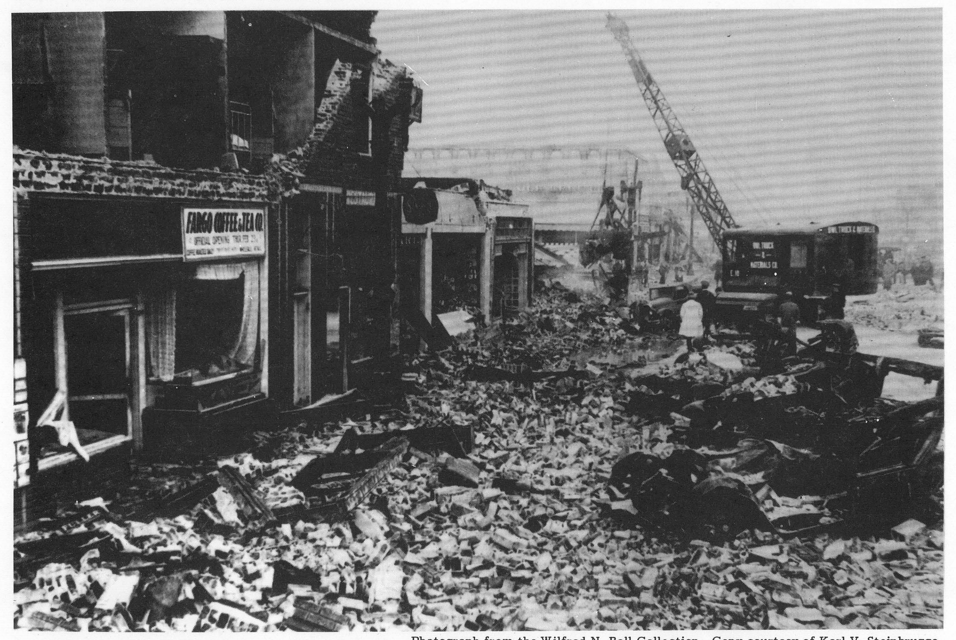


Photograph from the Wilfred N. Ball Collection. Copy courtesy of Karl V. Steinbrugge.

FIGURE 1.—Damage to downtown Compton, Calif., 40 km (25 mi) from the epicenter of the 1933 Long Beach earthquake. This damage is typical of the effects of a moderate to large (magnitude 6.3) earthquake on old, unreinforced brick masonry. Note that the second story wall has collapsed and the roof is supported only by the interior partition (nonbearing) walls.

Photograph by the Los Angeles Times. Copy courtesy of Karl V. Steinbrugge.

FIGURE 2.—Damage to Jefferson Junior High School from the 1933 Long Beach, Calif., earthquake. This earthquake caused the destruction of many public schools and caused the California legislature to pass the Field Act, mandating that all new public schools in the state be built to resist earthquake vibrations. The effectiveness of this legislation has been demonstrated by the superior performance of post-1933 schools in California earthquakes (Richter, 1958).

Photograph by Bureau of Land Management. Copy courtesy of Karl V. Steinbrugge.

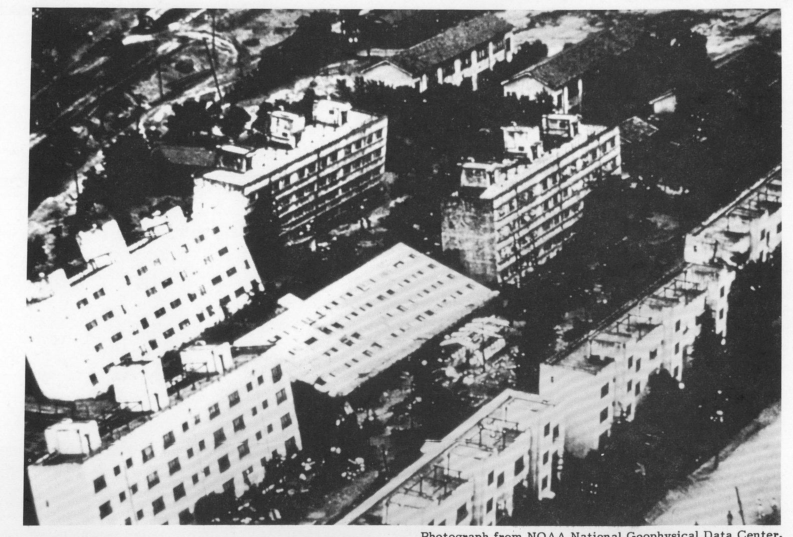
FIGURE 10.—Damage to the Penney Building in Anchorage during the 1964 Alaska earthquake. This building, constructed in 1962, was supported by bearing walls on all for parts of all sides except the north; this photograph shows the northeast corner. Lack of shear walls above the first story along the north side gave the building a U-shaped shear-wall bracing system, which is especially susceptible to torsional (twisting or rotational) forces. An eyewitness described the Penney Building as twisting, with movement along the second floor construction joints (Steinbrugge, Manning, and Degenkolb, 1967).

Photograph from the NOAA National Geophysical Data Center.

FIGURE 11.—Slump that destroyed a section of road during the Hebgen Lake, Mont., earthquake of 1959 (magnitude 7.1).

Photograph by J. K. Hillers. Copy from the NOAA National Geophysical Data Center.

FIGURE 12.—Sand blow created during the 1886 Charleston, S.C., earthquake. Sand blows are a result of liquefaction, a phenomenon that occurred over a wide area during the 1811-1812 New Madrid earthquakes. Liquefaction is the sudden transformation of a loose, sandy soil into a fluid, as a result of repeated vibrations such as those produced by a large earthquake. Earthquake shaking can pump or squeeze the fluid from a liquefied layer up through cracks in the overlying material, producing sand blows.



Photograph from the NOAA National Geophysical Data Center.

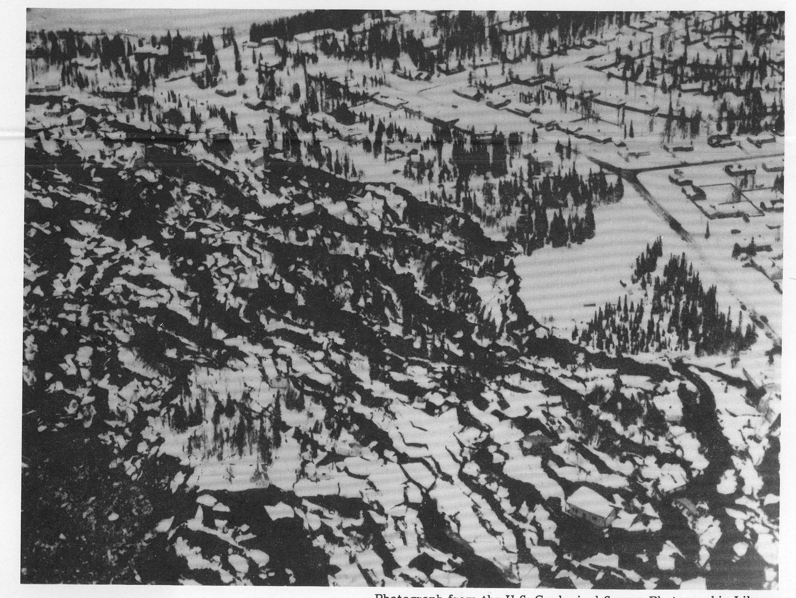
FIGURE 13.—Apartment buildings that tilted due to liquefaction at the base of the buildings during the 1964 earthquake in Niigata, Japan (magnitude 7.5). The buildings remained intact and the people inside escaped unharmed (Kawasumi, 1968).

Photograph by J. K. Hillers. Copy from the U.S. Geological Survey Photographic Library.

FIGURE 3.—Street in Charleston, S.C., after the 1886 earthquake (estimated magnitude m_b=6.8-7.1; Bollinger, 1977). Note that although some of the buildings have collapsed, others are relatively undamaged. There are even two tall chimneys still standing on the right.

Photograph by Arnold Genthe. Copy courtesy of Karl V. Steinbrugge.

FIGURE 4.—San Francisco after the earthquake of 1906 (magnitude 8.3). Note that many of the visible buildings are not seriously damaged. Much of the damage in 1906 was caused by the fire rather than the ground shaking (although the lack of water with which to fight the fire was caused by the mains broken by the shaking). In the photograph, note from the left, an intact wood-frame building, two masonry buildings (the first has two collapsed chimneys), more buildings standing in the distance, and the fire several blocks away. From the right, notice cracks below the second story window of the first building, the unreinforced brick front of the second building collapsed above the first floor level and its debris scattered across the sidewalk and street, other buildings on the right that seem relatively intact.

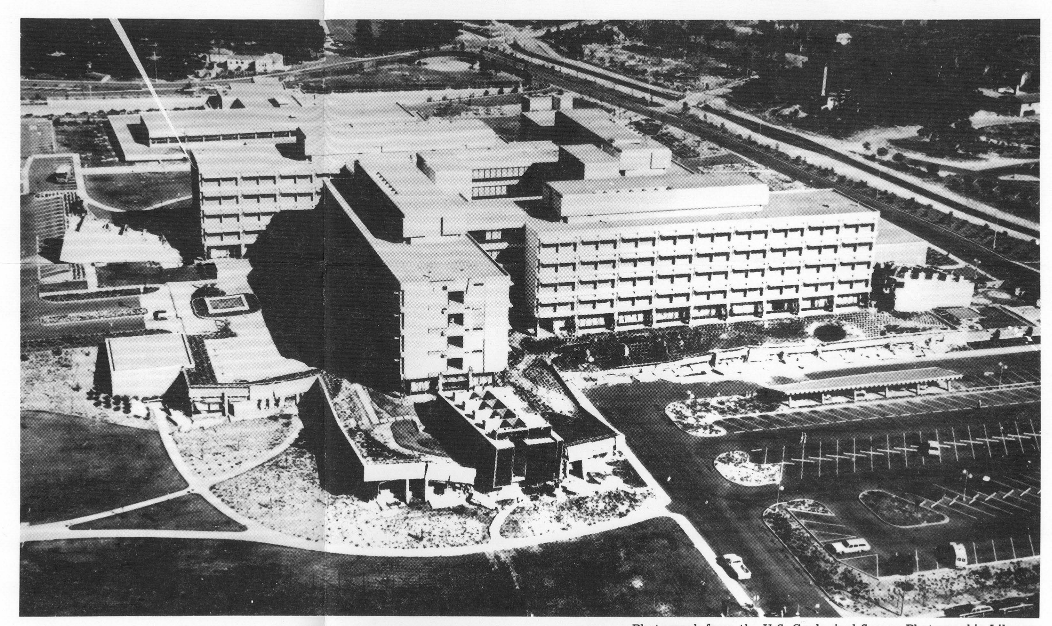


Photograph from the U.S. Geological Survey Photographic Library.

FIGURE 14.—Turnagain Heights slide after the 1964 Alaska earthquake. In this case, and in figures 15 and 16, upper strata slid on a liquefied lower layer known as the Bootlegger Cove Clay. If you look at this picture carefully you can see the houses on the blocks of earth that dropped.

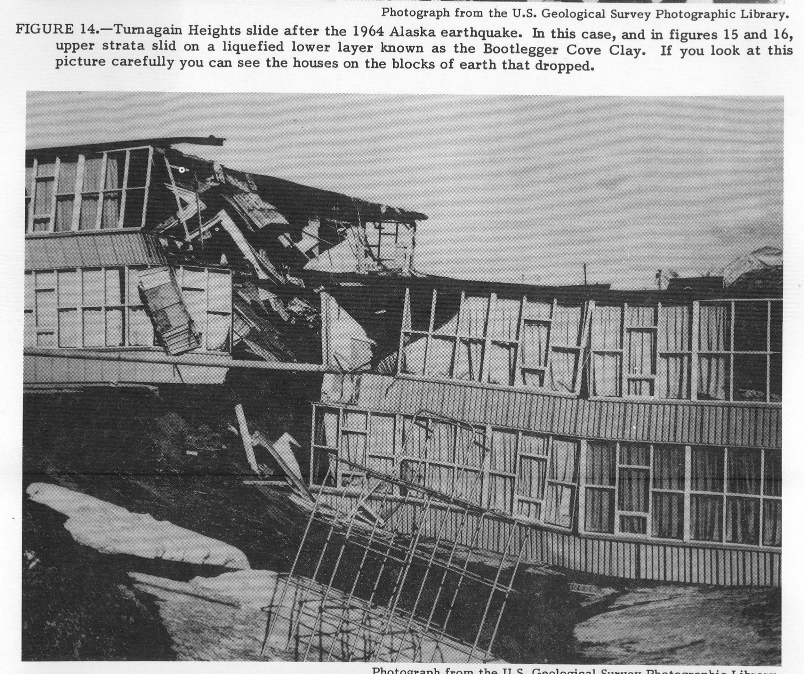
Photograph from the U.S. Geological Survey Photographic Library.

FIGURE 5.—Highway overpass that collapsed during the 1971 San Fernando, Calif., earthquake (magnitude M_S=6.5), and blocked an interstate highway, several other roads, and the main lines of the Southern Pacific Railroad (Youd and Olsen, 1971).



Photograph from the U.S. Geological Survey Photographic Library .

FIGURE 6.—Olive View Hospital, 10 km (6 mi) from the epicenter of the 1971 San Fernando earthquake. The hospital was new and complied with the 1965 Los Angeles County building code, but the actual ground motion at Olive View greatly exceeded the code levels. The hospital was only 5 km from the Pacoima Dam site where a horizontal ground acceleration of 125%g (g is the acceleration caused by the Earth's gravitational pull) was recorded. The lower two stories of the hospital had beam and column rigid frames, which supported the box structure with shear walls in the upper four floors. Note the three collapsed stair towers, the bent first-floor columns (wing on right), the collapsed floor below that (under the plantings), and the car port (in the back of the parking lot) that collapsed on top of a row of ambulances. The long, low building across the back of the picture was two stories high. The first story collapsed, leaving the second story at ground level (Johnston and Strand, 1973). Fortunately, the earthquake did not occur during working hours when most of the collapsed structures at Olive View would have been occupied.



Photograph from the U.S. Geological Survey Photographic Library.

FIGURE 15.—School partly on a dropped block, or graben, on the Government Hill slide in Anchorage in 1964.

Photograph by the Los Angeles Times. Copy courtesy of Karl V. Steinbrugge. Used by permission of the Times.

FIGURE 7.—Veterans Hospital (near Olive View, fig. 6.) which collapsed during the 1971 San Fernando earthquake killing 47 people (Olson, 1973). This reinforced concrete building was constructed in 1925 and not designed to be earthquake resistant (Johnston, 1973). Contrast this building with the earthquake resistant Olive View Hospital, where the structure remained standing and people escaped, even though the columns failed in the lower stories.

Photograph by Ward Wells. Copy courtesy of Karl V. Steinbrugge.

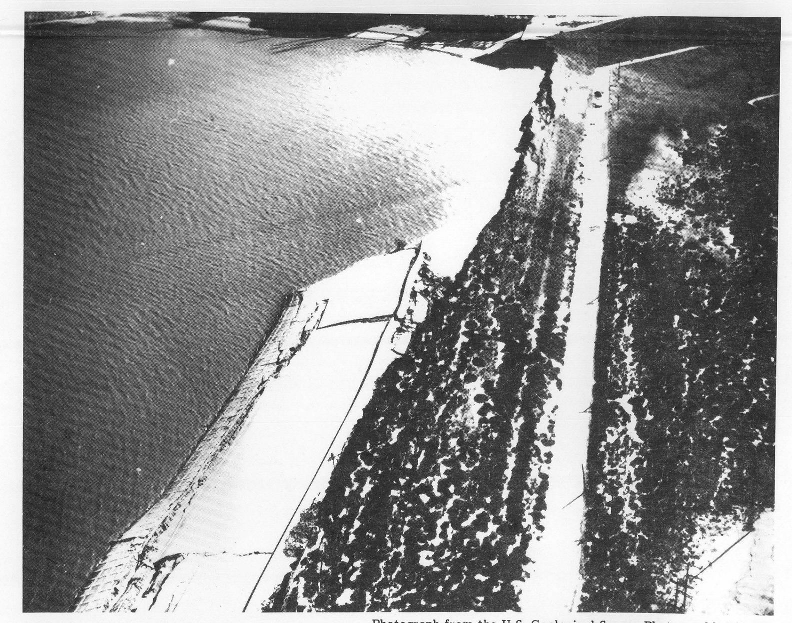
Photograph courtesy of Karl V. Steinbrugge.

FIGURE 8.—Damage to the Mount McKinley Apartment Building, 120 km (75 mi) west of the epicenter of the 1964 Alaska earthquake (magnitude M_S=8.3). This building was one of two virtually identical buildings in Anchorage that were almost identically damaged. One of the piers (white vertical parts of the walls between the windows) on the north end of the building (the end facing the viewer in both figs. 8 and 9) failed in compression at the third floor due to bending of the building and the attached floor slab at that level. The spandrel walls (wall spaces above and below the windows), being thinner and weaker than the piers, show the typical earthquake X-cracking, or shear-cracking, pattern on all four sides of the building. The cantilever spandrel walls on the corners were cracked horizontally where construction joints between floors separated. This building was constructed according to building codes in use in the early 1950's. The floors were supported by the outside reinforced concrete bearing and shear walls and by the reinforced concrete walls in the elevator and stair cores near the center of the building. Shear forces caused by the earthquake were transmitted from the upper floors to the foundation via the rigid roof and floor diaphrams to the bearing walls (Steinbrugge, Manning, and Degenkolb, 1967).

FIGURE 9.—Close-up view of the part of figure 8 indicated by the rectangle, showing the failure of the pier at the third floor level, cracking at each floor level at the corners of the building, and X-cracking.

Photograph by the U.S. Army. Copy from the U.S. Geological Survey Photographic Library.

FIGURE 16.—Streets that collapsed in downtown Anchorage along the Fourth Avenue slide during the 1964 Alaska earthquake.



Photograph from the U.S. Geological Survey Photographic Library.

FIGURE 17.—Lower Van Norman Dam after the 1971 San Fernando earthquake. This was an hydraulic-fill dam built in 1918. A massive slide in the dam's earthfill embankment, possibly due to liquefaction, dislodged a major segment of the embankment along with its concrete lining and crest. They were deposited on the reservoir floor. The rupture surface was only 1.5 m (5 ft) above water level, leaving the dam on the brink of failure. The Van Norman Dam held, although 80,000 people living below it had to be evacuated for four days while the reservoir water level was being lowered (Youd and Olsen, 1971). Had the magnitude of the earthquake been a little larger, and the vibrations continued for a few more cycles, the dam might well have failed.

TYPES OF DAMAGE THAT COULD RESULT FROM A GREAT EARTHQUAKE IN THE NEW MADRID, MISSOURI, SEISMIC ZONE

By

Margaret G. Hopper and S. T. Algermissen

1984

INTRODUCTION

In the winter of 1811-1812 a series of three great earthquakes occurred in the New Madrid seismic zone. In addition to the three principal shocks, at least 15 other earthquakes, $I_o \geq$ VIII, occurred within a year of the first large earthquake on December 16, 1811. The three main shocks were felt over the entire eastern United States. They were strong enough to cause minor damage as far away as Indiana and Ohio on the north, the Carolinas on the east, and southern Mississippi on the south. They were strong enough to cause severe or structural damage in parts of Missouri, Illinois, Indiana, Kentucky, Tennessee, Mississippi, and Arkansas. The section of this poster titled "Seismic history of the New Madrid region" describes what happened in the epicentral region. Fortunately, few people lived in the severely shaken area in 1811; that is not the case today. What would happen if a series of earthquakes as large and numerous as the "New Madrid" earthquakes were to occur in the New Madrid seismic zone today?

Photographs 1-10 show typical damage to structures that occurred during various earthquakes in the United States. Structural damage to buildings in the Modified Mercalli intensity scale, a scale used for assigning numbers to earthquake effects, begins at intensity VIII. Minor or architectural damage (cracked plaster, windows, and chimneys) occurs at intensities VI and VII, and effects on people and small objects predominate at intensities below VI (earthquake felt, direction and duration noted, dishes broken). Photographs 1-10 illustrate damage caused by intensity VIII and above. None of the damage shown in these photographs occurred in earthquakes larger than the 1811-1812 New Madrid shocks, and most of the examples are from considerably smaller shocks. Photographs 1-4 and 7 show damage to masonry buildings, mostly old and unreinforced, none designed to be earthquake resistant. How many such buildings are in use in your community? Photographs 5 and 6 show damage to modern structures close to the epicenter of a magnitude 6.5 earthquake, a small shock compared to the magnitudes (8.4-8.7) of the New Madrid earthquakes. Photographs 8-10 are typical of damage that can occur at large distances from great earthquakes. Tall buildings are particularly susceptible to ground motions with relatively long periods (greater than 1 second), while short, rigid buildings are generally more likely to be damaged by ground motions with periods of less than 1 second. Shorter period ground motions attenuate more rapidly with distance from the epicenter than do the longer period motions.

The 1811-1812 earthquakes produced extensive ground effects. Earthquakes can cause many different kinds of ground effects, ranging from minor fissures, slumps, and rockslides to major landslides and disturbances of the ground surface. Photographs 11-17 show typical earthquake ground effects and the kinds of damage they can cause to manmade structures.

Is another earthquake as large as the 1811-1812 shocks really likely to occur in New Madrid seismic zone? Great earthquakes such as the 1811-1812 series are estimated to occur in the zone on the average every 500 years. However, earthquakes strong enough to cause structural damage (VIII in the Modified Mercalli intensity scale) are estimated to occur in the seismic zone on the average every 50 years. The last such shock occurred in 1843.

How do you prepare for a possible earthquake and what do you do if one occurs? The section on "Earthquake safety tips" explains what to do before, during, and after an earthquake.

Want to know more? See "Sources of additional information." Other reports of interest are listed in "References cited."

THE "SIZE" OF AN EARTHQUAKE

Magnitude

Magnitude is an instrumental measure of the "size" of an earthquake—that is the total amount of energy released by the earthquake. Several different magnitude calculations can be made from the amplitudes of the seismic vibrations recorded by a seismograph. The two most common ones are m_b, derived from the body-wave vibrations, which travel through the earth, and M_s, derived from the surface-wave vibrations, which travel along the earth's outer crustal layers. Calculation of the magnitude of an earthquake takes into consideration the amplitude and period of the recorded vibrations and the distance of the seismograph from the source of the earthquake within the earth--the hypocenter. Thus, the same magnitude will be calculated from the recordings made by seismographs at different distances from the hypocenter. Because the first instrumental magnitude scale was developed in 1935 by Charles F. Richter, magnitude is commonly referred to as "the Richter scale."

Intensity

Intensity is a measure of the effects of an earthquake on people, animals, structures, and the ground. Intensity values are denoted by Roman numerals on the Modified Mercalli Intensity Scale (Wood and Neumann, 1931), which ranks seismic effects into twelve levels of increasing severity. An intensity map or isoseismal map for an earthquake is made by plotting on a map the intensities assigned to the effects produced by the earthquake at various places and then contouring the plotted values. The isoseismal or contour for the maximum intensity (I_o) usually includes the instrumentally located epicenter, the point on the earth's surface directly above the hypocenter.

For preinstrumental earthquakes, such as those that occurred in the New Madrid seismic zone in 1811-1812, no magnitudes or instrumentally-located epicenters are known, but intensities can be assigned on the basis of descriptive reports such as newspaper accounts. Intensities and isoseismal maps are used to estimate both the epicentral area and the magnitude of preinstrumental earthquakes. The epicenter is assumed to be near the center of the highest isoseismal, and the magnitude is usually estimated either from I_o or from the size of the areas enclosed by the isoseismals.

EARTHQUAKE SURVIVAL TIPS

(Quoted and extracted in part from Gates, 1982)

The actual movement of the ground in an earthquake is seldom the direct cause of death or injury. Most casualties result from falling objects and debris. Earthquake-related injuries are commonly caused by (1) partial building collapse, such as toppling chimneys, falling brick from wall facings and roof parapets, collapsing walls, falling ceiling plaster, light fixtures, and pictures; (2) flying glass from broken windows (this danger may be greater from windows in high-rise structures); (3) overturned bookcases, fixtures, and other furniture and appliances; (4) fires from broken chimneys, broken gaslines, and similar causes (this danger may be aggravated by a lack of water with which to fight fire caused by broken mains); (5) fallen powerlines; and (6) drastic human actions resulting from panic.

What You Can Do Before an Earthquake Occurs

1. Support the adoption and enforcement of building codes that have suitable requirements for earthquake-resistant design.

2. Check your home for earthquake hazards. Bolt down or provide other strong support for gas appliances and gaslines. Use flexible connections wherever possible.

3. Teach responsible members of your family how to turn off electricity, gas, and water at main switches and valves.

4. Provide for your family to receive instruction in basic first aid because medical facilites may be overloaded immediately after a severe earthquake.

5. Think about what you should do if an earthquake strikes when you are at home; at school; driving your car; at work; in a store, public hall, theater, or stadium.

What You Can Do During an Earthquake

1. If indoors, watch for falling plaster, bricks, light fixtures, high bookcases, and other furniture which might slide or topple. Stay away from windows, mirrors, and chimneys. If in danger, get under a table, desk, or bed; in a corner away from windows; or in a strong doorway. Usually, it is best not to run outside.

2. If in a high-rise office building, get under a desk. Do not dash for exits, since stairways may be broken and jammed with people. Power for elevators may fail.

3. If outside, avoid high buildings, walls, and power poles. Move to an open area away from all hazards.

What You Can Do After an Earthquake

1. Apply first aid or seek medical help for injured people.

2. Check for fires or fire hazards. Do not use matches, lighters, or open-flame appliances until you are sure that there are no gas leaks. Do not operate electrical switches or appliances if gas leaks are suspected.

3. Avoid downed powerlines or objects touched by the downed wires.

4. Obtain emergency water from water heaters, toilet tanks, melted ice cubes, and canned vegetables, if the water is off.

5. Check to see that sewage lines are intact before permitting continued flushing of toilets.

6. Do not use your telephone except for genuine emergency calls.

7. Check your chimney. Unnoticed damage could lead to a fire. The initial check should be made from a distance. Approach chimneys with caution.

8. Do not go sightseeing. Keep the streets clear for passage of emergency vehicles.

9. Be prepared for additional earthquake shocks called "aftershocks."

SEISMIC HISTORY OF THE NEW MADRID REGION

Earthquakes of 1811-1812

During the winter of 1811-1812, three great earthquakes occurred in the Mississippi Valley, each having magnitude M_S 8.4 or higher. (See section on "The 'size' of an earthquake" for an explanation of magnitude and other related terms.) No earthquakes larger than these have occurred within the conterminous United States during historic time. Their magnitudes are comparable to, and are probably larger than, those of the largest California earthquakes, and, because of the low attenuation of seismic intensities in the eastern and central United States, they were felt over areas much larger than the areas over which California shocks of similar magnitude are felt. The 1811-1812 earthquakes were felt with intensities greater than or equal to V on the Modified Mercalli intensity scale (that is, enough to cause alarm and knock small objects off shelves) over the entire eastern United States (Nuttli, 1973).

Main shocks of the 1811-1812
"New Madrid" earthquake sequence

(Nuttli, 1981)

Date	I_o	M_S	m_b
Dec. 16, 1811	XI	8.6	7.2
Jan. 23, 1812	X-XI	8.4	7.1
Feb. 7, 1812	XI-XII	8.7	7.3

The maximum intensities of the three 1811-1812 earthquakes range from X to XII. In the region of the epicenter of the first shock, the Saint Francis River area of northeastern Arkansas, a lake was uplifted and drained, whereas other places subsided as much as 12 ft (3.7 m). Sand and other materials were thrown from fissures or cracks in the swampland. The greatest disturbance occurred along the Mississippi River between Islands 30 and 40 along the Tennessee-Arkansas border north of Memphis (Nuttli, 1973). According to Fuller (1912), "Great waves were created, which overwhelmed many boats and washed others high upon the shore, the return current breaking off thousands of trees and carrying them out into the river. High banks caved and were precipitated into the river, sand bars and points of land gave way, and whole islands disappeared." Uplifted areas caused ponding and waterfalls along the Mississippi. Landslides were extensive along the river banks as far up the Ohio River as Indiana but were particularly severe along the Chickasaw Bluffs on the Mississippi River north of Memphis. The roads between New Madrid and Arkansas were made impassable by the earthquake. The area of marked earth disturbances extended from Cairo, Ill., to Memphis, Tenn., and from Crowley's Ridge (northeastern Arkansas) to the Chickasaw Bluffs (hills north of Memphis).

Five weeks after the first shock, another, nearly as large as the first, occurred northeast of the first one along the seismic zone. Two weeks after the second earthquake, yet another earthquake, greater than either of the preceding ones, occurred; its epicenter was near New Madrid at the northern end of the seismic zone. In addition to the three main shocks, there were numerous aftershocks, fifteen of them quite strong. These fifteen, plus the three main shocks, were all strong enough to be felt as far away as Washington, D.C., and when they occurred at night they awakened sleepers there (Nuttli, 1981). Nearly 2,000 aftershocks were reported felt at Louisville, Ky., some 200 mi (320 km) from the epicentral area, in the 3 months following December 16 (Nuttli, 1973; Fuller, 1912).

Seismicity of the New Madrid Seismic Zone

The New Madrid seismic zone is not a fault that breaks the ground surface, as does, for example, the San Andreas fault in California. The existence of a fault deep beneath the sediments has been inferred from the earthquakes that have taken place in the seismic zone; however, the fault's precise location could not be established using the scattered historical earthquake epicenters, which were mostly located by using intensity data rather than instrumental data. Insufficient information is available to make detailed isoseismal maps for the 1811-1812 New Madrid earthquakes because the region was sparsely settled in 1811. In fact, there is no information at all about the effects of the 1811-1812 earthquakes west of the Mississippi River.

Since the installation of a regional seismic network in 1974, numerous microearthquakes, for the most part not large enough to be felt, have been recorded. The lineation of these accurately located microearthquakes defines the location of the seismic zone. Large historical earthquakes have also occurred along or near the zone defined by this microearthquake activity. Two of the best documented of these large earthquakes are (1) the January 5, 1843, earthquake (I_o=VIII, m_b=6.0) with an epicenter near Memphis, Tenn., at the approximate southern end of the seismic zone, and (2) the October 31, 1895, earthquake (I_o=IX, m_b=6.2) with an epicenter near Charleston, Mo., near the northern end of the seismic zone. Because of the better documentation, it is possible to make more complete, detailed isoseismal maps for these large earthquakes than for the great shocks in 1811-1812.

The recurrence time in the central Mississippi Valley for earthquakes as large as the 1811-1812 shocks is estimated to be about 500 years. This does not mean it is safe to assume that another such earthquake cannot occur until 500 years after 1812. Rather, it is a statistical estimate that during, say, 500,000 years, about 1,000 earthquakes of this size are likely to occur. Smaller earthquakes in the region are much more frequent. For example, in this area earthquakes having maximum intensity I_o=IX have an estimated recurrence time of about 80 years (the last one was in 1895); and I_o=VIII, 50 years (last one, 1843). Earthquakes causing minor damage, that is I_o=VI, occur in this area at a rate of about one in 10 years (Algermissen, 1972).

Main shocks and aftershocks of the 1811-1812
New Madrid earthquake sequence
(Nuttli, 1981)

Number of shocks	I_o	M_S
3	X-XII	$\geq$8
5	IX-X	7-8
10	VIII-IX	6-7

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