

2.9 EARTHQUAKE

Earthquakes occur as a result of the constant motion of the earth. Current science describes the earth in three major regions: the core, mantle and crust. Figure 2.9.a provides a three dimensional representation of the earth's regions.

The core is hot and consists of two subsections. The very center of the planet's core is hottest and solid. Surrounding the solid center is a liquid (i.e. molten material / magma) layer.

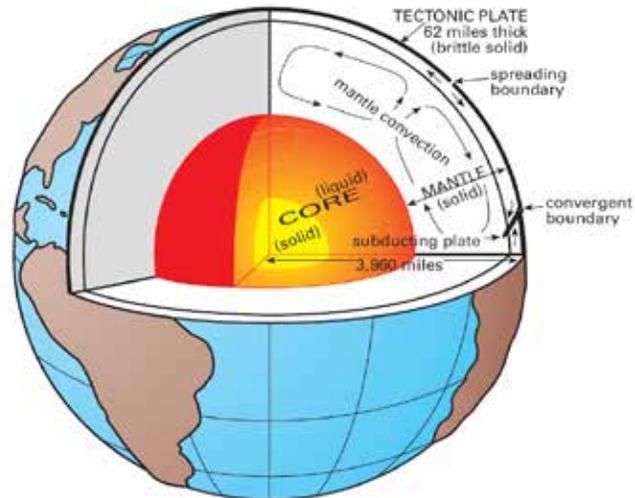
The mantle is cooler than the core and although solid, circulates with the consistency of malleable plastic. Through convection, the portion of the mantle closest to the core heats and subsequently rises in the same manner as the air in the earth's atmosphere. Conversely, the upper portion of the mantle transfers its heat to the crust, cools and descends back toward the core.

The crust is also solid; however, unlike the mantle it is rigid and brittle. The crust consists of a number of individual plates, each in constant motion, resting on the mantle. The boundaries where plates meet are the locations where new crust develops (spreading boundary) and alternately existing crust material returns to the mantle (convergent boundary.)

Understanding the composition of the earth is crucial because earthquakes are often associated with boundaries where the plates slide against, rise over or sink under each other. The movement at many of the plate boundaries is not smooth and consistent, but rather grinds and jerks. As entire plates move the boundaries become locked together and enormous amounts of tension build until a sudden release occurs, realigning the plate edges and creating the observed earthquake.

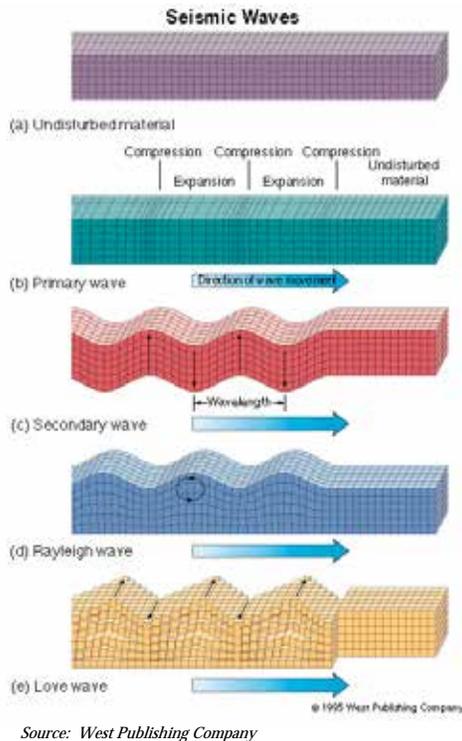
The locations where the crust is fractured and sliding are called faults. California has several famous faults (e.g. the San Andreas Fault), which can be clearly observed though aerial photography. In cases where the crust is pulling apart, the location is called a rift. The Reelfoot Rift and associated rift valley located in Missouri is one of the largest in North America. Ohio geologically contains both fault and rift zones.

Figure 2.9.a



Interior zones of the Earth (figure modified from Washington Division of Geology and Earth Resources, Information Circular No. 85, 1988). The Earth's crust consists of great plates that slowly move across the surface of the Earth in response to convection cells in the mantle. Most earthquakes occur where plates meet, such as at spreading or convergent boundaries.

Source: Educational Leaflet No. 9 Revised Edition 2007 Division of Geological Survey

Figure 2.9.b

Source: West Publishing Company

Another significant source of earthquakes is associated with large bodies of magma, which are located near the earth's crust. The Hawaiian archipelago and Yellowstone National Park are examples where magma deposits are altering the crust and generating both volcanic activity and earthquakes.

Earthquake locations are recorded based on the latitude and longitude of the occurrence, called the epicenter, and the associated depth underneath the earth's surface. The energy released in earthquakes travels from the epicenter in seismic waves through the earth. The four major types of waves are often referred to as primary, secondary (body waves), Rayleigh and Love (surface waves) (Figure 2.9.b). Primary waves compress the earth's surface in front of it as they travel. Secondary waves cause the earth's surface to rise and fall perpendicular to its line of travel. Rayleigh waves travel in a

circulating pattern similar to those in an ocean wave. Finally, Love waves cause the earth's surface to oscillate from side to side perpendicular to its line of travel. The primary and secondary waves travel faster than the Rayleigh and Love waves providing the initial evidence of an event.

Each wave affects structures differently. For example, secondary waves have much greater impact in tall structures. Additionally, each wave has unique characteristics. The secondary wave, for example, cannot travel through fluids, including the molten outer core.

Location of earthquake events has the added dimension of land / crust composition. Within the United States, areas like southern California are primarily young, hot rock that is broken by mountain ranges. Under these conditions seismic waves are somewhat limited in their ability to travel (attenuation) reducing the overall area of impact. Conversely, seismic zones in the central and eastern United States have flat-lying, cold, brittle rocks with much thicker deposits of soil and sediments. Loosely consolidated materials such as sand and soil cause seismic waves to amplify ground motion.

When seismic waves travel through unconsolidated materials it can have the effect of turning solid land into quicksand. When this phenomenon, called liquefaction, occurs, any object located in the affected area may slide over or sink into the soil. Entire buildings, roadways and bridges may be significantly damaged.

One factor which greatly determines the extent of damage from an event is duration. Events can last anywhere from a few seconds to minutes. The longer the event is promulgating seismic waves the greater the opportunity for damage.

Earthquake forces are generally measured using an instrumental scale developed initially in 1935 by Charles Richter. The scale is open ended but

Figure 2.9.c

Modified Mercalli Intensity Scale		Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibrations like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some awaken; dishes, windows, doors disturbed; standing autos rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	4.5
VIII	Panel walls thrown out of frames; walls, monuments, chimneys fall; sand and mud ejected; drivers of autos disturbed	5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	5.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	6.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	7

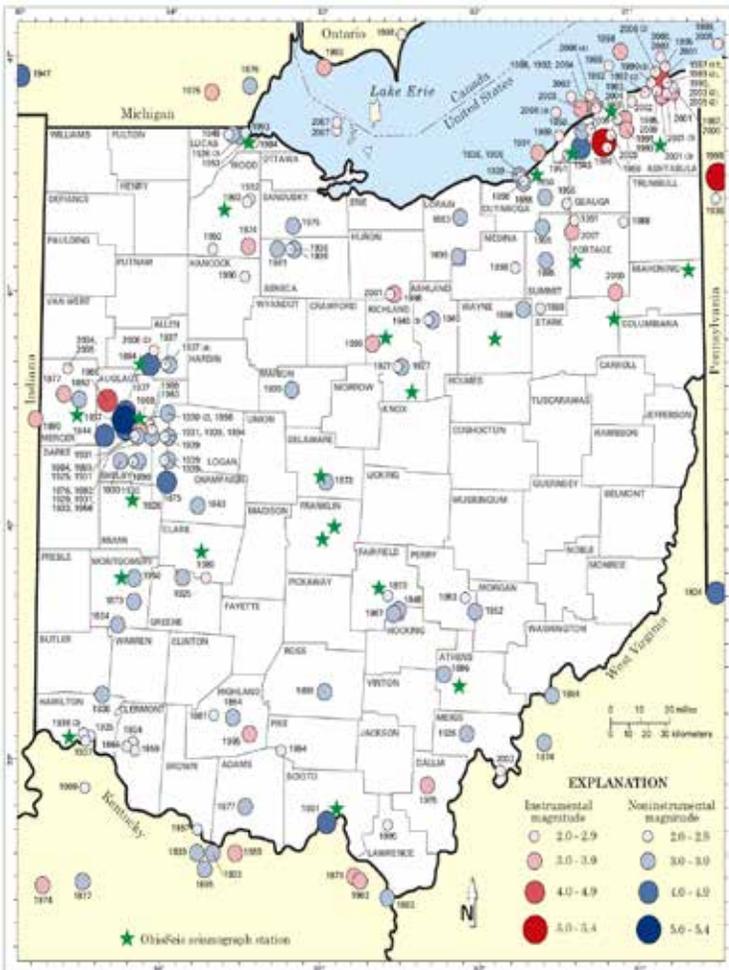
General relationship between epicentral Modified Mercalli intensities and magnitude. Intensities can be highly variable, depending on local geologic conditions. (Modified from D. W. Steeples, 1978, Earthquakes: Kansas Geological Survey pamphlet.)

Source: Educational Leaflet No. 9 Revised Edition 2007 Division of Geological Survey

generally ranges to 9+ (severe damage and ground deformation). The scale is logarithmic which can be confusing. For example, an earthquake of magnitude 2.0 is 30 times more powerful, in terms of energy released, than one rated 1.0.

Another method of measuring an earthquake event is by describing its intensity. Italian volcanologist Giuseppe Mercalli developed a widely used scale in 1902 based on the previous Rossi-Forel scale. Over time experts have altered the original scale creating the currently used version named the Modified Mercalli Intensity Scale (MMI).

Looking at Figure 2.9.c the exponential increases in damage for each single digit increase in the intensity scale is apparent. For example, MMI IX discusses shifted and damaged building while X describes mass destruction of masonry (brick) and frame (wood) buildings.



Locations of 600 earthquakes of 2.0 or greater in Ohio and its border area. Locations and magnitude of historic earthquakes are represented by symbols corresponding to felt area or maximum epicentral Modified Mercalli Intensity. Non-instrumental locations may be in error by a considerable distance, especially for early events.

Source: Educational Leaflet No. 9 Revised Edition 2007. ODNR - Division of Geological Survey

Map 2.9.a

the most earthquake-prone areas. Similarly, another earthquake-prone area is located in the west-central Counties of Auglaize, Champaign, Logan, Mercer, and

RISK ASSESSMENT

Location

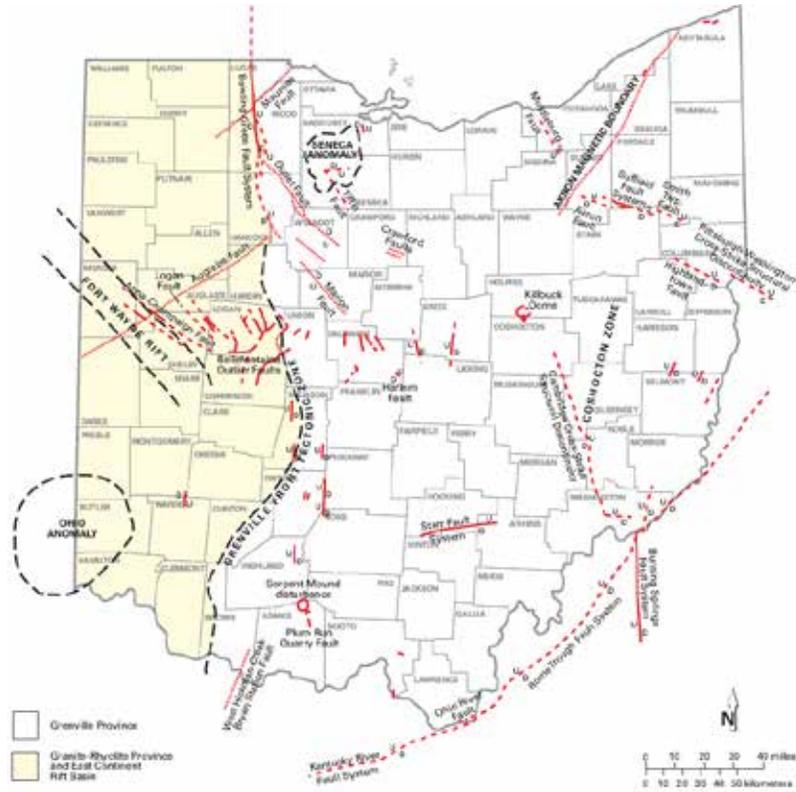
Earthquakes in Ohio are primarily located the northeast and far west-central portions of the state and historically have not exceed 5.4 magnitude (Map 2.9.a). The map of historical epicenters lists all the events with magnitudes greater than 2.0. The size of the location marker increases with the magnitude of the event. Red circles represent instrumentally recorded events. Blue circles represent non-instrumentally recorded.

The epicenter map clearly identifies the northeast Ohio counties of Ashtabula, Geauga and Lake in Region 1 as one of

Shelby (Region 3). Although there are clear clusters of activity, a limited number of events have occurred and are spread over a large portion of the state.

According to information published by the ODNR Division of Geological Survey, the origins of Ohio earthquakes, as with earthquakes throughout the eastern United States, are poorly understood at this time. Those in Ohio appear to be associated with ancient zones of weakness in the Earth's crust that formed during continental collision and mountain-building events about one billion years ago. These zones are characterized by deeply buried and poorly known faults, some of which serve as the sites for periodic release of strain that is constantly building up in the North American continental plate due to continuous movement of the tectonic plates that make up the Earth's crust.

Map 2.9.b



Basement structures in Ohio (modified from Division of Geological Survey Map PG-23, 2002). This map portrays a number of deep faults and other structures that have been identified by a variety of geologic studies. Some faults are well known, whereas others are speculative. Very few of them are visible at the surface. The Fort Wayne (Anna) rift in western Ohio is the site of numerous historic earthquakes.

The Division of Geological Survey has developed a map of geologic features, referred to as basement structures, which lie far below the earth's surface (see Map 2.9.b). The Region 1 active zone corresponds to the structure called the Akron Magnetic Boundary. Several geologists have speculated the boundary is a fracture zone in crystalline rocks lying more than 6,000 feet below the surface. The active area of Region 2 matches to better understood features. The Fort Wayne Rift along with the Anna-Champaign, Logan and Auglaize faults, though still poorly understood, can be evaluated using the existing understanding of how these structures behave.

LHMP Data

As indicated in the vulnerability analysis below, Hamilton County and Shelby County are the most likely counties in Ohio to be affected by a significant

earthquake (Hamilton County's issues are compounded by the county's susceptibility to landslide and soil liquefaction). Both the Hamilton County and the Shelby County LHMP considers earthquakes, ranked fifth and sixth, respectively, to be a high ranking hazard for them. They acknowledge that an earthquake is a low probability, high consequence event. The lack of public awareness, building standards, and aging infrastructure were the reasons cited by Hamilton County for ranking earthquakes within their top five concerns. Shelby County, considered to be one of the most active seismic zones within the state, experiencing more than 40 since 1875, ranked earthquakes sixth based on its history of earthquakes, which includes the most damaging earthquake to strike the state.

Auglaize County. The Auglaize County Hazards Mitigation Plan mentions an earthquake of a 4.5 magnitude wave was felt in Auglaize County on July 12, 1986. This quake occurred near the City of St. Marys and caused minor damage. It occurred on the Anna-Champaign fault which runs from Champaign County through Shelby, Auglaize, and Mercer Counties. Broken windows in the nearby Town of Moulton and medications falling off shelves at the Joint Township District Memorial Hospital were among the damages that occurred. These analyses projected 5,213 residential structures at risk at a value of \$215,567,580, an estimated 171 non-residential structures valued at \$22,564,664 and eight critical facilities valued at \$7,177,728.

Shelby County. The Shelby County Hazards Mitigation Plan provides a worst-case scenario by simulating a 5.4 magnitude wave earthquake with an epicenter in Anna, Ohio with no depth. Using a combination of HAZUS-MH and conversion charts, it was determined that such an event would yield an estimated 1,727 residential structures at risk at a value of \$293,222,603, an estimated 2,002 non-residential structures valued at \$341,732,742 and 35 critical facilities valued at \$5,974,349.

Lake County. The Lake County Multi-Jurisdictional Hazards Mitigation Plan updated in 2010 states that the county's largest earthquake occurred in 1986 in the central part of the county registering 5.0 – 5.4 instrumental magnitude. An earthquake of this size is classified as intermediate to severe on the Richter Scale. Lake County has experienced 15 quakes between 1858 and the present, with an approximate 9.7 percent chance of an event occurring in any given year with an estimate of 37,031 structures at risk valued at a loss of \$2,383,971,440.

Medina County. The Medina County All Hazard and Flood Mitigation Plan updated in 2011 states that the strongest quake was felt on January 31, 1986, where the magnitude wave reading was 5.0. There was only moderate to minor damage such as broken windows and cracked plaster. There have been a few instances that seismic activity has been felt and caused damage. An earthquake scenario estimates 6,089 residential structures at risk at a value of \$1,198,565,176.68 an estimated 1,846 non-residential structures valued at \$560,602,287.17 and 92 critical facilities valued at \$27,939,008.89.

SHARPP. Hazard identification data were queried from SHARPP to evaluate each hazard and its frequency. Considering all hazards identified in the local plans, earthquakes ranked nearly last in terms of frequency, as large instances have occurred in minimal numbers around the state (Chart 2.2.a). However, this hazard ranked the highest for onset, or warning time, whereby local plans indicated little to no warning. Also, dam/levee failure ranked at or near the top of the list for potential business, human (*i.e.*, loss of life), and property impacts. Overall, this hazard ranked fourth out of 15 hazards evaluated in SHARPP, which indicates earthquakes are considered to be a potential threat throughout the state. According to records and data entered to date into vulnerability assessments, potential losses from earthquakes are estimated at 386,095 residential structures (\$11,619,647,525), 39,228 non-residential structures (\$2,775,420,583) and 1,049 critical facilities (\$2,058,194,796). These and additional HIRA data queried from SHARPP can be found in Appendix J.

National Level Exercise, 2011 (NLE-11)

In September 2010, Ohio EMA's Mitigation Section was consulted to provide HAZUS runs for an earthquake tabletop exercise scenario. The scenario was designed for selected counties in southwest Ohio in preparation for NLE-11 (National Level Exercise 2011). The purpose is to test critical resource logistics and catastrophic planning in conjunction with FEMA Region V and participating States. HAZUS runs were produced for Hamilton, Butler, Clermont, Darke, Scioto and Warren Counties with a 5.7 moment magnitude scale epicenter in downtown Cincinnati to a depth of 10 kilometers.

The aggregate HAZUS runs resulted in 79,070 buildings with moderate damage and 4,418 buildings beyond repair. 487 essential facilities would be less than 50% functional. 1,468 transportation systems and 201 utility systems would be damaged. Destruction is projected to produce 3.513 million tons of debris and 93 fire ignitions resulting 13,490 people displaced from their residences with \$1,248,000,000 in damage. The social impact estimates 179 fatalities, 123 people with life-threatening injuries, 901 people would have to be hospitalized and 3,871 would have to be treated with first aid or at an aid station. 8,806 people would seek temporary shelter. The economic impact is projected to result in \$10,828,490,000 in lost income and, \$2,050,500,000 in capital stock loss. It is estimated to take 15 years for economic recovery from this event.

Past Occurrences

Earthquakes are a continuously occurring hazard in Ohio. Eleven events were recorded by the Division of Geological Survey for the first 11 months of 2007. Data are available for events dating back over 200 years.

Most of Ohio's earthquake events are small, registering between 2 and 4 magnitudes. Significant events are discussed in Geological Survey document *Educational Leaflet No. 9*, which follows.

Summer 1776: The earliest Ohio earthquake to be noted occurred at 8 a.m. sometime in the summer of 1776 and was chronicled by John Heckewelder, a

Moravian missionary, who reported that “the southwest side of the house was raised with such violence that the furniture of the room was nearly overturned.” Heckewelder spent the summer of 1776 at the Moravian mission of Lichtenau, which was in present-day Coshocton County. Because his report is the only account of this event, it is impossible to determine an epicentral location with any certainty. It should be noted the epicenter of this earthquake may not have been in Ohio.

1811 and 1812: On December 16, 1811, and January 23 and February 7, 1812, the largest earthquakes ever to strike the continental United States occurred at New Madrid, Missouri. These events were felt throughout an area of about 2 million square miles, including all of Ohio. In Ohio, some chimneys were toppled in the Cincinnati area, which experienced the strongest shaking from these events. Should earthquakes of this intensity be repeated at New Madrid, they would probably cause considerable damage in southwestern Ohio.

June 18, 1875: This earthquake was felt throughout an area of at least 40,000 square miles and was most intense at Sidney (Shelby County) and Urbana (Champaign County), where masonry walls were cracked and chimneys toppled. It has been interpreted to have had an MMI of VII.

September 19, 1884: An earthquake in the vicinity of Lima (Allen County) had an epicentral MMI of VI. There were reports of fallen ceiling plaster as far away as Zanesville (Muskingum County) and Parkersburg, West Virginia. On the basis of area feeling the earthquake (140,000 square miles), it is estimated to have had a magnitude of 4.8. Workmen on top of the Washington Monument in Washington, D.C., reported feeling this earthquake.

May 17, 1901: During this earthquake, bricks were dislodged from chimneys and some windows were cracked in Portsmouth (Scioto County) and chimneys were damaged in Sciotoville. Modified Mercalli intensities of VI were generated in the epicentral area. Based on felt area, this earthquake was assigned a magnitude of 4.3.

November 5, 1926: This earthquake was centered near Pomeroy and Keno, in Meigs County, where chimneys were toppled. A stove was over turned at Chester. Modified Mercalli intensities of VII were generated in the epicentral area, but the earthquake was felt only in portions of Meigs County and adjacent parts of West Virginia. On the basis of this small felt area, this event has been assigned a magnitude of 3.6. Explosive earth sounds were reported to have accompanied this earthquake.

September 30, 1930: This earthquake cracked plaster and toppled a chimney in Anna (Shelby County). An epicentral MMI of VII and a magnitude of 4.2 have been assigned to this event.

September 20, 1931: In this event, Anna and Sidney in Shelby County experienced toppled chimneys and cracked plaster. Store merchandise and crockery were knocked off shelves, and stones were jarred loose from the foundation of the Lutheran church in Anna. A ceiling collapsed in a school at

Botkins, north of Anna. An MMI of VII and a magnitude of 4.7 have been assigned to this earthquake.

March 2 and 9, 1937: These two earthquakes are the most damaging to have struck Ohio. Maximum intensities were experienced at Anna (Shelby County), where an MMI of VII was associated with the March 2 event and an MMI of VIII with the March 9 event. In Anna, chimneys were toppled, organ pipes were twisted in the Lutheran church, the masonry school building was so badly cracked that it was razed, water wells were disturbed, and cemetery monuments were rotated. Both earthquakes were felt throughout a multi-state area—plaster was cracked as far away as Fort Wayne, Indiana. The March 9th event was felt throughout an area of about 150,000 square miles. Analysis of seismograms from these earthquakes by the U.S. Geological Survey (Stover and Coffman, 1993) assigned magnitudes of 4.7 and 4.9, respectively, to these events. On the basis of felt area, these earthquakes have been assigned magnitudes of 4.9 and 5.4, respectively.

January 31, 1986: This earthquake, which had a magnitude of 5.0 and an MMI in the high VI range, occurred in Lake County, east of Cleveland, in the general vicinity of a 1943 event with 4.5 magnitude. The 1986 earthquake cracked plaster and masonry, broke windows, and caused changes in water wells. The epicenter was only a few miles from the Perry nuclear power plant. It is the most intensively studied earthquake in Ohio and was the subject of several scientific reports (*i.e.*, Nicholson and others, 1988).

July 12, 1986: Minor damage, consisting primarily of cracked windows and plaster and fallen bricks from chimneys, was reported from this MMI VI earthquake centered northwest of Anna, near St. Mary's, in Auglaize County. It had a magnitude of 4.5.

January 25, 2001: The city of Ashtabula was struck by a 4.5-magnitude earthquake that caused minor damage to about 50 homes and businesses. This earthquake was the largest in a series of shallow earthquakes that began in 1987 and were attributed to fluids from a Class I deep-injection well. Nearly 40 earthquakes above a magnitude of 2.0 were recorded at Ashtabula through 2001. Prior to 1987, no earthquakes had been noted in the area.

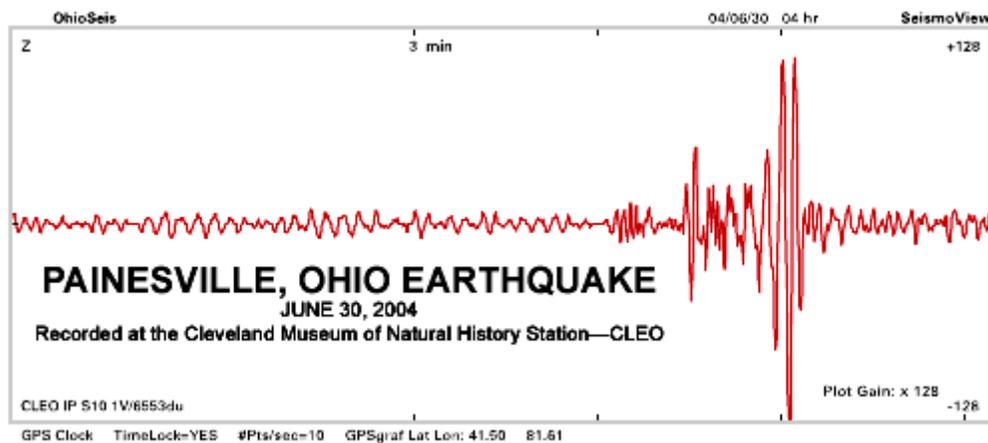
June 3, 2001: Residents of Ashtabula and nearby areas were shaken by another earthquake on June 3, 2001, at 6:36 p.m. This event had a magnitude of 3.2, as determined by the Ohio Seismic Network. No damage was reported, although more than 90 felt reports were received by the Ashtabula County Emergency Management Agency. A 2.3-magnitude aftershock was recorded at 4:27 a.m. on June 5. One person reported feeling it. The epicenter location is east of Ashtabula.

May 6, 2002: On Monday, May 6, 2002, a small earthquake occurred at 6:26 p.m. Eastern Daylight Time near the Ohio River in Meigs County, in the general vicinity of the communities of Racine and Antiquity. No felt reports were immediately received by the Ohio Seismic Network. The event was originally

noted and located by the Virginia Tech Seismological Observatory in Blacksburg, VA.

June 30, 2003: The Ohio Seismic Network recorded a small earthquake beneath Lake Erie, offshore from Lake County, on June 30 at 3:21 p.m.. The 3.5-magnitude earthquake was widely felt in Lake, Ashtabula, and Geauga Counties. There were no reports of injuries or damage, which would not be expected from an earthquake of this size.

June 30, 2004: A small 3.3 magnitude earthquake occurred at 12:03 a.m. EDT 9 miles ENE of Painesville, Lake County, Ohio. It was strongly felt at Painesville, Madison, and Perry, Ohio. No damages were reported. Many residents reported a loud boom followed by a sharp jolt and brief, but intense shaking. This is the second earthquake this year in the general area of Painesville. On March 14, 2004 a 2.4 magnitude earthquake was centered near Fairport Harbor.



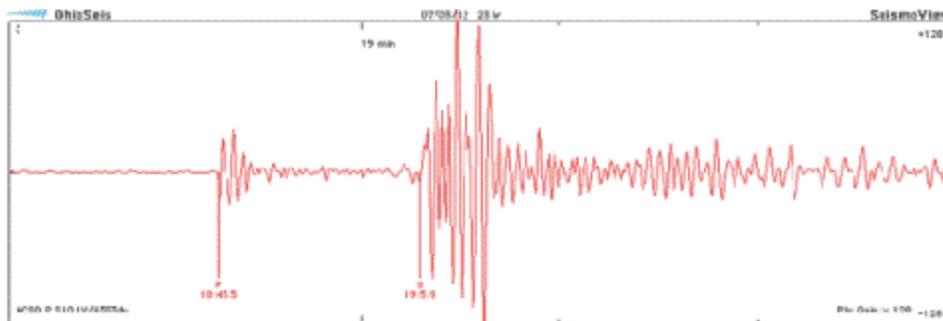
Filtered seismogram recorded at OhioSeis station CLEO (Cleveland Museum of Natural History).

March 11, 2006: A small, but widely felt, earthquake occurred on Saturday, March 11 at 7:27 a.m. Eastern Standard Time beneath Lake Erie about three miles offshore from Mentor and Mentor-on-the-Lake, Lake County. More than 300 felt reports were submitted to the Community Internet Intensity Web site from individuals in communities as far west as Euclid and as far east as Painesville. Most reports came from Mentor and Mentor-on-the-Lake and Eastlake but a significant number came from Willoughby and Willowick. Maximum Modified Mercalli Intensity was III. No damage was reported. Many residents reported a boom or jolt followed by a brief period of high-frequency shaking. Commonly, a first reaction was that a vehicle or tree limb had hit the house or that the furnace exploded. If you felt this earthquake and have not submitted a report, please follow the link below and fill out a short form. Collectively, this information is of great value to the Ohio Seismic Network in understanding how sediments respond to earthquakes. Such information will assist in future preparation of maps depicting seismic risk in various areas.

May 12, 2006: A small earthquake struck the east side of Lima on May 11 at 9:51 p.m. EDT (01:51 May 12 UTC). No damage was reported from the 2.8-magnitude event but many residents of Lima, particularly on the east side of town, reported a booming sound followed by a brief period of shaking. Many thought that the refinery exploded. Approximately 40 felt reports were submitted through the Internet. Most were from the east side of Lima, but reports were received from Ada, Beaver Dam, Elida, Harrod, and Ottoville. Modified Mercalli intensity was III. The event was recorded at Ohio Seismic Network stations throughout western and central Ohio.

June 20, 2006: A small earthquake occurred beneath Lake Erie about 10 km northeast of Painesville at 4:11 p.m. EDT. Many people from Eastlake to Ashtabula felt this event as a sharp shaking and some reported a booming sound. No damage was reported and would not be expected with an earthquake of this size. A number of small earthquakes, dating back to at least 1988 have occurred at this general location, including a 3.4-magnitude event on June 30, 2003. A small aftershock occurred at 4:57 p.m. No felt reports were received for this 2.2-magnitude earthquake.

March 12, 2007: A small, but strongly felt earthquake struck a several-county area of northeastern Ohio on Monday, March 12 at 7:18 Eastern Daylight Time. No damage was reported although many people were alarmed by the earthquake. The event was felt throughout an area of about 3,000 square miles as defined by contiguous zip codes from which felt reports were received. Maximum intensities (IV) were recorded at Aurora, Northfield, and Twinsburg.



Seismogram of the March 12, 2007 earthquake (3.3 mbLg) near Twinsburg as recorded at OhioSeis station ACSO at Alum Creek State Park, about 111 miles southwest of the epicenter. Arrival times of the P and S waves are noted.

October 10, 2007: A small earthquake occurred beneath Lake Erie about four miles northwest of Mentor-on-the-Lake and was widely felt along the Lake Erie shore area east of Cleveland. The 3.2 magnitude earthquake occurred at 4:04 p.m. EDT and caused much alarm among residents of Mentor, Willoughby,

Eastlake, and other communities and resulted in numerous calls to local law enforcement agencies, news media, and the Lake County Emergency Management Agency. Many described a booming sound and a sharp jolt. There have been several small earthquakes in this general area in recent years. No reports of damage were received.

September 18, 2008: A small earthquake occurred beneath Lake Erie about seven miles NNW of Mentor at 9:04 p.m. EDT. A number of small earthquakes have occurred in this general location, beginning in 2006. Felt reports were mostly from Mentor but individuals in Willoughby and Eastlake also reported feeling the event. There were no damages.

September 30, 2008: A small earthquake centered in northwestern Shelby County, north of Lake Loramie, was felt by residents in Shelby and surrounding counties at 9:06 p.m., September 29, 2008 EDT. This event was in the Anna Seismic Zone, which has traditionally been one of the most active seismic zones in Ohio. The epicenter of the earthquake is very close to the northwest-trending Anna-Champaign fault.

April 24, 2009: A small earthquake occurred about six miles WNW of Gallipolis, Gallia County, Ohio, at 9:42 a.m. EDT. The earthquake was felt over a several county area, including parts of West Virginia and Kentucky. There were no damage reports, which is consistent with an earthquake of this magnitude.

April 25, 2010: A small earthquake occurred in eastern Lake County between Perry and Madison on April 24, 2010, at 10:00 p.m. EDT. Many residents of both communities reported feeling the event. A 2.3 magnitude earthquake occurred very near this location on February 1, 2005 and a 3.3 earthquake occurred here on June 30, 2004. No damages were reported.

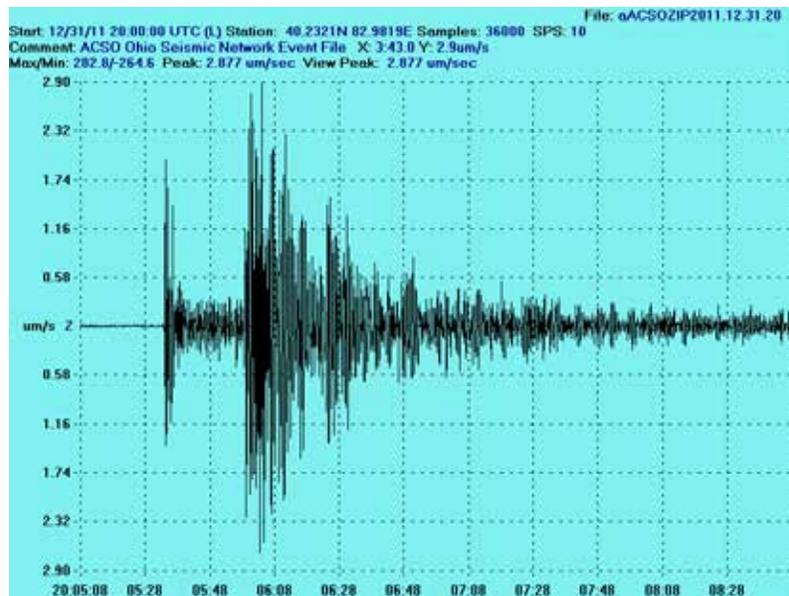
October 24, 2010: A small earthquake occurred at 4:12 a.m. EDT about 5 miles ENE of Marietta, Washington County, Ohio. It awakened residents in Marietta and Reno who described a loud boom and brief shaking that rattled glassware in cabinets. Many thought that their furnace had exploded or a car had hit the building. No damages were reported. There has been no previous record of earthquake activity in historic times in the Marietta area.

June 5, 2011: A small earthquake centered in southwest Medina County was felt by many residents in Medina and neighboring counties at 11:35 a.m. EDT. No damages were reported. Most felt reports were from Lodi, West Salem, and Creston but also came from Burbank, Litchfield, Medina, Spencer, Seville, and Wellington.

August 31, 2011: A small earthquake was felt in the Marietta, Ohio area at 05:35 a.m. EDT. An aftershock occurred at 01:36 p.m. EDT and was felt as well. Data are preliminary at this point and may be revised based on further analysis. No damages were reported from either event.

A second earthquake struck the Marietta, Ohio area at 1:36 p.m. EDT and was widely felt in Marietta and neighboring communities. No damages were reported for either event but many residents described a loud boom and brief shaking. Some residents thought that the afternoon event felt larger than the one in the early morning.

December 31, 2011: A 4.0 magnitude earthquake centered at Youngstown rocked northeastern Ohio just before 3:05 p.m. EST on New Year's Eve. This was the 11th earthquake in a sequence that began on March 17, 2011 at Youngstown. The December 31 earthquake was felt throughout northeastern Ohio, adjacent areas in western Pennsylvania, and in Ontario, Canada. Media reports indicate that damage was minor from this event with a few reports of cracked plaster and glassware falling from shelves. Earthquakes in the low 4 magnitude range would not be expected to cause major damage. More than 4,700 felt reports have been submitted by individuals to the U.S. Geological Survey's [Did You Feel It Web site](#). This event was the strongest quake felt in the area as Youngstown had experienced eleven more events between March 17, 2011 and January 13, 2012 registering from 2.2 to 4.0 magnitude wave.



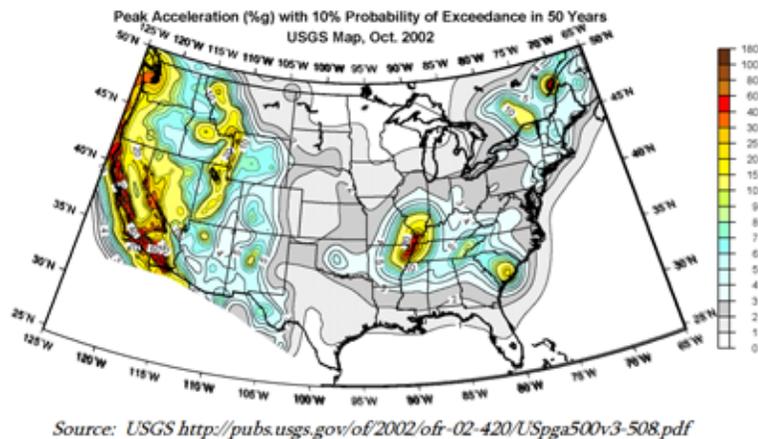
July 1, 2013: A small earthquake occurred at 03:48 a.m. EDT offshore, north of Fairport Harbor, Lake County. A number of small earthquakes have occurred in this general area in recent years. Felt reports were received from Fairport Harbor, Mentor, and Painesville.

Other earthquakes between March 2011 and March 2013 have occurred in northeast Ohio communities such as Lodi, Ohio (Medina County) and Rock Creek (southern Ashtabula County). Four earthquakes have occurred offshore with epicenters in Lake Erie. Two quakes occurred offshore of Lake County, one offshore of Cuyahoga County and one quake originated in the middle of the lake

along the Ohio-Ontario Canada border. In southeastern Ohio, five earthquakes occurred near Marietta (Washington County) and others have occurred in Gallia and Meigs Counties.

PROBABILITY OF FUTURE EVENTS

Map 2.9.c



Earthquakes have affected Ohio as early in history as written and oral records exist. There is clear precedence set to expect Ohio will continue to experience seismic events for the foreseeable future. Probabilities of future events have been developed and mapped by the USGS

(Map 2.9.c). The measurement used in this estimation is based on the chance of ground shaking (e.g. peak ground acceleration) as a percentage of the natural force of gravity over time. In this analysis the extreme southwestern portion of Ohio has one in ten chance of experiencing an earthquake equal in force to three percent of the earth's gravity in the next 50 years due to its proximity to the New Madrid seismic zone.

Although future earthquake events are highly likely to occur in Ohio, fortunately the state has not experienced any loss of life due to earthquakes. Damages are commonly limited to poorly built structures.

VULNERABILITY ANALYSIS & LOSS ESTIMATION

Methodology

Loss estimates for Ohio's earthquake hazard were developed using FEMA's hazard analysis and loss estimation software HAZUS-MH and its extensive inventory of historical events. HAZUS has been used successfully for over a decade in California's earthquake preparation and response efforts. For the purpose of this initial effort, level one analyses were completed using the program; unmanipulated, census-tract-level data were used. It is important to interpret HAZUS-MH MR4 (second release) results with the understanding that they are estimates and cannot be considered precise losses.

For the northeast Ohio analysis, the historical event of January 31, 1986 was used, which had a magnitude of 5.0 and was felt in 10 other states and southern

Canada. Estimates for the west-central portion of the state were based on the event of March 2, 1937 with an estimated magnitude of 5.4 and an eight kilometer depth. Analysis for the 1811/1812 New Madrid event could not be performed due to constraints within the software.

Beginning with the county where the epicenter was located, HAZUS-MH MR4 runs were performed on each contiguous county expanding outward, until loss estimates became negligible.

Results

Region 1 counties with notable losses included: Allen, Auglaize, Darke, Hardin, Logan, Mercer and Shelby, (see table 2.9.a). Results indicated very minimal losses of utility, transportation and critical facilities. The categories which reflected the greatest impact are associated with the building inventory and are the focus of the loss estimation. The only other category with any loss is

wastewater treatment, and those were negligible by comparison.

Figure 2.9.d



The total population for the impacted area is 375,177 with a total building value of \$27,875,000,000.

Impacts are reported in terms of damage degree, income losses and property damage. The HAZUS-MH MR4 User’s Manual provides a basic diagram to depict the degrees of damage, (see Figure 2.9.d).

Using the building category “Wood, Light Frame” as an example, the following descriptions are provided in the User’s Manual to clarify the degrees of damage.

Slight: Small plaster or gypsum board cracks at corners of door and window openings and wall ceiling intersections; small cracks in masonry chimneys and masonry veneer.

Moderate: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

Extensive: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of room-over-garage or other soft-story configurations; small foundations cracks.

Complete: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or

the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

HAZUS results for building counts indicate 13,700 slight, 5,257 moderate, 997 extensive and 157 completely impacted structures. The total loss of income is estimated at \$85,430,000, and total property losses are estimated at \$512,130,000. This represents approximately a 2.1 percent overall loss ratio.

Table 2.9.a

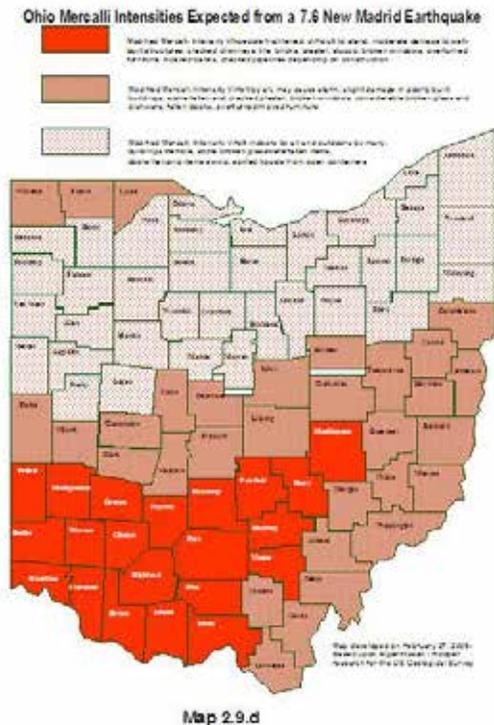
Estimate of Potential Losses to Earthquake								
Region 1								
County	2009 Pop.	Total Building Value	Slight Damage Count	Moderate Damage Count	Extensive Damage Count	Complete Damage Count	Income Loss	Property Loss
Allen	108,473	\$8,276,000,000	2,147	662	96	10	\$12,080,000	\$54,690,000
Auglaize	46,611	\$3,493,000,000	2,751	1,020	194	29	\$15,210,000	\$103,640,000
Darke	31,945	\$3,766,000,000	840	254	36	4	\$3,340,000	\$15,810,000
Hardin	53,309	\$2,110,000,000	430	129	16	1	\$5,990,000	\$1,500,000
Logan	46,005	\$3,496,000,000	2,000	709	105	12	\$6,890,000	\$40,410,000
Mercer	40,924	\$2,933,000,000	966	309	45	5	\$4,420,000	\$22,140,000
Shelby	47,910	\$3,801,000,000	4,566	2,174	505	96	\$37,500,000	\$273,940,000
TOTAL	375,177	\$27,875,000,000	13,700	5,257	997	157	\$85,430,000	\$512,130,000

Region 2 counties with notable losses included: Ashtabula, Cuyahoga, Geauga, Lake and Trumbull (see Table 2.9.b). Again the notable losses are associated with building stock in addition to negligible losses to wastewater treatment facilities. The total population for the impacted area is 2,040,228 with a total building value of \$179,111,000,000. HAZUS results for building counts indicate 13,729 slight, 4,170 moderate, 612 extensive and 67 completely impacted structures. The total loss of income is estimated at \$79,860,000 and total property losses are estimated at \$615,970,000. This represents approximately a 0.4 percent overall loss ratio.

Table 2.9.b

Estimate of Potential Losses to Earthquake								
Region 2								
County	2009 Pop.	Total Building Value	Slight Damage Count	Moderate Damage Count	Extensive Damage Count	Complete Damage Count	Income Loss	Property Loss
Ashtabula	102,728	\$7,704,000,000	914	262	30	3	\$3,310,000	\$20,400,000
Cuyahoga	1,393,978	\$126,156,000,000	4,395	1,184	138	11	\$27,930,000	\$132,920,000
Geauga	90,895	\$7,865,000,000	2,046	702	112	13	\$11,180,000	\$107,350,000
Lake	227,511	\$19,802,000,000	5,900	1,901	320	39	\$35,850,000	\$348,670,000
Trumbull	225,116	\$17,584,000,000	474	121	12	1	\$1,590,000	\$6,630,000
TOTAL	2,040,228	\$179,111,000,000	13,729	4,170	612	67	\$79,860,000	\$615,970,000

Although HAZUS evaluations of the 1811/1812 New Madrid Event cannot be conducted due to software constraints, the potential for damage from a similar earthquake exists. As part of preparations for a multi-state evaluation of the New Madrid hazard potential, the USGS developed an updated damage evaluation for Ohio (see Map 2.9.d). The area marked in solid red would experience the greatest impact with moderate damage (broken windows, damaged chimneys, cracked walls) from a hypothetical 7.6 event.



One consideration which is beyond the scope of this analysis is the impact a New Madrid event would have on the highly landslide-prone areas in Hamilton and Clermont counties. These counties are heavily urbanized, containing the greater-Cincinnati metropolitan area with millions of inhabitants and billions of dollars in development. In the case of Hamilton County, significant damage, including the temporary closure of Interstate-75 resulting from roadway slippage, has occurred due to landslide, without the impetuses of ground shaking or liquefaction. When a major New Madrid event occurs affecting Hamilton County, the impact could include the closure of multiple interstate highways, rail lines, and significant building losses

including many displaced inhabitants. There could also be significant secondary impacts if an event occurs during the winter months that disrupts utility infrastructure.

STATE-OWNED AND STATE-LEASED CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION

Methodology

The state-owned and state-leased facility data do not contain all of the attributes necessary for incorporation into HAZUS to assess risk. Therefore, the HAZUS results shown in Tables 2.9.a and 2.9.b were used to develop a “percent building loss.” This calculation was based on “Property Loss” / “Total Building Value.” The values calculated for each county were then used to estimate the state-owned and state-leased facility losses. While this does not represent a structure-by-structure risk assessment, it does provide a better look than the “governmental structures” values that HAZUS generates via 2000 census block data. Tables 2.9.c and 2.9.d list the results.

Results

The earthquake modeled in the HAZUS analyses affected only portions of Region 1 and 2, which are listed in Tables 2.9.c and 2.9.d. For Region 1, the highest critical facility losses could be expected in Allen County, with over \$800,000. The second highest would be in Shelby County, where nearly \$730,000 could be lost. There were no state-leased critical facilities affected in this Region. Concerning state-owned non-critical facilities, Allen and Auglaize County losses were the highest in Region 1, with \$116,000 and \$90,962, respectively. Overall, Allen County exhibited the largest state-owned facility loss, with nearly \$1 million in assets vulnerable.

Region 2 had much lower losses than demonstrated in Region 1. For state-owned critical facilities, Ashtabula County had the highest with nearly \$100,000 in losses, while state-leased critical facility losses were negligible. Geauga County had the greatest vulnerability for state-owned non-critical facilities. Overall, Geauga County exhibited the greatest losses in Region 2 for state-owned facilities with over \$141,000.

Table 2.9.c

Estimate of Potential Losses to Earthquake for State-Owned and State-Leased Facilities in Region 1											
County	Percent Building Loss	State-Owned Critical Facility Value	State-Owned Critical Facility Loss	State-Owned Non-Critical Facility Value	State-Owned Non-Critical Facility Loss	State-Leased Critical Facility Value	State-Leased Critical Facility Loss	State-Leased Non-Critical Facility Value	State-Leased Non-Critical Facility Loss	Total Estimated State-Owned Losses	Total Estimated State-Leased Losses
Allen	0.66%	\$129,644,317	\$856,724	\$17,589,855	\$116,238	\$0	\$0	\$584,976	\$3,866	\$972,962	\$3,866
Auglaize	2.97%	\$4,306,792	\$127,786	\$3,065,702	\$90,962	\$0	\$0	\$20,388	\$605	\$218,748	\$605
Darke	0.42%	\$4,098,855	\$17,207	\$12,776	\$54	\$0	\$0	\$0	\$0	\$17,261	\$0
Hardin	0.07%	\$1,236,823	\$879	\$5,500	\$4	\$0	\$0	\$0	\$0	\$883	\$0
Logan	1.16%	\$4,056,192	\$46,885	\$612,000	\$7,074	\$0	\$0	\$0	\$0	\$53,959	\$0
Mercer	0.75%	\$3,365,812	\$25,407	\$366,365	\$2,766	\$0	\$0	\$0	\$0	\$28,173	\$0
Shelby	7.21%	\$10,118,878	\$729,273	\$306,000	\$22,054	\$0	\$0	\$123,684	\$8,914	\$751,326	\$8,914
TOTAL	--	\$156,827,669	\$1,804,161	\$21,958,198	\$239,151	\$0	\$0	\$729,048	\$13,385	\$2,043,312	\$13,385

Table 2.9.d

Estimate of Potential Losses to Earthquake for State-Owned and State-Leased Facilities in Region 2											
County	Percent Building Loss	State-Owned Critical Facility Value	State-Owned Critical Facility Loss	State-Owned Non-Critical Facility Value	State-Owned Non-Critical Facility Loss	State-Leased Critical Facility Value	State-Leased Critical Facility Loss	State-Leased Non-Critical Facility Value	State-Leased Non-Critical Facility Loss	Total Estimated State-Owned Losses	Total Estimated State-Leased Losses
Ashtabula	0.26%	\$36,672,165	\$97,107	\$4,399,911	\$11,651	\$0	\$0	\$47,232	\$125	\$108,758	\$125
Cuyahoga	0.11%	\$19,815,718	\$20,878	\$57,101,659	\$60,163	\$0	\$0	\$1,882,083	\$1,983	\$81,041	\$1,983
Geauga	1.36%	\$3,749,863	\$51,182	\$6,585,511	\$89,886	\$0	\$0	\$11,400	\$156	\$141,068	\$156
Lake	1.76%	\$3,150,402	\$55,472	\$503,069	\$8,858	\$0	\$0	\$176,676	\$3,111	\$64,330	\$3,111
Trumbull	0.04%	\$28,726,632	\$10,831	\$12,032,218	\$4,537	\$10,716	\$4	\$49,152	\$19	\$15,368	\$23
TOTAL	--	\$92,114,780	\$235,470	\$80,622,368	\$175,095	\$10,716	\$4	\$2,166,543	\$5,393	\$410,565	\$5,397