precipitous riverbank could slide downhill because of shaking. Bridges may collapse, thus interrupting transportation routes needed in rescue efforts. Other problems are created by rupture of power, gas, and water mains, with resultant potential for fires—another great hazard associated with earthquakes.

Figure 12B. Sand ridges, formed by fluid injection of sand in ground cracks following the 1964 Alaskan earthquake. Reprinted from U.S. Geological Survey Circular 690, p. 23.

Figure 13A. A car damaged by falling bricks from an unreinforced parapet, which collapsed during the moderate (magnitude 5.7) 1969 Santa Rosa, California earthquake. Reprinted from U.S. Geological Survey Circular 690, p. 17.

EARTHQUAKE SAFETY

Throughout the history of humankind earthquakes have taken an awesome toll in lives and property damage. Earthquakes in Kansu, China in 1920 and in Japan in 1923 each took 100,000 lives. Another in Port Royal, Jamaica in 1692 killed 20,000. The Guatemalan earthquake of 1976 killed as many as 30,000 people. Many other seismic events of this century have resulted in the deaths of thousands of people. Large parts of Tokyo, San Francisco, and other cities have been destroyed by earthquakes. For most of recorded history people have been nearly helpless to protect themselves and their property. This is because no one understood the cause of earthquakes, and fear and superstition prevailed. Technology for construction of quake-resistant buildings was nonexistent, and predictability of future events was beyond imagination.

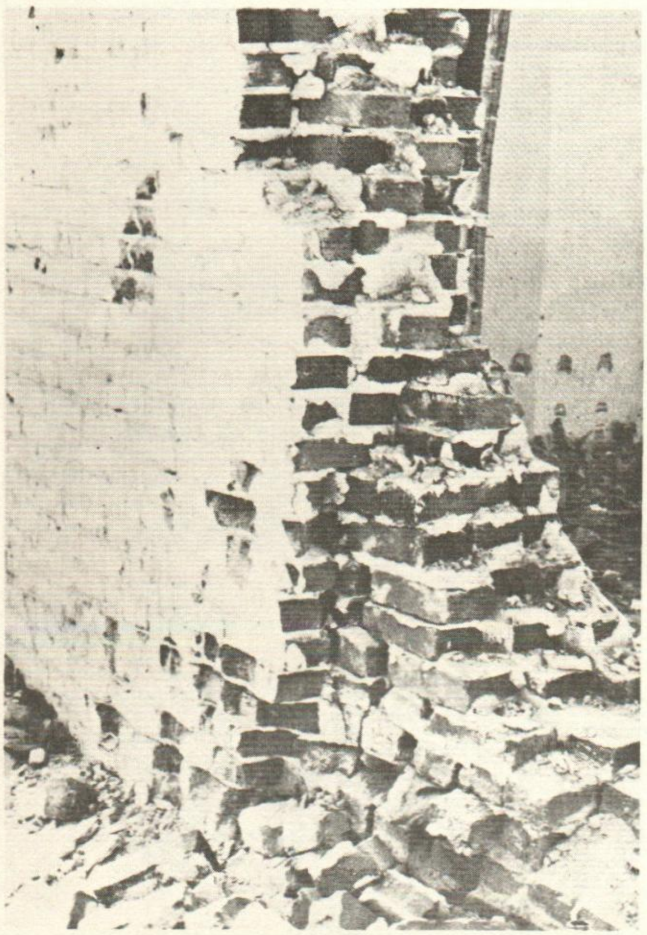


Figure 13B. Remains of an unreinforced brick wall. Note incomplete filling of spaces between bricks and poor bond between mortar and brick. Reprinted from U.S. Department of Commerce, v. 1, part II, p. 644.

Earthquake safety involves both personal action during a quake to protect oneself and family, and longer term individual, group and public action to minimize danger. We will offer some suggestions as to long-term or advance action and, subsequently, will list emergency safety guidelines.

Individual and community planning efforts can result in safer placement of buildings where shaking will be minimal and where danger of foundation collapse is slight. Further, buildings themselves can be constructed and furnished so that they will be relatively safe in an earthquake. Codes can be revised and implemented so that buildings constructed in the future will be safer. Existing buildings can be made safer by various means short of expensive reconstruction. Individuals in earthquake-prone areas can effectively increase the safety of their homes and offices by fastening down heavy furniture which might tip or slide and by installing furnishings that do not include heavy, but weakly suspended, objects.

Long-term safety is perhaps best accomplished by proper attention to location and the construction of safe and strong building foundations. Building locations on low ground downstream from any dam or reservoir should be recognized as hazardous. Locations on or near precipitous slopes made of unconsolidated formations should be avoided, or at least recognized as a hazard. (The authors might themselves favor a home with a scenic overlook or a location on a pleasant stream, but would also weigh potential hazards in any home location decision.) Even though individuals might choose to accept the risk involved, certainly critical buildings such as fire stations and hospitals, and those with high occupancy rates, like school buildings and apartments, should be safely placed. A strong and shake resistant foundation and main bearing wall, floor, or pillar is a must in areas of extra hazard, such as any place near the Mississippi River. It is not always possible to do so, but where it can be done, foundations should be anchored into bedrock. Unfortunately, this is not possible in far West Tennessee, the area of greatest danger. Structures there can be designed to minimize the effects, however.

It is hoped that seismic research in the future will lead to the development of an ability to predict earthquakes and warn people of impending danger. To achieve this goal continued scientific research is necessary on earthquakes themselves, and such related hazards as landslides, liquefaction, and earth fissuring.

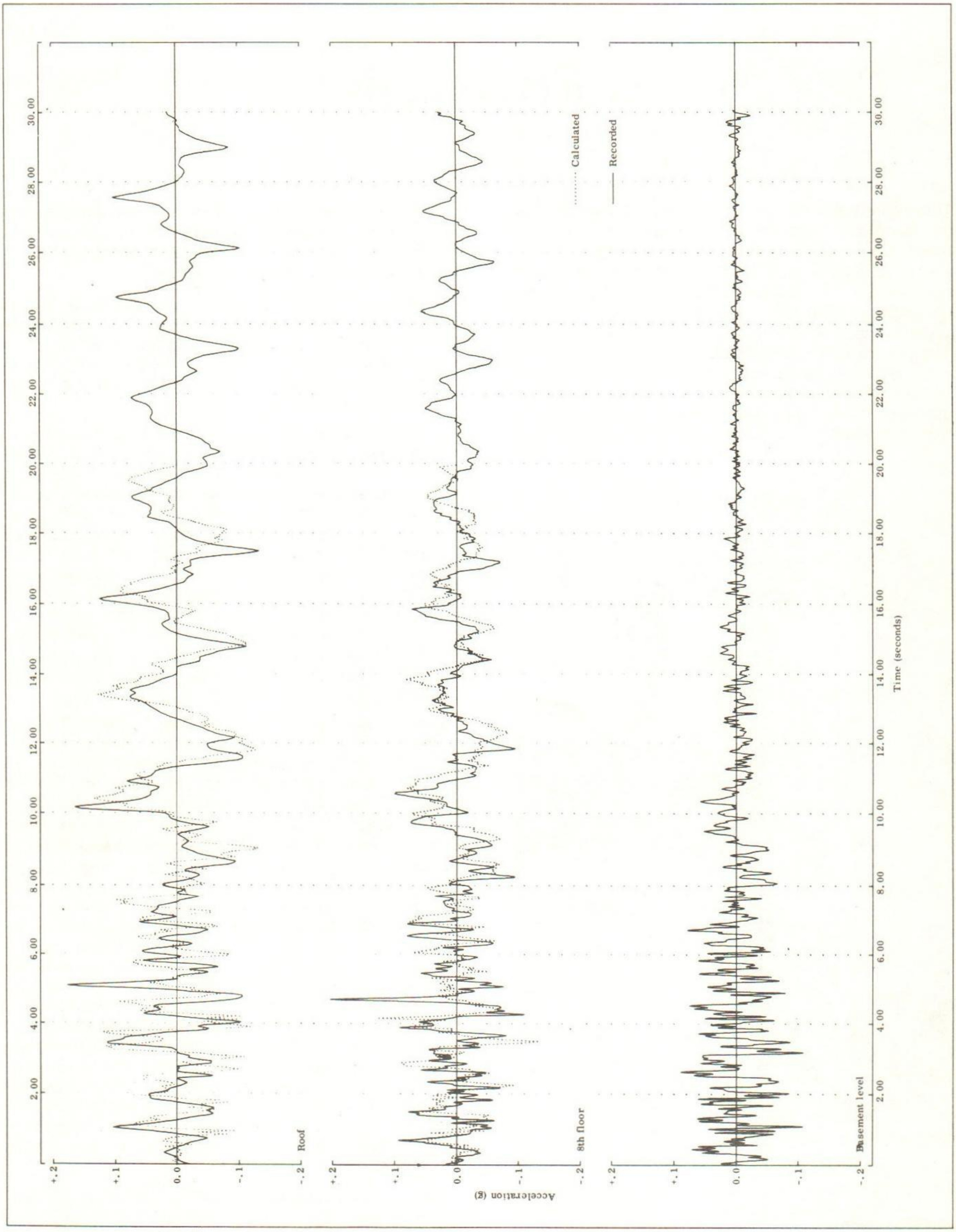


Figure 14. "Seismograms" (actually graphs of acceleration which is a measure of the force of back and forth movement) for three levels in a building. Note that upper levels oscillated harder and longer than the basement. This record is from the Kajima International Building in the Los Angeles area, during the San Fernando earthquake of Feb. 9, 1971.

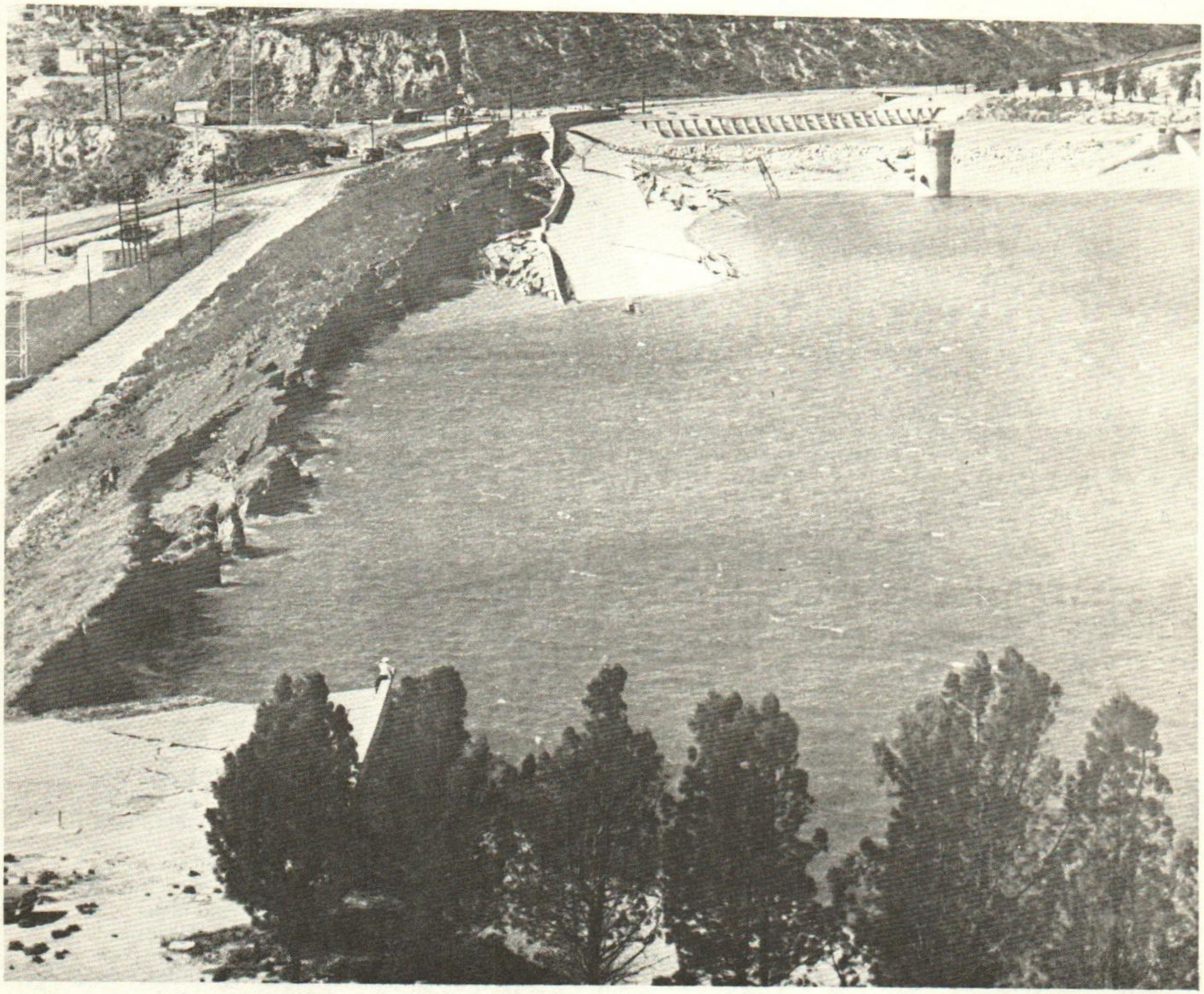


Figure 15. An earth dam that nearly failed during the San Fernando earthquake of February 1971. Reprinted from U.S. Geological Survey and the National Oceanic and Atmospheric Administration, The San Fernando, California, Earthquake of February 9, 1971, Geological Survey Professional Paper 733, p. 237.

All of these elements of safety require investigation and careful planning. Various types of maps must be compiled, stress accumulation measured, materials tested, and seismic stations staffed and maintained. Zoning, construction codes, and public safety information must be given high priority by public officials in regions of seismic risk. Also, good emergency communication is necessary.

Unfortunately we are not presently at such a high level of preparedness. Earthquakes will continue to occur, and there will be danger and damage. In the event of an earthquake, some safety guidelines are offered by the National Earthquake Information Service (See next page).

We do not wish to overdramatize the danger from earthquakes in Tennessee. Another great earthquake like the New Madrid event will probably not result in much loss of life in individual homes, although personal injury and considerable property damage will result. In urbanized areas, however, damage from a great earthquake will be enormous, costing many lives and injuries and hundreds of millions of dollars in property losses. We emphasize that, according to the best estimate available, the odds are very large against such a quake happening next year or even over tens of years. Compared with having an illness, accident, or being involved in violent storms, the risk to an individual of experiencing a major earthquake in Tennessee is small. The long-term danger is real, however, and a violent earthquake someday is inevitable. We should be prepared.

EARTHQUAKE SAFETY RULES

During the shaking

1. Don't panic. Remain calm. Before taking any action, think through the possible consequences. Remember, the greatest immediate danger is from falling objects.
2. If indoors, stay indoors. Take cover under a desk, table, bench, or in a doorway, hall, or against an inside wall. Stay away from windows and from high furniture that might slide or topple over.
3. If in a high building, do not dash for the exits or attempt to use the elevators or stairways. Take cover under a desk or other sturdy furniture.
4. If outside, move to an open area away from buildings, utility lines, or other high structures and remain there. Do not run through the streets.
5. If in a moving vehicle, stop in an open area away from buildings or bridges and remain inside.

After the shaking

1. Check for injuries and apply first aid if needed.
2. Check for fires and fire hazards.
3. Check utilities. Shut off gas lines if there is any evidence of leakage. Do not use or operate anything that could ignite gas until after you have made sure that there are no leaks. If water pipes are damaged, shut off the supply at the main valve. If electrical wiring is shorted, turn off power at the main box. Make sure sewage lines are intact before using toilets and other plumbing.
4. Listen to a radio if available for emergency information. Do not use the telephone except for emergency calls.
5. Do not go sightseeing. Stay out of heavily damaged buildings. Severe earthquakes are often followed by aftershocks. Although aftershocks are usually less severe than the first or main shock, they can cause the collapse of structures already weakened by the initial earthquake.

In the aftermath of a major earthquake you can contribute toward the safety and survival of yourself, your family, and others by observing several commonsense precautions. Immediately clean up spilled materials such as medicines and chemical compounds that could be harmful. If the water is off, emergency water may be obtained from water heaters, toilet tanks, and canned drinks or foods. Do not eat anything from an open container near shattered glass without first straining it through a clean cloth. If your power is off, check your freezer and plan to use foods first that might spoil easily. If your home has a chimney, inspect it over its entire length for cracks or other damage. Unnoticed damage could lead to a fire. Chimneys should be approached with caution until you are certain that they are safe. Open closet and cupboard doors carefully and watch for objects that might have fallen against the doors. Do not travel unless absolutely necessary. Help keep the streets clear for emergency vehicles. Respond to requests for help from police, firefighting, civil defense, and relief organizations. Cooperate fully with public safety officials. Do not do anything that might hamper disaster operations.

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