Scholarly Paper

Tort Liability for the Central United States Earthquake Hazard

Timothy D. Stark, Ph.D., P.E., J.D., D.G.E., F.ASCE[1]

Abstract: Although the probability of a major earthquake is lower in the central United States than in California, the expected loss from a large earthquake may be higher because of extensive transportation infrastructure and inadequate preparations for what is perceived to be a low-frequency event. In many cases, low-cost precautions, such as gas shutoff valves, can reduce expected losses, and potential tort liability may facilitate implementation of seismic retrofit techniques. This paper discusses the seismicity of the central United States, possible tort liability, and available retrofit techniques to reduce liability. **DOI: 10.1061/(ASCE)LA.1943-4170.0000061.** © *2011 American Society of Civil Engineers.*

CE Database subject headings: Earthquakes; Liability; Soil mechanics; Vibration; Subsurface environment.

Author keywords: Earthquakes; Liability; New Madrid Seismic Zone; Negligence; Soil mechanics; Vibration; Subsurface investigation.

Introduction

The first part of this paper examines earthquake risk in the central United States with particular emphasis on the New Madrid Seismic Zone (NMSZ), which experienced three large earthquakes from 1811–1812 near New Madrid, Missouri. The paper also describes potential tort liability resulting from this risk and available retrofit techniques to reduce the potential risk and liability.

Although the probability of high-magnitude earthquakes may be lower in the Midwest than on the West Coast, the projected damage from a high-magnitude earthquake is potentially much higher in the Midwest.[1] In part, this is because public authorities and private actors in California, perceiving the risk, have taken steps to retrofit bridges, freeways, buildings, and other structures so as to minimize property damage and loss of life. The effectiveness of this strategy was illustrated in the 1989 Loma Prieta earthquake (magnitude 7.1) when only 62 people died, with the majority of these deaths (42) occurring in the collapse of the Cypress Street Viaduct, a double-deck highway structure near Oakland. The total damage caused by the Loma Prieta earthquake reached as high as US$10 billion with direct damage estimated at US$6.8 billion.[2] In contrast, an earthquake of similar magnitude (6.9) and similar fault-rupture mode[3] killed 5,300 people near Kobe, Japan, in 1995. The earthquake-induced losses in the Kobe area were estimated to be as high as US$200 billion.[4] Thus, risk perception has led to public-policy responses that have lowered the absolute level of earthquake risk in California.

It appears that the opposite dynamic has shaped earthquake policy in the Midwest. Because the risk is not perceived to be high, public authorities and private actors have been relatively slow in responding to the threat of earthquakes. The expected damage and economic loss from a major earthquake event in the Midwest may therefore be higher than in California because of the large number of vulnerable structures. The following briefly outlines the history of earthquakes in the Midwest and shows that although the probability of a major earthquake is lower than in California, it is hardly negligible.

Central U.S. Earthquake Risk

The NMSZ of the central United States encompasses a multistate region from northern Mississippi to central Missouri and from eastern Missouri to western Indiana, and includes the major cities of Memphis, Tennessee, and St. Louis. The NMSZ is named for the epicenter of three large earthquakes (estimated earthquake magnitudes of 8.1, 7.8, and 8.0) that occurred during the winter months of 1811–1812.[5] Historic accounts suggest that these earthquakes are among the largest, if not the largest, earthquakes ever experienced in the United States.[6] The earthquakes reportedly rang church bells 1,000 miles away in Boston[7] and changed the topography of the region. Some of the geomorphic features that resulted from these earthquakes include the displacement and rerouting of the Mississippi River, subsidence that created Reelfoot Lake in Tennessee,[8] and extensive soil liquefaction features, such as sand blows or sand volcanoes, throughout the NMSZ.[9,10]

The first comprehensive study of the New Madrid earthquakes was published by the USGS approximately 100 years after the earthquakes.[11] Interest in the seismicity of the Mississippi River Valley increased significantly in the 1970s when proposals for construction of nuclear power plants in the midcontinent were being considered.[12] Since the 1970s, extensive research has been conducted and numerous technical papers written on the seismic hazard.[13,14,15,16]

Although most people associate the New Madrid fault with the great earthquakes of 1811–1812, the central Mississippi Valley is the most earthquake-prone area of the United States east of the Rocky Mountains.[17] The Arkansas General Assembly determined that the "1811–1812 earthquake swarm" includes 55 of the approximately 2,010 earthquakes occurring during the 3-month period in the NMSZ having magnitudes of 6.0–8.7 on the Richter scale and

[1]Professor of Civil and Environmental Engineering, Univ. of Illinois at Urbana-Champaign, 205 N. Mathews Ave. Urbana, IL 61801. E-mail: tstark@illinois.edu

Note. This manuscript was submitted on June 11, 2010; approved on January 11, 2011; published online on February 8, 2011. Discussion period open until April 1, 2012; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Legal Affairs and Dispute Resolution in Engineering and Construction***, Vol. 3, No. 4, November 1, 2011. ©ASCE, ISSN 1943-4162/2011/4-152–159/$25.00.

affecting in excess of 2,072,000 km^2 (800,000 mi^2) and that recurrences remain a possibility in the region.[18]

Table 1 presents a list of the earthquakes with a Richter magnitude greater than or equal to 5.0 in the NMSZ since 1838. Earthquakes with estimated magnitudes of 6.4 and 6.8 occurred in 1843 and 1895, respectively. More recent earthquakes in the NMSZ have exhibited an earthquake magnitude of less than 5.0. For example, the magnitudes of the September 26, 1990, and May 3, 1991, earthquakes in southeastern Missouri were 4.8 and 4.6, respectively.[19] The December 6, 1996, earthquake near Blytheville, Arkansas, which is just south of the Missouri border, had a magnitude of 4.3. On May 4, 2001, a magnitude 4.4 earthquake occurred near Little Rock, Arkansas, which is a little farther west than Blytheville.[20] These four earthquakes did not cause any significant damage but illustrate that strain energy continues to accumulate in the NMSZ, which attests to the ongoing seismic hazard that the area poses.

An examination of the historical setting of the NMSZ shows that the three large earthquakes of 1811 and 1812 are not isolated events. In fact, the geologic data suggest that as few as two and as many as four large earthquakes occurred in the 2,000 years prior to 1811.[21] This reinforces the possibility that future large earthquakes will occur in the NMSZ because the earthquakes prior to 1811 and 1812 prove that this area is subject to a strain buildup over time that eventually results in large earthquakes. If large earthquakes had not occurred prior to 1811 and 1812, it could be argued that the large strain or energy release in 1811 and 1812 was an isolated event and thus seismic retrofitting techniques would not have to be implemented today. The finding of recurring large earthquakes is significant because it implies that the more frequent low-magnitude earthquakes that continue to occur in the NMSZ are not releasing all of the strain energy, so the hazard is not eliminated and people are frequently made aware of the seismicity.

Two pieces of evidence that suggest the occurrence of large earthquakes prior to 1811 are the dating of soil liquefaction features and the rapid subsidence that formed Big Lake and St. Francis Lake in northeastern Arkansas.[22] Radio carbon dating of organic matter from soil liquefaction features, termed paleoliquefaction features, allows dating of earthquakes large enough to cause soil liquefaction. Backhoe trenching of paleoliquefaction features and radio carbon dating of organic matter from these features between Blytheville, Arkansas, and Caruthersville, Missouri, has shown that soil liquefaction features occurred around CE 800–1000 and CE 1200–1400.[23] Thus, it appears that two different earthquakes large enough to cause soil liquefaction occurred prior to 1811 and 1812.

Another piece of prior evidence regards the formation of Big Lake, which suggests the lake was formed by subsidence during at least two seismic events.[24] This is inferred from soil borings that reveal two distinct organic layers that reflect the subsidence caused by the 1811–1812 earthquakes and a prehistoric subsidence event.[25] The presence of a distinct organic layer suggests a rapid subsidence of the ground surface and quick deposition of soil above the existing organic material. At St. Francis Lake, similar soil borings indicate four separate subsidence and ponding events that preserved four distinct organic layers in the last 8,000 years.[26] In summary, paleoliquefaction and geologic studies indicate a recurrence interval of 550 to 1,000 years for large (magnitude 8) earthquakes in the NMSZ.[27] These data also suggest a recurrence interval of about 450 years for earthquakes large enough to produce soil liquefaction (magnitude 6.5–7.5).[28]

Table 1. History of Earthquakes with Magnitude Greater than 5.0 in the Central United States (Adapted from CUSEC 1996)

Year	Magnitude	Location
1811	7.8–8.1	New Madrid, MO
1838	5.1	Southern Illinois
1843	6.4	Marked Tree, AR
1857	5.1	Southern Illinois
1865	5.2	Southern Missouri
1895	6.8	Charleston, MO
1903	5.0	Southeastern Missouri
1968	5.4	Southcentral Illinois
1987	5.0	Southeastern Illinois
2002	5.0	Evansville, IN

Impact of Central U.S. Earthquakes

The potential losses from a future earthquake of magnitude 8 or greater in the NMSZ are expected to range from US$60 billion to $100 billion.[29] This is several times the damage of the 1989 Loma Prieta earthquake.[30] There are at least four reasons for this high damage estimate for the NMSZ: first, the area is now inhabited by approximately 100 million people; second, the population centers, notably Memphis, Tennessee, and St. Louis, have many structures that are not constructed to withstand the effects of earthquake shaking; third, the Mississippi floodplain region is underlain by loose sandy soils that are susceptible to earthquake-induced liquefaction or ground-motion amplification,[31,32] and fourth, a New Madrid earthquake would impact a large multistate region as illustrated in Fig. 1, which is about 10 times larger than the area impacted by a California earthquake of comparable size. In comparison to the loss estimate of US$60 billion to $100 billion, the 1994 Northridge earthquake resulted in US$20 billion of damage over a smaller, albeit more heavily populated, area that had implemented significant seismic design and construction techniques.[33] In addition, the Midwest transportation network includes substantial portions of the nation's highway and railroad systems, major waterways and shipping facilities on the Mississippi, Missouri, and Ohio rivers, and airports that serve as hubs for the nation's airline (St. Louis) and air-freight (Memphis, Tennessee) operations. For example, the Memphis airport is ranked first in the world in the volume of air freight and the St. Louis airport is ranked seventeenth in the world for passenger volume.[34]

Probability of Future Damaging Earthquakes

The probability of moderate-to-large earthquakes occurring in the NMSZ in the near future was estimated in 1985[35] and updated in 1997.[36] Table 2 presents the probabilities of earthquake magnitudes of greater than 6.0, 7.5, and 8.0 in the NMSZ in the next 15 or 50 years. Table 2 shows that the probability of a magnitude 8.0 earthquake in the next 50 years is less than 4%. However, the probability of a moderate earthquake, between 6.0 and 7.5,[37] in the next 15 years is 45 to 70% and in the next 50 years is approximately 90%. This is significant because even a moderate earthquake, between 6.0 and 7.5, is likely to cause damage in the NMSZ because of the widespread presence of liquefiable soils, the large area over which shaking will be felt (see Fig. 1), and the number of vulnerable structures.

This and other seismological information has been used by the USGS (Frankel et al. 1997) to develop seismic-hazard maps that are used for seismic design. These maps present another measure of earthquake strength and peak horizontal bedrock acceleration for different probabilities of exceedance and return periods. The USGS

Journal of Legal Affairs and Dispute Resolution in Engineering and Construction 2011.3:152-159.

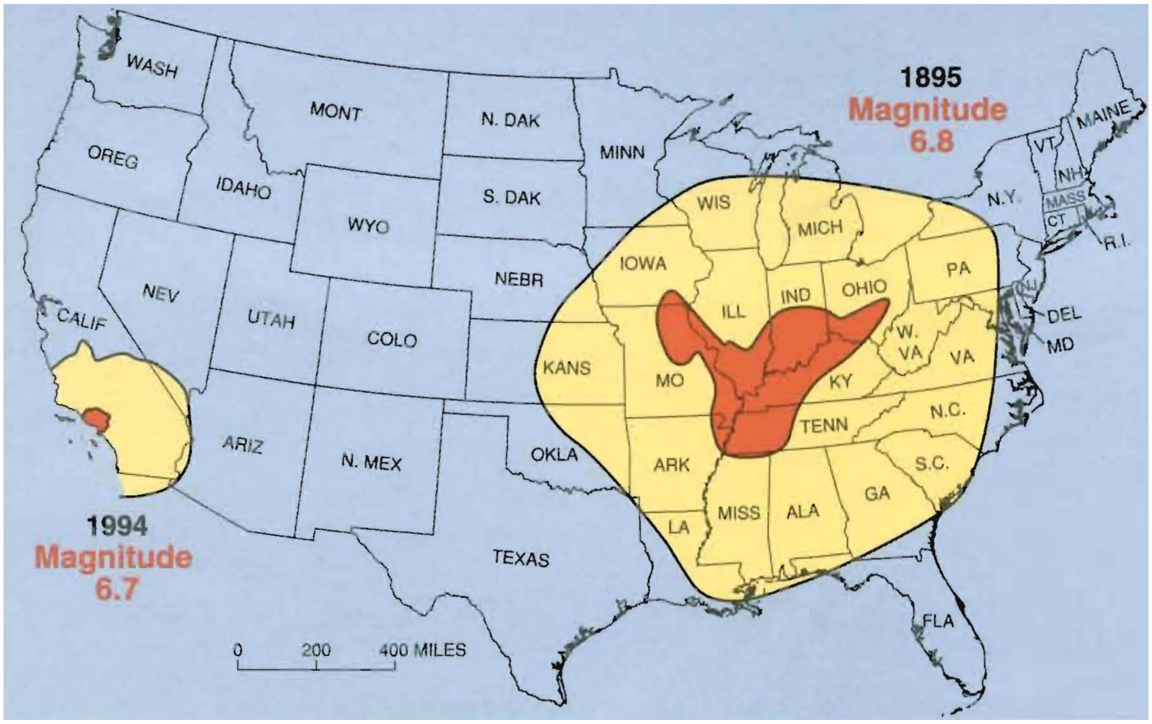

Fig. 1. Comparison of zones of impact between California and NMSZ earthquakes (darker enclosed area indicates major damage and lighter enclosed area indicates shaking felt] (reprinted from Schweig et al. 1995)

Table 2. Earthquake Probability Estimates for the New Madrid Seismic Zone (Adapted from Johnston 1997)

Earthquake magnitude (M)	Probability of recurrence (%)	
	next 15 years	next 50 years
$6.0 \leq M \leq 7.5$	45–70	88–98
$7.5 \leq M \leq 8.0$	6–10	21–33
$M \geq 8.0$	0–1	2–4

seismic hazard map for a 2% probability of exceedance in 50 years predicts a peak horizontal bedrock acceleration greater than 1.6 times gravity in the NMSZ. For comparison purposes, the highest peak horizontal bedrock acceleration for the same probability of exceedance and return period in California is only 0.8 times gravity and is located near Los Angeles. Therefore, the predicted peak horizontal bedrock acceleration in the NMSZ is approximately twice as high as in California, according to the USGS. This, coupled with the lack of seismic preparedness, suggests potentially extensive damage.

Earthquake Awareness in the Central United States

A factor that may increase the potential tort liability is that the earthquake risk is fairly well known. In other words, real property owners know or should know of the risk. The single largest event that increased the awareness of Midwestern residents was probably the prediction by Iben Browning, a meteorologist, that another great earthquake would occur near New Madrid, Missouri, on December 3, 1990 (Farley 1998). Of course, a great earthquake did not occur but the small town of New Madrid was inundated with news media and tourists who lined the levee that parallels the Mississippi River in New Madrid to witness the predicted earthquake. Although the earthquake never materialized, the widespread coverage of the event at least initiated a discussion about earthquakes in the central United States. Since 1990, many more news stories have documented the hazard. Today, visitors to New Madrid can tour the earthquake museum that is located adjacent the Mississippi River levee and dine on a quake burger at a local restaurant.

More recently, the NMSZ has been the subject of national newspaper stories (Watson 1999; Leiser 1999). In summary, there has been some national television news and newspaper coverage of the seismic hazard in the NMSZ. Recognizing the potential for large earthquakes in the Midwest, a number of organizations have been formed and existing agencies refocused to address the estimated loss of life and property from future earthquakes in the NMSZ (Schweig et al. 1995). In 1983, seven states (Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee) formed the Central U.S. Earthquake Consortium (CUSEC) to improve public awareness and education. CUSEC is located in Memphis, Tennessee, and is active in a number of earthquake-related programs, such as coordinating the studies of the state geological surveys in the seven states, continuing earthquake awareness and education activities in the NMSZ, and coordinating the emergency response of the departments of transportation in the seven states.

In 1990, the USGS intensified study of the NMSZ, culminating in Memphis, Tennessee, being named as one of three cities (along with Seattle and Oakland, California) that would be foci for long-term earthquake-related research in 1999. In addition, the Kentucky state legislature has mandated earthquake education in schools (Schweig et al. 1995). Missouri has passed legislation, described subsequently in detail, establishing a Seismic Safety Commission that prepared a strategic plan for earthquake safety in 1997.

The increased earthquake awareness has resulted in the retrofit of some existing critical structures, such as highway bridges and dams. In particular, the bridges over the Mississippi River on interstates 40, 57, and 55 in Memphis, Tennessee, St. Louis, and

Journal of Legal Affairs and Dispute Resolution in Engineering and Construction 2011.3:152-159.

Cairo, Illinois, respectively, have undergone seismic retrofit. New bridges, such as those near St. Louis and Cape Girardeau, Missouri, are being designed and constructed using modern earthquake-design standards. Some corporations are also starting to implement seismic design in new construction, such as the AutoZone corporate headquarters in Memphis, Tennessee, which is the first building in the NMSZ to utilize a base isolation foundation system to reduce the level of shaking transferred to the structure (Schweig et al. 1995). However, the majority of the structures in St. Louis and Memphis consist of unreinforced masonry or brick and remain unretrofitted. Previous earthquakes, e.g., the 1906 and 1989 earthquakes near San Francisco, have shown the vulnerability of unreinforced masonry or brick buildings to damage during earthquakes. Until the mid-1980s, the primary building material in St. Louis was brick, and thus St. Louis is especially vulnerable to earthquake-induced damage. In particular, the area of St. Louis known as Soulard consists of beautiful unreinforced brick buildings and houses dating back to the 1800s that have not been seismically retrofitted, and thus are susceptible to earthquake-induced damage.

Tort Liability for Earthquake-Induced Damages

Given the widespread knowledge of the earthquake risk and availability of retrofit techniques briefly discussed subsequently, the question arises as to property owners' legal responsibilities to mitigate earthquake hazards in the central United States. Traditionally, earthquakes present the quintessential act of God for which there is no tort liability. Although it is possible to induce earthquakes that might lead to tort liability (Cypser and Davis 1994), these are not the norm and not the situation in the central United States. For example, few firms or government agencies are involved in the type of activities that might risk inducing an earthquake. The more salient question is, what liability might lie for property owners choosing to ignore a risk of earthquakes that is ultimately realized? This question implicates virtually every firm and individual that owns or operates real property in the Midwestern region and in particular the New Madrid Seismic Zone. Because public entities are usually shielded through statutory immunity (Arkansas Code Annotated §21-9-301; Missouri Statute 537.600; Illinois Statute Chapter 745, Act 10, Section 1-101; *Mikkelsen v. State of California, 1976*; *Stevenson v. San Francisco Housing Authority, 1994*; *Haggis v. City of Los Angeles, 2000*), this paper focuses on private property owners.

Negligence for No or Limited Action

Of course, much of the relevant earthquake-related case law comes from California, but it can be used to assess possible tort liability in the central United States because of earthquake-induced damage. In determining when an actor is negligent for not undertaking property improvement, the paradigm approach is the rule developed by Judge Learned Hand in *United States v. Carroll Towing Co. (1947)*. The Hand Rule, which has produced a voluminous academic literature (Posner 1972; Grady 1983; Landes and Posner 1987; Shavell 1987; White 1990; Cooter and Porat 2000), provides that an actor will be liable for negligence when failing to undertake a burden that costs less than the expected harm of the accident without the burden.

The expected harm is the product of the probability of a harm occurring multiplied by the severity of the harm should it occur. Thus, if an actor could prevent a significant harm with a minor preventative measure, the actor will be liable. This formula has obvious implications for private property owners confronting earthquake risk. Property owners might be liable for failing to undertake seismic retrofitting or other forms of risk mitigation, or for negligently designing and constructing seismic retrofits. A separate question that is not addressed herein is the failure to comply with state laws for earthquake preparedness. For example, if a state law requires retrofit, the burden calculus is not relevant because the retrofit is mandated by law.

In equation form, the Hand Rule that indicates liability because the actor was negligent for not undertaking property improvement is

$$B < P^{*}L \tag{1}$$

in which B = burden or cost to implement seismic retrofit; P = probability that earthquake damage will occur; and L = harm or loss that will occur if the design earthquake occurs.

Alternatively, the Hand Rule that indicates the actor was not negligent for not undertaking property improvement and thus has no tort liability is

$$B \geq P^{*}L \tag{2}$$

For example, the burden to install a gas shutoff valve (described subsequently) is US$150, the probability of an $M = 6.0$ New Madrid Seismic Zone earthquake in the next 15 years is 70% (*see* Table 2), and the loss that will occur if the design earthquake occurs and causes a gas line to rupture, e.g., at the water heater, is US$50,000, which is the cost of only the house structure and not the property for a US$150,000 single-family home. With these facts, the property owner should install a gas shutoff valve because the burden is significantly less than the social cost ($P^{*}L$):

$$B < P^{*}L \quad \text{or} \quad \text{US\$150} \lll 0.7^{*}\text{US\$50,000} = \text{US\$35,000}$$

Using the earthquake probabilities in Table 2, a sensitivity analysis for installing a gas shutoff valve to prevent US$50,000 of damage for earthquake-return periods of 15 and 50 years can be performed and is shown in Table 3. The social costs in Table 3 are calculated by multiplying the earthquake probabilities in Table 2 for return periods of 15 and 50 years by a loss of US$50,000. Table 3 indicates that a US$150 gas shutoff valve can be justified in the New Madrid Seismic Zone even for an unlikely $M \geq 8.0$ earthquake with a recurrence in the next 15 years because of its low burden.

Of course, a jury would apply the Hand formula in a real case and thus would balance the harm or loss against possible actions to prevent the harm. Juries will probably not view the Hand formula as mechanically as shown previously, but instead use a more qualitative approach to balancing the harm against possible remedial actions. For example, a jury may simply conclude that an earthquake is an act of God regardless of the level of predictability, and impose liability even though the burden to prevent the harm, e.g., install a gas shutoff valve, is small.

Scholars have criticized the Hand formula on a number of grounds, including the impracticability of determining the values at issue. But these criticisms are less salient in the context of earthquake research. For example, in response to the charge that it is

Table 3. Sensitivity of Social Cost in Hand Formula to Earthquake Probability Estimates for the New Madrid Seismic Zone shown in Table 2

Earthquake magnitude (M)	Probability of recurrence (%)	
	next 15 years	next 50 years
$6.0 \leq M \leq 7.5$	$22,500–$35,000	$44,000–$49,000
$7.5 \leq M \leq 8.0$	$3,000–$5,000	$10,500–$16,500
$M \geq 8.0$	$0–$500	$1,000–$2,000

Note: all dollar amounts are given in U.S. dollars.

difficult to determine what the values are in the formula, it is important to note that scientists have made great advances in risk estimation models (see Table 2). So, although it may be difficult to determine the marginal benefit of looking both ways twice before crossing the street, sophisticated econometric tools are available for determining both earthquake probability and magnitude of expected harm. These tools provided the basis for the earthquake-probability estimates given in Table 2.

There are at least two possible theories under which a plaintiff could recover from a private property owner for earthquake damage. The first is for negligent initial construction that results in seismic vulnerability (*London Guarantee & Accident Co. v. Industrial Accident Commission of California, 1928*) and the second is for lack of or negligent seismic retrofitting so that the structure remains seismically deficient (*KPFF, Inc. v. California Union Ins. Co., 1997*).

Negligence for Initial Construction

A typical example of a claim of negligent construction in a commercial context is found in *London Guarantee & Accident Co. v. Industrial Accident Commission of California (1928)*. In *London*, a plaintiff was able to recover for the fatal injury of her spouse that resulted from the Santa Barbara earthquake of June 29, 1925, because of defective construction, even though he was covered by the Workmen's Compensation Act. In this case, Segismundo Mosteiro was struck and killed by falling concrete walls of a Santa Barbara building while employed as a janitor. Although the *London* court noted that earthquakes are considered force majeure and hence would be outside the ordinary scope of employer liability, it still awarded damages to the plaintiff because it was shown that the building would not have collapsed had it been constructed of proper materials. In particular, considerable evidence was introduced that showed the concrete used to construct the reinforced concrete building was defectively mixed, resulting in an improper bond between the cement and the gravel.

London is of particular relevance to private property owners in the NMSZ because it is likely that many buildings in the area will suffer damage from earthquake loading even though they have successfully withstood gravity loads for some time. In other words, earthquake shaking in the NMSZ could expose construction defects that have not manifested themselves in the absence of earthquake loading, and thus cause property owners, insurers, contractors, engineers, and others to be liable for earthquake-related damage and injuries. Courts also might find that buildings that are not designed to resist seismic forces are defective because the design process did not take into consideration a foreseeable design and widely known force. This may allow courts to impose liability without having to show a specific defect in the building materials or construction.

A typical defective residential construction case is *Aas v. Superior Court (2002)* in which a homeowners' association and individual homeowners brought a claim for negligence against the developer, contractor, and subcontractors for failure to conform to building standards. In particular, the plaintiffs claimed that the absence of shear walls made the residences more susceptible to damage and personal injury from seismic and wind forces. Seismic and wind forces are lateral forces, and shear walls provide lateral resistance to exterior walls of a structure. The negligence claim was denied because the property had not experienced any damage, but if damage had occurred because of seismic loading, the plaintiffs appeared to have a valid claim. In stressing the importance of seismically resistant construction, the court referred to a California Seismic Safety Commission (1994) recommendation that states

> "The greatest opportunity to ensure seismic safety is during a building's design and construction…. The Northridge earthquake and other past earthquakes have clearly and repeatedly demonstrated the remarkable effectiveness of paying attention to quality in reducing earthquake losses. Quality assurance is the single most important policy improvement needed to manage California's earthquake risk."

Negligence Retrofit Construction

There also have been several cases against contractors who failed to retrofit, under a negligent construction or retrofit claim. In the aftermath of the Northridge earthquake, in *Keru Investments, Inc. v. Cube Co. (1998)* the California Court of Appeals denied a claim brought against the contractor by a noteholder who purchased an earthquake-damaged building. A man named Kaila was the owner of an apartment building in Hollywood, California; some time prior to 1988, he sold it to the Moross Group. During that year, those owners hired an engineer and contractor, respectively, to design and effectuate a "seismic retrofit for the building." In January 1994, the Northridge earthquake hit the area and the building was badly damaged and ultimately yellow-tagged by the city, which means the structure was moderately damaged to the degree that its habitability was limited, e.g., only during the day. The Moross Group then conveyed the building to Keru Investments (Keru), a company wholly owned by the original property owner, Kaila. Under their sales agreement, Keru assumed the loan obligations of the Moross Group and the latter agreed that the property was being bought on an as-is basis only, i.e., without any warranties. The agreement even specifically recited the building's "damages and need for repairs." Sometime later, Keru concluded that both the seismic retrofit design and construction work were faulty and sued both the engineer and the contractor. However, the court held that there was no cause of action for the noteholder because the Moross Group had been the owner at the time the damage occurred as well as during the retrofit. In general, a cause of action for negligent design, engineering, or construction of buildings accrues in favor of the owner of the building at the time the damage occurs (*Krusi v. S. J. Amoroso Construction Co., 2000*). This means that a tort duty runs from an architect, designer, or contractor to not only the original owner for whom the real property improvement services are provided, but also to subsequent owners of the same property.

The evidence shows that the retrofit had been partially successful, i.e., greater damage would have occurred in the absence of retrofitting, but also negligent in that a proper retrofit would have led to less damage than actually occurred because a proper retrofit would have reduced nonuse of building from six months to one. *Keru* suggests, then, that had the plaintiff been properly situated, he could have brought a case.

Insurance-Related Recovery

Another category of claim involves insurance-related claims, which are not limited to property damage. In *Continental Cas. Co. v. Thompson (1966)*, a plaintiff recovered on an insurance claim on the basis of an accidental death caused by mental shock from the great Alaskan earthquake of 1964. A typical example of the many cases that appeared after the great San Francisco earthquake of 1906 involves fire insurance. Damage in this case was caused not by the earthquake directly, but by the large fire that engulfed the city after the earthquake. Problems for property owners in such cases can result from insurance exclusion clauses stating that if the building or any part thereof falls, except as a result of fire, all insurance on the building or contents shall cease because the remaining part of the building is subject to an increased fire risk

(*Fountain v. Connecticut Fire Ins. Co. of Hartford, 1910*). Accompanying case law defined the "fallen building" clause of these fire insurance policies as "either the fall of the building as a structure, or of such a substantial and important part thereof as impairs its usefulness as such, and leaves the remaining part of the building subject to an increased risk of fire." It is anticipated that if a large NMSZ earthquake occurs, substantial damage will occur to the large number of unreinforced masonry structures and the remaining issue may be whether or not the damaged portion of the building subjects the contents to an increased risk of fire. Of course, the main reason for the structural damage is that the vast majority of unreinforced masonry structures in the NMSZ were constructed with no seismic resistance, unreinforced masonry cracks easily because of shaking, and these structures have not been retrofitted.

Thus, existing earthquake-related case law suggests that there is a duty to retrofit and that tort liability may accrue to owners who fail to do so or do so negligently. This duty to retrofit lies with the owner (*Prudential Ins. Co. of America v. L. A. Mart, 1995*). For example, *Prudential* shows that private property owners cannot transfer retrofit liabilities to a lessee even though the property is secured by a long-term lease or sale-leaseback condition. Even if the seismic retrofitting is required by ordinance or law, such as in *Hadian v. Schwartz (1994)*, courts have been reluctant to require the lessee to assume the costs of earthquake hazard reduction because the enhancements usually remain with the building.

Would such private liability exist in the Midwest? A simple application of the Hand formula suggests that the objective risk may be as high as in California. Although the probability of a large-scale earthquake is lower, the potential loss may be as high because of inadequate preparation. Certain low-cost preventative measures, such as the seismic gas shutoff valves discussed subsequently, almost certainly ought to be adopted in the Midwest under of the Hand formula. Larger-scale retrofits would depend on the retrofit cost and the proximity the structure to the NMSZ.

The existence of seismic safety-commission recommendations in California is one factor that might lead courts to find that a reasonable property owner would engage in retrofits. Missouri also has a seismic safety commission that has issued similar recommendations as the California commission. Once such a duty exists, it must be done competently or lead to liability. It might be argued that the lack of earthquake awareness in the Midwest would lead courts to find that no such initial duty exists. However, growing awareness of the earthquake hazard in the Midwest means that earthquake-related damages are becoming more foreseeable and, hence, recoverable. Private actors in the NMSZ ought to closely examine their potential liability and take preventative steps to mitigate their liability exposure, including constructing seismically safe buildings or seismically retrofitting existing buildings. Public agencies, e.g., state departments of transportation, are implementing seismic design in new structures, e.g., highway bridges. Private property owners will not enjoy the immunity that public entities and private lessees enjoy for seismic-related injuries or seismic upgrade costs.

In addition, federal earthquake-related legislation, which emphasizes the need for increased public awareness, development of new building technologies, and implementation of model building codes, recognizes the seismic hazard in the NMSZ. In 1977, the Earthquake Hazards Reduction Act (86 U.S. Code 7701–7706) was passed. The Congressional findings declare that all 50 states are vulnerable to earthquakes and at least 39 of them are subject to major or moderate seismic risk, including Missouri and Illinois. One of the areas identified in the Act as being subject to a major earthquake risk is the NMSZ. Thus, not only has the NMSZ been recognized on the federal level, FEMA and other agencies have been charged with increasing public awareness of the earthquake risk in the NMSZ. Evidence of this includes the earmarking of US $450,000 to continue CUSEC's efforts "to reduce the unacceptable threat of earthquake damages in the New Madrid seismic region through efforts to enhance preparedness, response, recovery, and mitigation" (86 U.S. Code 7706).

In summary, this potential source of private liability is related to public regulation in two ways. First, the development of legislative frameworks related to earthquakes may be seen as evidence that property owners are, or should be, becoming more aware of the risk. This could lead to an expansion of private liability, even if the statutes do not require specific steps, because the reasonable property owner should be aware of potential earthquake-related damage. Second, the legislative frameworks can ameliorate some of the hardship or cost incurred by private owners in retrofitting through loans or tax incentives. Indeed, such an approach has been adopted in California legislation.

Earthquake Retrofit Techniques

This section briefly describes some of the techniques property owners can utilize to reduce the potential of structural collapse and damage in existing or new structures in the NMSZ. These measures not only provide resistance against earthquakes but also other natural hazards, such as tornados, ice storms, and fires ignited by an earthquake or other means (Olshansky 1994). This is an important point because it may help encourage public support for retrofits that convey collateral benefits in mitigating damages from other, higher-frequency natural disasters. The retrofit techniques most relevant to a low-frequency earthquake region are emphasized and it will be shown that property owners could implement these techniques to reduce the structural hazards imposed by a New Madrid earthquake.

California Government Code §8894.2 defines seismic retrofitting to encompass three categories or levels of strengthening. The first and least encompassing is retrofitting or reconstruction to significantly reduce structural collapse and falling hazards from structural or nonstructural components including, but not limited to, parapets, appendages, cornices, hanging objects, and building cladding that poses serious danger to the occupants or adjacent areas. The second technique is structural strengthening to modify the seismic response that would otherwise be expected by an existing structure to significantly reduce hazards to life and safety while also providing for the safe ingress and egress of the building occupants immediately after an earthquake. The third and most protective technique is retrofitting or strengthening of a structure to allow the structure to remain functional immediately after an earthquake.

The most common technique of seismic retrofitting is strengthening the structure by additional steel, concrete, and/or timber. Other more advanced techniques for retrofitting structures have been implemented in Japan and California. One category of advanced retrofitting techniques involves the installation of structural control measures to reduce the effect of earthquake shaking on structures (Soong and Constantinou 1994). The structural control measures can be separated into five major categories: active control, semiactive control, hybrid control (combined use of active and passive control), passive control, and structural health monitoring (Housner et al. 1997). Because the NMSZ is a low-frequency earthquake zone, passive control measures are probably most appropriate for the region.

Property owners in the NMSZ can implement passive control or structural-strengthening techniques that reduce the potential for damage and collapse. The implementation of passive-control devices may be less costly and less intrusive than other retrofit techniques. In summary, retrofit techniques are available and could be implemented in the NMSZ.

There are also inexpensive measures that property owners can implement to reduce the risk of fire, which was the major cause of damage after the 1906 San Francisco earthquake. For example, California is more stringent than the states in the NMSZ and requires that all buildings open to the public install earthquake-sensitive gas shutoff devices (California Health and Safety Code §19181). These devices stop gas supply to the building in the event of an earthquake to reduce the potential for fire. In addition, California requires seismic gas shutoff valves for individual structures connecting to main gas lines (California Health and Safety Code §19204) and local governments are authorized to adopt ordinances requiring installation of earthquake-sensitive gas shutoff devices in buildings (California Health and Safety Code §19180). However, the California State Architect must certify operation and functionality of seismic gas shutoff valves before manufacturers can market the devices (California Health and Safety Code §19202).

Conclusions

Although the probability of a major earthquake in the NMSZ is less than that in California, the expected damage from an earthquake if one occurs is much greater because of geological features and because policy makers and the public have not taken adequate steps to mitigate damages. A simple application of the Hand formula suggests that, given the significant risk, policy makers and the public should take reasonable steps to mitigate expected damages. In the case of private actors, this will shield them from tort liability that might otherwise accrue and possibly from more expensive rebuilding costs. Liability also may accrue because of negligent initial construction or negligent seismic retrofit.

Acknowledgments

The author gratefully acknowledges Thomas B. Ginsburg, formerly Professor of Law at the University of Illinois at Urbana-Champaign and now Professor of Law at the University of Chicago Law School, for his suggestion to pursue this topic and his guidance throughout the study.

List of Cases

Aas v. Superior Court, 101 Cal.Rptr.2d 718 (2000)
Continental Cas. Co. v. Thompson, 369 F.2d 157, at 157 (1966)
Fountain v. Connecticut Fire Ins. Co. of Hartford, 117 P. 630, (1910)
Hadian v. Schwartz, 35 Cal.Rptr.2d 589, at 589 (1994)
Haggis v. City of Los Angeles, 78 Cal.Rptr.2d 826 at 826 (1998), 93 Cal.Rptr.2d 327 (2000)
Keru Investments, Inc. v. Cube Co., 63 Cal.App.4th 1413, 74 Cal. Rptr. 2d 744 (Ct. App. 1998)
KPFF, Inc. v. California Union Ins. Co., 66 Cal.Rptr.2d 36 (1997)
Krusi v. S.J Amoroso Construction Co., 97 Cal. Rptr. 2d 294 (2000)
London Guarantee & Accident Co. v. Industrial Accident Commission of California, 259 P. 1096, at 1097 (1927); *see also* Collins v. Industrial Acc. Commission, 205 Cal. 727, 273 P. 33 (1928)
Mikkelsen v. State of California, 130 Cal. Rptr. 780, at 780 (1976)
Prudential Ins. Co. of America v. L.A. Mart, 68 F.3d 370 at 371 (1995)
Stevenson v. San Francisco Housing Authority, 29 Cal.Rptr.2d 398 (1994)
United States v. Carroll Towing Co., 159 F.zd 169 (2d Cir. 1947)

List of Statutes

Arkansas Code Annotated §12-77-102 (Earthquake Preparedness Act)
Arkansas Code Annotated §21-9-301—Tort Liability—Immunity Declared
California Government Code §8894.2—Seismic Retrofit
California Health & Safety Code §19180—Seismic Gas Shut-Off Valves
California Health & Safety Code §19181—Seismic Gas Shut-Off Valves
California Health & Safety Code §19202—Seismic Gas Shut-Off Valves
California Health & Safety Code §19204—Seismic Gas Shut-Off Devices—Application of article
Illinois Statute Chapter 745, Act 10, Section 1–101—Civil Immunities Act, Local Government Employees Tort Immunity
Missouri Statute 537.600—Torts and Actions for Damages
Tennessee Code §11-14-108—Designation of areas (Reelfoot Lake a “natural, earthquake-formed lake, consisting of approximately eighteen thousand (18,000) acres of land and water in Lake and Obion counties”)
86 U.S. Code 7701–7706. The Act was amended in 1980, 1981, 1983, 1984, 1985, 1988, 1990, and 1994, and expanded in 2000

Endnotes

[1]Central U.S. Earthquake Consortium (CUSEC). 1996. “Earthquake vulnerability of transportation systems in the central United States,” Memphis, TN, September.
[2]EQE International, Inc. 2002. “The October 17, 1989 Loma Prieta Earthquake,” Report on Local Effects of Loma Prieta Earthquake, summarized at www.eqe.com/publications/lomaprie/introduc.htm.
[3]Kimura, M. 1996. Special issue of Journal of Soil Mechanics and Foundations, editor, Vol. 1.
[4]Earthquake Engineering Research Institute (EERI). 1995. Hokkaido-Nansei-Oki earthquake and tsunami of July 12, 1993—Reconnaissance report, earthquake spectra, Vol. 11 supplement, April, 165 pp.
[5]Van Arsdale, R. 1997. Hazard in the heartland: The New Madrid Seismic Zone, 4 Geotimes, 16–19.
[6]Johnston, A. C. 1996. Seismic moment assessment of earthquakes in stable continental regions—III. New Madrid 1811–1812, Charleston 1886, and Lisbon 1755, 126 Geophysics Journal International 314–344.
[7]Schweig, E. S., Gomberg, J., and Hendley, J. W. II. 1995. The Mississippi Valley—Whole lotta shakin’ goin’ on, U.S. Geological Survey Fact Sheet, No. 168–95, 2 p.
[8]Tennessee Code §11-14-108—Designation of areas (Reelfoot Lake a “natural, earthquake-formed lake, consisting of approximately eighteen thousand (18,000) acres of land and water in Lake and Obion counties”).
[9]Van Arsdale, R. 1998. Seismic hazards of the upper Mississippi embayment, U.S. Army Corps of Engineers, Waterways Experiment Station, Contract Report GL-98-1.
[10]Van Arsdale, R.B. 2009. Adventures through deep time: The central Mississippi River Valley and its earthquakes. Geological Society of America Special Paper 455, 107 p.
[11]Fuller, M. L. 1912. New Madrid Earthquake, U.S. Geological Survey Bulletin 494, 120 p. (1912).
[12]Van Arsdale 1998.
[13]Johnston, A. C., and Schweig, E.S. 1996. The enigma of the New Madrid earthquakes of 1811–1812, 24 Annual review of Earth and Planetary Sciences, 339–384.
[14]Schweig and Van Arsdale 1996.
[15]Johnston 1996.
[16]Van Arsdale 2009.
[17]Hildenbrand, T. G., Langenheim, V.E., Schweig, E.S., Stauffer, P.H., and Hendley J.W. II. 1996. “Uncovering hidden hazards in the Mississippi Valley,” U.S. Geological Survey Fact Sheet, No. 200-96, 2.
[18]Arkansas Code Annotated §12-77-102 (Earthquake Preparedness Act).
[19]CUSEC 1996.
[20]Center for Earthquake Research and Information (CERI). 2002. University of Memphis, Memphis, TN, http://folkworm.ceri.memphis.edu/recenteqs/Quakes/quakes.big.html.
[21]Johnston and Schweig 1996.
[22]Johnston and Schweig 1996.

Journal of Legal Affairs and Dispute Resolution in Engineering and Construction 2011.3:152-159.

[23]Johnston and Schweig 1996.
[24]Johnston and Schweig 1996.
[25]Johnston and Schweig 1996.
[26]Johnston and Schweig 1996.
[27]Schweig and Van Arsdale 1996.
[28]Schweig and Van Arsdale 1996.
[29]CUSEC 1996.
[30]EQE International, Inc. 2002.
[31]Seed, H. B., Romo, M.P., Sun, J., Jaime, A., and Lysmer, J. 1987. Relationships between soil conditions and earthquake ground motions in Mexico City in the earthquake of Sept. 19, 1985, Report No. UCB/EERC-87/15, Earthquake Engineering Research Center, University of California, Berkeley, October, 112 p.
[32]Idriss I. M. (1990). Response of soft soil sites during earthquakes, Proceedings H. Bolton Seed Memorial Symposium, 273, 285.
[33]Schweig et al. 1995.
[34]Stark, T. D., Abrams, D. P., and Hawkins, N. M. 2000. Seismic bridge research in transportation networks program of Mid-America Earthquake Center, paper presented at Transportation Research Board (TRB) session on seismic design of bridges, TRB Annual Meeting, Washington, DC, January, at 1.
[35]Johnston, A. C., and Nava, S. J. 1985. Recurrence rates and probability estimates for the New Madrid Seismic Zone, v. 90, Journal Geophysical Research, pp. 6737–6753.
[36]Johnston, A. C. 1997. Earthquake probabilities in the New Madrid Seismic Zone: An update for the year 2000, in Addressing the Earthquake Risk in the Central U.S., A Forum for Insurance and Earthquake Hazards Professionals, Memphis, TN, December 3.
[37]Johnston 1997.

References

California Seismic Safety Commission. (1994). "Northridge Earthquake: Turning loss to gain." *SSC Rep. No. 95-01*, Sacramento, CA.

Center for Earthquake Research and Information (CERI). (2002). "Recent Earthquakes in Central US." ⟨http://folkworm.ceri.memphis.edu/recenteqs/Quakes/quakes.big.html⟩ (Jan. 22, 2011).

Central U.S. Earthquake Consortium (CUSEC). (1996). "Earthquake vulnerability of transportation systems in the central United States." Memphis, TN.

Cooter, R., and Porat, A. (2000). "Does risk to oneself increase the care owed to others? Law and economics in conflict," *J. Legal Stud.*, 29(1), 19–34.

Cypser, D. A., and Davis, S. D. (1994). "Liability for induced earthquakes," *J. Envtl. L. & Litig.*, 9(551), 551–589.

Earthquake Engineering Research Institute (EERI). (1995). "Hokkaido-Nansei-Oki earthquake and tsunami of July 12, 1993, reconnaissance report." *Earthquake Spectra 11*, Supplement A, El Cerrito, CA.

EQE International, Inc. (2002). "The October 17, 1989 Loma Prieta earthquake." *Rep. on Local Effects of Loma Prieta Earthquake*, summarized at ⟨http://www.eqecat.com/post-event-reports.html⟩, Oakland, CA (Jan. 22, 2011).

Farley, J. E. (1998). *Earthquake fears, predictions and preparations in mid-America*, Southern Illinois University Press, Carbondale, IL.

Frankel, A. D., et al. (1997). "Seismic-hazard maps for the conterminous United States." *U.S. Geological Survey*, *Open-File Rep. 97-131*, Open-File Services Section, Denver, ⟨http://earthquake.usgs.gov/hazards/products/conterminous/2008/maps/⟩ (Nov. 17, 2011).

Fuller, M. L. (1912). "New Madrid earthquake." *USGS Bulletin 494*, 120, Washington, DC.

Grady, M. (1983). "A new positive economic theory of negligence." *Yale Law J.*, 92(5), 799–829.

Hildenbrand, T. G., Langenheim, V. E., Schweig, E. S., Stauffer, P. H., and Hendley, J. W., II. (1996). "Uncovering hidden hazards in the Mississippi Valley." *USGS Fact Sheet*, *No. 200-96*, 2, Washington, DC.

Housner, G. W., et al. (1997). "Structural control: Past, present, and future." *J. Eng. Mech.*, 123(9), 897–971.

Idriss, I. M. (1990). "Response of soft soil sites during earthquakes." *Proc., H. Bolton Seed Memorial Symp.*, BiTech Publishers, Vancouver, Canada, 273–285.

Johnston, A. C. (1996). "Seismic moment assessment of earthquakes in stable continental regions—III. New Madrid 1811–1812, Charleston 1886, and Lisbon 1755." *Geophys. J. Int.*, 126(2), 314–344.

Johnston, A. C. (1997). "Earthquake probabilities in the New Madrid Seismic Zone: An update for the year 2000." *Addressing the Earthquake Risk in the Central U.S., A Forum for Insurance and Earthquake Hazards Professionals*, Central United States Earthquake Consortium (CUSEC), Memphis, TN.

Johnston, A. C., and Nava, S. J. (1985). "Recurrence rates and probability estimates for the New Madrid Seismic Zone." *J. Geophys. Res. [Solid Earth]*, 90(B8), 6737–6753.

Johnston, A. C., and Schweig, E. S. (1996). "The enigma of the New Madrid earthquakes of 1811–1812." *Annu. Rev. Earth Planet Sci.*, 24(1), 339–384.

Kimura, M. (1996). "Overview of 1995 Hyogoken-Nambu Earthquake." *Soils Found.*, 1, 3–10.

Landes, W., and Posner, R. (1987). *The economic structure of tort law*, Harvard University Press, Cambridge, MA.

Leiser, K. (1999). "Quake project for Highway 40 doubles in cost—Agency also seeks more money for Page Avenue job." *St. Louis Post-Dispatch*, Dec. 8, A1.

Olshansky, R. B. (1994). "Seismic hazard mitigation in the central United States: The role of the states." *USGS Professional Paper 1538-G at G-10*, Washington, DC.

Posner, R. (1972). "A theory of negligence," *J. Legal Stud.*, 1(1), 29–96.

Schweig, E. S., Gomberg, J., and Hendley, J. W. II. (1995). "The Mississippi Valley—Whole lotta shakin' goin' on." *USGS Fact Sheet*, *No. 168-95*, 2, Washington, DC.

Schweig, E. S., and Van Arsdale, R. (1996). "Neotectonics of the upper Mississippi embayment." *Eng. Geol.*, 45(1–4), 185–203.

Seed, H. B., Romo, M. P., Sun, J., Jaime, A., and Lysmer, J. (1987). "Relationships between soil conditions and earthquake ground motions in Mexico City in the earthquake of Sept. 19, 1985." *Rep. No. UCB/EERC-87/15*, Earthquake Engineering Research Center, University of California, Berkeley, CA.

Shavell, S. (1987). *Economic analysis of accident law*, Harvard University Press, Cambridge, MA, 26–46.

Soong, T. T., and Constantinou, M. C., eds. (1994). *Passive and active structural vibration control in civil engineering*, Springer, New York.

Stark, T. D., Abrams, D. P., and Hawkins, N. M. (2000). "Seismic bridge research in transportation networks program of Mid-America Earthquake Center." *Transportation Research Board Annual Meeting*, Washington, DC.

Van Arsdale, R. (1997). "Hazard in the heartland: The New Madrid Seismic Zone." *Geotimes*, 42(5), 16–19.

Van Arsdale, R. (1998). "Seismic hazards of the upper Mississippi embayment." *Contract Rep. GL-98-1*, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Van Arsdale, R. B. (2009). "Adventures through deep time: The central Mississippi River Valley and its earthquakes." *Geological Society of America Special Paper 455*, 107.

Watson, T. (1999). "Scientists downgrade risk of central U.S. quake." *USA Today*, Apr. 23, 6A.

White, B. A. (1990). "Risk-utility analysis and the Learned Hand formula: A hand that helps or a hand that hides?" *Ariz. Law Rev.*, 32(1), 77–136.