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# New Madrid Seismic Zone

IMPLICATIONS FOR INSURERS

March 2015

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# Executive Summary

The New Madrid Seismic Zone (NMSZ) is potentially one of the geographically largest and most hazardous earthquake zones within the United States. While events of any significant magnitude occur infrequently, their effects are widespread and severe.

Despite the 1811-1812 earthquakes being some of the largest in United States history, detailed information is hard to come to come by due to the fact that they occurred at a time when the area was sparsely populated, unlike today.

NMSZ is currently one of the most significant tail drivers for most insurers and reinsurers due to the potentially large footprint, multiple event series, less stringent seismic building codes and lower perceived risk when compared to British Colombia, California and Japan for example.

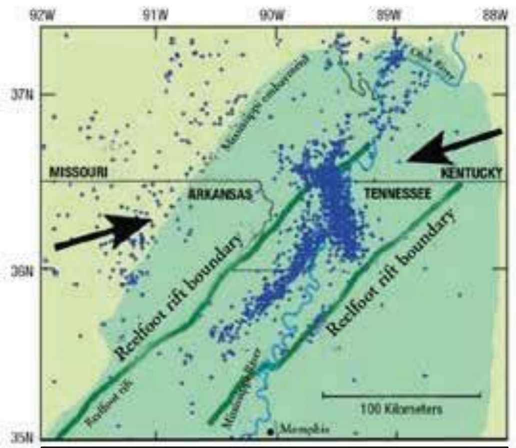


**Figure 1.** The Reelfoot Rift boundary line that runs over the NMSZ. Almost all earthquakes epicenters are confined by the Reelfoot Rift's borders.

NMSZ is a series of poorly defined faults, buried deep underground, which run parallel to the Mississippi River Valley. It lies over the Reelfoot Rift, an ancient subterranean structure that formed during the attempted breakup of the North American Plate, over 750 million years ago. Despite the age of the fault, studies backed by the United States Geological Services (USGS) show that seismic activity in the region is ongoing.

It is a hazard that risk managers should consider carefully, as the area of shaking from the 1811-1812 earthquakes was three times larger than the 1964 Alaska earthquake and 10 times larger than the 1906 San Francisco earthquake. The 1811-1812 earthquakes affected 4,000 $mi^2$, an area where 11 million Americans now live.

We must be mindful that beyond the financial risk of underwriting in NMSZ, there is also systemic model risk. As part of our underwriting process, we rely on catastrophe modeling that is predicated upon scientific studies including the USGS Seismic Reports. With no clear scientific consensus on the cause and frequency of New Madrid earthquakes, the insurance market's reliance on a small number of vendor models creates an ingrained level of risk in the insurance industry. If there are inherent inaccuracies within catastrophe models, our ability to accuractely price and assess the risk will be substantially impaired.

The following paper provides an overview of the seismic and societal risks arising out of New Madrid. It can act as a reminder that if an estimated $M_w7.7$ or greater earthquake were to hit NMSZ today, economic loss, insured loss and disruption to everyday life would be substantial and widespread.

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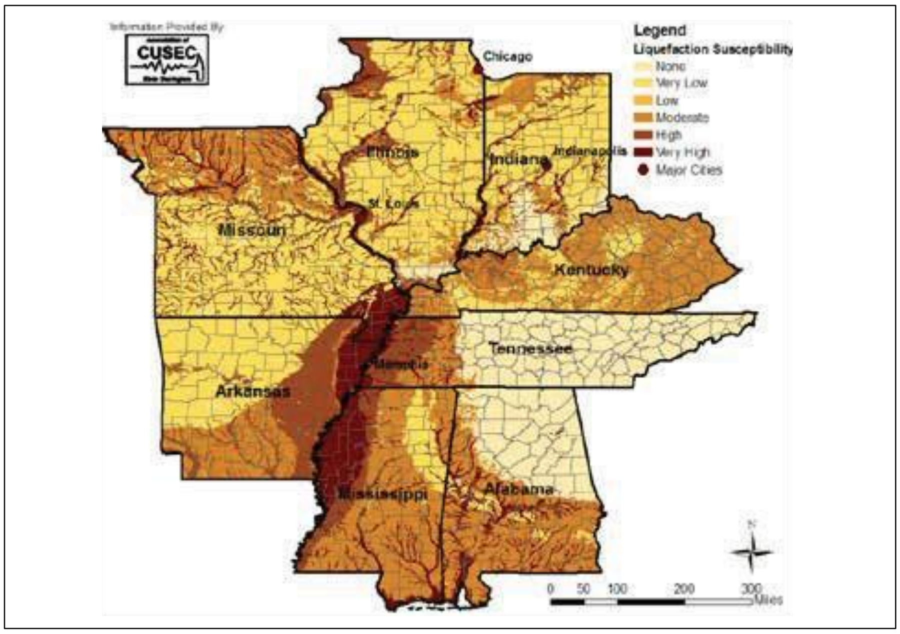


Figure 2. Liquefaction susceptibility of the eight state region surrounding NMSZ. The soft soils surrounding the seismic zone lead to higher vulnerability to liquefaction. Earthquakes cause the soft soils to behave like liquids, endangering any people or structures built over liquefaction-prone areas.

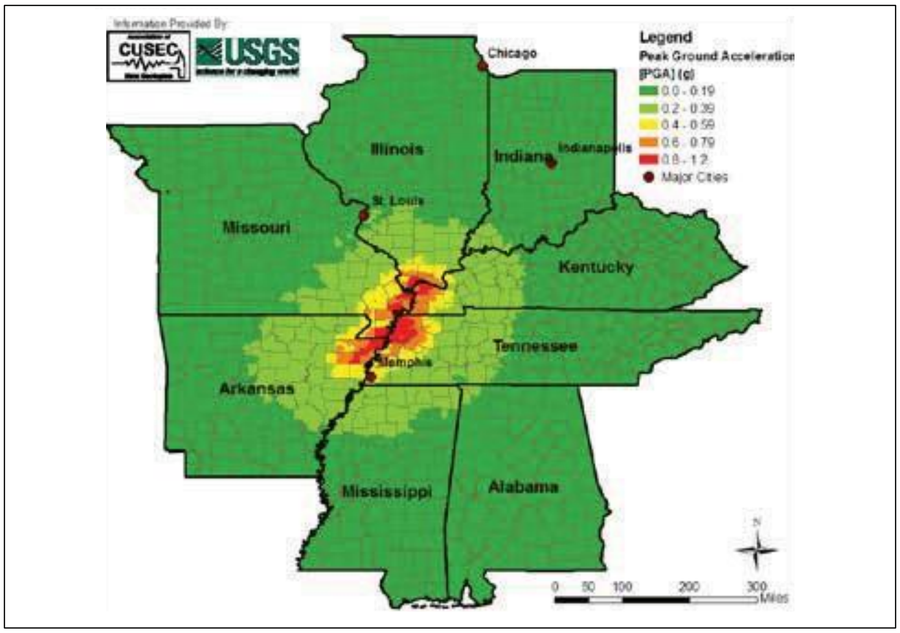


**Figure 3.** Peak Ground Acceleration (PGA) from a hypothetical $M_w$7.7 event that ruptures all three segments of the NMSZ, sequentially. PGA is a measure of how violently the earth shakes in a given geographic region from an earthquake. 11 million people live in areas of moderate-to-high strength shaking from a significant NMSZ event.

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# Introduction

Despite the rarity of extreme events, NMSZ is the most active seismic zone in eastern North America. From 2011-2013, an average of 100 earthquakes hit the area per year, up from an average of 20 per year from 1970-2000. The reasons for the increase are unclear, but the impact of fracking cannot be ruled out. Whether the earthquakes are human-induced or natural, the tremors are not severe, with most following between magnitude 3 and 4 on the Richter scale.

While the most frequent earthquakes are small, NMSZ hosted some of the largest recorded earthquakes in the continental United States. A series of destructive earthquakes in and near New Madrid, Missouri from December 1811 to February 1812 affected Illinois, Alabama, Indiana, Missouri, Arkansas, Kentucky, Tennessee and Mississippi (Stein 2010).

After the 1811-1812 earthquakes, records of the events went largely overlooked until the 1970s, when the Mississippi River Valley was evaluated for the construction of nuclear power plants. Since the installation of seismometers in the region in 1970s, the NMSZ has been identified as an area of significant earthquake hazard.

According to the Elnashai *et al.* publication from 2009, an estimated $300 billion of direct economic loss could be incurred from a repeat of the 1811-1812 events. Multiple lines of insurance would be impacted, including residential and commercial property, workers compensation, marine, personal accident and auto lines. The event could potentially bleed into many other lines, including specie/fine art, liability, cancellation, mortgage credit, aviation and business interruption.

Since the 1970s, countless research projects have delved into the science of NMSZ. However, consensus about the cause of the hazard remains elusive. The faults are hidden beneath thick layers of river deposited soil, making the physical fault-lines difficult to identify, and even more challenging to study.

The best research available combines Geographic Information Systems (GIS) mapping/analysis and geophysical models to estimate past, present and future behavior. Many research teams have attempted to pinpoint the mechanisms and nature of NMSZ, with a wide range of results. Estimates of the 1811-1812 earthquakes range from $M_w$6.8 up to $M_w$8.1. An $M_w$8.1 earthquake is 89 times more powerful than an $M_w$6.8.

Summarized in this paper are a collection of investigations undertaken in the region to demonstrate the uncertainty in understanding of the hazard.

# Historical Occurrences

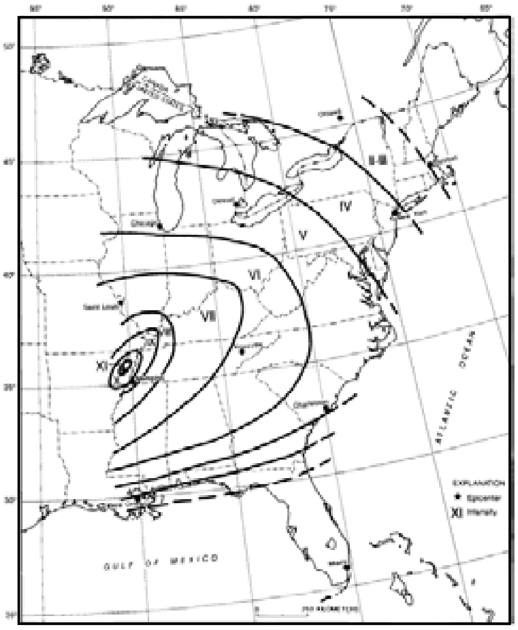


**Figure 4.** An Isoseismal map for the Arkansas earthquake of December 16, 1811. The map shows lines of equally perceived seismic intensity from the destructive earthquake (USGS Paper 1527).

The NMSZ is a series of poorly-defined faults, buried deep underground and invisible to the naked eye, that run parallel to the Mississippi River Valley. The most recent set of large earthquakes occurred in three large shocks and one aftershock from December 1811 to February 1812. The faults have been host to at least four other large earthquake sequences in the prior 4,500 years (Frankel *et al.* 2012). Evidence has shown similar earthquakes occurred in 1450 A.D., 900 A.D and 300 A.D and 2350 B.C. (Intraplate Earthquakes, 2014).

The isoseismal map in Figure 4 shows the area of strong shaking associated with the December 16, 1811 shock. The area where shaking was felt was three times larger than that of the 1964 Alaska earthquake and 10 times larger than that of the 1906 San Francisco earthquake. Shaking from this quake caused minimal damage to man-made structures (due to the sparse population at the time) but was strong enough to alarm an area of 2,500,000 $km^2$, from Quebec to New Orleans, and from Minneapolis to New York[1].

NMSZ earthquakes are different than earthquakes in California or Alaska, where faults are often visible on the earth's surface. The Californian or Alaskan earthquakes typically occur at depths no greater than 35 km, and are interplate earthquakes. NMSZ earthquakes occur between 5km and 20km, and are classified as intraplate earthquakes. A discussion of the difference between interplate and intraplate faults follows on page 6.

Earthquakes in NMSZ also differ in how the energy spreads or attenuates. In the western United States, seismic energy is absorbed by bedrock. In the central United States, seismic energy spreads further due to the loose soil in the Great Plains that are prone to liquefaction (Hubenthal *et al.* 2011).

**Figure 5.** An example of a liquefaction deposit found in California. Furrows are spaced 4 feet apart, which gives us idea of the magnitude of liquefaction deposits. These are very similar to those found in NMSZ (USGS).

Liquefaction is one of the inherent dangers in NMSZ. It occurs when a saturated or semi-saturated soil loses strength and stiffness due to stress Earthquake shaking causes an increase in water pressure, to the point where soil particles behave like a liquid (Stein, 2010).

Residual liquefaction deposits are often the best way to track the history of earthquakes in a region. Sand blows can be recognized in the field and on aerial photographs, as shown in Figure 5. Such features from past events are found with subsurface geophysical techniques that locate earthquake-induced liquefaction.

In the case of NMSZ, there were no publicly documented fissures, landslides or liquefaction deposits until 1904, when Myron Fuller of the USGS found evidence in the landscape (Intraplate Earthquakes, 2014). These findings are plotted in Figure 6.

[1] USGS Paper 1527

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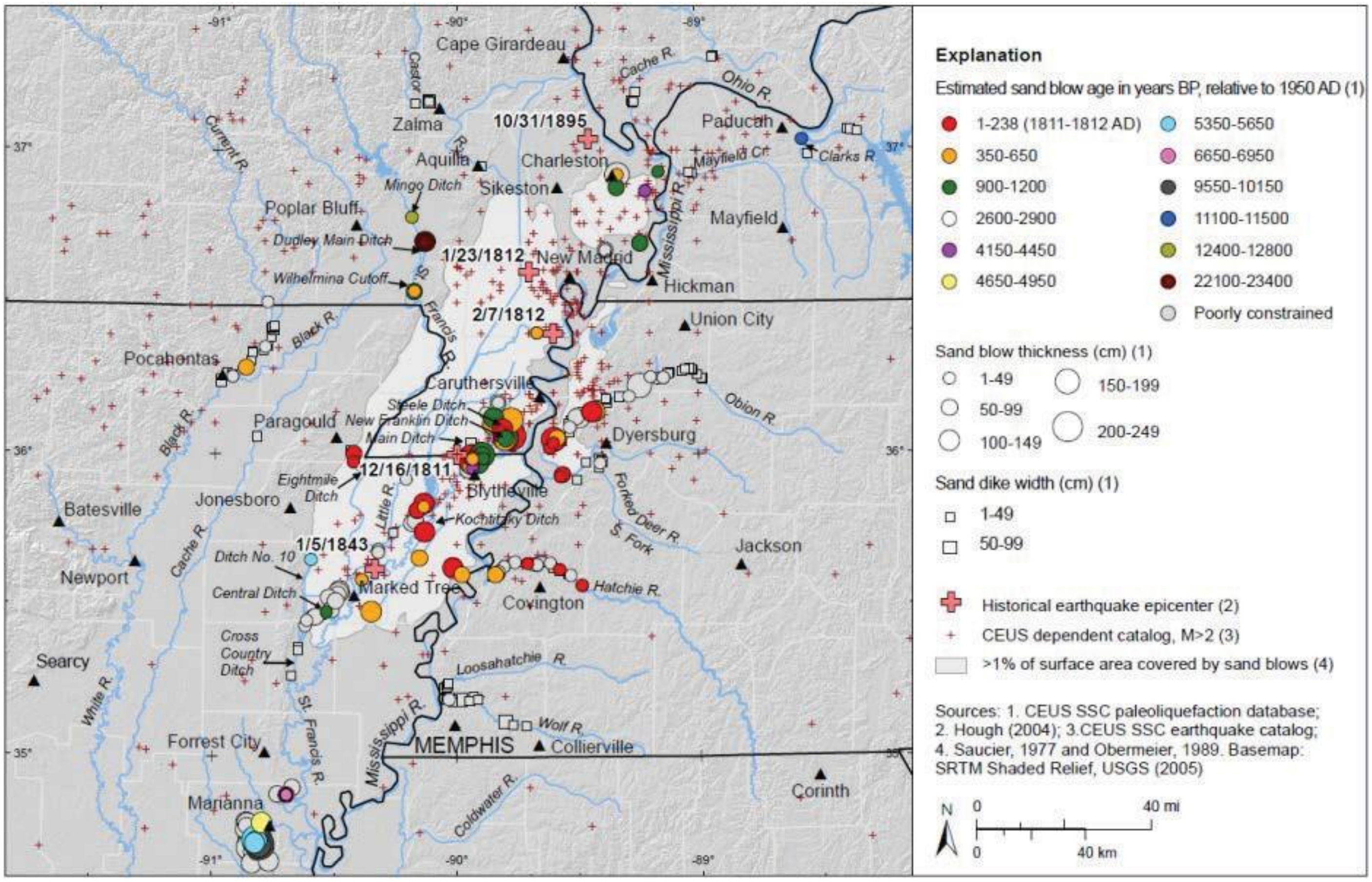


**Figure 6.** Map of earthquake liquefaction deposits in the New Madrid Seismic Zone region. The different color and size circles represent the relative strength and location of each historical earthquake sequence by relating sand-blow thickness to liquefaction deposit size.

The figure provides researchers with a paleoseismic record of activity along the Reelfoot Rift. Much of this data was gleaned from extensive fieldwork, focusing upon surface deformation, fluvial and biological responses to strong earthquakes and active faulting (Tuttle and Hartleb, 2012).

*BP=Before Present

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# Intraplate Faults and Interplate Faults

Intraplate earthquakes occur in the middle of tectonic plates on zones of weakness. These zones require more complex models than at interplate boundaries, because intraplate boundaries do no adhere to the elastic rebound theory (ERT).

ERT, the accepted explanation for earthquakes at interplate boundaries, is the theory that earthquakes occur when sufficient 'elastic strain' builds up over time due to motion between two sides of an active fault. Energy is stored in between faults until stress on a given fault exceeds its frictional strength. When the critical value is breached, accumulated strain is released as the fault slips into an earthquake. This cycle is repeated until the next earthquake, and in perpetuity.[2]

The ERT is well-established in plate boundary regions, such as the Juan de Fuca-North American boundary (most western US earthquakes) and Indian-Eurasian boundary (Himalayas and Chinese/Indian earthquakes).

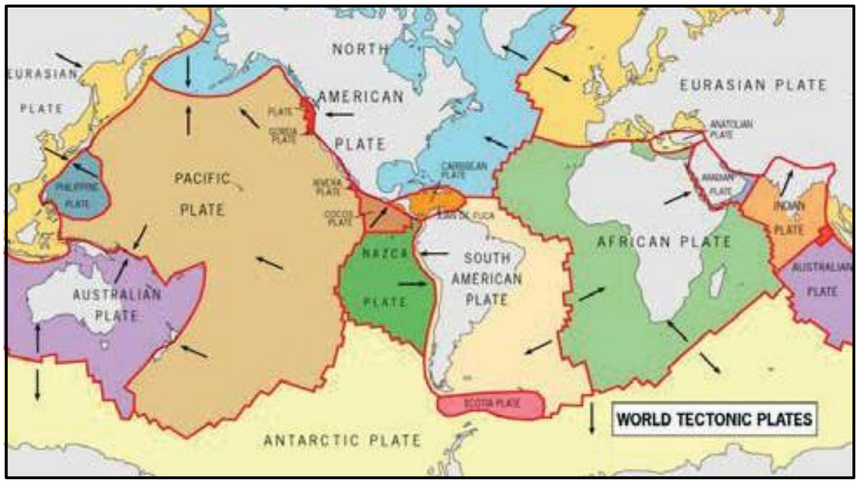


**Figure 7.** Relative motion of the world's tectonic plates. Most earthquakes occur along plate boundary regions, such as those between the Nazca and South American Plates.

However, when considering intraplate zones such as the NMSZ, the simplicity of the ERT is inconsistent. Small-to-medium size earthquakes occur frequently in NMSZ. The ERT would require adequate strain build-up and plate movement for these earthquakes to occur. But Global Positioning System (GPS) studies, past and present, do not support such stress accumulations (Liu *et al.* 2011). This confirms that ERT cannot be applied to intraplate faults.

The issue of reconciling GPS studies with historical and ongoing seismic activity is the largest area of research in intraplate tectonics. Understanding the USGS fault models and related science sheds light on how the intraplate tectonics function according to different designs than the ERT.

[2] Stein, 2007


**Figure 9.** Representation of the five fault traces of NMSZ (2014 USGS Report).


**Figure 10.** Representation of the CEUS-SSCn model (2014 USGS Report).

# NMSZ Tectonics and Seismic Hazard

The NMSZ lays over an *aulacogen* - a failed triple junction of a tectonic rift system. Between 1.1 billion and 750 million years ago, the land masses on earth were organized into the supercontinent Rodinia. When the supercontinent split, a triple-junction beneath the North American plate initiated a three-way breakup of the plate. One of the three ridges failed and halted the spreading, resulting in a failed rift called the Reelfoot Rift.

Earthquake hazard in NMSZ is difficult to comprehend, as the Reelfoot Rift is analogous to a basement structure covered by 4 miles of sediment. The few indications we get of the Reelfoot Rift come from liquefaction findings and GPS measurements. They show miniscule movements every year relative to the extremities of the North American Plate in California and Alaska (Csontos and Van Arsdale 2008).

In regards to the 1811-1812 earthquakes, as well as the 1350, 900, 300 and 2350 BC earthquakes, some scientists postulate that after hundreds of millions years of inactivity, pressure along the Reelfoot Rift had built up substantially from the east-west compression of the North American plate. This could explain activity over the last 4000 years.[3]

The challenge of modeling seismicity in NMSZ is that exact locations of fault lines are unknown. Using all available evidence, the USGS has created two different theoretical models that explain New Madrid fault geometry. These are assigned equal weight by the USGS in the latest report issued in 2014.

The first is composed of five ‘fault traces’, which are estimations of the rupture sources for the north, central and south branches of the Rift. The hypothetical faults are given probabilities that represent observed data. The central trace is weighted at 70%, the traces just outside are weighted 10% each, and the outer traces are weighted at 5% each (USGS 2014 Seismic Report). This is represented in Figure 9.

The second model, called the CEUS-SSCn model, is predicated on fault-based characteristics, or repeating large magnitude earthquake sources in the region. They include the Wabash Valley (Illinois-Indiana), Commerce Geophysical Lineament (Arkansas-Indiana), Eastern Rift Margin (western Tennessee), Marianna (east-central Arkansas), Charlevoix (eastern Canada) areas source zones and New Madrid (Arkansas-Kentucky) fault source (USGS 2014 Seismic Report). Figure 10 shows this model.

Much of the research in geotectonic science over the past 20 years has focused on intraplate earthquakes, with particular attention to the NMSZ. However, there is no unanimous model for intraplate earthquakes. As such, there is considerable uncertainty in estimating the possible seismic activity much less the potential loss over time.

[3] Liu *et al* (2011)

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# Impact on Built Environment

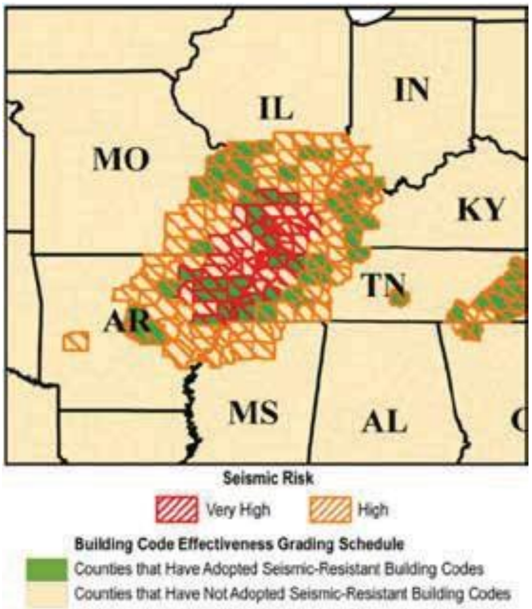


**Figure 11.** Map showing counties in NMSZ that have high seismic risk, relative to their building code adoption for commercial buildings (FEMA).

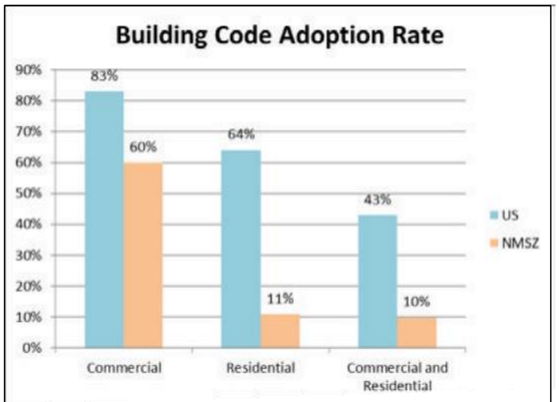


**Figure 12.** Code adoption comparisons between the New Madrid area and the United States (FEMA).

The most recent large-scale study on New Madrid was the 2014 Update of the United States Seismic Hazard Maps by the USGS. A notable caveat to the findings arising from the USGS 2014 Report is that the seismicity assessment only describes motion of the underlying bedrock. It does not address how waves propagate through soft soils in the American plains; soils that are specifically found around New Madrid. The NMSZ fault lines are covered by 100-200 feet of alluvial soils. The soils, as a physical characteristic, amplify ground motion. An earthquake that passes through such soils has ground motion that is five-to-six times greater than on solid bedrock. Alluvial soils also explain the propensity for liquefaction after NMSZ earthquakes (Newman *et al.* 2007).

Today, an estimated 11 million people live in the NMSZ, which gave way to almost 4,000 square miles of liquefaction during the 1811-1812 earthquakes. Much of those 4,000 $mi^2$ are now residential and commercial zones, populated by homes, hospitals, bridges, schools, highways, airports, hazardous material facilities and power plants.

The absence of scientific consensus is reflected in local and state building codes within the seismic zone. Arkansas, Indiana, Kentucky and Tennessee have statewide building codes, but each has adopted different standards. Illinois, Mississippi and Missouri have no statewide building codes as minimum requirements. They pass responsibility to local jurisdictions, where there is no unanimous code (FEMA). This stands in stark contrast to states like California, where building codes are updated every three years.

At the local level, building code adoption is below par. Many cities, towns, counties and parishes lack qualified staff to enforce local building codes, let alone establish what codes to implement. Only 60% of high or very high seismic risk jurisdictions enforce building codes with full seismic provisions for commercial buildings. Eleven percent do so for residential buildings, and 10% for both commercial and residential buildings (FEMA).

By comparison, elsewhere in the United States, 83% of communities have adopted codes for commercial buildings, 64% for residential buildings, and 43% for commercial and residential. This shows the lag from certain states located within NMSZ to adopt full-strength building codes for protection from earthquakes (FEMA).

Figure 13 presents potential damage if all three NMSZ fault segments sequentially ruptured from an $M_w$7.7 event. Liquefaction susceptibility is included in the analysis (Elnashai *et al* 2009).

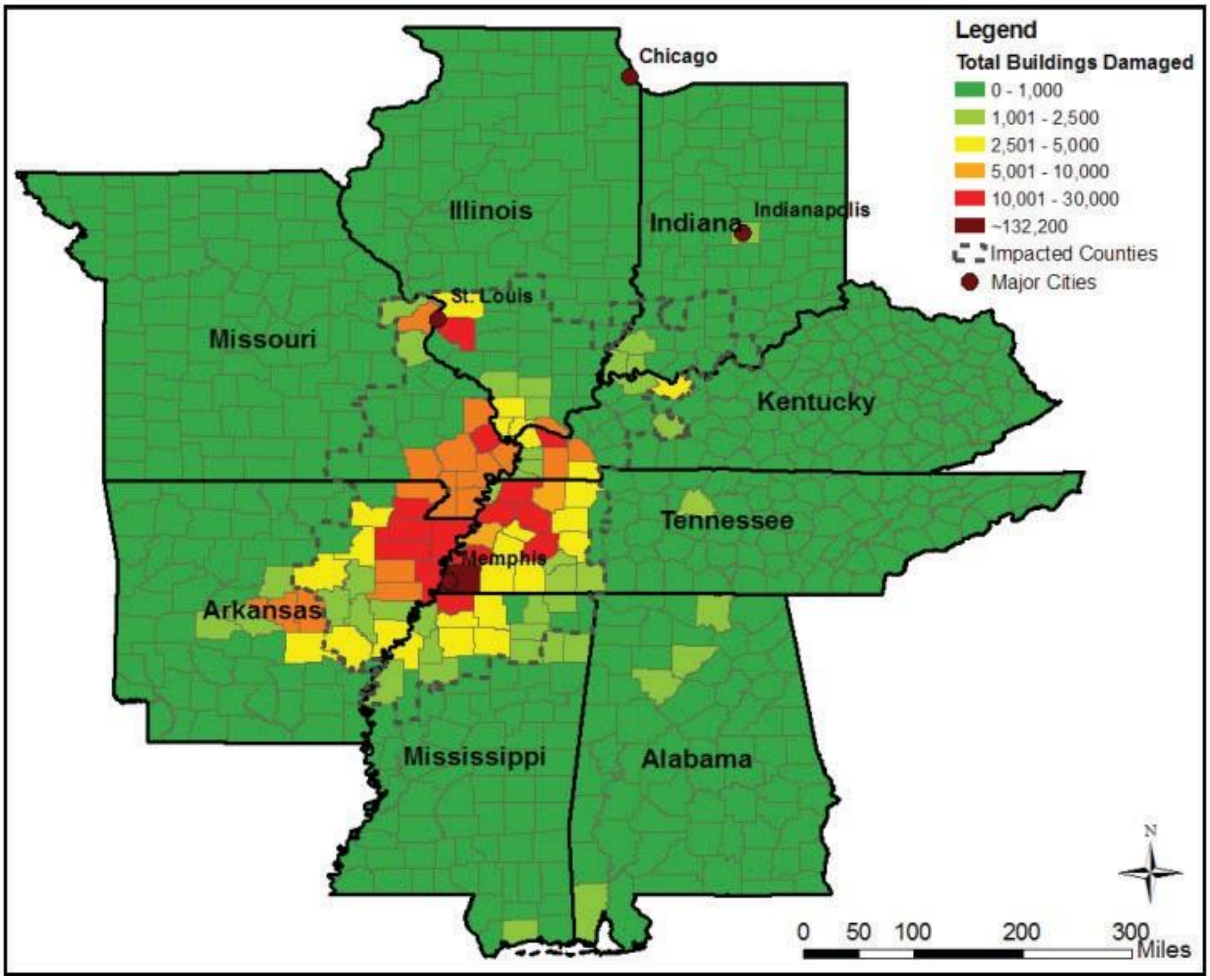


**Figure 13.** General building damage in an eight-state study region surrounding NMSZ. The study was commissioned by University of Illinois' Department of Civil and Environmental Engineering.

Map shows estimated number of buildings damaged by county. The approach uses three components: hazard, inventory and fragility (vulnerability). The study used three models in conjunction- HAZUS MR3, FEMA, 2008 and MAEviz, Mid-America Earthquake Center, 2008. USGS approved the employed magnitude and hazard approach.

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Assuming a damage footprint such as that depicted in Figure 13, the Elnashai study expects significant damage to 16 million buildings in the study area. Table 1 presents those results by construction type.

**Table 1.** Damage by building type in an eight-state study region surrounding NMSZ (Elnashai *et al* 2009).

| Building Damage by Type | | | | | |
|---|---|---|---|---|---|
| Building Type | Total Buildings | At Least Moderate Damage | % of Moderate Damage | Complete Damage | % of Complete Damage |
| Wood | 11,370,700 | 354,000 | 50% | 180,500 | 60% |
| Steel | 167,800 | 19,600 | 3% | 6,500 | 2% |
| Concrete | 77,300 | 5,000 | 1% | 2,000 | 1% |
| Precast | 43,500 | 4,600 | 1% | 1,700 | 1% |
| Reinforced Masonry | 34,200 | 2,400 | 0% | 1,000 | 0% |
| Unreinforced Masonry | 2,373,800 | 132,300 | 19% | 59,200 | 20% |
| Manufactured Housing | 1,710,000 | 195,300 | 27% | 49,300 | 16% |
| Total | 15,777,300 | 713,200 | 100% | 300,200 | 100% |

Over 713,000 buildings are moderately damaged in eight states and over 300,000 are total losses. 35% of all the moderate or more severe building damage occurs in Tennessee, yet only 13% of regional buildings are located in Tennessee (Elnashai *et al* 2009).

Another study by the Central United States Earthquake Consortium (CUSEC) expands on University of Illinois' study. They find direct economic losses for this event might total $56.6 billion in the state of Tennessee, alone. This is through a combination of losses to building, transportation and utility infrastructure. Portions of Tipton and Crockett Counties in Tennessee were estimated to incur loss ratios of 40% and 62%. While the majority of Tennessee has loss ratios of 2% or less, the loss values in a small portion of the state show the destructive capability of a serious NMSZ event (CUSEC).

The most affected county would be Shelby County, Tennessee which incurs moderate-to-complete damage in 21,500 buildings, more than any other county. This is due to the high levels of ground shaking and substantial liquefaction, coupled with the high density of buildings in Memphis, which lies in the Northwest corner of Shelby County. The city of Memphis would independently experience loss ratios between 20% and 40%, attributed to the high proportion of unreinforced masonry structures in the city (CUSEC).

Arkansas, with only 8% of the regional building inventory, incurs 25% of all building damage. Illinois, Mississippi, Alabama, Kentucky and Missouri incur far less damage than Tennessee and Arkansas (CUSEC).

Kentucky and Missouri lead the region in earthquake insurance coverage with roughly 55-60% of the states covered. Take-up rates in Arkansas, Indiana, Mississippi and Tennessee are closer to a third for residential and commercial lines, and Alabama and Illinois fall far behind that benchmark.

**Table 2.** Take-up rate by state for Residential and Commercial zones (AIR Worldwide).

| State | Peril | Residential Take-Up Rate | Commercial Take-Up Rate |
|---|---|---|---|
| Alabama | EQ | 8.88 | 9.28 |
| Arakansas | EQ | 30.53 | 33.31 |
| Illinois | EQ | 16.43 | 15.13 |
| Indiana | EQ | 33.52 | 36.77 |
| Kentucky | EQ | 53.64 | 56.50 |
| Mississippi | EQ | 37.67 | 39.95 |
| Missouri | EQ | 55.65 | 59.05 |
| Tennessee | EQ | 28.28 | 30.29 |

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# Closing Thoughts

While prone to a frequency of small earthquakes, the infrequent nature of sizable events within NMSZ makes it difficult for many individuals to grasp the full damage potential of larger events, such as those seen in 1811-1812. There is more uncertainty surrounding NMSZ than any other earthquake zone within the United States. An example of this uncertainty would be the broad range of return periods of events similar to the 1811-1812 earthquakes that range from 250 years up to 10,000 years.

Regardless of such unpredictability, we know that the financial burden of a serious event would be enormous, with the potential to drive the tail exposures of many insurance companies present in the region. Insured losses at the 1-in-500 year return period could reach US $51 billion, versus industry surplus of US $627 billion (at year end 2013). This would impact many lines of business beyond property, inland marine, aviation and liability, leaving all at risk.

Losses might be inflated by a phenomenon known as ‘red zoning’ which was seen after the recent Christchurch earthquake in 2011. Following earthquake shaking and liquefaction, red zoning arises when the government declares land as ‘unsound’ even though the buildings themselves might be undamaged and still fit for use.

Regardless of whether red zoning would follow a large NMSZ event, uninsured economic loss in New Madrid would be substantial. Such burden would fall upon the shoulders of government and taxpayers.

The lack of conclusive research surrounding the New Madrid hazard results in a certain level of systemic risk being present within the third party catastrophe models that insurers and reinsurers use. This could lead to more uncertainty around what is already one of the least understood hazards our industry is faced with.

While not conclusive, we hope this paper will help stimulate much needed discussion, research and interest around this underestimated and sometimes ignored hazard.

# Glossary

**Alluvial Soil**- Fine grained fertile soil deposited by water flowing over flood plains or in river beds.

**Earthquake Attenuation**- The decrease in size, or amplitude, of an earthquake's energy and waves as it travels from its source.

**Epidemic Type Aftershock Sequence**- A point process model representing the activity of earthquakes in a region during a period of time. It is based on the decay in the conditional rate of aftershocks with time elapsed since a triggering event, as well as the overall rate of earthquakes as a function of magnitude.

**Fault Trace**- The intersection of a geologic fault with the ground surface. In the case of NMSZ, the fault traces are theoretical; they do not leave a visible mark on the surface.

**Fissures**- A long narrow opening in the earth.

**Geosciences**- All-embracing term referring to the fields of science dealing with planet Earth. In this paper it specifically refers to tectonic sciences.

**Loading**- Application of earthquake-generated agitation to a structure. Occurs at contact surfaces of a structure, either with the ground or adjacent structures.

**Interplate Earthquake**- An earthquake that occurs at the boundary between tectonic plates.

**Intraplate Earthquake**- An earthquake that occurs in the interior of a tectonic plate

**Isoseismal Map**- A map used to show lines of equally felt seismic intensity, generally measured on the Mercalli scale.

**New Madrid Seismic Zone (NMSZ)**- The major seismic zone and prolific source of intraplate earthquakes, stretching to the southwest from New Madrid, Missouri.

**Paleoliquefaction**- Liquefaction features attributed to seismic events, before measurements or detailed records of earthquakes were kept.

**Reelfoot Rift**- The internal rift structure that provides the hazard in the NMSZ.

**Sand Blow-** Cone of sand formed by the ejection of sand from a central point. Occurs during earthquake liquefaction.

**Stress**- Force per unit acting on a plate within a body.

# Contacts

To discuss any of the contents of this paper, please contact:


**James Rohman**
Global Catastrophe Management

T: 1 (212) 365 2438
E: jrohman@transre.com


To discuss the implications of this paper, and your reinsurance needs in response, please contact:


**Paul Mckeon**
Chief Underwriting Officer, North America

T: 1 (212) 365 2120
E: pmckeon@transre.com

**Lisa Moser**
Head of US Property Broker Market Underwriting

T: 1 (212) 365 2185
E: lmoser@transre.com

**Carl Cooper**
Head of US Property Direct Market Underwriting

T: 1 (415) 399 5910
E: ccooper@transre.com

**Cornel Green**
Head of US Property Facultative Underwriting

T: 1 (312) 416 6605
E: cgreen@transre.com

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