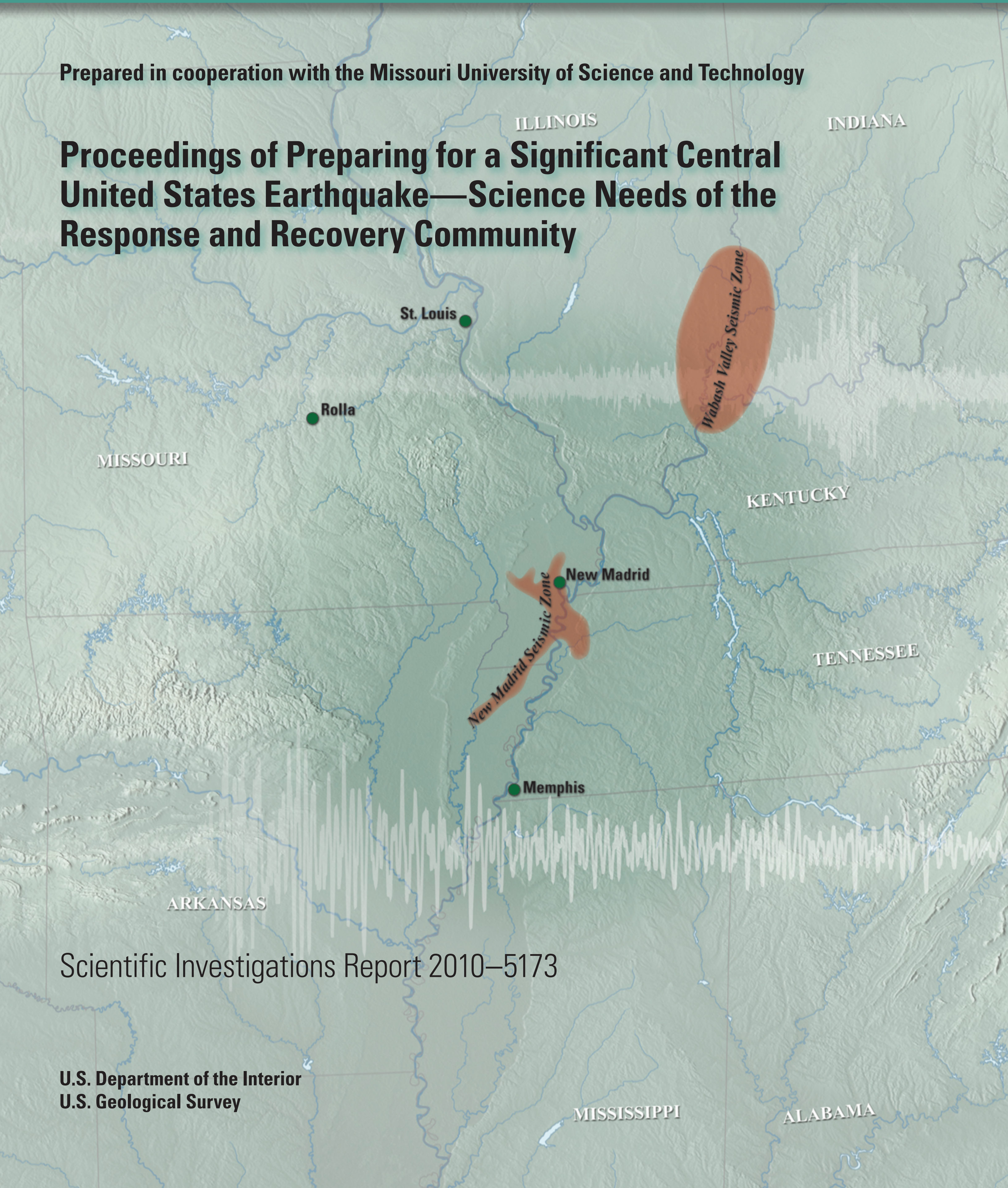
Prepared in cooperation with the Missouri University of Science and Technology

Proceedings of Preparing for a Significant Central United States Earthquake—Science Needs of the Response and Recovery Community



Scientific Investigations Report 2010–5173

U.S. Department of the Interior
U.S. Geological Survey

Front cover. Map of the Central United States showing location of the New Madrid Seismic Zone.

Back cover. Map of seismicity (red circles—size is proportional to magnitude between 3 and 7.5) in the Central and Eastern United States since 1964.

Proceedings of Preparing for a Significant Central United States Earthquake—Science Needs of the Response and Recovery Community

Edited By Emitt C. Witt, III

Prepared in cooperation with the Missouri University of Science and Technology

Scientific Investigations Report 2010–5173

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

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Suggested citation:
Witt, E.C., III, ed., 2010, Proceedings of preparing for a significant Central United States earthquake—Science needs of the response and recovery community: U.S. Geological Survey Scientific Investigations Report 2010–5173, 76 p.

Preface

Imagine waking up at 2 o'clock in the morning by a violent rumbling that causes ceilings to fall, furniture to topple over, and windows to break. Your home is crumbling, it is dark, and by the time you realize what is going on the shaking stops. You quickly determine that your family members are okay, but you also realize your power is out, all the windows are broken, and there is substantial damage to your home possibly making it unsafe to remain inside. The temperature outside is in the 20s, there is a heavy snow on the ground, and the flu season is at its peak with two of your family members affected. Unfortunately your family is one of thousands in a similar circumstance and the response to your needs may not be immediate, if at all. Could an earthquake like this happen unannounced? It did in the Central United States during the great New Madrid earthquake of 1811–12. A resident of New Madrid, Missouri writes (Martin, 1848):

> *"On the 16th of December 1811, about 2 o'clock, AM, we were visited by a violent shock of an earthquake accompanied by a very awful noise resembling loud but distant thunder, but more hoarse and vibrating, which was followed in a few minutes by the complete saturation of the atmosphere with sulphurious vapor, causing total darkness. The screams of the affrighted inhabitants running to and fro, not knowing where to go, or what to do—the cries of the fowls and beasts of every species—the crackling of trees falling, and the roar of the Mississippi—the current of which was retrograde for a few minutes, owing as is supposed to an irruption in its bed—formed a scene truly horrible."*
>
> *Eliza Bryan, March 22, 1816*

The residents of the Central United States during the great New Madrid earthquake were accustomed to living rugged life styles. Electrical power was not a reality, water was drawn from shallow hand-dug wells or retrieved from streams, food was hunted or grown, and the homes typically were log structures with dirt floors. Though these inhabitants were primitive by today's standards, they could survive because they did not rely on the supporting infrastructure we rely on today. What would you do if such an event struck as you read this? As a society, are we prepared for a similar event? Could you live for an extended period without power, refrigeration, heat, air conditioning, or fresh water?

Missouri and its adjacent states have experienced more than 450 recorded earthquakes greater than magnitude 3 since 1964 (Petersen and others, 2008); however, none of these Central United States earthquakes has been as severe as the 1811-12 event. The 1811–12 events actually were a series of three very large earthquakes followed by many smaller but significant aftershocks (Johnston and Schweig, 1984). Ground shaking was reported as far away as Pittsburgh, Pennsylvania, and Charleston, South Carolina.

Seismicity in the Central United States is related to two major interplate fault systems buried deep within the Mississippi River and Wabash/Ohio River alluvium. They are collectively known as the New Madrid and the Wabash Valley Seismic Zones. The New Madrid Seismic Zone extends north along the Mississippi River from Memphis, Tennessee, to the confluence of the Ohio and Mississippi Rivers. The Wabash Valley Seismic Zone extends north along the Wabash River from its confluence with the Ohio River to Terre Haute, Indiana. Together, these two seismic zones cover an area nearly 45,000 square miles. The cities of St. Louis, Missouri: Memphis, Tennessee: Little Rock, Arkansas; and Evansville, Terre Haute, and Indianapolis, Indiana, all are located in or adjacent to the New Madrid and the Wabash Valley Seismic Zones.

Geologic studies of seismic activity for the region indicate that both zones are capable of producing large magnitude earthquakes (Gomberg and Schweig, 2006). Unfortunately, little is known about the mechanisms supporting large earthquakes in the Central United States, and few earthquakes of significant magnitude happen with any frequency in this region. This has led to complacency among Central United States residents regarding the potential for another destructive earthquake. When a future significant earthquake does happen, it likely will occur without warning, causing widespread confusion and delayed response. A significant event could cause substantial damage and interrupt the east to west flow of transportation, communication, electricity, natural gas, and oil throughout the United States. Preliminary estimates indicate that economic losses from a magnitude 7.7 event in the New Madrid Seismic Zone could reach $50–$80 billion in direct losses alone (Elnashai and others, 2008). There could be thousands of fatalities, tens of thousands of injured victims, and hundreds of thousands left without homes. Much is being done to prepare the region for a significant earthquake. But like any disaster, many lessons are not often learned until the event occurs and many lives are lost.

On August 12–15, 2008, the U.S. Geological Survey and Missouri University of Science and Technology hosted "Preparing for a Significant Earthquake: Science Needs of the Response and Recovery community," in Rolla, Missouri. The purpose of this conference was to bring together scientists, engineers, and the response and recovery community who are stakeholders in activities resulting from a significant no-notice seismic event in the Central United States. The objective was to provide a regional forum for the presentation, exchange of ideas, and potential solutions involved with preparing for a significant Central Unites States earthquake. The conference opened communication avenues with academia, government, non-government agencies, and the private sector to address the current and forecasted needs of the response and recovery community. The ultimate objective was to facilitate the development of relevant science in preparation for a significant Central United States earthquake similar to the events of 1811–12, and to begin establishing a long-term consistent system of data development that can support holistic interpretations leading to products that can support the response and recovery community following an earthquake.

This report contains the abstracts and selected papers for oral and poster sessions and the results of the breakout and table-top sessions. During the three day conference workshop participants learned about first response training, attended presentations from esteemed speakers, and participated in a facilitated discussion on the next steps necessary to prepare for a significant seismic event in the Central United States. The first day of the conference consisted of six training events:

- Missouri's State Emergency Management Agency's (SEMA) Structural Assessment and Visual Evaluation (SAVE) training;

- The Central United States Earthquake Consortium (CUSEC) summary brief of the Disaster Medicine 101 course and an overview of public health concepts related to the earthquake threat in the New Madrid Seismic Zone;

- Red Cross training in mass care;

- The U.S. Army Chemical, Biological, Radiological, and Nuclear School's presentation on the employment of joint task forces of military, federal, Department of Transportation, and local organizations in a disaster environment;

- The Missouri National Guard's Weapons of Mass Destruction Civil Support Team's (CST) exploratory session on how CSTs can support the emergency response community during a seismic event. The class also included a live demonstration of specific communications capabilities including a live "hot zone" video, video teleconference, and Voice over Internet Protocol (VOIP) capabilities; and

- Central Plains EarthScope Partnership presentation on the coalition of universities, schools, State geological surveys, and State and Federal agencies organized to promote earth science research and education in Kansas, Nebraska, Iowa, and Missouri by utilizing the National Science Foundation-funded EarthScope facility.

The second day of the conference addressed specifically topics, including the consequences of a major earthquake, engineering effects and stresses, socioeconomic impacts, mitigation plans for transportation and infrastructure, geological and structural monitoring, and geologic mapping activities. The third day was divided into two tracks to facilitate discussion and input into the needs of the response and recovery community. Presentations focused on Federal and State agency mapping activities, and the lessons learned from State and Department of Defense natural disaster exercises. Both tracks included a facilitated panel discussion to develop a list of challenges to response and recovery operations that can be supported through relevant science and engineering activities. SEMA also conducted a table-top exercise that brought concerns from the response and recovery community to the attention of the science community. Comments made by speakers not affiliated with the USGS do not necessarily reflect the positions of the USGS.

Lessons Learned and Next Steps

A survey of attendees indicated that most were somewhat to extremely concerned that a significant no-notice earthquake could strike within the New Madrid region. Most all indicated that their organizations had some sort of a plan for responding to such an event and the roles of these individuals would include coordination, science advising, inspection engineering, data collection, and geospatial information provider. All respondents indicated that science and engineering was used extensively in their response and recovery plans. They recommended better cooperation between research groups, and more specific data collection and analysis of the region's geology.

From the geospatial perspective, respondents cited the need for better elevation data and a current structures database that meets the Homeland Security Infrastructure Program (HSIP) guidelines. Geospatial products that were communicated as being valuable for implementing response plans included road maps, image maps, topographic maps, geologic hazard maps, GIS databases, river and stream stage data, and locations of earthquake epicenters.

Although we may never be able to predict the coming of the next great New Madrid earthquake, we do know that such events have occurred with some frequency in the past, and that recurrence is a probability. In the case of intraplate seismicity, what we know is not necessarily what we understand. Science can take us only so far in the understanding of the earth's dynamic process; it is up to society to be prepared. This conference was extremely successful in bringing the science and response communities together. Never before has this been done with the goal of identifying from both camps the needs for preparing for a significant catastrophic earthquake. During the three days there was much discussion, interaction, and certainly praise from the attendees for having such an event. Through further refinement it should serve as a model to facilitate our need for open, cross-discipline communication on natural disaster preparation. In the end, it is recognized that scientists, emergency managers, and community planners together are collectively the responders. The exchange of ideas among this group will facilitate the best use of limited resources. When the "big one" happens there will be a limited number of responders to help thousands of people in need; therefore it is critical that science focus its research on ways to mitigate the catastrophe and prepare the emergency managers to do their jobs more efficiently. Likewise, it is critical that emergency managers and resource planners engage with the scientific community to ensure their needs are communicated.

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Acknowledgments

A special thanks to the conference organization committee who over the course of a year worked together to plan and execute a successful conference. The committee included: Krista Karstensen, Laura Grentz, Sue Evers, Allen 'AJ' Lehmen, Steve Besemer, Eugene 'Buddy' Schweig, Oliver Boyd, Russ Caton, Bob Bauer, Sue Turner, Neil Anderson, Raymond Fox, Steve Tupper, Mimi Garstang, Joe Gillman, Genda Chen, Jim Pasley, Ronaldo Luna, Brian Blake, Phyllis Steckle, Richard Stephenson, Angie Rolufs, Greg Reed, Andrea Dargush, Larry Pierce, Jeff Spooner, Mark Newell, Carl Shapiro, David Rogers, David Hoffman, and the editor, Emitt Witt.

Thank you to all of the speakers and poster contributors for presenting your research and findings. The conference organization committee was honored to have three distinguished keynote speakers for this event; U.S. Representative, Jo Ann Emerson; Missouri Adjutant General, King E. Sidwell; and the Missouri State Emergency Management Agency Director, Ron M. Reynolds.

The sponsors of the conference are to be commended for their contributions and interest. These organizations include the Fort Leonard Wood chapter of the Society of American Military Engineers; St. Johns Health System; the Missouri State Emergency Management Agency; the Missouri Department of Natural Resources, Division of Land and Geologic Survey; the Center for Transportation Infrastructure and Safety; the U.S. Geological Survey; and the Missouri University of Science and Technology.

Special recognition goes to the Mr. Steve Tupper for securing funds from the Fort Leonard Wood chapter of the Society of American Military Engineers to support the luncheon and the keynote presentation given by the Missouri Adjutant General, and to Dr. Randall Huss, President of St. John's Health System–Rolla for his interest and generous contribution to support scholarships for first responders throughout the State. Without the contributions offered by these two organizations, this conference could not have been such a success.

Pre-conference training was a successful addition to this conference. Special thanks goes to Steve Besemer, Edna Bridges, Roger J. Arango, Lt. Col. Christian Van Alstyne, Lt. Col. David Boyle and the 7th Weapons of Mass Destruction Civil Support Team, Tina Niemi, Ross Black, and Kelly Liu.

Lastly, a special 'thank you' goes to the more than 300 individuals who participated as attendees at the conference. Your interest and enthusiasm in the subject clearly demonstrates the need for further preparations in the region. We look forward to your future participation in similar events.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)

Inch/Pound to SI

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Proceedings of Preparing for a Significant Central United States Earthquake—Science Needs of the Response and Recovery Community

Emitt C. Witt III, Editor

The Agenda

The following is the agenda as presented during the conference. The agenda, along with a questionnaire contained in a conference padfolio, was provided to each participant of the conference. Powerpoint presentations for each speaker can be found at *http://conference.mst.edu/newmadridconf/presentations.html.*

Tuesday, August 12, 2008—Training Opportunities:

Structural Assessment and Visual Evaluation Training
Missouri State Emergency Management Agency

Community Disaster Response Training
The Central United States Earthquake Consortium (CUSEC)
The American Red Cross

Using Civil Support Teams (CSTs) For Seismic Event Responses
The U.S. Army Chemical, Biological, Radiological, Nuclear School
The Missouri National Guard's Wepons of Mass Destruction Civil Support Team

The Central Plains Earth Scope Partnership (CPEP)
Central Plains EarthScope Partnership

Wednesday, August 13, 2008

0800-0845	Welcome
0845-0915	Keynote Speaker, U.S. Representative Jo Ann Emerson
0915-0945	The USGS Earthquake Hazard Program
0945-1000	Break
1000-1025	Consequences Resulting from a Major Earthquake in the Central United States
1030-1055	Earthquake Hazards (Timing/Reoccurrence/Probability of an Event)
1100-1125	State and Regional Impact of Central United States Earthquakes on the Physical Infrastructure
1130-1155	Resilience, Response, and Recovery: Societal Components of Catastrophe
1200-1315	Lunch Keynote Speaker, Major General King Sidwell
1330-1400	State-of-the-Art Earthquake Research for Critical Transportation Systems
1400-1430	Missouri Department of Transportation (MoDOT) Earthquake Preparedness
1430-1500	Break
1500-1530	The Advanced National Seismic System: Earthquake Monitoring for Science, Engineering, Rapid Response, and Public Information
1530-1600	Critical Infrastructure Monitoring: The Bill E. Emerson Bridge
1600-1630	Products and Capabilities of the Science/Engineering Community for Emergency Response
1630-1700	Highway Bridge Performance During the May 12, 2008, M7.9 Wenchuan Earthquake in China
1700-2000	Networking Reception

Thursday, August 14, 2008—Track 1: Science, Maps, and Engineering

0830-0845	Opening Remarks
0845-0915	*The National Map*: Status of National Geospatial Base Data in the Central United States
0915-0945	USGS-State Partnerships and the Future of Standard Quadrangle Maps
0945-1000	Break
1000-1030	Data Sources and Development for the New Madrid Zone in Missouri
1030-1100	New Data for a New Age

1100-1130	The Land-Use Portfolio Model: A GIS-based Decision Support System for Evaluating Seismic Risk Mitigation Policies
1130-1200	Panel/Discussion: Geospatial Information
1200-1315	Lunch Keynote Speaker, Ronald Reynolds
1330-1400	Missouri's Catastrophic Event Planning
1400-1430	U.S. Army Corps of Engineers Spatial Data and Capabilities
1430-1500	Break
1500-1530	The Role of USNORTHCOM in Disaster Response
1530-1600	FEMA Region VII Response and Recovery Operations Planning
1600-1630	Panel/Discussion: Federal and State Government Resources
1630-1645	Closing Remarks

Thursday, August 14, 2008—Track 2: Federal and State Response and Recovery

0830-0845	Opening Remarks
0845-0915	SONS07 Overview
0915-0945	USGS Lessons Learned from SONS07
0945-1000	Break
1000-1030	SEMA '07 Statewide Earthquake Exercise
1030-1115	The Role of Missouri National Guard to Civil Authorities Following a Seismic Event
1115-1200	Panel/Discussion: Federal and State Response and Recovery
1200-1315	Lunch Keynote Speaker, Ronald Reynolds
1330-1400	Draft National Catastrophic Earthquake Plan
1400-1630	Panel/Discussion: New Madrid Earthquake Table-Top Exercise
1630-1645	Closing Remarks

Keynote Addresses

U.S. Representative Jo Ann Emerson

U.S. Representative Emerson represents Missouri's Eighth District.

Thank you for your warm welcome. I am very glad to be at this conference today because you are all going to address a critical issue for our region and our nation.

I know from personal experience in Congress how difficult it can be to direct much-deserved attention and the resources to the New Madrid Seismic Zone. I have made this repeated point as a member of the Homeland Security Appropriations subcommittee and as a current member of the Interior Appropriations subcommittee: we have a sleeping giant beneath our feet. Eventually it is going to wake up. We will have no notice when the New Madrid Seismic Zone unleashes a major earthquake on our region. We have to prepare today like it will happen tomorrow. That is the major reason why I am glad for this Conference. The cooperation and coordination of experts, emergency management officials and the media that is present in this room today focuses us all on what is being done to prepare, and what remains to be done before we can call ourselves ready.

Over 75 million Americans in 39 states are at direct risk of damage as a result of an earthquake. The primary sources of this danger are on the West Coast and in the New Madrid Seismic Zone. However, every American will surely experience the consequences of a major earthquake in the Central United States, at the nexus of American ground transportation infrastructure, where pipelines for natural gas distribute fuels to the nation, in the heart of the U.S. agricultural and manufacturing economies. The 1994 earthquake in Northridge, California caused $15 billion in property damage—it was the most expensive natural disaster in the history of our nation up until Hurricane Katrina. But a coastal earthquake is not the same as an earthquake in the center of the continent. A major quake in the New Madrid Seismic Zone would be felt from coast to coast—both literally and figuratively.

Very few of the bridges across the largest river in our continent would be passable. The major transportation corridors of the Heartland would be disrupted or destroyed. Interstate 40—cut in half; Interstate 55—broken into pieces; Interstate 57—totally impassable.

Set aside the fact that these thoroughfares would be relied upon to carry relief and aid to the areas worst hit and consider that these roads carry the commerce of our entire nation. They are the link between East and West, between the Mid-South and the North-East, carrying food and goods to the urban centers of our whole nation. Pipelines from Texas that travel thru the heartland deliver fuel to every corner of the Northeast and Upper Midwest. If ruptured, repairs to those lines would take months or more—and those regions of our country would be forced to limp through winter on limited supplies of home heating fuel.

Ultimately, the economy of our entire nation rests on this region. If these systems fail? Decimation. I don't use the word "cataclysm" lightly, but I am using it today. A major earthquake here in the Heartland would be nothing less than that. And we have a precedent to measure the power of such an event. The largest earthquakes in the history of the lower 48 states were the 1811–12 earthquakes in the New Madrid Seismic Zone. Three of them were estimated at over 8.0 on the Richter scale.

Now, an earthquake at 6.0 is about 32 times more powerful than an earthquake at 5.0. An 8.0 earthquake literally boggles the mind. Scientifically, I am sure the experts in this room could measure the energy of this event—but in terms of lives and property, economic repercussions and the infrastructure of our nation—no one can measure the danger we face.

An earthquake similar in magnitude to the one predicted in the New Madrid Seismic Zone during the next 50 years occurred in China on May 12, 2008. This powerful quake toppled buildings, schools and chemical plants. It weakened dams, contributed to landslides, damaged the infrastructure necessary to the emergency response, and killed more than 70,000 people.

While this event happened a hemisphere away from Missouri, it should serve as a wake-up call to the destructive force of a major, no-notice seismic event.

Closer to home, less than four months ago, on April 18, 2008, we experienced a 5.2 magnitude earthquake near southern Illinois. This quake was felt for as long as 30 seconds as far West as Kansas City and as far East as Atlanta, Georgia. While the damage was minimal, it is an indication that seismic activity—and possibly severe activity—can still occur in the Central United States today.

If this region should experience an earthquake similar to the Chinese quake, we can expect many of the same consequences in the New Madrid Seismic Zone and surrounding areas. The world will watch how we handle this situation, and tough questions will be asked of us in the aftermath.

This conference will bring to light many of the preparations we have made as well as what we could expect from a major seismic event. Hopefully, we will be able to identify areas of concern—response and recovery issues we may not yet have considered. I mentioned Hurricane Katrina earlier; right here in Rolla we constructed the post-disaster maps that were used to respond to that storm. The same technologies would certainly be called upon after an earthquake.

So we must ask: Have we incorporated all the other lessons of Katrina into the response and recovery plans for a major New Madrid Seismic Zone earthquake? Are we making the proper connection between our response plans and seismic science, engineering and sociology? Do we have enough data, and the right kind, in the right format, for our recovery plans? Finally, are the scientific products we're counting upon easily understood by and useful to our emergency responders? These are questions that will dominate this forum and press us to discuss the bedrock issues (if you will) of earthquake response and recovery. The bottom line is this: we may not know when to expect an earthquake, but we can make many reasonable assumptions about what to expect. The more familiar individuals are with the earthquake plan, the better able they will be to help themselves. Empowering them lifts a crucial burden from first responders as we all come together in response to a worst-case scenario. Even a simple discussion of aftershocks, which can be nearly as intense as the original event, can help bring the public to a better understanding of the "what" we may be dealing with—and aftershocks provide a poignant example of how science has made it possible to predict the timing and location of seismic events.

I've made a priority of stressing the importance of these plans to citizens in our region. I've brought a congressional coalition together to address the threat of an earthquake in the New Madrid Seismic Zone. I'm fighting for Federal funding to continue geographic hazard mapping. We must anticipate difficult circumstances: bridges that cross the Mississippi River may fare better than the innumerable bridges along our highways that cross over creeks and smaller tributaries. Power and gas lines are deadly threats to homeowners. Phone lines and cell phone towers will make communications impossible. Water lines may be unstable—creating challenges not just in putting out earthquake-related fires, but also in finding safe drinking water.

This conference can give us the confidence and the background knowledge to meet all of these challenges as best as we can under impossible conditions. To all of the speakers and poster presenters who have gathered for this occasion, I cannot express my appreciation enough. We are so fortunate to have our nation's brightest minds working on all of these unique problems posed by an earthquake in the middle of the continent.

I commend the sponsors of this conference for their vision and dedication, including the U.S. Geological Survey, the Missouri University of Science and Technology, the Missouri State Emergency Management Agency, the Society of American Military Engineers, St. John's Health System, the U.S. Army and the Center for Transportation, Infrastructure and Safety. Your support for this event is crucial. Furthermore, I would like to thank you, the audience on this occasion, for your attendance and participation in this important fact-finding event. You are here because you believe preparation is not just important—it is critical.

I am very pleased that my two good friends, Major General King Sidwell, Adjutant General of the Missouri National Guard, and Ron Reynolds, Director of the Missouri State Emergency Management Agency, are here this week as Keynote Speakers. If a major earthquake were to occur in this region, these individuals will be at the forefront of response and recovery operations. Their participation in this conference is a clear sign of the promise that exists for collaboration between the scientific community and first responders. And finally, I'd like to single out Emitt Witt, the Conference Chairperson, and his team for organizing this event. Their effort in developing the agenda and involving so many partners is clearly the type of exceptional leadership that I and others in Congress hope is cultivated throughout our Federal services agencies. Thanks again to all of you. We are very lucky to have so many great advocates for this purpose. I wish you a very productive conference as we all continue to work towards a state of total preparedness for whatever the future may hold.

Major General King E. Sidwell

Major General King E. Sidwell served as Adjutant General of the Missouri National Guard from 2005–08. The address below was written and delivered by Col. L Mark A. McCarter, Missouri National Guard, and is used in place of the keynote address.

The Missouri National Guard (MONG) response to an earthquake is essential to the citizens of Missouri. Preparedness through training, planning, interagency efforts, and appropriate application of military capabilities to support civil authorities are essential tenets of the MONG response. Today, the Missouri National Guard stands prepared to support the citizens of the State of Missouri in any natural/man-made disaster.

Today, the Soldiers and Airmen of the Missouri National Guard are the most trained, intelligent, and prepared than at any time in its history. Missouri has deployed over 8,000 Soldiers and several hundred Airmen into combat operations since 2001. These combat experiences transfer over to the preparedness of soldiers to support the citizens of our state. The ability to operate in small groups, exercise leadership, deliver commodities, and finally exercise independent judgment in life and death situations. These abilities are logical transition points to military support to civil authorities.

Similar to the individual training experiences, the units within the Missouri National Guard have deployed and have gained collective experience. Brigade level commands, battalion level commands, commodity distribution units, engineer units, and communication units are a few examples of the kind of war fighting experience that transitions to military support to civil authorities. The application of these competent capabilities enables quicker support to the citizens of our state. Our organizations continue to train and develop those skills that are essential to timely and effective collective capability application. The Missouri National Guard has responded effectively to the Governor of Missouri 13 times in past 3 years.

For a New Madrid earthquake scenario, our intent is to automatically activate every member of the MONG immediately upon the identification of a 6.5 or higher earthquake in the New Madrid Fault. The foundation of this response force is based on the Governor's intent to push resources as soon as possible to the affected area. It will take every effort of the State and maximum Federal resources to effectively move from response phase to a recovery phase. If in the event of a 6.4 or below, the local MONG commanders are empowered by state statute to respond to save life, limb, or property. They will take immediate action to assist/support the local civil authorities to ensure that human suffering is reduced.

Additional immediate actions include establishing communication with affected county leadership, reconnaissance of available ground routes, identify supportable runways to deliver supplies and assist in evacuation. All of these actions are in support of the civil authorities, not in lieu of civil authorities.

As the situation develops, the MONG will assist civilian authorities with receiving Federal response support. This will be in the form of other uniformed soldiers from other State National Guard, Department of Defense Forces, FEMA manpower, and FEMA supplies for affected citizenry. Earthquake response is a team sport and will require the citizenry to reach out and help those in need.

Although the MONG is a strong force of over 11,000 Soldiers and Airmen, this will not be enough to provide adequate assistance to our citizens within Missouri. The chart below indicates the true availability given on 2 Aug. 08.

Fortunately, there are many systems in place to assist the MONG with its response. The Emergency Management Assistance Compact (EMAC), signed by all 54 States and territories, is a Governor to Governor agreement to provide any assets available to the requesting state. The EMAC procedure has proven utility with operations in support of Hurricanes Katrina, Rita, Gustav, and Ike recovery.

Ronald M. Reynolds

Missouri Governor Matt Blunt named Ronald M. Reynolds Director of Missouri State Emergency Management Agency in January 2005.

Thank you and Good Afternoon. I appreciate the opportunity to be with you today at this important event. I want to thank USGS, Missouri University of Science and Technology and others who have worked to organize this conference. I want you to know that the State Emergency Management Agency appreciates your efforts and is happy for the opportunity to participate. There are several members of SEMA here today and I would ask that they stand and be recognized at this time.

I want to talk to you today about our agency and how we are involved in planning to respond after a major earthquake in the New Madrid Seismic Zone. First, SEMA's mission is to save lives. Our task is to coordinate the state's response, while working with our local and Federal partners, following a significant event such as an earthquake. We work on plans, exercises, and coordinate response and recovery efforts with other State agencies and departments, in order to protect the lives and safety of Missourians.

If you take a look at SEMA's organizational structure, you'll see that we are part of the Missouri Department of Public Safety. I report to the Director of the Department, who in turn reports to the Governor. We are divided up into Operations, Planning, Logistics and Fiscal sections, along with the Missouri Emergency Response Commission and our Statewide Volunteer Coordinator.

In case you are not aware of how SEMA assists jurisdictions, we do not become involved after an event until we are requested to do so by that local jurisdiction. Once a major event occurs which is beyond the scope of the local responders to handle, the State can provide assistance once the Governor declares a State of Emergency. SEMA then begins to coordinate the State-level response and assists the Governor in asking the President for a Federal disaster declaration, if needed. Once a Federal disaster is declared, we can then also begin receiving assistance from FEMA and other Federal-level partners.

In case you have not heard by this point of this conference, Missouri is Earthquake Country. There are two fault systems which are in Missouri or nearby—the New Madrid Seismic Zone and the Nemaha Seismic System, which runs through eastern Kansas and could affect our western border.

We do have history of moderate and large earthquakes within the State. Of course, beginning in late 1811 and continuing into 1812, we experienced hundreds of earthquakes. Some of those earthquakes were among the strongest ever felt in the United States. We continue to have about 200 to 250 earthquakes per year in the New Madrid Zone. Some other notable earthquakes since the 1811–12 events include the 1895 magnitude 6 earthquake in Charleston, earthquakes in the magnitude four and five range in the early 1990s near Chaffee and Risco, and the 5.2 magnitude earthquake near Mount Carmel, Illinois, that was felt over much of Missouri. Fortunately, though, we have not had a damaging earthquake in the Midwest for many years. I certainly hope we can continue that trend, but we must be ready just in case that trend changes.

We have been working on a catastrophic earthquake response plan in the State for the past several years. Governor Blunt approved this plan in 2007. The plan is actually an annex to our existing State emergency operations plan. We invited all of the State agencies and departments to the table to help us formulate this annex—many of those agencies already had their own catastrophic earthquake plan in place. The State's catastrophic event annex—known as Annex Y—was exercised during our statewide earthquake exercise in June of 2007. All State agencies, their Federal partners, and 80 local jurisdictions from around the State participated in this exercise.

One of the new things that is part of our annex is the idea of an automatic response, which means once we know that an earthquake of a 6.5 magnitude or greater has occurred in or near Missouri, we begin our response activities. An earthquake that large is likely to damage some jurisdictions' ability to communicate with us, so if we know a significant earthquake has occurred and we cannot communicate with that area, we are going to be pro-active and respond as soon as possible.

Part of that response, which also is identified in Annex Y, is that our State Emergency Operations Center will be activated, with DPS leadership serving as the Unified Command. We will open our Area Coordination Centers in Sullivan for Region "C" and in Poplar Bluff for Region "E". This will allow us to better manage our response at points closer to the affected area while maintaining overall coordination of it from our State EOC. We have also been working to pre-script anticipated resource requests that could be sent out after an earthquake through the Emergency Management Assistance Compact. This is important because we know we will need personnel and equipment from other States and, since we will not be the only State affected by this event, we will be in competition with those States for these valuable items.

Prior to the 2007 statewide earthquake exercise, SEMA helped to organize regional exercises to help those involved prepare for that main exercise. We developed a local planning template based off of our Annex Y and distributed it to the 47 counties considered to be the most "at risk." This planning template is Annex "O" to the local emergency plans. We held workshops in Hannibal, Poplar Bluff and Sullivan to formally introduce Annex O to local jurisdictions and assist them with utilizing it. We will soon be holding additional workshops to help local emergency managers complete work on their local annexes.

At those local planning workshops, we held breakout sessions to discuss critical parts of these catastrophic event annexes. Those sessions dealt with: Direction and Control, Search and Rescue, Damage Assessment, Evacuation, Medical, Housing, Transportation, Communications, and Emergency Public Information. These correspond with some of the key ESF's which fall under the National Incident Management System.

In recent years, logistics has played a larger role in emergency management planning and response. You must remember that logistics will play a huge role in our response to a catastrophic earthquake. The amount of resources that will be needed following a New Madrid event is significant. The National Guard will play a key role in assisting us at staging areas and point-of-distribution sites; the private sector will be badly needed to step in and assist us with our many resource shortfalls, and the coordination of personnel and equipment moving in, around, and then out of the affected area will be a huge and challenging undertaking.

The State of Missouri has been fortunate to have a great working relationship with Director Hainje and his staff at FEMA Region VII. The planning challenges brought on by New Madrid have made it more important for us to work even closer together. We are working to identify resource gaps, prescript resource requests, plan with our neighboring States of Iowa, Kansas, and Nebraska, and to better familiarize ourselves with EMAC and how we might use it after an earthquake.

Our State is one of eight States in the Central United States Earthquake Consortium, or CUSEC. We all try to work together through CUSEC to coordinate our planning efforts for a catastrophic New Madrid earthquake. Of course, knowing that "the Big One" will affect most if not all of these States means we will likely not be able to assist one another and will likely be competing for assets from outside the Midwest. It will likely be very difficult, if not impossible, to communicate with some of our neighboring States right after a large earthquake. These eight States also fall under four FEMA regions, which presents planning and response challenges on the Federal level.

So what are the State assets that we do have for our anticipated disaster response?

We have the Missouri Seismic Safety Commission, which is a group of 17 citizens from various backgrounds who address seismic safety issues around the State. The Commission recently released their updated Strategic Plan for Earthquake Safety in Missouri. That plan was divided into Objectives about: Increasing Awareness and Education, Reducing Hazards through Mitigation, Improving Emergency Response, Improving Recovery Response, and Assessing the Earthquake Hazard in Missouri.

Missouri also benefits from our CERT teams, which are Community Emergency Response Teams. We would expect to need them after a major earthquake for such tasks as basic first aid and search-and rescue.

The SAVE Coalition is a group of architects, engineers and other building professionals who could be used as a volunteer State asset to go to an affected area to help quickly assess structures. We have about 1,000 members currently in our SAVE database.

Another Missouri asset would be Missouri Task Force One for Urban Search and Rescue, along with our DMAT folks from the Disaster Medical Assistance Teams.

In any disaster, we depend on the help of volunteers. We anticipate after a catastrophic earthquake, our MO-VOAD (Volunteer Organizations Active in Disasters), Faith-Based Organizations, and the Partnership for Disaster Response would be of great assistance to SEMA and to the residents who were affected by the earthquake. Organizations such as Americorps, the American Red Cross, and the Salvation Army have been of great assistance to us in previous disasters. Our Volunteer Coordinator, Dante Glinecki, is continuing to work with those and other worthy organizations to ensure that our volunteers will be able to provide help to our citizens in the most efficient manner.

Governor Blunt recently attended the kickoff meeting for his Faith-Based Initiative, which was held in Jefferson City. Additional training meetings will be held soon in all regions of the State.

In summary, a catastrophic earthquake in the New Madrid Seismic Zone will impact the entire United States in one way or another. Business, transportation and energy will certainly be affected. We are in the process of coordinating local, State, and Federal plans along with coordinating plans with our other CUSEC States. We are continuing to work with our volunteer organizations, with the business community on response and recovery issues, and with the media on public information issues we anticipate will arise after an event. We are also now working on pre-scripting requests for personnel and resources which can be quickly sent out to FEMA and through EMAC. This is a process that should be a continuous one, as we update and exercise our plans to better prepare for this catastrophic event.

I would like to thank Mr. Emitt Witt from USGS in Rolla and the others involved in organizing this terrific conference. This is certainly a subject very much on the minds of us at SEMA and we appreciate the interest in this conference. Please feel free to contact me or any of my staff if we may be of assistance to you in the future.

Thank you.

Presentation Titles, Abstracts, and Papers for Wednesday, August 13, 2008

The USGS Earthquake Hazard Program

By David Applegate

U.S. Geological Survey, Reston, Virginia 20192, applegate@usgs.gov

Abstract not submitted.

Consequences Resulting from a Major Earthquake in the Central United States

By J. David Rogers

Department of Geological Sciences & Engineering, Missouri University of Science and Technology, Rolla, Missouri 65409, rogersda@mst.edu

Abstract not submitted.

Post-Conference Paper

Overview of Likely Consequences of a Magnitude 6.5+ Earthquake in the Central United States

By J. David Rogers

Abstract

A very real threat is posed to developed urban areas of the United States by three distinct seismic sources zones, located in the upper Mississippi Embayment, along the Wabash Valley, and beneath South Central Illinois. The most likely damaging earthquake is a magnitude 6.0 to 6.8 event, which has a 25 to 40 percent probability of occurrence in the next 50 years. This risk is much greater than other places, such as California, because the basement rocks are less fractured and seismic energy is conveyed over 10 times more efficiently than in California. The impedance contrast between the unfractured basement rock and the unconsolidated alluvial cover creates a situation promoting more site amplification than any other location in the world. A quake in the upper end of that expected range (M>6.5) could cause unprecedented damage to the American Midwest, because the region is crisscrossed by numerous pipelines, commercial transportation corridors, power transmission grid network,

telecommunications networks, and so forth. It is impossible to accurately gauge the potential economic impact of such an event, because it would be unprecedented, and many human factors, such as the public's perception of the disaster and the time to recover from such a widespread catastrophe, are impossible to manage or estimate with any reliability. Recent natural disasters have shown that the role of the news media in influencing the public's perceptions of the disaster recovery is growing each year. These perceptions tend to control the ultimate extent of the loss because people refrain from economic activity (spending) until the perceived crisis is concluded. Scientists, engineers, emergency responders, and relief agencies are all encouraged to work with the news media in any natural disaster, to provide cogent explanations of recovery plans and operations, which can serve to encourage the actual recovery.

Introduction

The New Madrid Seismic Zone (NMSZ) was responsible for over 2,000 earthquakes in 1811–12, felt throughout the upper Mississippi and lower Ohio River Valleys, when very few settlers lived west of the Mississippi River (Fuller, 1912). At least four of these earthquakes had surface wave magnitudes (M_s) of ~8+ (Nuttli, 1973; 1987), which are now believed to have been moment magnitudes (M) of between 7.0 and 7.5 (Bakun and Hooper, 2004). M6.0–6.2 quakes occurred at either end of the NMSZ in 1843 (Marked Tree, Arkansas) and 1895 (Charleston, Missouri). Despite these events, the seismic threat posed by the NMSZ was not included in any of the region's municipal building codes until 2002, when St. Louis and St. Charles Counties in Missouri adopted the International Building Code (IBC).

In 1973, the NMSZ was more-or-less "re-discovered" during geologic studies for a nuclear power plant in West Memphis, Arkansas, which came under review by the Nuclear Regulatory Commission (NRC). Soon thereafter (1974) the NRC engaged the advice and expertise of the USGS to assist in regional monitoring (Russ, 1982). These monitoring activities enlarged to include regional evaluations of relative seismic risk after an earthquake prediction by Iben Browning in December 1990, which garnered national attention (Spence and others, 1993).

Between 1979–99 the Wabash Valley Seismic Zone (WBVSZ) was investigated and eventually recognized as another seismic source zone (Bristol and others, 1979; Bear and others, 1997), although it has not been monitored as closely as the NMSZ (fig. 1). The WBVSZ is thought to be responsible for M5+ quakes in 1968, 1987, and 2008. An amorphous zone of active seismicity also exists in South Central Illinois (SCI), (McBride and others, 1997), which has spawned M5+ quakes in 1838, 1857, and 1891. These seismic source zones are shown in figure 1.

In 2002, the U.S. Geological Survey released new earthquake probabilities for the New Madrid Seismic Zone, based on recent paleoseismic studies (Tuttle and others, 2002).

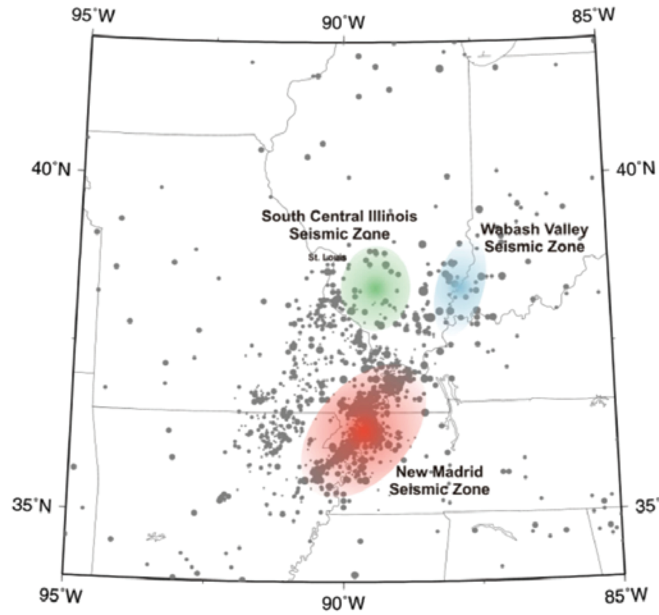

Figure 1. Seismic source zones in the Central United States. South Central Illinois is an area of diffuse seismicity which is not well documented or yet understood, because it is covered by glacial outwash.

A magnitude 6.0 or greater earthquake has an estimated 25–40 percent chance of occurrence in the next 50 years. Such an earthquake could pose serious risk of damage to schools and masonry buildings between Memphis and St. Louis. The USGS also estimates a 7–10 percent chance of a magnitude 7.5–8.0 earthquake occurring in the next 50 years (equal to the four largest quakes in 1811–12).

Discussion

Shaking Intensity Versus Distance

The most troubling aspect of Midwestern quakes is the severe site amplification that exists in alluvial-filled valleys and dissected loess-covered uplands (Anderson and others, 1996). This is because of the marked impedance contrast between the unconsolidated alluvium and aeolian loess (Vs ~ 185 m/sec) and the less fractured Paleozoic age basement rocks, which typically transmit shear waves (Vs) at a speed of ~2,800 m/sec (Chung, 2007). This means that seismic energy travels much farther and is felt more severely in the Midwest than in regions subject to more tectonic deformation, like California (fig. 2). If the alluvial or aeolian sediments are more than 12 to 15 m thick, site amplification can be magnified by as much as 1,300 percent for M6 earthquakes occurring 200 to 300 km from their source (Rogers, Karadeniz, and Chung, 2007). This creates a situation making Midwestern quakes much more lethal than California quakes of equal source magnitude, because there is less damping of seismic energy.

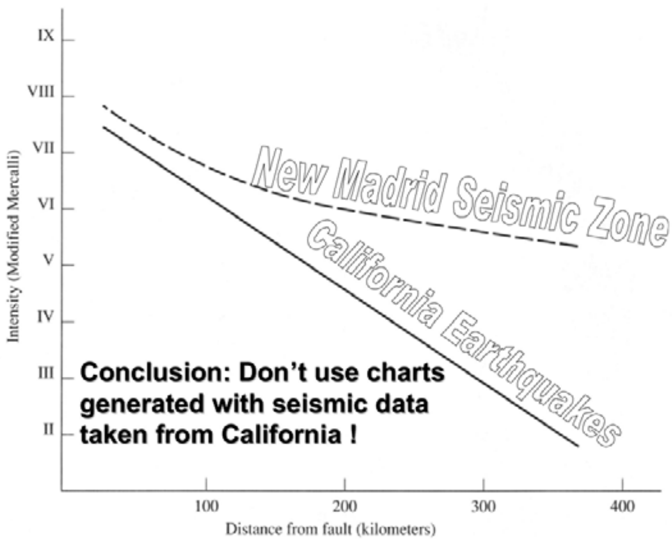

Figure 2. Contrast between damping of shaking intensity with distance from seismic sources in California and the Midwestern United States (from Bolt, 2003). Most damping models before 2000 were biased by data from California earthquakes.

Potential Economic Impact of Soil Liquefaction

Liquefaction is a failure mechanism by which cohesionless materials (sand and silt) lose shear strength when the pore water pressure equals the effective confining stress. It is usually limited to the upper 50 feet and typically occurs in silt, sand and fine gravel. Recent sand blows dot the landscape surrounding New Madrid, Missouri, testifying to massive liquefaction, across a larger land area than any other U.S. earthquake (Fuller, 1912). Recent studies by Chung and Rogers (2010) predict massive liquefaction could occur in the Mississippi and Missouri River flood plains for magnitude >6.5 quakes emanating from the NMSZ, WVSZ, or SCI areas, where the depth of saturated alluvium exceeds ~18 m. Loess covered upland areas would be at far less risk for liquefaction. Though their main spans are supported on concrete caissons extending into the underlying bedrock, the simply-supported approach spans of most highway and railroad bridges are vulnerable to collapse if the driven piles supporting them tilt (lurch) in response to localized liquefaction. Fiber optic cables strung across these same bridge corridors bridges would also be severed in this scenario. The major river valleys are filled with old channels, cutoffs, and oxbows. Many of these features have been infilled to support development. Transportation infrastructure crossing such fills would be at greater risk because these areas can be expected to shake more violently than adjacent portions of the flood plains.

Shaking Intensity Varies According to Underlying Geology

Shaking intensity is controlled by a factor called 'Seismic Site Response.' The type, depth, and size of fault, combined with physical properties of the Earth's crust and geophysical properties of overlying surficial soils, all combine to affect the seismic site response. Site response is used to describe the fundamental period of vibration and lateral forces generated by a typical earthquake at any particular site. The thickness of unconsolidated soils also affect the peak ground acceleration that can be generated at any given site, as shown in figure 3.

The potential effect of soil thickness on shaking intensity is often portrayed in response spectra. A response spectrum is a plot of the maximum amplitudes of simple oscillators of varying periods (for example, consider a series of inverted pendulums of increasing height) produced by a recorded or assumed ground motion. The effect of soil thickness in the lower Missouri River floodplain on the response spectra is shown on figure 4. This illustrates the variation in expected spectral acceleration with alluvial thickness in the St. Louis area.

As a consequence, the alluvial thickness is the single most important factor in expected seismic site response in the Midwest. Future seismic hazard maps for the Midwestern United States will likely take the general form presented in figure 5, which is based on the areal distribution and thickness of Pleistocene and Holocene age alluvial filled floodplains.

Likely Impacts of Most Probable Quake

The probability of a moderate earthquake occurring in the New Madrid Seismic Zone in the near future is high (fig. 6). Scientists estimate that the probability of a magnitude 6 to 7 earthquake occurring in this seismic zone within the next 50 years is higher than 90 percent. Such an earthquake could hit the Mississippi Valley at any time. Recent simulations at the Missouri University of Science and Technology (Missouri S&T) suggests that a M6.5 quake emanating from the NMSZ would adversely affect structures sitting on fill, alluvium, and/or other unconsolidated materials more than 15 m thick. Those structures most impacted would likely be taller buildings or towers, with fundamental periods of vibration > 0.70 seconds. Embankments placed on unconsolidated alluvial materials, where fill + alluvium > 15 m thick. Structures more than eight stories high situated on old soil-filled basins greater than 25 to 35 m thick would also be subject to marked amplification of incoming seismic energy.

Some of the critical infrastructure that would likely be impacted by a M6.5 quake at a distance from 210 to 240 km include: multiple span bridges (in particular, tail spans); buried oil, gas, coal slurry, water, and sewer pipelines crossing flood plains; high voltage (tall tower) transmission lines crossing flood plains; power plants situated along major river channels; water treatment and sewage treatment plants along channels; and underground storage tanks. Non-critical transportation infrastructure elements that would likely be affected include: barge traffic on navigable channels; fuel pumps made inoperative by loss of electricity; drainage ditch network in reclaimed flood plains; railroad corridors; interstate and secondary highway network; airport runways, and fuel handling

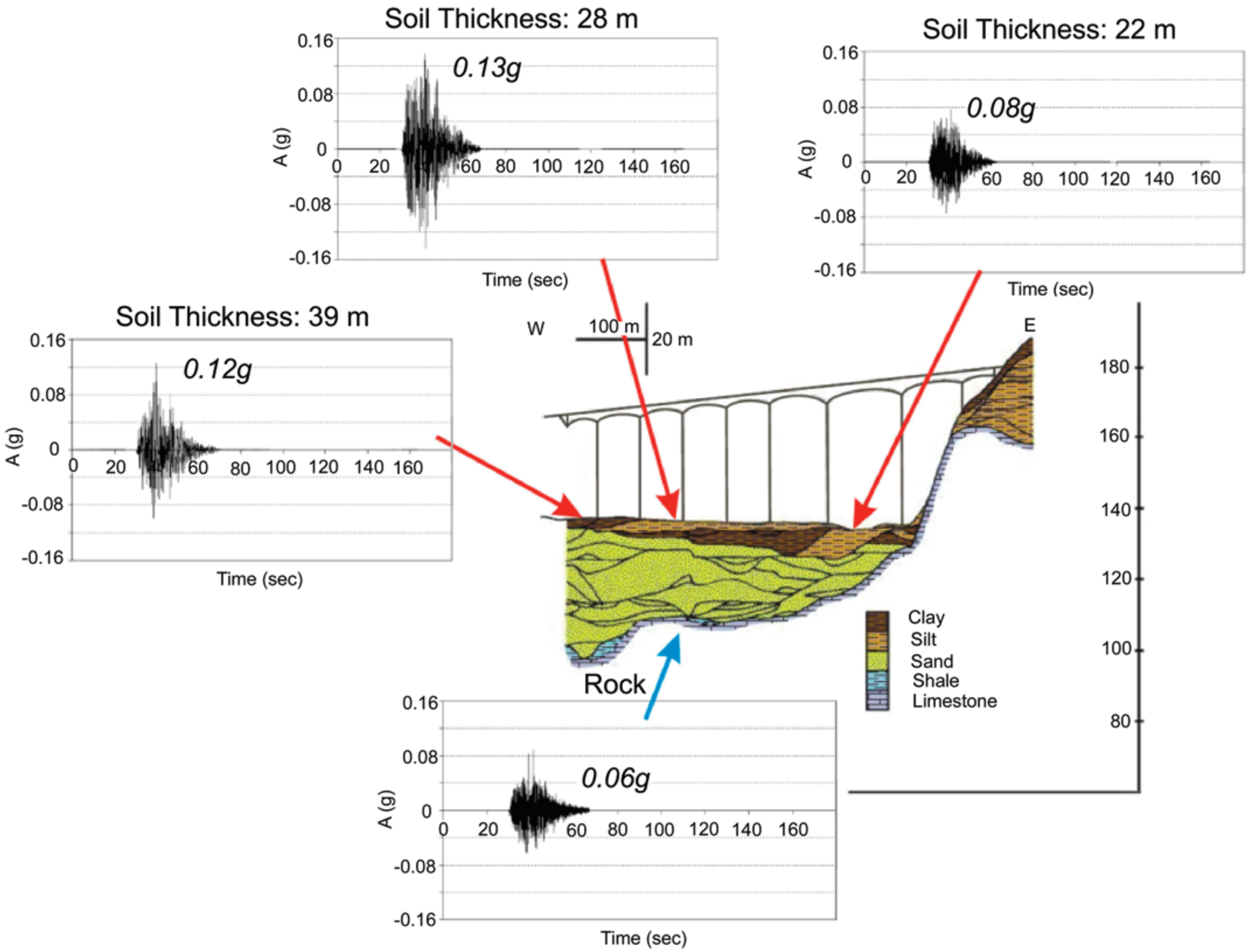

Figure 3. Effect of soil thickness on peak ground acceleration from a magnitude 6.8 earthquake striking the Creve Coeur Bridge on the southern bank of the Missouri River about 110 kilometers from a quake centered in South Central Illinois.

facilities; and municipal off-stream water storage. Refined product service lines convey petroleum products between refineries and major metropolitan markets, from which these products are distributed. Significant disruption of the domestic refined product distribution lines has never occurred. The 'shock factor' of fuel unavailability would be unprecedented, likely necessitating rationing. Five of the six crude oil and natural gas pipelines crossing the Mississippi River could be compromised in a M6.5+ earthquake emanating from the NMSZ (fig. 7). Four of the nine largest natural gas trunk lines in the United States also cross the Mississippi River and could be expected to suffer considerable damage in a M6.5+ quake. There are seven major pipelines crossing the Mississippi River in eastern St. Charles County, just north of St. Louis. All of these lines are buried in the loose unconsolidated sediments of the Missouri-Mississippi River flood plain most susceptible to liquefaction. Spillage of these lines would contaminate the municipal water supply for St. Louis.

The Bill Emerson Bridge, across the Mississippi River in Cape Girardeau, Mo. is the only highway bridge south of St. Louis that has been designed to resist earthquake ground motions. The newer highway bridges in St. Louis area, constructed since 1995, have also been designed for seismic loads. The I-64/US 40 double deck section in downtown St. Louis was recently retrofitted for seismic loading. None of the railroad bridges have been designed or detailed for seismic loads.

Most fossil fuel and nuclear power plants are located on unconsolidated alluvium, including many along the Mississippi and Missouri Rivers. The effect of power generation loss depends on a number of factors, including the time of year an earthquake strikes. The largest impacts would likely be those stalling disaster recovery, and some short term overloading of the surrounding transmission grid. Recovery time would be the single greatest effect on economic recovery of the region. The speed of recovery, ease of recovery, time span of recovery,

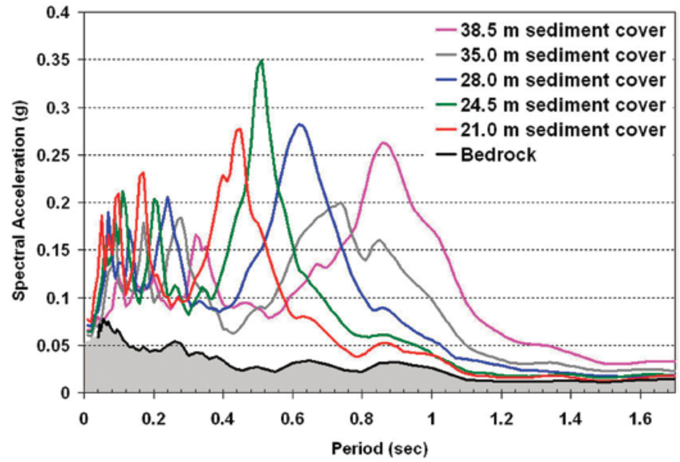

Figure 4. Variation in expected spectral acceleration with alluvial thickness in the St. Louis, Missouri area.

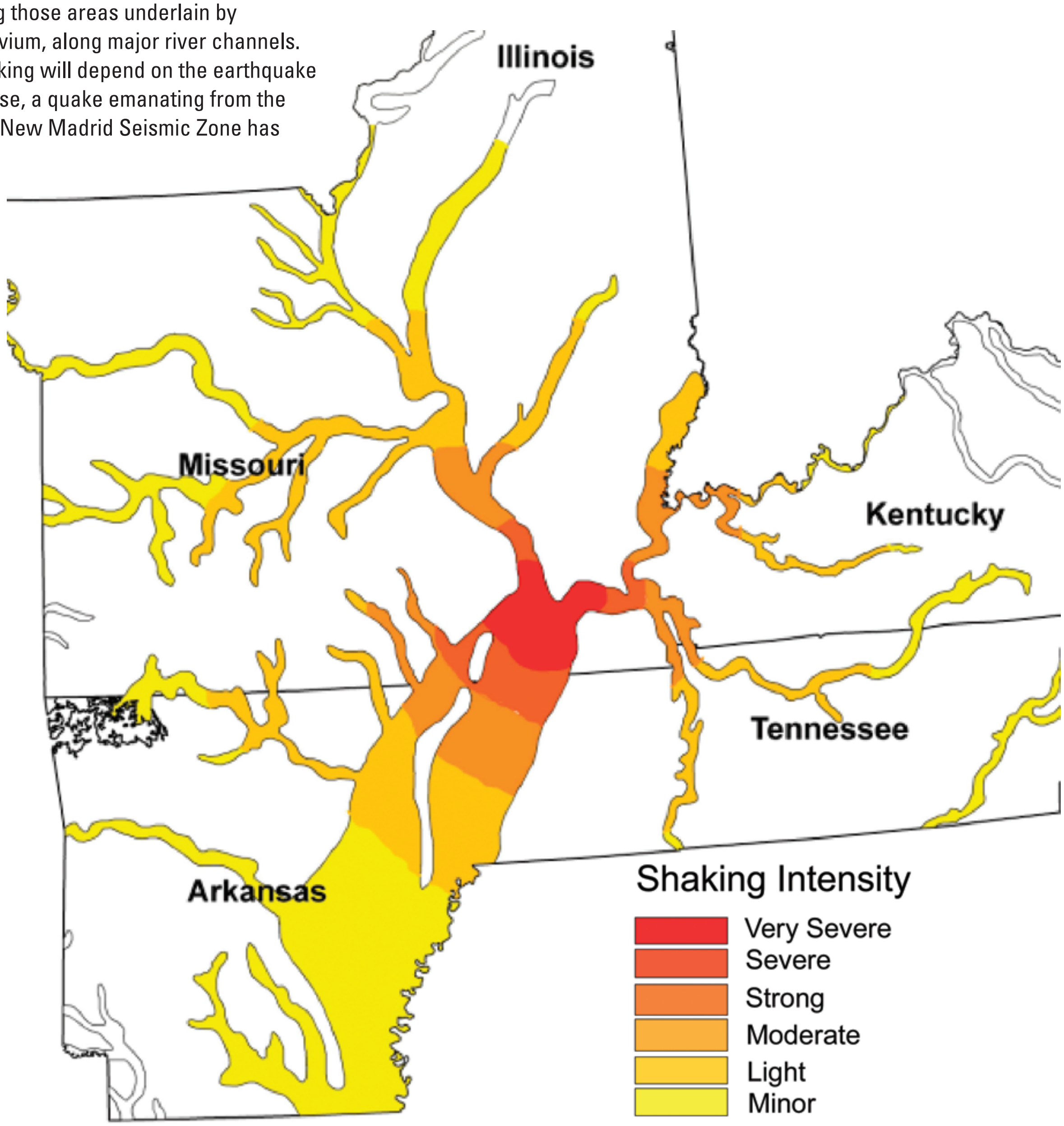

Figure 5. Future earthquake hazard maps of the Midwestern United States will likely look something like this; highlighting those areas underlain by unconsolidated alluvium, along major river channels. The intensity of shaking will depend on the earthquake epicenter. In this case, a quake emanating from the northern end of the New Madrid Seismic Zone has been assumed.

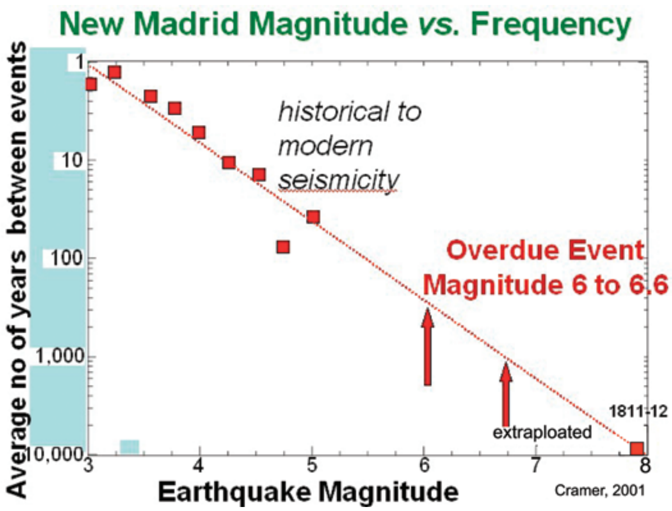

Figure 6. Plot comparing earthquake magnitude and frequency for the New Madrid Seismic Zone, modified from Cramer (2001). The most likely destructive earthquake is an magnitude 6 to 6.6 event, which is believed to have a recurrence frequency of once every 70+/- 15 years. The last magnitude6+ quake occurred in 1895.

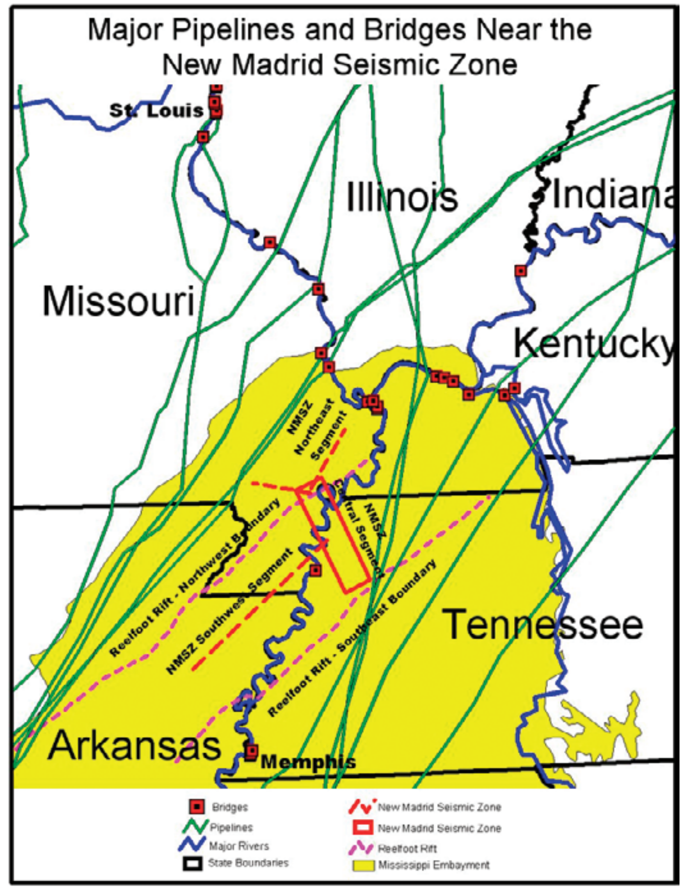

Figure 7. Major pipelines (in green) and highway bridges (red squares) in the New Madrid Seismic Zone, compiled by David Hoffman at Missouri University of Science and Technology. The faults are shown as dashed red lines, while the approximate limits of the underlying Reelfoot Rift are delineated by dashed pink lines.

and the public perception of recovery success all figure prominently in the various models examining the potential economic impact of a M>6 earthquake emanating from the NMSZ. In today's culture, the economic impact of being without electrical power is stupendous. Most homes and businesses cannot function for more than a few days without electricity. Businesses forced to relocate rarely return to their original pre-disaster locations, because of the cost. These problems were born out in the M6.9 Loma Prieta earthquake in 1989 and the M6.7 Northridge quake in 1994. These quakes saw a record number of business failures occur in their wake, and economic recovery did not occur for about 10 years.

Planning Aspects

State emergency management agencies need to identify critical facilities and components for disaster response on an unprecedented level, in regards to loss of transportation infrastructure, fuel pipelines, and electrical power. Some of the more vulnerable components of these systems include: cellular phone transmission towers; fiber optic data transmission cables; insuring redundancy in electrical power grid; identifying alternate routes and fuel sources for emergency responders and alternate route packaging for commerce; realizing the limitations of temporary shelters; and employing sensor systems using GPS location fixed motes to provide monitoring feedback of transient conditions. Unlike atmospheric events, such as hurricanes, earthquakes strike without warning. There is no evacuation ahead of the actual event. As a consequence, gasoline will be unavailable in areas without electrical power. Government agencies will not be able to count on sufficient aerial response assets, such as helicopters, to rescue stranded victims unless we know where they are located. We can expect that an earthquake will take down a fair number of the cellular repeater towers and that telephone transmission systems will be overtaxed.

Text messaging and GPS receivers are rapidly emerging as the preferred method of hailing assistance in the wake of disasters, natural or man-caused. This is because text messaging does not require as much bandwidth as voice calls. Disaster victims are more likely to have a text message reach someone than a voice call.

GPS-equipped phones can also transmit user's location when calling 911, although this capability will likely be compromised. Cell towers will likely be compromised (iPhones employ triangulation between existing cell towers to fix their positions). However, victims may be able to text message coordinates or an interstate mile marker taken from a phone or external GPS device, even if cell towers are down.

Everyone agrees that people have to be educated about what to do in specific scenarios. Extreme events, like combat, are always treacherous because most responders don't have first-hand experience with such catastrophes. Mass evacuations are difficult to plan for without recurring exercises and a thorough program of public education (this was born out in the response to the 1960 Chilean tsunami). Emergency managers will be lucky to get two-thirds of any populace to evacuate an area ahead of a natural disaster, if it is the first exposure to the natural peril. Those people with children are more prone to leave than those without children.

Emergency responders should be provided with appropriate training to "expect the unexpectable;" which requires considerable innovation (for example, San Francisco's loss of fire mains in the 1989 Loma Prieta quake). The most effective instruction is usually performed by responders who have personal experiences to share. Realistic training is the most crucial aspect of preparedness (for example, fire fighters practicing on real fires). Sending responders to other agency's disasters is probably our single best training option; there is no education like experience.

Regional and National Economic Impacts

A 1992 study by the National Research Council (National Research Council, 1992) estimated that a repeat of a M7.5 to 7.7 event on the New Madrid Seismic Zone would cause upwards of $30 billion in damage. A more recent study has revised that estimate (Mid-America Earthquake Center [MAE], 2008). Now a M 7.7 event on the southwest arm of the NMSZ would cause $200 million in hard damage to Memphis alone, and $50 to $70 billion in overall damage to the affected region. Comparisons between projected damages and actual damages are extremely complex, for many reasons, not the least of which is that fickle factor so aptly dubbed "public confidence."

It is difficult to estimate local, regional, and national disaster-driven economic impacts. The FEMA HAZUS software models cannot accurately gage many of the most important metrics, such as: infrastructure disruption impacts (as opposed to structural damage); trickle-down economic impacts, such as loss of confidence by consumers; people's reactions (for example, people tend to hold onto their money after any sort of disaster, such as the 9/11 attacks); and the record number of retail business failures that usually result (for example, 70 percent of the retail businesses in downtown New Orleans were lost in Hurricane Katrina in 2005).

Other "spin-off" and "spin-down" factors are very difficult to gage. In Hurricane Katrina, the government is implementing a plan to remunerate those people who lost their homes and personal property. This process, along with re-building, will likely take from 3 to 10 years, or longer, to implement. Adjacent residents may not have lost their homes, but have lost their jobs/livelihood, the ability to sell their homes and relocate; and difficulty getting homeowners insurance.

When raw materials or product stockpiles are suddenly or unexpectedly reduced/or their flow is constricted; the news media reports the potential shortages and all sorts of speculation ensues. This speculation can easily lead to inflated prices, which triggers consumer reaction, and often leads to unforeseeable consequences, such as a drop in sales of SUVs while everyone waits to see what will happen to the price of gasoline at the pump.

Media coverage is essential to the success or failure of any emergency response scenario. Media tends to search out stories that elicit emotional responses or show graphic images to spike their viewing audience. Media market consultants recognize that viewers tend to select one channel rather than all others during any important event, often remaining loyal to that station thereafter (for example, CNN in 1990–91 Gulf War; Fox News in 2003 Iraq invasion).

Conclusions

Based on historic activity and paleoseismic studies, the New Madrid Seismic Zone is overdue for triggering a magnitude 6 earthquake (Tuttle and others, 2002). Quakes of up to M7 could also emanate from the Wabash Valley Seismic Zone or the amorphous zone of seismic activity in South Central Illinois, although these are less probable (Street and others, 2004). An earthquake of M6.5 in the NMSZ could exert serious damage to densely populated urban areas of the Midwest, such as St. Louis, 220 to 300 km away from the NMSZ.

The most vulnerable components are petroleum product pipelines, highway and railway bridges, fiber optic communications, tall structures, cellular repeater towers, electric transmission line towers, and power plants situated along major rivers. The loss of any or all of these infrastructure elements could severely affect these urban centers and serve to stall economic recovery of America's heartland, which lies at the center of vast transportation and commerce corridors.

A major complication with economic recovery will be the perception of public confidence about the recovery. The public receives virtually all of their information through mainstream media outlets. The media swiftly deploy their best correspondents into harm's way to report on conditions. Live streaming via satellite and video phone has changed viewer's expectations of being able to witness historic events when they occur. The media depends on cueing from: 1) government agencies and officials; 2) the public (via cell phones and e-mail); or 3) from other media outlets (local affiliates, wire services, newspapers). They only tend to report what fails; not what remains standing.

Whether we like it or not, emergency responders are obliged to "court the media." The television media covers the "breaking news" as never before, and their stories are now posted Online for everyone to view. Those stories can instill public confidence or hinder it. We shouldn't forget that news networks are profit-making corporations operating in a highly competitive marketplace. Courting positive media coverage is not only an essential aspect of disaster response, it will be good for the nation's economy and benefit the recovery, more than most scientists or engineers realize.

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Earthquake Hazards (Timing/ Reoccurrence/Probability of an Event)

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Conference Abstract

In this paper, I give the reader an appreciation for earthquake hazard, and particularly earthquake recurrence, in the New Madrid region. The earthquake hazard in the New Madrid region is of the same order as that in the Western United States at hazard levels of interest to public and private sectors. Earthquakes in the Central United States are less frequent—a magnitude 6 or above occurring on average once every ~100 years, but the ground motions, for the same size earthquake, are greater, resulting in roughly the same level of hazard.

Post-Conference Paper

Earthquake Hazard and Recurrence in the New Madrid Region

By Oliver Boyd

Abstract

In this paper, I give the reader an appreciation for earthquake hazard, and particularly earthquake recurrence, in the New Madrid region. The earthquake hazard in the New Madrid region is of the same order as that in the Western United States at hazard levels of interest to public and private sectors. Earthquakes in the Central United States are less frequent—a magnitude 6 or above occurring approximately once every ~100 years—but the ground motions for the same size earthquake are greater, resulting in roughly the same level of hazard.

Introduction

Earthquake hazard refers to how the Earth's surface responds to earthquakes. Earthquake risk, on the other hand, refers to how earthquake hazard affects the man-made environment. Herein, I cover two aspects of earthquake hazard: earthquake ground motion and earthquake recurrence. For the former, I present felt areas for similar sized earthquakes in the Central and Western United States to show how ground motions differ between these regions. For the latter, I present results from paleoseismology, a discipline that can address the recurrence of large and rare events, such as those that occurred in 1811–1812. I then discuss the recurrence of small to moderate events, which can be addressed using the instrumental seismicity catalog.

Earthquake Hazard

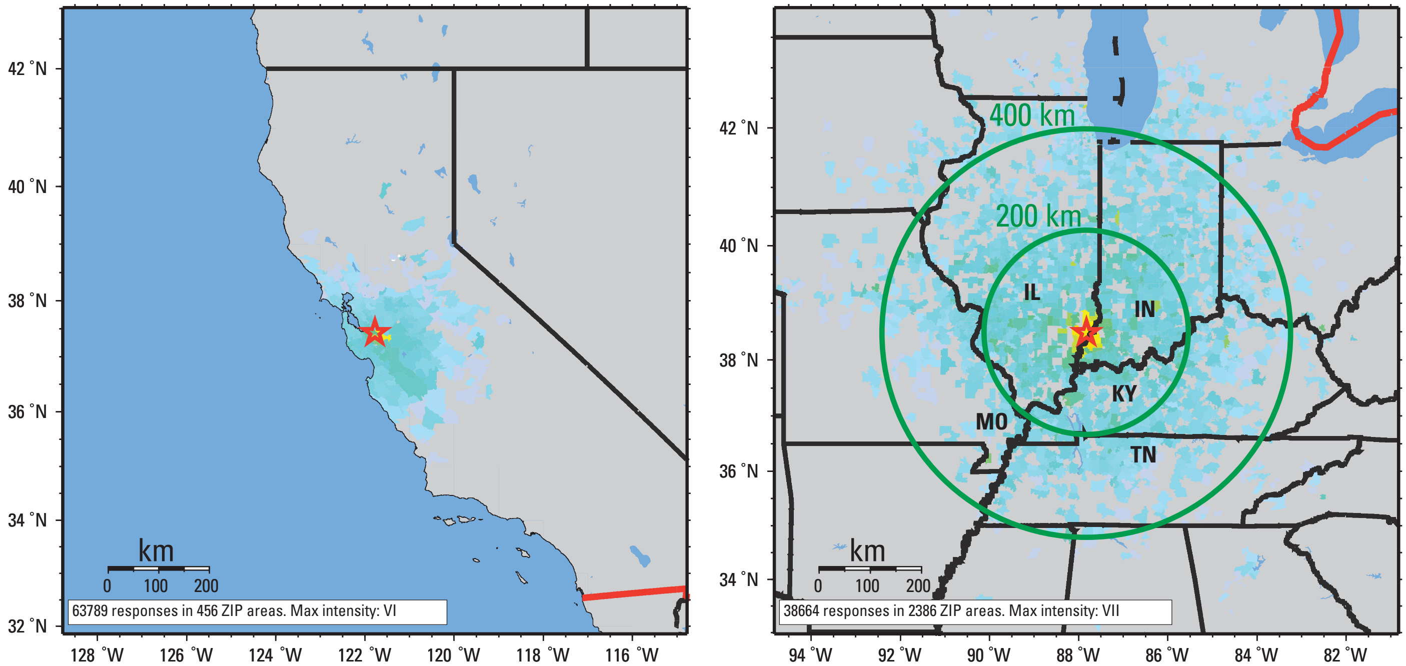
Earthquake hazard analysis (Reiter, 1990) addresses the questions, "How hard and how often will the ground shake?" To answer these questions, we need to know how seismic energy propagates away from the earthquake. How quickly will ground motions die off with distance from the earthquake? At the site for which we are considering ground motions, how do local site effects amplify or dampen ground motions? We also need some basic information about the earthquake sources. Where are they located? How big are they? How often do they occur?

The U.S. Geological Survey produces the National Seismic Hazard Maps (Petersen and others, 2008). These maps address these questions and show the ground shaking that is expected to be exceeded with either a 2 percent or 10 percent chance in the next 50 years. These maps are a critical input to the International Building Codes, are used to evaluate risk, and help emergency managers prepare for earthquake hazards.

Earthquake Ground Motions

One thing that makes earthquakes in the Central and Eastern United States more damaging relative to earthquakes in the West is that, in the east, ground motions do not die off as quickly with distance from the earthquake. The area over which the estimated Modified Mercalli Intensity (MMI) was VII or greater (at least strong shaking with minor structural damage) for the 1811–1812 earthquakes is about 200,000 square miles (Johnston, 1996) while for the 1906 San Francisco event, a similar magnitude earthquake, it is only about 12,000 square miles (Lawson, 1908; Nuttli, 1973), an order of magnitude smaller. A comparison of "Did you feel it?" reports for two smaller earthquakes shows that a M5 earthquake in Illinois was felt over a much greater area (more than 20 States) than a M5 earthquake in California (fig. 1; D. Wald, U.S. Geological Survey, oral commun., 2008).

In addition to seismic energy not dying off quickly with distance in the Central and Eastern United States relative to the Western United States, Central and Eastern U.S. earthquakes tend to have greater stress drops for the same magnitude earthquake (Atkinson and Silva, 1997; Campbell, 2003), which means that ground shaking at higher frequencies is more severe. Furthermore, local site conditions in both the Western and Central and Eastern United States and elsewhere play an important role (Cramer, 2006). When soft sediments overlie hard rock, ground motions can be amplified and last considerably longer (fig. 2). For example, Memphis lies near the middle of the Mississippi embayment, not far from the southern strand of New Madrid seismicity, and sits more than about one-half a mile of loose sediment. Both factors, proximity to the earthquake source and the thick column of loose sediment, can act to increase earthquake ground motions in



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very heavy

Figure 1. "Did you feel it?" felt intensities for the 2007, magnitude 5.4 Alum Rock, California earthquake and the 2008, magnitude 5.2 Mt. Carmel, Illinois earthquake. "Did you feel it?" figures courtesy of D. Wald. Black lines are State boundaries. Red lines are country boundaries.

Memphis relative to locations farther from the fault located on hard rock.

The Earthquake Source

In addition to assessing how quickly ground motions die off with distance from an earthquake source and the effects of local site conditions on ground motion, we need to know more about the earthquakes themselves. Where are the earthquakes located? What are their magnitudes? How often do they occur?

In figure 3*A*, I present a map of earthquakes in the Central and Eastern United States that have occurred since 1964 when seismic monitoring became a priority. There are many earthquake sources in the Central and Eastern United States: along the Appalachians, northwest up into eastern Canada, southeast from eastern Tennessee down across South Carolina, across Oklahoma and Texas, up through Nebraska and South Dakota, and in the New Madrid region along the Mississippi river, the location of the 1811–1812 series of earthquakes (Johnston and Schweig, 1996).

When we look more closely at seismicity in the New Madrid region (fig. 3*B*), among the first things we notice are northeast and northwest trends of seismicity, which appear to delineate faults. These bands of seismicity and nearby earthquakes are referred to collectively as the New Madrid Seismic

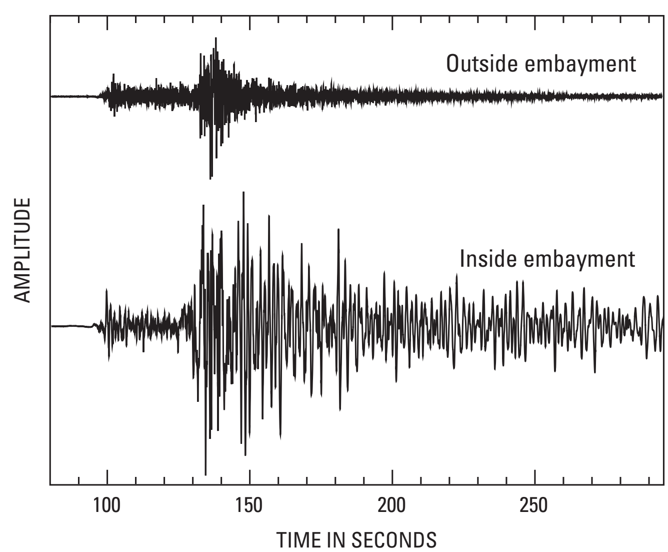


Figure 2. Ground-motion time series for a location inside and outside the Mississippi embayment 280 kilometers from the 2008 Mt. Carmel, Illinois earthquake. Time series courtesy of C. Cramer.

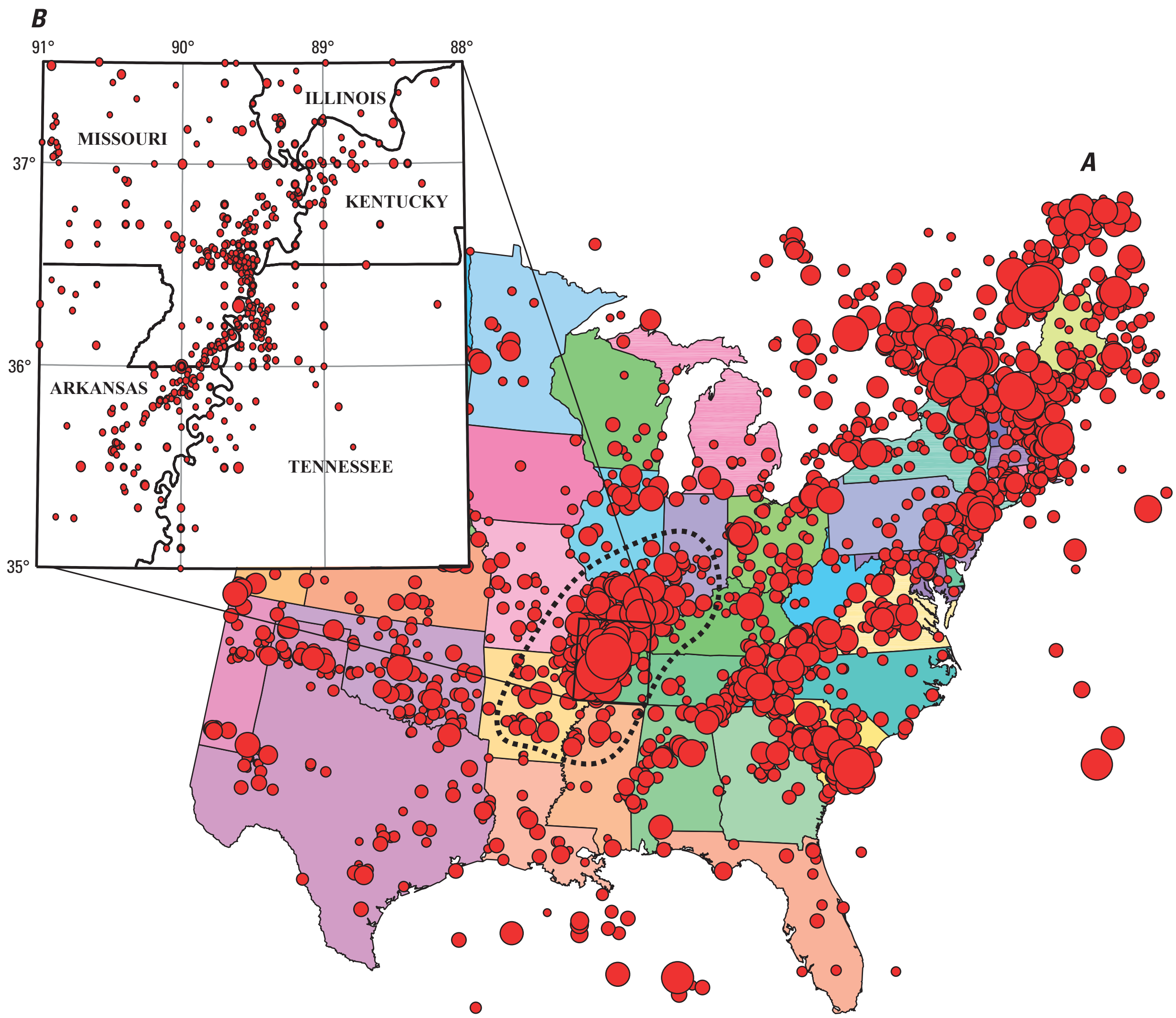


Figure 3. *A*) Map of seismicity (red circles—size is proportional to magnitude between 3 and 7.5) in the Central and Eastern United States since 1964. The inset (*B*) depicts seismicity along New Madrid Seismic Zone. The dotted outline in *A* refers to the region considered in the recurrence analysis using the instrumental catalog.

Zone, and we think that the 1811–1812 series of events took place somewhere along these bands. Seismicity also occurs to the northeast of the New Madrid zone in the Wabash Valley seismic zone, which is where the April 18th, 2008, Mt. Carmel earthquake occurred (Herrman and others, 2008).

Earthquake Recurrence

Paleoseismology and Large Infrequent Earthquakes

Many small to moderate earthquakes have occurred in the Central and Eastern United States in the last 40 years, but how should we prepare for future earthquakes? Will they be damaging? How often do damaging earthquakes occur? The expectation of damage from future earthquakes can be addressed by reviewing the effects of some significant, moderate to large, historic earthquakes in the region (Stover and Coffman, 1989; Wheeler and others, 2003).

On April 18, 2008, a M5.2 earthquake occurred near Mt. Carmel, Illinois. There were no casualties and only minor damage such as toppled chimneys and masonry that fell out from around windows. It was felt in more than 20 States from Florida to Canada and resulted in more than 45,000 felt reports. Stepping back to the 1960s, Illinois experienced another moderate earthquake, a M5.4. Like the more recent earthquake, there was damage to chimneys and the masonry around windows. It was felt in 23 States from Minnesota to Georgia and Pennsylvania to Kansas. Just before the turn of the 20th century, in 1895, a M6.6 earthquake occurred near Charleston, Missouri. Damage was much more extensive. Chimneys toppled throughout Charleston and to a lesser extent, in Cairo, Illinois. Windows shattered and plaster walls cracked. Liquefaction features were produced along a line roughly 20 miles long. In the mid-19th century, there was another large earthquake, a M6.3 in Marked Tree, Arkansas.

This quake produced damage in Memphis, 40 miles away. Like other moderate earthquakes in the region, it produced damage consisting of toppled chimneys, shattered windows and cracked walls. The most famous historic earthquakes occurred in 1811–1812 and were known as the New Madrid Earthquakes of 1811–1812. The event consisted of three large earthquakes, each about a month apart, somewhere between magnitude 7 and 8 (Johnston and Schweig, 1996; Hough and others, 2000; Bakun and Hopper, 2004). Chimneys were knocked down as far away as Cincinnati, Ohio, 350 miles from the epicenter. Trees near the epicenter were snapped and uprooted and landslides occurred along the river bluffs. Fortunately, the region near the epicenter was sparsely populated.

Large earthquakes leave behind clues in the geologic record, and to understand these catastrophic events paleoseismology, a field of study in which researchers use geological markers to interpret the location, timing, and magnitude of prehistoric earthquakes, is essential. Practicing paleoseismology in the Central and Eastern United States is rather difficult given that earthquake ruptures rarely reach the surface and can be buried by hundreds of meters of sediment. Within regions of more active tectonics and arid climate like the Western United States, this is not the case. Rupture features may be preserved at the surface for tens and maybe hundreds of years. Paleoseismologists can trench across these features to study faults and their offsets. Geologic markers such as old stream channels are easily seen to be displaced across active faults. But in the Central and Eastern United States, where fault slip rates are low and processes like erosion and deposition rapidly destroy or bury the geologic record, more indirect approaches, such as the study of liquefaction features, must be made.

The liquefaction features that have provided the most insight into earthquake recurrence in the New Madrid region are sand blows. During strong shaking, sandy water-saturated layers may liquefy. If a crack can form in the competent silt and clay layers above, pressurized sand and water can break through and erupt onto the surface (sand blow), possibly burying dateable remains such as charcoal, sticks, or human artifacts. A sand blow in which there are two episodes of liquefaction, one from 1811–1812 and one from a prior large earthquake (Tuttle and Schweig, 1996; Li and others, 1998), as shown in figure 4*A*. To give some idea of the extent of liquefaction, figure 4*B* shows an aerial photograph with sand blows, the lighter colored areas, strewn through fields in southeastern Missouri. Some are from 1811–1812, but others are from earlier events.

From the study and dating of sand blows, paleoseismologists have determined that there have been several series of large earthquakes occurring at least three times in the last 1,500 years (Tuttle and others, 2002). The average recurrence interval for the most recent, well studied events is about 500 years. Therefore, based on this information and the assumption that the New Madrid region will continue to experience earthquakes at the same rate as it has in the past, the probability of a repeat of an 1811–1812 type earthquake in any 50 year period is about 10 percent.

Earthquake Recurrence from the Instrumental Catalog

Another means of assessing recurrence, particularly for smaller earthquakes, is with the use of instrumental seismicity. Based on the seismicity observed in the New Madrid region (the dotted outline in fig. 3*A*), we can ask, for example, what is the annual rate of earthquakes greater than or equal to magnitude 5 or greater than or equal to magnitude 6? To answer this question, we assume that the number of earthquakes greater than or equal to some magnitude follows an exponential (or so-called Gutenberg-Richter) relation (fig. 5). We also assume the following completeness as was used in the USGS National Seismic Hazard Maps. Reporting of earthquake magnitudes is considered complete for earthquakes greater than or equal to M3 occurring since 1974, greater than or equal to M4 occurring since 1940, greater than or equal to M5 occurring since 1860, and greater than or equal to M7 occurring since 1800 (Frankel and others, 1996).

This assumption is common in seismology. When you look at nearly any earthquake catalog, you see an exponential magnitude-versus-frequency relationship, $N(\geq M)=10^{a-bM}$. The number of earthquakes having a magnitude greater than or equal to M is equal to 10 raised to a constant *a* minus a constant *b* times magnitude. The *a*-value reflects the overall level of seismic activity; greater *a*-values indicate more seismicity. The *b*-value reflects the relative frequencies of large and small earthquakes. Worldwide, *b* is generally close to 1, which means that, for example, magnitude 4 earthquakes occur ten times more often than magnitude 5s or that magnitude 5s occur ten times more often than magnitude 6s.

When we perform this analysis for seismicity for the New Madrid region (fig. 5), we find an *a*-value of 3.48 ± 0.15 (for M equal to or greater than 0) and a *b*-value of 0.92 ± 0.05. The estimation of *a*- and *b*-values is performed on incremental rates of earthquakes rather than cumulative rates. In other words, a line is fit to the log of the number of earthquakes occurring within magnitude bins rather than fitting a line to the log of the number of earthquakes greater than or equal to a given magnitude. An outline of this method as well as its justification is documented in Weichert (1980). If the *b*-value were exactly 1, the *a*-value would represent the minimum magnitude we would expect to see once per year, on average. We can then use this equation and these values to ask how often we expect to see a magnitude greater than or equal to 5. This turns out to be, on average, about once every 11 to 17 years. For a magnitude greater than or equal to 6, we can expect to see one about once every 80 to 150 years. The ranges in return periods result from synthesizing random catalogs with an earthquake catalog subject to the aforementioned levels of magnitude completeness.

This analysis is, however, imperfect and uncertain. Because the earthquake catalog is limited to a short period of time relative to the return period of magnitude 5 and larger earthquakes, we could easily argue that earthquakes with these magnitudes are poorly represented. It is interesting to see that in figure 5, the number of earthquakes greater than about M4.7

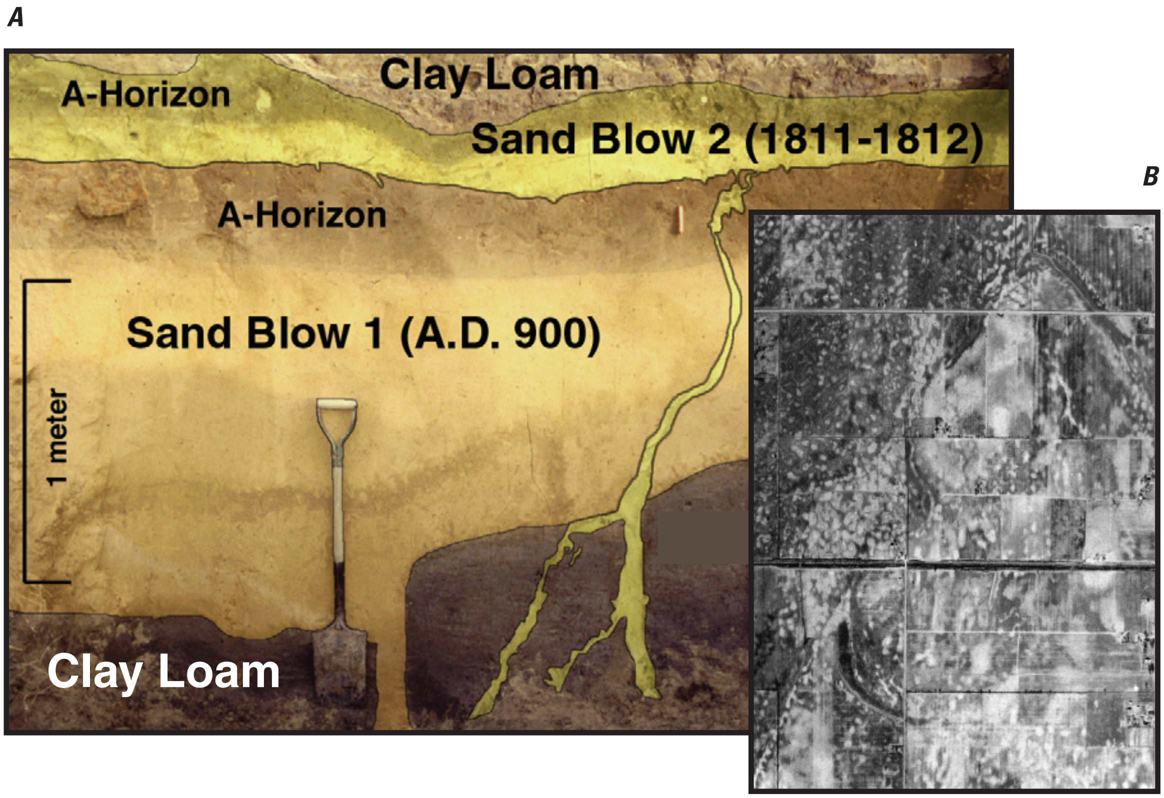


Figure 4. *A*) Profile of two episodes of sand blow formation (Tuttle and Schweig, 1996; Li and others, 1998) and *B*) sand blows (light colored areas) throughout fields in southeast Missouri. The photo in 4*A* was taken by M. Tuttle. The aerial photo in 4*B* was taken by the U.S. Department of Agriculture in 1964.

lies beneath the predicted values, which may indicate that the future rate of magnitude 5s will be greater than what has been observed in the instrumental record. It should be noted that an analysis using the instrumental catalog does not apply to large New Madrid type earthquakes, which in many cases do not follow exponential recurrence behavior (Schwartz and Coppersmith, 1984).

The return periods of M5 and M6 earthquakes can be expressed in terms of the probability of occurrence within a given period of time as was presented for the large 1811–1812 type earthquakes. The probability of a magnitude 5 or greater in any 50-year period in the entire New Madrid region is very high, between 95 and 99 percent. The probability of a magnitude 6 or greater is somewhere between 28 and 46 percent.

Conclusions

In this article, several points were made with regard to earthquake hazards: those related to earthquake ground motions and those related to earthquake probabilities. With respect to the former, seismologists have observed that earthquake ground motions maintain energy to greater distances and have greater high-frequency energy content in the Central and Eastern United States relative to the Western United States. They may also be amplified and last longer depending on the thickness of soft sediment beneath a site of interest. With respect to earthquake probabilities, observations from paleoseismology and the instrumental catalog are essential. From the instrumental catalog, we find that a magnitude 6 or larger earthquake can be expected once every 90 to 135 years in the New Madrid region, while, from paleoseismology, we find that a repeat of an 1811–1812 type series of earthquakes may be expected once every 500 years, on average. In terms of the probability that these earthquakes will occur in any 50-year period, these return periods correspond to roughly 37 percent and 10 percent probability, respectively.

Acknowledgments

Charles Mueller, Mark Peterson, and Art Frankel provided outstanding reviews of the original manuscript. I also want to acknowledge Emitt Witt, Krista Karstensen, and Ronaldo Luna for organizing a very successful conference in which this work was presented.

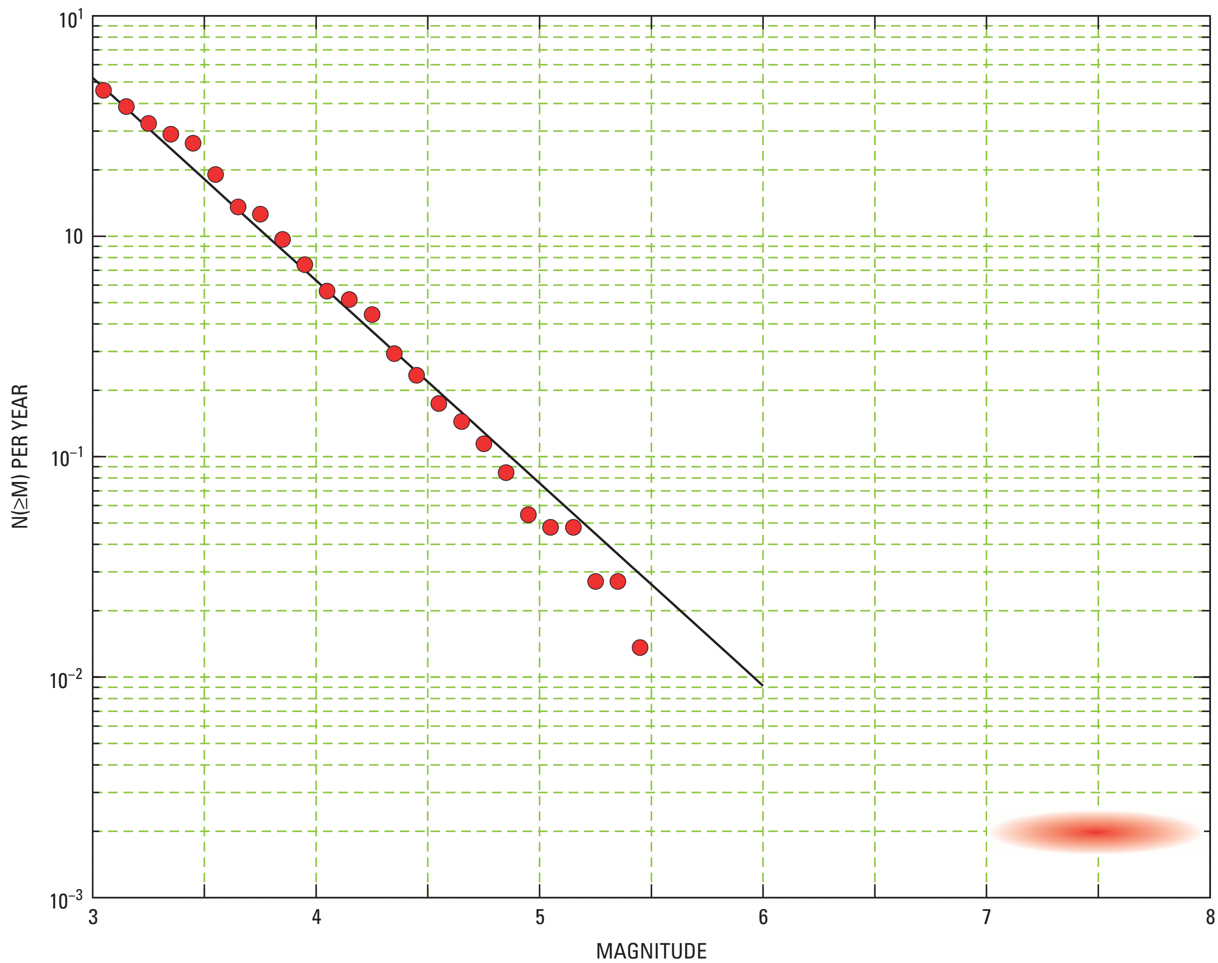


Figure 5. The annual rate of earthquakes greater than or equal to magnitude, M, versus magnitude for the New Madrid region (dotted outline in figure 10*A*). Red circles with black outlines are observations. The black line is a fit to the data and the dashed green lines represent the standard deviation. The red shaded region between magnitudes 7 and 8 represents the recurrence of the New Madrid earthquakes, which is determined from paleoseismology.

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State and Regional Impact of Central U.S. Earthquakes on the Physical Infrastructure

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Conference Abstract

The Central United States is a seismically active area with infrequent but potentially catastrophic earthquakes, as evidenced by the 1811 and 1812 earthquakes. These earthquakes occurred as a cluster of 3 large magnitude events in late 1811 and early 1812 in the New Madrid region. This study seeks to determine the maximum probable impacts of a repeat of the 1811–12 earthquakes in the New Madrid Seismic Zone, as well as other seismic activity in the region. The earthquake impact assessment models discussed herein utilize the best available hazard characterizations and regional inventory for the Central United States. An examination of numerous scenarios shows that a M_w7.7 earthquake on the New Madrid Fault system generates the most substantial damage to buildings and lifelines in Tennessee, Missouri, Kentucky and Illinois depending upon the location of the fault rupture. A single scenario event for the State of Tennessee shows direct economic losses of nearly $60 billion with more than 60,000 casualties (both injuries and fatalities). Severe damage and losses are estimated for the other seven States, as detailed in the presentation.

Post-Conference Paper

Earthquake Impact on the Built Environment in the Central United States

By Lisa J. Cleveland[1] and Amr S. Elnashai[2]

Abstract

The Central United States, a seismically active area with infrequent but potentially catastrophic earthquakes, as evidenced by the 1811 and 1812 earthquakes. These earthquakes occurred as a cluster of 3 large magnitude events in late 1811 and early 1812 in the New Madrid region. This study seeks to determine the maximum probable impacts of a repeat of the 1811–12 earthquakes in the New Madrid Seismic Zone, as well as other seismic activity in the region. The earthquake impact assessment models discussed herein utilize the best available hazard characterizations and regional inventory for the Central United States An examination of numerous scenarios shows that a M_w7.7 earthquake on the New Madrid Fault system generates the most substantial damage to buildings and lifelines in Tennessee, Missouri, Kentucky and Illinois depending upon the location of the fault rupture. A single scenario event for the State of Tennessee shows direct economic losses of nearly $60 billion with more than 60,000 casualties (both injuries and fatalities). Severe damage and losses are estimated for the other seven States, as detailed in the paper.

Introduction

Scenario earthquake impact assessments provide estimates of damage to infrastructure and the effects of that damage on the exposed population. Emergency response agencies utilize the best available damage and loss predictions to prepare for disaster response in a post-earthquake environment. Conversely, organizations charged with mitigations review impact assessment damage estimates and identify critical infrastructure for repair and retrofit before catastrophic events with the intent of improving the performance of those structures during an earthquake. Furthermore, government agencies and private organizations make use of earthquake impact assessments to promote individual and community preparedness and educate vulnerable areas on the possible impacts of earthquakes.

Seismic activity in the Central United States is less frequent than the west coast. However, because of the geological differences between the two regions, earthquakes in the Central United States would affect a much larger area than a comparable event on the west coast. Amongst the largest earthquakes in United States history are the three earthquakes in the New Madrid Seismic Zone (NMSZ). During the winter of 1811–12 three earthquakes with magnitudes between 7 and 8 shook the Central United States and were reportedly felt many hundreds of miles further away (Hough and Bilham, 2006). Many earthquakes are recorded in the Central United States, all of which are only mildly destructive. More recently, a magnitude 5.2 earthquake on April 18, 2008, in southern Illinois was reportedly felt in Georgia and Kansas which are hundreds of miles from the epicenter near West Salem, Illinois (U.S. Geological Survey, 2008).

The Mid-America Earthquake Center (MAEC) is investigating the impacts of various earthquakes on the Central United States in an effort to provide county, State and Federal emergency planners with the impact estimates necessary to develop comprehensive response plans based on realistic and scientifically-defendable damage and loss predictions. This multi-year, multi-phase project includes the examination of various seismic events including those in the New Madrid, Wabash Valley, and East Tennessee Seismic Zones. Initial

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investigations of roughly 250 counties nearest to the New Madrid Fault primarily focused on the effect of earthquake hazard on impact assessment results. Various source mechanisms were considered including point and line sources. In addition, the effect of liquefaction susceptibility was evaluated. Estimates indicate economic losses range from $40 to $50 billion with more than 35,000 casualties (Elnashai and Cleveland, 2007) when line source fault representation and liquefaction susceptibility are used. Current modeling efforts seek to build upon the knowledge gained in these initial studies and improve upon the damage and loss estimates provided by these preliminary models. Additionally, the region of interest is larger and includes the States of Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee.

Definition of Scenario Components

It is highly probable that the New Madrid Fault will generate the most catastrophic seismic event while the Wabash Valley and East Tennessee Faults will generate moderate earthquakes of magnitude 6 to 7. Even with source zones identified, the exact source, path, and rupture mechanism must still be determined before conducting scenario earthquake impact assessment. One of the most important considerations in scenario definition is the seismo-tectonic environment of the region under consideration. The NMSZ is not a single fault but rather a region in which ruptures are likely to occur. Indeed, the 1811–12 events were probably associated with three different faults. The location of the NMSZ is illustrated in figure 1. The line represents the most likely rupture location, though it is possible for seismic events to deviate slightly from this fault layout (Johnston and Schweig, 1996). The fault itself is comprised of three segments, with each segment representing a possible rupture. This means that only the northeast segment may rupture at a given time, for example. It also is possible that a single segment ruptures, a second segment follows weeks or months later, and the final segment ruptures in some additional period of time. Only individual segment fault ruptures are used in this study each with a magnitude of M_w7.7. Though not shown here, additional scenario events considered include a M_w7.1 in the Wabash Valley Seismic Zone and a M_w5.9 in the East Tennessee Seismic Zone.

Developing the most comprehensive and precise earthquake impact models requires the best available input data. Once the scenario source is chosen the method used to define ground motion must be determined. Elnashai and Cleveland (2007) confirmed that using the line source definition of ground motion in the Central United States produces significantly greater impacts and also represent a more realistic depiction of ground shaking. The U.S. Geological Survey (USGS) developed three sets of ground motion maps representing magnitude M_w7.7 events on each segment of the New Madrid Fault. Soil amplification is accounted for in these maps using a two-dimensional soil model (Cramer, 2006). The soil data utilized to develop these maps are designed for regional-level analyses only because of the coarse level of refinement in soil characterization. Each set of maps includes peak ground acceleration (PGA), peak ground velocity (PGV), short-period spectral acceleration (S_a 0.3 sec.), and long-period spectral acceleration (S_a 1.0 sec.) since the modeling software, HAZUS-MH MR2 (Federal Emergency Management Agency, 2006), requires these ground shaking parameters. Reference is made to figure 2 for the PGA map used to model the southwest fault segment rupture.

Hazard is further defined by ground deformation which is modeled with liquefaction susceptibly maps. The liquefaction data included in this study was developed based on a proxy correlating a National Earthquake Hazards Reduction Program (NEHRP) soil site class (A–F) to a relative level of liquefaction susceptibility (spanning from 'none' to 'very high'). The combination of ground shaking and ground deformation provides better description of regional hazard in the Central United States where soft and liquefiable soils significantly affect the behavior of structures and performance of lifelines.

Achieving the most accurate impact assessment also requires the best available inventory. There are numerous types of infrastructure common to earthquake impact assessment, such as general buildings (residential, commercial, and so forth), transportation lifelines, utility lifelines and high potential-loss facilities (dams, levees, hazmat, and so forth.)

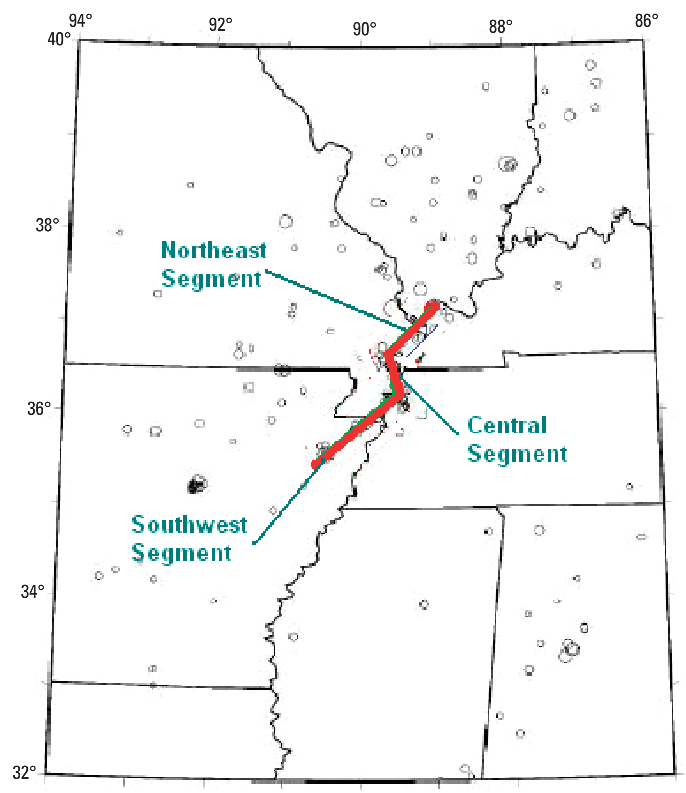

Figure 1. Fictitious faults (red) used to characterize the uncertainty in source location for New Madrid earthquakes. Circles are earthquakes with magnitude greater than or equal to 3.0 since 1976.

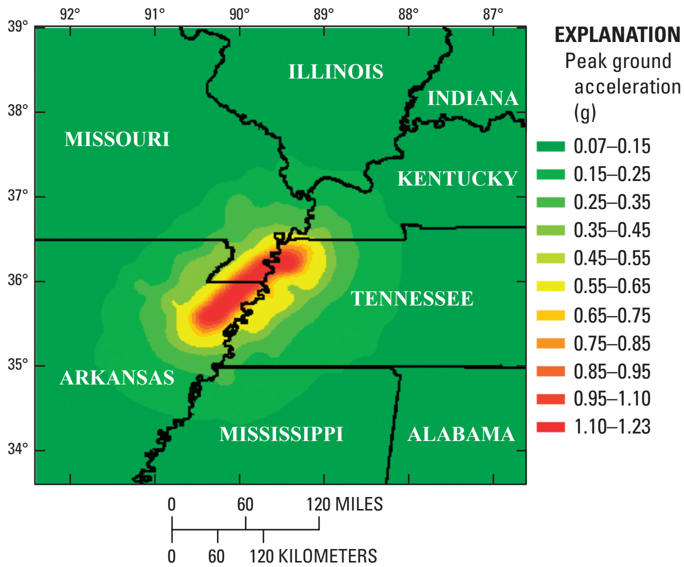

Figure 2. Peak Ground Acceleration (PGA) for the Southwest Fault Extension of the New Madrid Seismic Zone.

as well as population demographic data. In addition to the location of each infrastructure components, various structural parameters are required to complete an analysis. Several critical parameters include structural system, height or length, year of construction and level of seismic design and replacement value of each structure for the computation of economic loss.

The study conducted by the MAEC sought to update the inventory data for critical structures such as essential facilities for emergency response and lifelines. The Homeland Security Infrastructure Program (HSIP) Gold Dataset from 2007 (National Geospatial-Intelligence Agency Office of America, 2007) was used to update a pre-existing set of inventory provided with the impact assessment program, HAZUS-MH MR2. The HSIP provides more than 200 datasets detailing the locations and characteristics of various critical infrastructure systems throughout the United States. The addition of 200,000 critical facilities across the eight States of interest substantially improved the quality of inventory data. Inventory improvements were made to essential, transportation, utility and high potential-loss facilities. Two new inventory types were added to the utility inventory as well, namely major regional transmission pipelines for oil and natural gas.

An Overview of Impacts Assessment Results

A total of ten scenarios were completed throughout the eight States. A NMSZ event was modeled for each State while impact assessments were also conducted for Wabash Valley and East Tennessee events in Indiana and Alabama, respectively. The New Madrid scenarios considered the single fault rupture closest to the State of interest. This was designed to provide the worst case impacts for each State. Several States showed significantly greater impacts than others such as Illinois, Kentucky, Missouri and Tennessee, and are the focus of this discussion.

The State of Illinois is most critically impacted by a rupture of the northeast segment. Approximately 30,000 buildings in southern Illinois are moderately or more severely damaged leading to ~6,300 casualties, which include all injuries and fatalities. In many cases moderate damage indicates cracking of interior non-structural walls and large cracks in chimneys. More than 100 hospitals, fire stations, and police stations are not operating the day after the earthquake, severely inhibiting the healthcare sector's ability to care for the injured and provide emergency services. Travel in southern Illinois is impeded by more than 250 damaged bridges. Roughly 70,000 households are without drinking water and electricity the day after the earthquake and is likely to prevent residents from remaining in their homes. Direct economic losses are estimated at more than $34 billion with $27 billion attributed to utility lifeline damage alone.

The NMSZ scenario event for Kentucky is located along the northeast segment as well. Most of the impacted infrastructure is located in western Kentucky. Approximately the same number of essential facilities is not operating and the same number of bridges damaged in Kentucky as were affected in Illinois. Conversely, more than 500 waste water facilities and 1,000 communication facilities are damaged. Also, more than 100,000 are expected to be without drinking water the day after the earthquake in western Kentucky. More than 82,000 buildings are moderately or severely damaged and lead to nearly 10,000 casualties. Total direct economic losses exceed $46 billion in Kentucky alone, which is 75 percent greater than Illinois.

An event nucleating from the central segment of the fault is employed in the scenario earthquake for the State of Missouri. Nearly 85,000 buildings incur moderate or more severe damage and more than 95 percent of the buildings are residential structures. Of the 85,000 buildings damaged, 37,000 experience complete damage meaning these structures are damaged beyond repair. Such extensive damage to residential buildings causes nearly 16,000 casualties. In addition, nearly 200 schools are damaged, severely reducing the number of public shelter locations for those displaced because of the earthquake. Also, most hospitals, police, and fire stations in southeast Missouri are not operating immediately after the earthquake leaving residents without critical emergency services and medical care. Transportation lifelines are critically impaired with nearly 1,400 bridges and 30 airports in southeast Missouri not functioning. Without these lifelines it is difficult for residents to evacuate and emergency aid workers to enter the most severely affected regions. About 1,600 communication facilities are damaged, requiring emergency aid teams to seek alternate forms of communication immediately after the event. Water pipelines experience more than 15,000 leaks and 20,000 breaks leaving nearly 150,000 people without drinking water in southeast Missouri. Total direct economic losses reach nearly $40 billion, with $25 billion attributed to utility lifeline loss alone.

The State of Tennessee incurs far greater damage than any other State in the New Madrid region. The scenario earthquake for this State employs a rupture of the southwest segment. This generates significant shaking in the city of Memphis which has a highly vulnerable population of unreinforced masonry (URMs) buildings. Nearly 260,000 buildings are moderately damaged to completely destroyed, with nearly 50,000 being URMs. Such extensive damage to residential buildings causes more than 63,000 total casualties, which is far more than the three previous scenarios combined. At least 4,000 of those casualties are fatalities and another 15,000 injuries require hospitalization.

Most counties in western Tennessee, where most of the casualties occur, are without operational hospitals in the days immediately after the earthquake, inhibiting the region's ability to care for the injured. More than 600 schools, 120 police stations and 250 fire stations are damaged and all are located in western Tennessee as well. Nearly 900 bridges are severely damaged limiting the amount of aid workers and supplies that can enter the most affected counties in western Tennessee. Thousands of utility facilities are damaged, particularly communication facilities which show nearly 3,500 damaged structures. Regional and local natural gas pipelines incur 16,000 leaks and more than 10,000 breaks in nearly 50,000 miles of pipelines and will require substantial repair work to render the pipeline network operational again. Nearly 450,000 households are without drinking water while 425,000 households are without electric power the day after the event. Such widespread service losses will prevent residents from staying in their homes, even if the structures themselves are not damaged. Total direct economic losses are far greater than previous scenarios at nearly $57 billion. More than $40 million is attributed to building losses while $15 billion is attributed to utility lifelines.

Various scenarios are employed for each State impact assessment and hence the individual States should not be added directly to determine regional impacts, though the following table does permit general estimations of possible regional impacts. In these four States alone, several hundred thousand buildings and thousands of bridges are likely damaged by a New Madrid event. It is possible that more than 100,000 casualties occur and direct economic losses exceed $150 or $200 billion as shown in table 1. When the remaining four States are considered these regional estimates will be even greater. All the above does not include economic loss from indirect effects, such as business interruption, loss of market share, loss of tax revenue base and others.

Conclusions

This study investigates the effect of various earthquakes on the Central United States. Catastrophic earthquakes on the New Madrid fault are considered, as well as less severe events on the Wabash Valley and East Tennessee faults, though the New Madrid events are the primary focus of this discussion. When conducting scenario impact assessment it is critical to consider the best available inputs such as hazard characterization and regional infrastructure inventory. As shown here, the location of faulting can vary within the NMSZ and impact assessment results change substantially based on the rupture location chosen, the site condition, and the susceptibility to large ground deformation.

Though these models were current when the study was completed, numerous advances in hazard and structural response modeling have taken place since then and must be considered via new modeling for Central United States earthquakes. More comprehensive soil amplification and liquefaction susceptibility maps for the eight States of interest will improve the hazard characterization throughout the region. Various new types of inventory are now being considered and include long-span bridges, dams, levees and hazardous materials facilities. New fragility relationships for buildings and bridges are also available and will be used in the next generation of impact assessment models. Continued efforts to improve impact assessment modeling will lead to more accurate results and ideally provide emergency response planners, mitigation teams and the public with a better understanding of the potential effects of earthquakes in the Central United States. The detailed results from the study reported in this paper are available in a report downloadable from *https://www.ideals.uiuc.edu/handle/2142/8971*.

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Table 1. Damage and loss values.

Type of damage or loss	Illinois	Kentucky	Missouri	Tennessee
At least moderately damaged buildings	29,500	81,600	84,600	258,000
At least moderately damaged bridges	260	200	1,360	900
Total casualties (injuries and fatalities)	6,250	9,740	15,600	63,100
Total direct economic losses ($, billions of dollars)	$34.1	$46.0	$38.7	$56.6

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Resilience, Response, and Recovery: Societal Components of Catastrophe

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Abstract not submitted.

State-of-the-Art Earthquake Research for Critical Transportation Systems

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Abstract not submitted.

The Advanced National Seismic System: Earthquake Monitoring for Science, Engineering, Rapid Response, and Public Information

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Conference Abstract

Seismic monitoring in the Central United States is a cooperative effort by six institutions organized under the umbrella of the Advanced National Seismic System (ANSS). These partners include Center for Earthquake Research and Information (CERI) at the University of Memphis, St. Louis University (SLU), the University of Kentucky (UKY), the University of South Carolina at Columbia (USC), and the U.S. Geological Survey (USGS).

The mission of the ANSS is to provide accurate and timely data and information products for seismic events, including their effects on buildings and structures, employing modern monitoring methods and technologies. The ANSS includes 7000 measuring instruments and associated infrastructure and human resources at a capitalization cost of $170 million and $47 million each year for operation and maintenance (U.S. Geological Survey Circular 1188, An Assessment of Seismic Monitoring in the United States; Requirement for an Advanced National Seismic System). Public Laws 106-503 and 108-360 authorize full funding but annual appropriations are about 10 percent and operation and maintenance costs preclude appreciable additional modernization. Significant improvements are realized since the ANSS inception in 2000 though there remain significant gaps in data (for example, sparse coverage and/or obsolete hardware) and product quality disparities in different parts of the country (from lack of instrumentation, software, infrastructure, and human resources).

Post-Conference Paper

Monitoring by the Science Community

By Mitch Withers

Seismic monitoring in the Central United States is a cooperative effort by six institutions organized under the umbrella of the Advanced National Seismic System (ANSS). These partners include Center for Earthquake Research and Information (CERI) at the University of Memphis, St. Louis University (SLU), the University of Kentucky (UKY), the University of South Carolina at Columbia (USC), and the U.S. Geological Survey (USGS).

The mission of the ANSS is to provide accurate and timely data and information products for seismic events, including their effects on buildings and structures, employing modern monitoring methods and technologies. The ANSS includes 7,000 measuring instruments and associated infrastructure and human resources at a capitalization cost of $170 million and $47 million each year for operation and maintenance (U.S. Geological Survey, 1999). Public Laws 106-503 and 108-360 authorize full funding but annual appropriations are about 10 percent and operation and maintenance costs preclude appreciable additional modernization. Significant improvements are realized since the ANSS inception in 2000 though there remain significant gaps in data (for example, sparse coverage and/or obsolete hardware) and product quality disparities in different parts of the country (from lack of instrumentation, software, infrastructure, and human resources).

Monitoring in the Central and Eastern United States is accomplished using a national backbone network, regional monitoring, and urban strongmotion monitoring. The national backbone operated by the USGS provides a uniform level of high quality coverage across the entire country with a threshold of about magnitude 3.5. Higher density coverage is implemented as resources permit by regional partners in areas of relatively elevated hazard as defined by a 10 percent probability of exceeding 8 percent g in ground motion within the next fifty years (U.S. Geological Survey, 2002, hazard map as of this writing). The map in figure 1 shows the locations of broadband (squares) shortperiod (triangles) and strongmotion (diamonds) instrumentation operated by the USGS National Earthquake Information Center (brown) and the USGS National strong motion program (unfilled diamonds), CERI (red), SLU (green), UKY (yellow), USC (magenta) and Virginia Tech (orange). There just under 300 stations on the map.

Data flowing from an earthquake which generates seismic waves that travel outward away from the epicenter not unlike ripples from a pebble in a pond is illustrated in figure 2. These waves are measured by seismic instruments and those data are sent, in many cases by radio to a processing facility. In many instances the processing facility is remote and unstaffed where data are concentrated, stored as backup, and forwarded to a central facility. The central facility exchanges data in near-real-time with other seismic networks usually using public internet. The ANSS regional processing facility at CERI processes more than 900 channels and each channel contains from 40 to 100 data points per second. The data are processed to produce rapid automated alarms and reviewed products.

The ANSS provides a suite of products available from one source but with contributions from all participants. There are at least two primary benefits to this system. First, it provides one-stop shopping instead of gathering components and different pieces of information from different seismic networks. The ANSS combines those pieces into a single seamless product suite. Secondly, it provides for a base level of product availability for the entire country regardless of the capabilities of any individual seismic network. See *http://www.anss.org/products.*

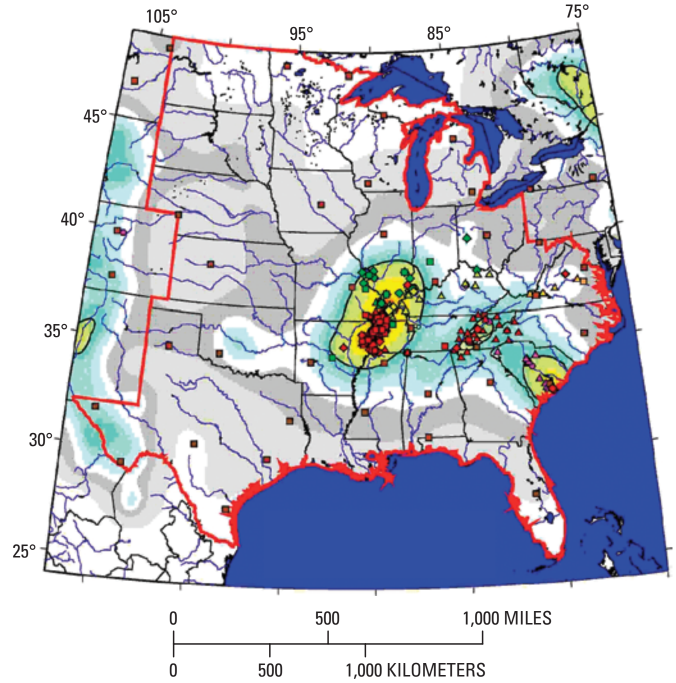

Figure 1. Advanced National Siesmic System (ANSS) seismic stations in the Central and Eastern United States.

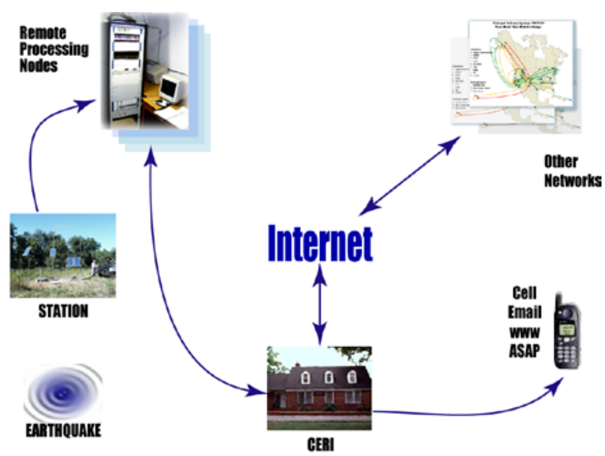

Figure 2. Conceptual diagram of seismic data flow.

The products include recent earthquake maps and lists, maps of intensity based on felt reports, maps of ground shaking based on instrumental observations where instrumentation is sufficiently dense, an email and cell phone earthquake notification service, earthquake catalogs and data, and near-real-time images of seismograms.

The magnitude 5.2 earthquake in southeast Illinois on April 18, 2008 serves as a good example of an ANSS monitoring success as well as highlights notable shortcomings because of lack of instrumentation and infrastructure. There were more than 38,000 felt reports (fig. 3) for this earthquake from Chicago to Atlanta.

The earthquake provided the best data set to date for a Central and Eastern United States earthquake that provides an observation of how seismic waves attenuate with distance. This is a key parameter in estimating seismic hazard. The earthquake also provided an excellent opportunity to calibrate the ANSS instrumentation. There were also excellent data to provide estimates of sedimentary basin amplification and resonance, also critical to accurate estimates of seismic hazard. These and more data like it help to provide the basic science necessary to more accurately estimate hazards and thereby develop better informed building codes that safeguard lives and property without undue conservatism that may unnecessarily increase development costs.

Additional information is available at *http://www.anss.org and at http://www.ceri.memphis.edu*.

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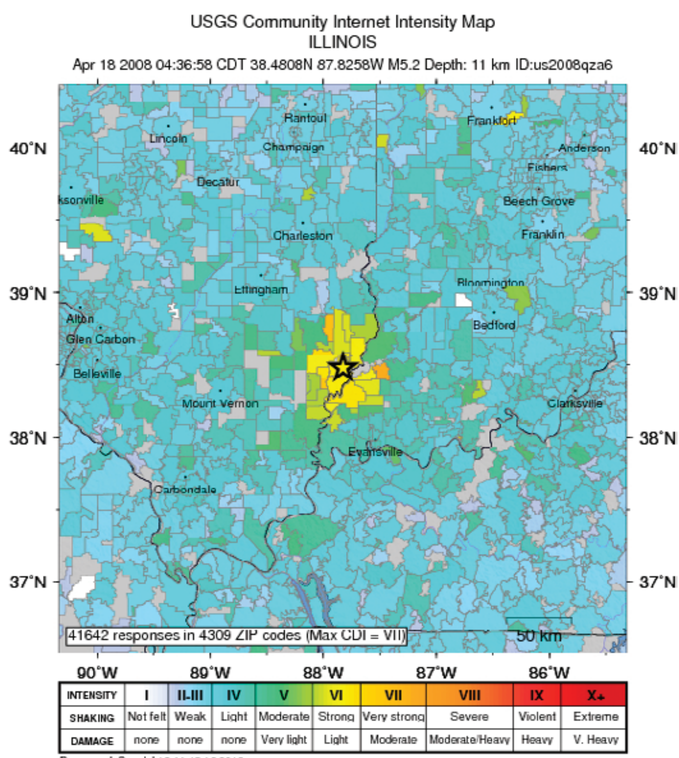

Figure 3. Intensity map for the magnitude 5.2 southern Illinois earthquake of April 18, 2008.

Critical Infrastructure Monitoring: The Bill E. Emerson Memorial Bridge

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Abstract not submitted.

Products and Capabilities of the Science/Engineering Community for Emergency Response

By Robert Bauer

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**Publication authorized by the Director, Illinois State Geological Survey*

Conference Abstract

Many scientists and engineers from State and Federal agencies, universities, consulting firms and professional organizations participate in post-earthquake response and recovery. Collectively, they bring a wide range of experience, documentation procedures, equipment, and facilities.

Some of these experts, such as State and Federal agency representatives, are responsible for gathering data and providing advice to their emergency management officials who use this information for decision support during response and recovery operations. Structural engineers and building code officials can provide rapid inspections of structures to assess entry conditions which are posted on buildings. All of these experts are collecting data using various techniques and equipment to document perishable features associated with buildings, infrastructure and the earth surface. Ideally, information is compiled at central locations and provided to the public through information officers, via press releases, interviews and internet content. This allows for maximum distribution of information on what is known, what can be expected and ways to stay safe during aftershocks and future events.

To help with analysis and explanation, earthquake data are combined with various maps, aerial photography, satellite imagery, and other remotely sensed ground conditions that are available from State and national clearinghouses and with newly acquired imagery from specially tasked aircraft flights and satellites. In addition to response and recovery efforts, all information is later used to better understand and predict impacts from future earthquake events to help mitigate future damage.

Post-Conference Paper

Products and Capabilities of Science/Engineering Community for Earthquake Response and Recovery*

By Robert A. Bauer

Abstract

Many scientists and engineers from State and Federal agencies, universities, consulting firms and professional organizations participate in post-earthquake response and recovery. Collectively, they bring a wide range of experience, documentation procedures, equipment, and facilities.

Some of these experts, such as State and Federal agency representatives, are responsible for gathering data and providing advice to emergency management officials who use this information for decisions during response and recovery operations. Structural engineers and building code officials can provide rapid inspections of structures to assess entry conditions which are posted on buildings. All of these experts are collecting data using various techniques and equipment to document perishable features associated with buildings, infrastructure, and the earth surface. Ideally, information is compiled at central emergency operation locations and provided to the public through information officers, via press releases, interviews, and internet content. This centralization of information and communication allows for maximum distribution of information on what is known, what can be expected and ways to stay safe during aftershocks and future events.

To help with analysis and explanation, earthquake data are combined with maps, aerial photography, satellite imagery, and other remotely sensed ground conditions that are available from State and national clearinghouses and with newly acquired imagery from specially tasked aircraft flights and satellites. In addition to immediate response and recovery efforts, all information is later used to better understand and predict impacts from future earthquake events to help mitigate potential future damage.

Introduction

Immediately following a damaging earthquake, a number of State and Federal emergency management agencies are responsible for handling and alleviating life threatening situations. They are assisted by a cadre of other agencies which have resources or capabilities that can be brought to bear on the situation. Part of this also is a group who more fully document the effects of the earthquake, who may be with State and Federal agencies, academia, or consulting firms. Shortly after the event some of this information is valuable for emergency response and long term recovery. Furthermore, it is of value for understanding the event and its effects from shaking and damage related to the Central United States conditions. Each group brings different products and capabilities for use during response and recovery.

Discussion

Following a damaging earthquake, the first information available is provided by the U.S. Geological Survey's seismograph networks. The information is automatically analyzed and then distributed within minutes by the U.S. Geological Survey (USGS). The USGS distributes this information through an email, cellular phone, and pager notification system. Anyone can sign up for receiving the data constrained by different magnitudes, location and hours of notification set by the user. Once this notification is sent, anyone who felt the event may use the website to fill out a questionnaire "Did You Feel It?" Thousands of people perform this task within minutes, producing the first map showing levels of shaking and potential damage indicated by the Intensity Scale. Following the deployment of the "Did You Feel It?" map, the USGS produces a ShakeMap which uses the seismograph instruments in the region to produce a map of ground motion and shaking intensity.

The Emergency Operations Center (EOC) in each State is opened when damage is suspected, assistance may be warranted, or a coordinated assessment may be required. The EOC handles policy (strategic) decisions. It is usually a fixed facility located within the State's capital city and has the ability to communicate to outside sources, view incident specific information and allocates resources. It is isolated from confusion, media and weather. The EOC has designated desks for 20 to 30 different agencies with resources or capabilities to assist in the response. The State geological survey occupies one of these positions to analyze and explain reported earthquake information and to assist in communicating these interpretations, safety messages, and aftershock expectations to both responders and the public through the designated public information officers. The EOC and its associated agencies are responsible for the assistance to citizens within their State, but unaffected States may be called on to assist in damaged States through the Emergency Management Assistance Compact.

If the event causes a large amount of damage, a field or forward operations center may be established by the emergency managers. This center is located close to the disaster area, can provide immediate on-scene response, and coordinates disaster site operations. Most State emergency management agencies and some other agencies such as State police are equipped with recreational or tractor trailer vehicles equipped for this field operation. For a damaging event, scientific and engineering investigators would be coming into the damage area to document perishable information. The State geological surveys, in cooperation with their State emergency managers, are responsible for setting up a technical clearinghouse near the forward operations center to coordinate and assist this influx of investigators. With smaller events and no forward operations center established, the technical clearinghouse may be located within the geological survey's main office where a coordination of a much smaller number of people can be easily handled. Utah has published their State geological survey's response plan (Solomon, 2001).

The technical clearinghouse would be part of a system where investigators would be credentialed at some location and their specialty coordinated with others so that critical areas and features will be fully documented. These investigators would also be responsible for providing regular status updates to the forward operations center for immediate response and relay critical information to the EOC. The technical clearinghouse is intended to relieve emergency managers from coordinating the investigators and provide emergency managers with an accounting of investigators' locations in case people need to be removed from certain areas because of life threatening circumstances. For a large earthquake, there will be investigators who specialize in liquefaction, landslides, fault rupture, lateral spreading, societal impacts, infrastructure damage, bridge performance, seismic retrofit performance, structural engineering, deployment of portable seismographs (Bodin and others, 2003), and so forth. Short reports from the California Geological Survey on their clearinghouse activities for the Loma Prieta and Northridge earthquakes can be found in Streitz and others (1990), and Nathe (1999), respectively.

In addition to the investigator coordination role, the technical clearinghouse would also be staffed with geographic information system (GIS) specialists and resources to track, summarize, and display documented damage on various maps. Other State specialists include interpreters of remotely gathered information from satellites through the International Charter which can be tasked to gather imagery during disasters and from high altitude flights which could be tasked through State and Federal agencies.

The Central United States geologic conditions which allow ground motions to travel a much farther distance than Western United States, results in more than one State responding to damage within their State boundaries from even a moderate earthquake. An example is the April 18, 2008, Mt. Carmel 5.4 magnitude earthquake which caused damage in three States and was felt in 28 States and Canada. The Central United States Earthquake Consortium (CUSEC) State Geologists along with CUSEC, CERI, and USGS are working to establish a regional technical clearinghouse run by CERI/USGS in Tennessee. This regional clearinghouse would collect information from the individual State technical clearinghouses to develop a regional perspective required for the Federal response plan (Holzer and others, 2003).

Conclusion

Damaging earthquakes in the Central United States present unique emergency responses as compared to the earthquakes in the Western United States since the geologic conditions allow damaging ground motions to travel greater distances causing damage in multiple States even for moderate earthquakes such as the 5.4 magnitude event of April 18, 2008. The State and Federal agencies responsible for handling or alleviating life threatening situations following damaging earthquakes continue to develop and coordinate response plans for this multistate response.

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Highway Bridge Performance During the May 12, 2008, M7.9 Wenchuan Earthquake in China

By Genda Chen

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Conference Abstract

A five-member U.S. reconnaissance team (Dr. Genda Chen, Dr. Youssef Hashash, Mr. Curtis Holub, Mr. Mark Yashinsky, and Dr. Phillip Yen) visited China on July 20–24, 2008, to inspect 14 highway bridges that were affected by the May 12, 2008, Wenchuan earthquake in Sichuan Province. In this paper, surface features of the seismic fault rupture near two bridge sites, representative bridge damage scenarios, and main lessons learned from the earthquake are documented and discussed.

Post-Conference Paper

Highway Bridge Performance During the May 12, 2008, M7.9 Wenchuan Earthquake of China

By Genda Chen

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Abstract

A five-member U.S. reconnaissance team (Dr. Genda Chen, Dr. Youssef Hashash, Mr. Curtis Holub, Mr. Mark Yashinsky, and Dr. Phillip Yen) visited China on July 20–24, 2008, to inspect 14 highway bridges that were affected by the May 12, 2008, Wenchuan earthquake in Sichuan Province. In this paper, surface features of the seismic fault rupture near two bridge sites, representative bridge damage scenarios, and main lessons learnt from the earthquake are documented and discussed.

Introduction

At 06:28:01 (UTC) on May 12, 2008, an M7.9 earthquake hit the Wenchuan County in Sichuan Province, China. The Wenchuan earthquake and several strong aftershocks resulted in massive landslides and rock falls. They damaged more than 1,000 bridges, approximately 20 of which had to be replaced. Massive landslides covered or undermined the roads, making it difficult to bring in equipment and supplies during the earthquake evacuation and response. These events caused approximately 70,000 fatalities and economic loss of more than $110 billion in U.S. dollars.

The Wenchuan earthquake occurred in the Longmen-Shan thrust zone, 10 km beneath the earth's surface. Its epicenter is located at 30.989°N and 103.329°E near a town called Yingxiu in Wenchuan County, Sichuan Province. The highest recorded peak ground acceleration is approximately 0.65 g. Within the first three months after the main shock, at least 35 after-shocks with magnitudes equal to or greater than M5.0 were recorded with the strongest aftershock of M6.4. The Longmen-Shan thrust zone was formed by the Eastern Tibetan Plateau pushing against the Sichuan Basin. The thrust zone has three faults: the front fault (Guanxian-Jiangyu-Guangyuan), the center fault (Yingxiu-Beichuan-Chaba-Linjueshi), and the back fault (Wenchuan-Maoxian-Qingchuan). Based on the distribution of aftershocks, approximately 300 km of the faults was estimated to have ruptured, breaking the ground surface along the Yingxiu-Beichuan segment of the center fault (210 km) and the Guanxia-Jiangyu segment of the front fault (70 km). The highest vertical fault displacements measured were more than 5 m.

Bridges Near the Earthquake Fault

Structures Near the Epicenter

The surface rupture of the center fault in the Longmen-Shan fault zone was observed in Yingxiu. As illustrated in figure 1, the thrust fault appeared to cross the Ming River at a right angle. The earthquake left behind a distinct dislocation on the riverbed at the northeast (NE) end of the surface rupture. The northwest (NW) side of the fault on the upstream of the river moves upward against the southeast (SE) side of the fault. The fact that one deck panel along the expressway elevated viaduct was still supported by one pier in figure 1 indicated the sudden push by a near-field pulsing effect.

Over the Ming River and approximately 500 meters north (upstream) of the fault is the Mingjiang Bridge, as shown in figure 2*A*. The bridge is a T-girder structure with two-column bents that are supported on pile shafts. It had some damage because of a landslide at the east span. As a result, a Bailey bridge was built over the east span to carry vehicles. The bridge structure is nearly parallel to the fault line. In comparison with the nearby elevated viaduct (fig. 2*B*), which is perpendicular to the fault line, the Mingjiang Bridge suffered considerably less damage because of the near-field directivity effect of the earthquake fault.

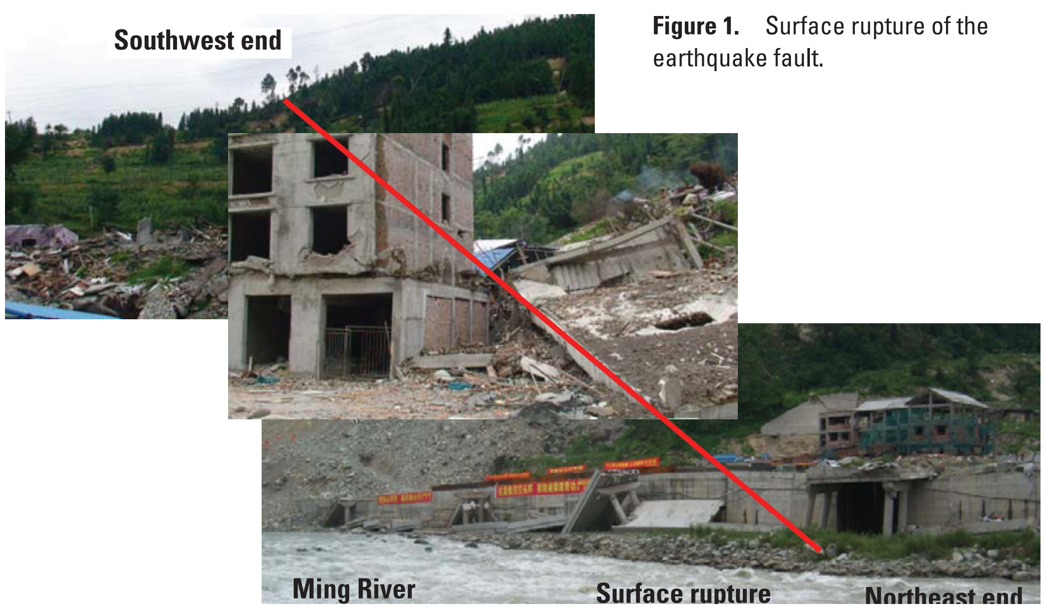

Figure 1. Surface rupture of the earthquake fault.

Figure 2. Mingjiang Bridge versus viaduct near the epicenter in Yinxiu Town.

On the other side of the Ming River was a five-story building with a construction joint between two similar parts as illustrated in figure 1. The right side of the building was completely collapsed while the left side of the building lost the second story and suffered structural damage in walls. As shown in figure 1, a sudden change was also evidenced on the slope of the mountain behind the building. A closer examination at the old Dujiangyan-Wenchuan highway in front of the building indicated that the vertical dislocation was approximately 1.5 m as illustrated in figure 3.

Structures Away from the Epicenter

At the Xiaoyudong Bridge (31.1859°N and 103.7677°E) between the front and center faults in the Longmen-Shan fault zone, surface rupture was also observed as shown in figure 4 (*http://www.uky.edu/KGS/geologichazards/Sichuan_Earthquake.pdf*). The vertical offset was more than 1 m. The highest peak ground acceleration of 0.65 g recorded during the Wenchuan earthquake was actually taken from somewhere northeast but close to the Xiaoyudong Bridge.

Built in the 1980s, Xiaoyudong Bridge was a four-span reinforced concrete (RC) arch structure with long approaches, supported on two abutments and three intermediate bents. Each bent consisted of one cap beam and two rectangular columns; it was supported on two drilled shaft foundations of 2 m each in diameter. The bridge deck of each span was supported by five planar structures of 40 m long, each being an arch strengthened with two struts. The arch and struts were both supported on the pile cap of drilled shafts. The bridge deck is integrally cast with the top of strut and arch but seated at the bent caps and abutments. Expansion joints exist at each abutment and bent.

The two spans on the west side of the bridge collapsed and the easternmost span were severely damaged as shown in figure 5. The remaining span suffered little damage. It can be seen from figure 5 that Bent 2 is located in the middle of the river with the longest pile shafts exposed above the ground. Bent 2 was significantly tilted while the other intermediate bents appear to have little rotation. The difference in the stiffness of various bents most likely contributed to the collapse of two western spans. Under severe shaking, Bent 2 rotated, resulting in unseating of the two spans. The bent cap was approximately 850 mm across; the seat length of each girder was approximately 300 mm, which is limited for strong shaking at the bridge site.

The easternmost span also suffered significant damage. As shown in figure 6, shear failures were observed on the top end of the struts and on the bottom end of the arches. The shear key on the east abutment was damaged. At the top end,

Figure 3. Surface rupture along the Old Highway near the collapsed building.

Figure 4. Surface rupture at Xiaoyudong Bridge site (*http://www.uky.edu/KGS/geologichazards/Sichuan_Earthquake.pdf*).

Figure 5. Overview of the damaged Xiaoyudao Arch bridge.

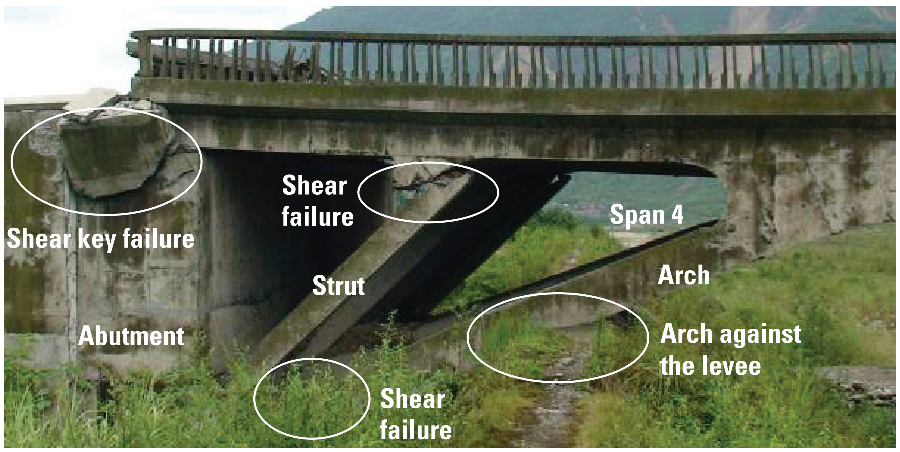

Figure 6. Damage in the easternmost span.

each strut seems to be reinforced with 15 #25 bars (metric unit). Some of them were fractured.

The damage scenario to the easternmost span is likely caused by the surface fault near the east abutment as shown in figure 4. When the hanging wall of the thrust fault moved up right relative to the foot wall that supported the east abutment, the levee began to bear on the arches and added significant shear forces and bending moments especially at the east ends of the arches. Designed for axial forces, the arches failed in shear at their east ends. The top end of the arches remained intact due mainly to its larger section. Because of the shear failure in arches, the east span deflected downward substantially, as evidenced in figure 6, and added more loads to the strut, resulting in its shear failure as well. At the same time, Span 4 pushed toward Bent 4 and caused flexural cracks at the pile shaft.

Other Representative Damages

Bridge Span Loss

Near the Nanba Town, a 10-span river crossing (on a 10° skew) was under construction during the earthquake, as shown in figure 7. Each 6 m long span was simply supported on two-column bents and seat-type abutments with 560 mm seats. As shown in figure 8, each span consisted of eight precast box girders with a cross section of 1,067 mm by 1,520 mm. Each girder was supported on two 200 mm round elastomeric bearings at each end. The girders were in place but the concrete deck had not yet been poured at the time of the earthquake as seen from figure 8.

As shown in figures 7 and 8, most of the box girders of the new bridge were dropped into the river and the two-column bents were distorted. The edge box girders were transversely displaced by approximately 760 mm. The extensive damage in the 10-span bridge likely resulted from several factors: the deck had not been poured, no transverse bracing or shear key was used, and girders were slightly skewed. Many bents were leaning or distorted with no visible damage above the waterline.

Miaozhiping Highway from Dujiangyan to Wenchuan was also under construction during the earthquake. The highway was scheduled to open in October, 2008. The bridge of approximately 1.4 km long consisted of three segments: a southeast (SE) approach span, a main span, and a northwest (NW) approach span, as illustrated in figure 9. The SE approach span was a two-span, RC girder structure with 50 m span length each. The bridge deck was supported on five RC girders and two-column bents with several cross struts. The main bridge was a continuous, non-prismatic, three-span structure supported on two intermediate wall piers with 125 m, 220 m, and 125 m length, respectively. The superstructure was a single-cell box girder structure. The depth of each girder varied approximately from 1.5 m to 4.5 m. The NW approach span had three segments of 250 m, 250 m, and 100 m, respectively. Each of the two longer segments had five spans of 50 m

Figure 7. Damage scenario of the 10-span bridge under construction during the earthquake.

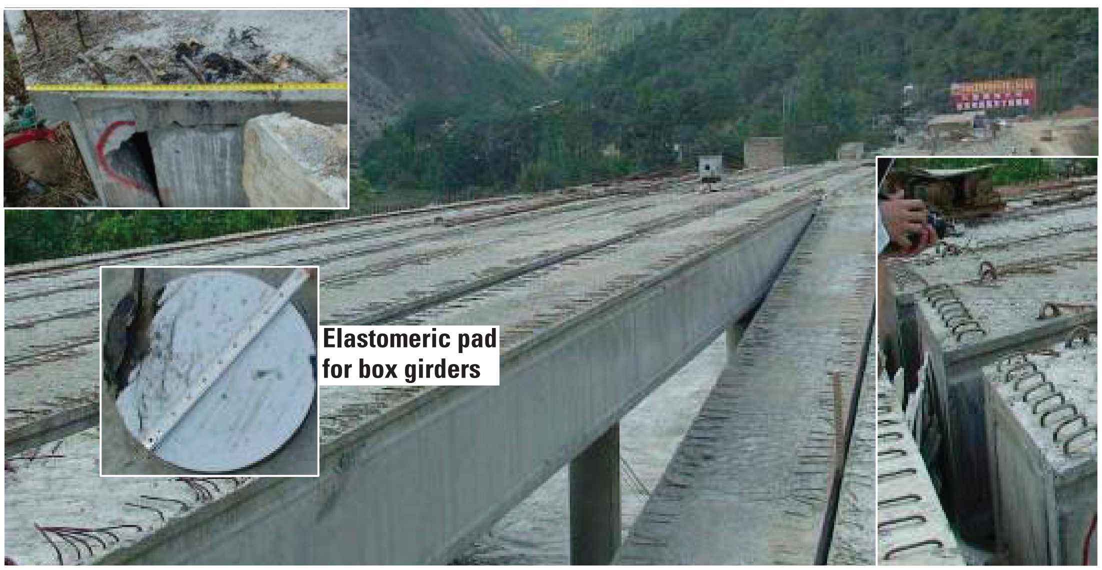

Figure 8. Damage to the 10-span bridge under construction.

Figure 9. Overview of the Miaozhiping bridge.

long, supporting 10 RC girders. The shorter segment had two spans of 50 m each.

All girders of the Miaozhiping Bridge were simply supported on the bents for dead load but bridge decks were continuous for live load. The bents were as tall as 105 m. In the main span of the bridge, bents were 40 m deep into water in the Zidingdu Reservoir of the Dujiangyan Dam. Expansion joints were used between the parts and between the approach and main bridge.

The most severe damage was to the end span of a five-span T-girder segment that became unseated at the expansion joint end, fractured in the continuous deck at the other end because of gravity load, and fell off the supporting bent caps during the earthquake. The bent seats were approximately 300 mm in length but the bridge experienced at least 500 mm of longitudinal movement because of earthquake shaking. Since the columns of each bent were approximately 105 m tall, the accumulated displacement at the bent cap was likely substantial during the earthquake.

Column Shear Cracks

Mianyang Airport Viaduct is a "U" shaped structure built in 2001. The middle of the "U" shaped structure is a double deck system of the airport terminal. Two approaches (NW and SE) are connected to the upper level of the airport. They are supported on two-column bents as shown in figure 10.

The SE approach consists of a five-span structure supported on columns of varying heights. The five-span structure is continuous with expansion joints at both ends. The diameter of the upper portion of the columns (approximately 1.0 m) is smaller than that of the lower portion (approximately 1.5 m). The columns have a smooth #5 (metric) spiral spaced at 15 cm and 32 cm - #29 for longitudinal reinforcement. The NW approach also has five spans. They are similar to those on the SE approach except that the lower portion of the tallest circular columns at Bent 5 is connected by a concrete wall as shown in figure 10. The concrete wall makes Bent 5 much stiffer than its adjacent bents.

The column damage at Bent 5 of NW approach likely resulted from several factors: large gravels used in the concrete mix (approximately 100 mm), loose tie bars, and the relatively rigid wall effect that leads to an irregular stiffness distribution. Signs of torsion on cracked columns resulting from asymmetry in stiffness of the structure most likely caused the different levels of shear damage in two columns at Bent 5. The SE approach structure had minor flexural cracks at the lower portion of the columns at Bent 4.

Conclusions

The May 12, 2008, Wenchuan earthquake will have potential effect on China's seismic hazard evaluation near known faults and bridge design in earthquake areas. Such an effort would ensure that China could rely on its highway infrastructure during the frequent earthquakes that strike this and other regions. Based on the field reconnaissance, the following observations can be made:

1. The collapse of most arch and girder bridges is associated with surface rupturing of the faults in the Longmen-Shan Thrust Zone. A significant portion of roadways and bridges were pushed away or buried by overwhelming landslides in the mountainous terrain of steep slopes.

2. The representative damage types in bridge superstructure include unseating of girders, longitudinal and transverse offset of decks, pounding at expansion joints, and shear key failure.

3. The bearings of several girder bridges were either crushed or displaced substantially. The substructure and foundation of bridges were subjected to shear and flexural

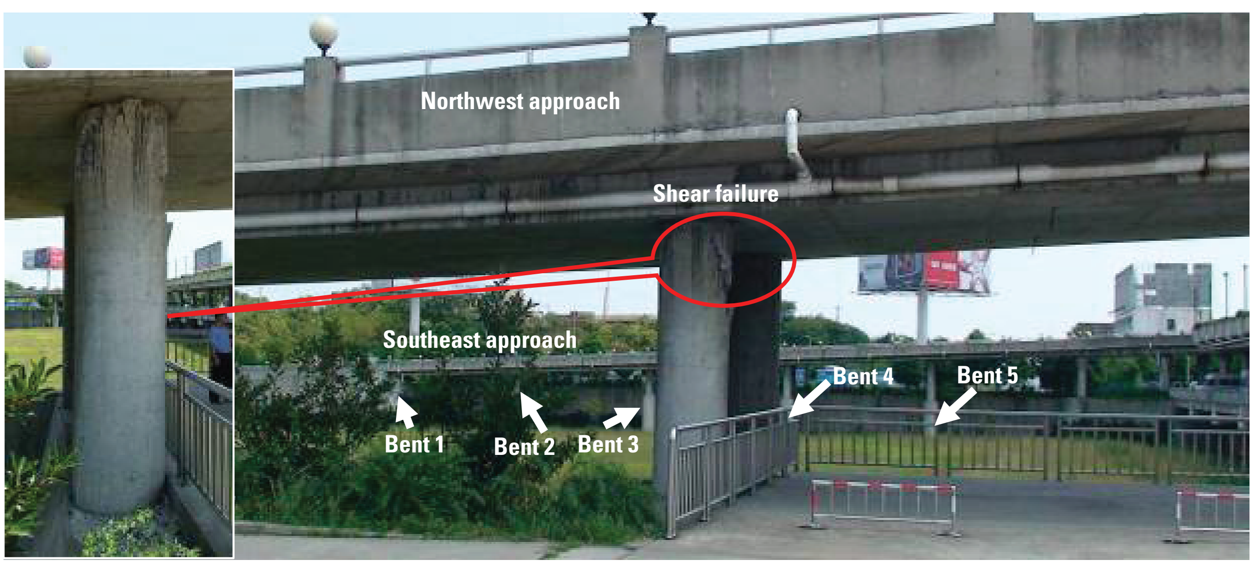

Figure 10. Overview of the viaduct structure.

cracks, concrete spalling, stirrup rupture, excessive displacement, and loss of stability.

4. More damage occurred in simply-supported bridges in comparison with continuous spans. The directivity effects on the bridges near the earthquake epicenter were evidenced during the earthquake.

Presentation Titles, Abstracts, and Papers for Thursday, August 14, 2008—Track 1: Science, Maps, and Engineering

The National Map: Status of National Geospatial Base Data in the Central United States

By Kari Craun

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Conference Abstract

In the early 1990s, the U.S. Geological Survey (USGS) completed first-time topographic mapping of the conterminous United States at a nominal scale of 1:24,000. Since the completion of primary-scale mapping for the United States, the agency's base mapping program has focused on development of digital mapping products, in many cases derived from the information contained in the primary scale topographic maps. As the average age of the information contained on the topographic maps nears a quarter of a century, the USGS is focused on developing *The National Map*, or nationally consistent, seamless base topographic data to create the next generation of topographic maps and derived products. Conceptually, *The National Map* will provide the programmatic and technological infrastructure for bringing information from multiple sources together into a seamless, consistent, current set of base geographic data for the nation.

In 2008, the USGS and its partners nearly have completed public domain, digital coverage of the Nation for primary-scale or equivalent base geographic data for eight themes. These themes include orthoimagery, elevation, hydrography, geographic names, land use/land cover, structures, transportation, and boundaries. The currency, quality, and consistency of these data for the Central United States varies by geographic area based on a number of criteria, including data availability from partners and historical funding availability from appropriated and reimbursable sources to improve the data. One goal of *The National Map* is to work with partners to improve and maintain these data.

USGS-State Partnerships and the Future of Standard Quadrangle Maps

By Laurence R. Moore

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Conference Abstract

The 1:24,000-scale topographic quadrangle was the primary product of the U.S. Geological Survey's (USGS) National Mapping Program from 1947 to 1992. This map series includes about 54,000 map sheets for the conterminous United States, and is the only uniform map series ever produced that covers this area at such a large scale.

This map series partially was revised under several programs, starting as early as 1968, but these programs were not adequate to keep the series current. Through the 1990s the emphasis of the USGS mapping program shifted away from topographic maps and toward more specialized digital data products. Topographic map revision dropped off rapidly after 1999, and stopped completely by 2004.

Since 2001, emergency-response and homeland security requirements have revived the question of whether a standard national topographic series is needed. Emergencies such as Hurricane Katrina in 2005 and California wildfires in 2007–08 demonstrated that familiar maps are important to first responders. Maps that have a standard scale, extent, and grids help reduce confusion and save time in emergencies.

Traditional maps are designed to allow the human brain to quickly process large amounts of information, and depend on artistic layout and design that cannot be fully automated. In spite of technical advances, creating a traditional, general-purpose topographic map is still expensive.

Although the content and layout of traditional topographic maps probably is still desirable, the preferred packaging and delivery of maps has changed. Digital image files are now desired by most users, but to be useful to the emergency-response community, these files must be easy to view and easy to print without specialized geographic information system expertise or software.

Post-Conference Paper

USGS Standard Quadrangle Maps for Emergency Response

By Laurence R. Moore

Abstract

The signature product of the U.S. national map series is the 7.5-minute topographic quadrangle. This series was completed in 1992 and few of its maps have been revised

since. Most maps in this series are cast on an outdated datum and do not contain a full-line Universal Transverse Mercator (UTM) grid, making them unsuitable for emergency response operations, even where the content is still current. Hurricane Katrina and other recent (2008) emergencies have revived the debate about whether or not traditional, printed maps are still important. The U.S. Geological Survey (USGS) is reviving 1:24,000-scale quadrangle maps by designing new products that are essentially image maps with linework and text enhancements. State and local agencies are interested in participating in the design and production of new quadrangle maps; a cooperative project with the State of Missouri to map part of the New Madrid Seismic Zone is in progress.

Introduction

National mapping programs have been a characteristic of nation-states since the mid-1700s. The national mapping program of the United States dates from the Jefferson administration and has been the responsibility of the USGS since 1879. In the 20th century, the signature product of this program was the 1:24,000-scale, 7.5-minute topographic quadrangle.

The original production history and the revision history of the 7.5-minute topographic series for the coterminous 48 States is shown in figure 1. The program began after World War II and peaked in the 1970s and 80s. The map series officially was declared complete in 1992.

Revision programs became significant starting in the 1960s. In the 1990s, several digital revision programs were attempted, with the objective of revising topographic maps quickly and cheaply. These programs did not meet their goals of high-quality maps at low cost, and by 2004 the USGS had stopped publishing topographic maps except for reprints to replace shelf stock.

Discussion

Following the completion of the 7.5-minute topographic map series, the USGS mapping program turned its attention to other types of geospatial data, particularly four national digital datasets: the National Hydrography Dataset, the National Orthoimage Database, the National Elevation Database, and the Geographic Names Information System. At the same time, budgets and staffing of the mapping program were shrinking (fig. 2). In the 1960s, the topographic mapping program employed around 2,000 people; by 2005, that number had been reduced to about 250.

One reason for this shift in emphasis and resources is that traditional topographic mapping is expensive. The cost of the original 7.5-minute series, expressed in 2007 dollars, was on the close order of $1,000 per square mile, or about $3 billion to map the coterminous 48 States. Estimates based on the 1990s digital revision programs indicate that modern information technology might reduce this cost by an order of magnitude if the same maps were made today. Cost reduction to $100 per square mile is an improvement, but is still about $5,000 per quadrangle. Elapsed time also is considered a hidden cost. The clean, graceful appearance of a traditional map requires human craftsmanship, which is inherently slow.

The cost of traditional mapping, combined with the ready availability of other types of spatial data, call into question the need for traditional maps. The allocation of resources in most government mapping agencies, including the USGS, implies that this is a settled question; however, Hurricane Katrina and other recent emergencies have revived the debate.

The U.S. Senate's report (2006) on Hurricane Katrina said, "Officials from nearly every search-and-rescue agency told Committee staff that they lacked basic maps of the area. At one point, State and local officials tore maps out of telephone books, so that out-of-state search-and-rescue teams could have some sense of where they were going. However, high floodwaters in New Orleans hid street signs from view, complicating their efforts."

It seems reasonable to suppose that the rescuers referred to in this quote were not geographic information system (GIS) oriented; that when the power was out and the city was filling up with water, they wanted traditional paper maps, not digital spatial data. Telephone-book street maps are not appropriate for emergency response operations for many reasons, including the lack of standard scale and standard coordinate systems.

The search-and-rescue problem of accurately communicating location by voice radio or short text message was acute during Katrina. People trapped in their homes could call for help on cell phones, but could describe their location only by street address. As noted in the Senate report, street signs and house numbers were destroyed or under water, and many rescue crews were not familiar with the area. Converting addresses to geographic coordinates did not solve the problem because first responders had no common protocols for using coordinates.

The cartographic aspect of this problem is that most USGS 7.5-minute topographic quadrangles are published on the outdated North American Datum of 1927 (NAD 27), and most do not have full-line grids of the type needed for search-and-rescue operations (table 1). The need for maps with current content is important, but the need for maps on modern coordinate systems and with common grids is critical and urgent.

In the wake of World War II, the U.S. military designed the Military Grid Reference System (MGRS) to address the location problem. Recently, a civilian version of the MGRS, the U.S. National Grid (USNG), was adopted as a Federal Geographic Data Committee (FGDC) standard. This standard, and the direction of OMB Circular A-16 and Executive Order 12906, made the USNG the official grid system of the Federal government; however, the USNG is not yet implemented in a national map series and is not familiar to most domestic emergency response organizations.

To address these issues, the USGS is now working on a new generation of quadrangle maps. These maps will not duplicate the 7.5-minute topographic map series, because current (2008) data sources do not easily support production

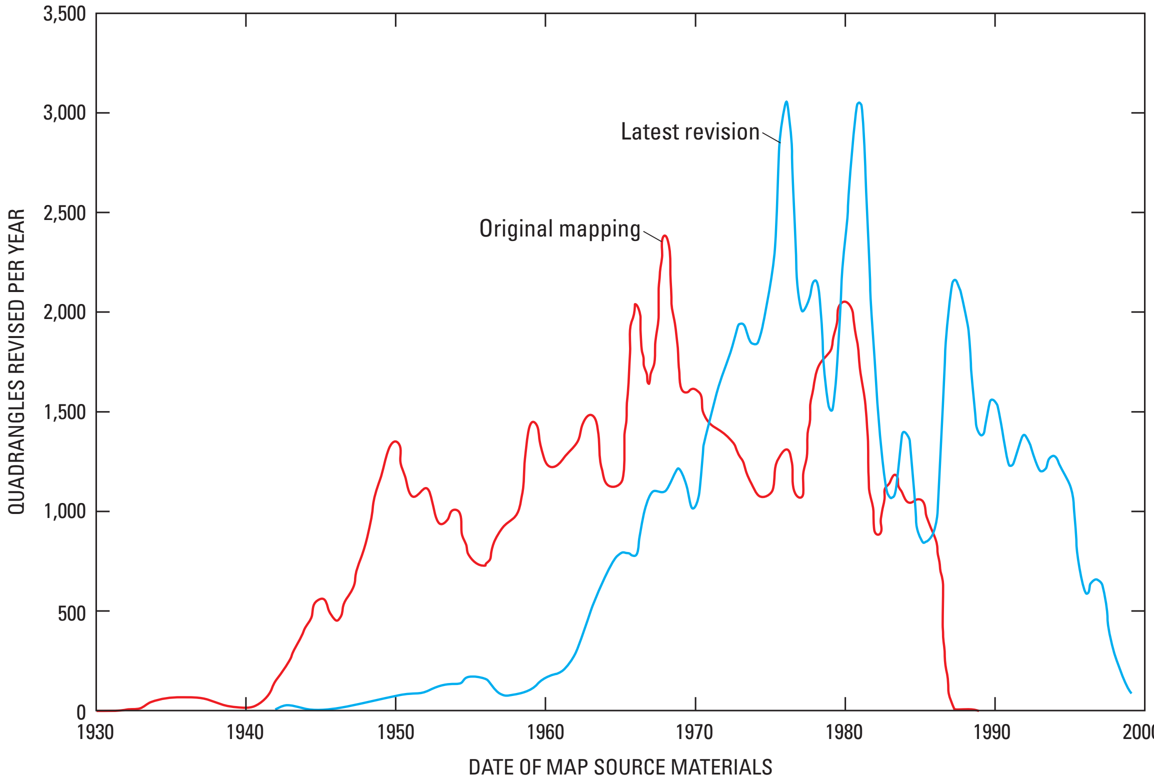

Figure 1. Currency of 7.5-minute topographic maps for the coterminous 48 States. The red line is the currency of the set of original printings (median = 1968), the blue line is the currency of the set of most recent revisions (median = 1979). About 54,000 quadrangles.

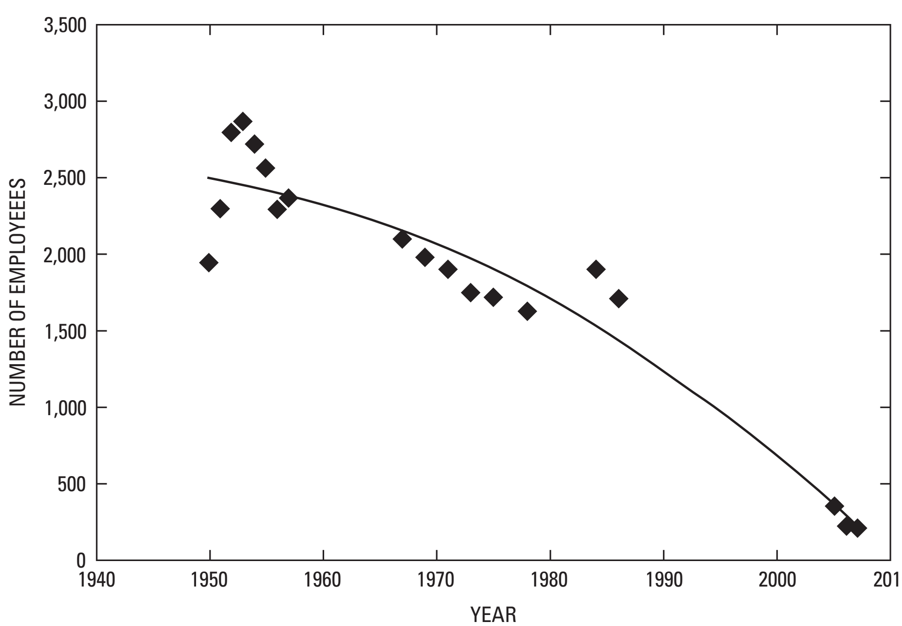

Figure 2. National Mapping Program Employees, selected years for which data are available.

Table 1. Universal Transverse Mercator (UTM) representation and datums of 7.5-minute quadrangles.

[UTM, Universal Transverse Mercator; NAD 27, North American Datum of 1927; NAD 83, North American Datum of 1983]

	NAD 27	NAD 83
UTM tick marks	29,320	1,467
Full UTM grid	13,014	371

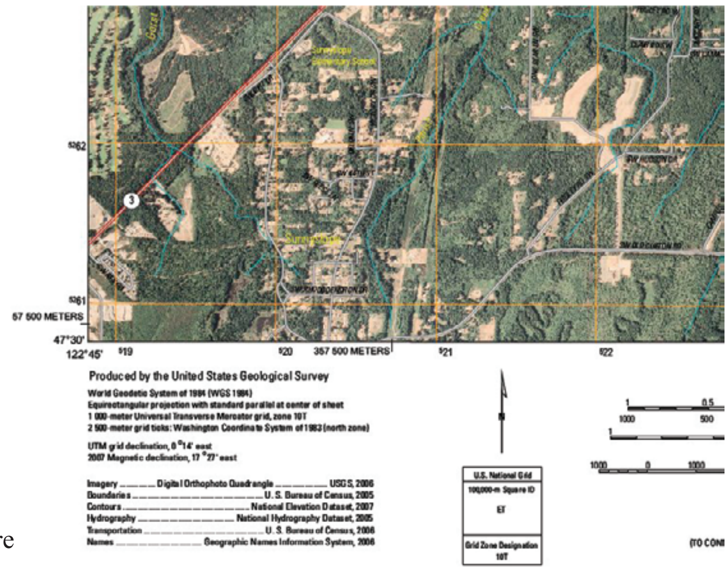

Figure 3. Detail of an image map quadrangle showing the image background, line and place enhancements, grid systems, and map margin.

of traditional topographic maps. In the near term, the core characteristics of these new maps will include:

- Static, printable images (as opposed to dynamic GIS data)
- Can be viewed and printed with normal office software and normal computer expertise
- Orthoimage background, enhanced with some map linework, point features, and place names
- Standard 7.5-minute extent
- 1:24,000 scale
- Traditional map collars
- NAD 83/WGS 84 datum
- Transverse Mercator projection
- Full 1,000-meter U.S. National Grid

The first two items in this list are addressed by using layered GeoPDF as the physical format of the product. GeoPDF is a proprietary format of TerraGo Technologies that adds georeferencing information to a standard Adobe Portable Data Format (PDF) file. Such a product is a softcopy analog of a traditional map, allowing map users to find coordinate locations and make simple measurements without specialized skills or software.

The third item in the list declares the product to be cartographically simple. It leverages the fact that high-quality orthoimagery is common, relatively cheap, and (thanks to Google and other online maps) is familiar to today's map users. The simplicity of map content means the product can be made quickly and, therefore, can be kept up to date with the most recent data available (fig. 3).

The packaging and presentation is traditional, even old-fashioned. The hypothesis is that familiar map forms have value to workers in stressful field conditions.

Because standardized quadrangle maps are valuable resources for search-and-rescue and emergency response, State and local governments have strong incentives to help create such maps. State and local agencies often own better GIS data than Federal agencies and are more familiar with ground conditions. Partnerships between the USGS and State and local agencies may assist with creating a new national map series. In Missouri, a partnership of this type has been formed between the Missouri Spatial Data Information Service (MSDIS) and the USGS. The two organizations are working on a pilot project of about 50 quadrangles in the New Madrid Seismic Zone in southeast Missouri. The USGS is providing standards and technical support; MSDIS is gathering the data and doing the actual work of making the maps.

Conclusion

Traditional topographic maps are still valued for many field operations, including search-and-rescue and emergency response. Though a national map series with the same look and content as the 7.5-minute topographic series may not be possible today, it is possible to produce relatively inexpensive large- and medium-scale quadrangle maps. Key characteristics of these maps include being cast on a standard coordinate system, having a standard scale, being easily viewable and plottable without advanced GIS or computer expertise, and having a full-line UTM grid conforming to the USNG standard.

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Data Sources and Development for the New Madrid Seismic Zone in Missouri

By Tim Haithcoat

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Conference Abstract

This presentation will outline the data development activities that the State of Missouri is conducting in collaboration with many partners within the New Madrid Seismic Zone. The talk will outline the parameters gathered to outline the data collection activity, the processes and activity currently underway, and the products and deliverables that will result from these activities to include new 7.5-minute quadrangle maps, structures data, map books, GeoPDF files, and other map or map-like information that the State is going to predeploy within this area.

New Data for a New Age

By Dean Gesch

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Conference Abstract

Geospatial data are a critical resource in planning for, responding to, and recovering from natural disasters. In particular, digital elevation data have many applications for natural disasters, including portrayal of topography on base maps, 3-D visualization of affected sites, hydrologic modeling, inventory of manmade structures, and vulnerability mapping. The U.S. Geological Survey's (USGS) National Elevation Dataset (NED) provides the best publicly available elevation data for the United States in a multi-resolution database derived from various sources, including existing topographic maps, photogrammetry, and remote sensing. High-accuracy, high-resolution elevation data derived from airborne lidar (light detection and ranging) surveys are currently being used to upgrade many areas in the NED. These data have proven useful in response to Hurricane Katrina and Hurricane Rita, including inundation modeling and studying storm surge dynamics. Derivative products from high-resolution lidar are being used to model susceptibility to debris flows in southern California wildfire areas. The high-resolution elevation data provide an important framework within which ground-based lidar survey data can be referenced. Because of the multitude of geospatial data applications that require highly accurate, up-to-date topographic surface measurements, the USGS is working with Federal, State, local, and industry partners to explore the concept of a national lidar survey so that all areas may benefit from the availability of high-quality elevation data and derivative products. The lessons learned from recent disaster events, especially Hurricane Katrina, demonstrate the high value in the ready availability of high-accuracy lidar elevation data in the NED immediately following a disaster event. The same benefits would be realized if high-quality elevation data were available for both planning and immediate response to a high-impact earthquake event in the Central United States.

The Land Use Portfolio Model: A GIS-based Decision Support System for Evaluating Seismic Risk Mitigation Policies

By Paul Hearn

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Conference Abstract

Policy decisions regarding the mitigation of natural hazards are made by Federal, State, and local government agencies, as well as by the private sector and individuals. Because resources are rarely sufficient to provide full protection from hazards, some compromise or tradeoff between safety and cost is necessary. The societal objective is to find a reasonable level of mitigation to reduce damage without incurring unacceptable expenses. While mitigation choices affect the vulnerability of specific locations, government policy implementation will have unanticipated consequences for urban areas that include negative and positive effects on property values. Individual risk preferences for loss reduction and mitigation choices are affected by these policies, (such as tax incentives, building codes, ordinances, and regulations). For this reason, determining the effectiveness of any one policy requires GIS-based regional risk assessments to evaluate the societal benefits and costs to a community.

The Land Use Portfolio Model (LUPM) is a GIS-based modeling, mapping, and risk communication tool designed to assist communities in understanding and reducing natural-hazards vulnerability and in making loss reduction investment decisions. Memphis, Tennessee was chosen as a test site to evaluate the usefulness of the model to local planning authorities, emergency managers, and businesses in evaluating the

economic consequences of alternative earthquake mitigation strategies.

The goal of this effort is to adapt the LUPM to develop a web-based tool for the quantitative policy analysis of improved construction standards for commercial and public property. The tool is designed to allow local managers and agency staff to quickly estimate the regional return on mitigation investment for a proposed level of risk reduction.

Probabilistic seismic hazards analysis (PSHA) is used to generate loss probability curves characterizing the vulnerability of private commercial and public buildings. Variable planning horizons are used to represent typical lifetimes of commercial and public buildings and infrastructure (50–75 years). Varying the planning period makes it possible to distinguish between the different private and public asset lifetimes and their sensitivities to risk, and to account for these differences in cost-benefit analyses. The model also allows for buildings to be removed from the calculations when they reach the end of their productive lifetimes, and for new buildings to be added based on a user-selected growth rate. Ultimately, the tool will allow planners to characterize the continuum of risks and mitigation costs for the entire range of possible earthquake magnitudes and planning horizons, and in this way better represent different policy options.

Post-Conference Paper

Application of the Land Use Portfolio Model for the Analysis of Long-term Earthquake Risk Mitigation Policy in the City of Memphis, and Shelby County, Tennessee

By P.P. Hearn, Jr.[3], R.L. Bernknopf[4], D. Strong[3], N. Luco[5], and E. Karaca[6]

Introduction

Earthquakes occurring near major population centers can have devastating consequences. Thanks to the substantial public and private investment in developing and implementing seismically resistant building codes in the United States, the loss of life during major earthquakes within the last several decades has been relatively small. However, U.S. cities in seismically active areas continue to be vulnerable to structural damage to buildings and infrastructure, indirect functional losses to critical facilities, economic disruption, and substantial decreases in the standard of living. State and local officials responsible for crafting policies to protect lives and infrastructure from natural hazards face a daunting task. Since the costs of mitigation make it impossible to afford complete protection, policy makers make tradeoffs between ensuring a level of protection and the accompanying costs to limit risk to an acceptable level for a portfolio of buildings in a community. These choices are made even more difficult by the inherent complexity of forecasting the timing and magnitude of seismic events, the resulting damages to buildings and infrastructure, and the level of protection and costs associated with alternative building codes. Furthermore, effective mitigation policies must also distinguish between the different planning horizons (effective lifetimes) associated with public and private assets. All of these factors must be taken into account when conducting a benefit-cost analysis of building standards for earthquake risks to a given building portfolio.

Traditional benefit-cost analysis usually is predicated on evaluating changes in individual welfare. This paper does not use this standard welfare economics framework because an individual decision about mitigation investments may not represent a social optimum. Instead it relies on a framework that assumes a community has an objective to limit its earthquake risk. Further, we assume that the inhabitants of a community are willing to pay a mitigation cost to achieve that objective. But, is the cost of implementing a particular standard cost effective in limiting the level of risk? To answer this question, policy makers must draw on knowledge from multiple fields of expertise, including geology, seismology, engineering, statistics, computer science, geographic information systems (GIS) technology, economics, and sociology. While risk-related work in all of these fields has become increasingly sophisticated, integrated and non-proprietary efforts combining physical science, engineering, information technology and social science are a relatively recent phenomenon (Bernknopf and others, 2001; Bernknopf and others, 2007; Jones and others, 2007; Sherrouse and others, 2008).

Because of the relative infrequency of earthquakes and the consequent lack of data, models and simulation studies are usually required. An increasingly active field is the integration of data and models in Decision Support Systems (DSS) that allow users to quickly evaluate and compare different mitigation scenarios. The USGS Land Use Portfolio Model (LUPM) is a GIS-based modeling, mapping, and risk communication tool designed to assist communities in understanding and reducing natural-hazards vulnerability and in making loss reduction investment decisions (Bernknopf and others, 2001). The LUPM has been tested in both Squamish, British Columbia, and Watsonville, Calif. (Bernknopf and others, 2001, Wein and others, 2006). Memphis, Tennessee, was chosen as another test site to evaluate the usefulness of the LUPM to local planning authorities, emergency managers, and businesses in evaluating the economic consequences of alternative earthquake mitigation strategies.

This paper describes the technical approach taken to adapt the LUPM to a web-based and GIS-enabled DSS for use by decision makers in Memphis, Tennessee, in evaluating alternative earthquake risk mitigation strategies. The DSS is intended to provide: 1) quantitative policy analysis of

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construction standards for earthquake risk mitigation for commercial and public property for long planning periods by estimating the expected return on investment for a proposed level of safety, and 2) estimation of the net benefits (losses avoided less mitigation costs) of alternative building standards as a regional policy for earthquake risk mitigation.

Study Area

The city of Memphis and surrounding Shelby County lie within the New Madrid Seismic Zone, which extends from northeast Arkansas, through southeast Missouri, western Tennessee, and western Kentucky to southern Illinois. Historically, this area has been the site of some of the largest earthquakes in North America (fig. 1). Earthquakes with magnitudes greater than 7.0 occurred in this area between 1811 and 1812. The estimated recurrence interval of a moment magnitude 7.0 or larger earthquake is approximately 500 years (Gomberg and Schweig, 2002). Metropolitan Memphis has a dense urban population near faults capable of producing major earthquakes and has a 25–40 percent probability of being affected by a magnitude 6.0 or greater earthquake in the next 50 years. Furthermore, the Central United States has a relatively low regional attenuation. In other words, seismic energy can travel faster than in the West and thus an earthquake can do damage over a greater area than for the same magnitude earthquake in the Western United States.

Earthquake Hazard

Considering the potential for earthquakes and the low regional attenuation mentioned in the preceding section, the USGS has developed so-called urban seismic hazard maps for Memphis/Shelby County, Tennessee (*http://earthquake.usgs.gov/regional/ceus/products/grid_download.php*). Analogous but less region-specific hazard maps have also been developed by the USGS for the entire United States and its territories (*http://earthquake.usgs.gov/hazmaps*). These maps are interpolated from seismic hazard curves that report the mean annual frequencies of exceedance (roughly equal to annual exceedance probabilities) computed via probabilistic seismic hazard analysis (PSHA; Cornell, 1968) for each in a range of ground shaking intensity levels. As explained in a later section, the hazard curves for Memphis are used in calculating the risk analysis results that are in turn used by the LUPM to analyze risk mitigation policy options.

Building Inventory

Using the built-on and vacant land parcels in Shelby County and the existing building inventory

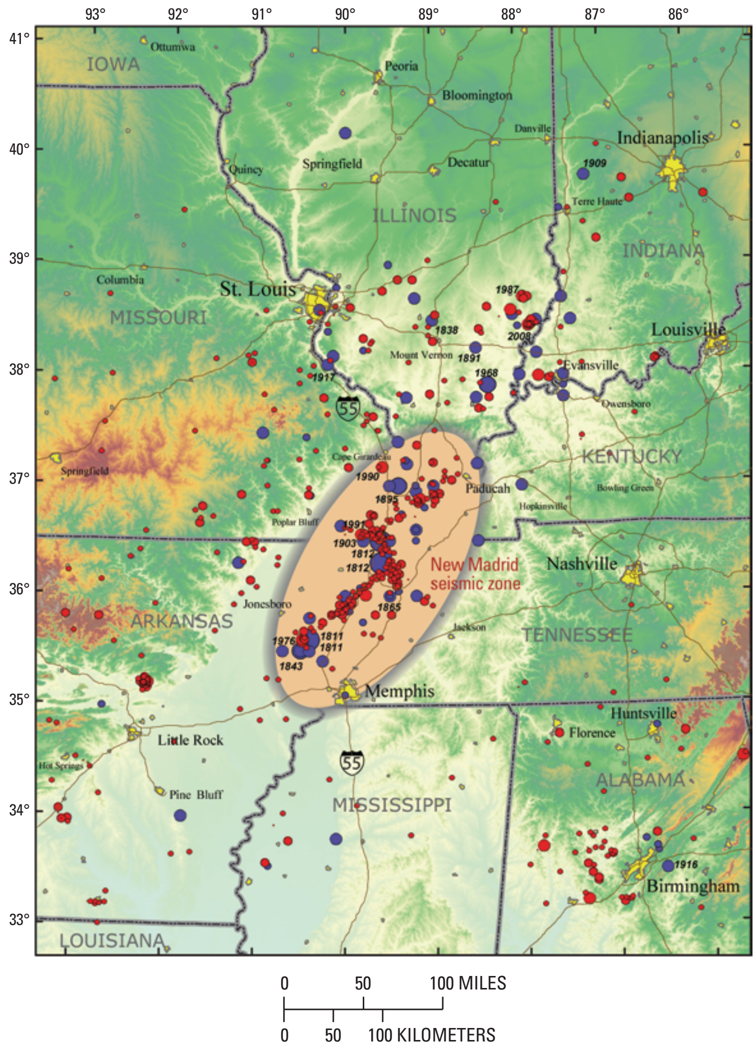

Figure 1. Topographic map of the New Madrid Seismic Zone showing earthquakes greater than magnitude 2.5 (circles) of the Central United States. Red circles are earthquakes that occurred after 1972 (U.S. Geological Survey (USGS) Preliminary Determination of Epicenters (PDE) catalog). Blue circles are earthquakes that occurred before 1973 (USGS PDE and historical catalog). Larger earthquakes are represented by larger circles. Yellow patches show urban areas with populations greater than 10,000. (From Frankel and others, 2009).

developed by French and Muthukumar (2006), a hypothetical inventory of future commercial buildings on vacant parcels was simulated in a time series of investments. The zoning assigned to each of the existing buildings in the inventory was determined using parcel data provided by Shelby County. Then, for each of the vacant parcels, possible buildings that could be built on the parcel based on existing buildings with the same zoning code were simulated. For a given vacant parcel, the assigned building type was chosen by selecting it at random from the 50 closest existing buildings with the same zoning code as the vacant parcel. A check of whether the randomly selected building fits in the area of the vacant parcel was performed, and if it did not another building was randomly selected. Only one building was selected for each vacant parcel.

The properties of each building include number of stories, structure type, occupancy type, replacement cost, contents value, total value (that is, replacement cost plus contents value), zoning, and land value. All of the properties of the simulated buildings are taken to be the same as those of the randomly-selected existing building except the replacement cost. The building inventory developed by French and Muthukumar (2006) has replacement costs assigned to the existing buildings, but their variability is surprisingly large, so alternatively replacement costs were assigned using unit cost data from HAZUS (Federal Emergency Management Agency, 2003) and the square footage of the buildings. As a first approximation, values of building contents were not considered in this study.

The vacant parcels considered for projecting future commercial or industrial buildings are limited to the following zoning codes: light or heavy industry; planned, local, or highway commercial; central business; and limited or general office. The total number of vacant parcels within these zoning codes is 5,145. Depending on the selected growth rate, all the parcels in the inventory may or may not be filled. Agricultural parcels are not included even though some of the commercial or industrial buildings in the building inventory used are located on existing agricultural parcels. 4,423 of the 5,145 simulated buildings are classified as commercial/industrial.

Building Fragility and Vulnerability

Building fragility curves relate ground motion intensity (for example, spectral acceleration, S_a) to the probability of exceeding various building damage states or performance levels. Building vulnerability curves relate ground motion intensity to the expected loss in value because of structural damage. Both are integral components of seismic risk assessment tools or studies. These curves are used with building inventory and ground motion intensity estimates in deterministic scenario earthquake studies, or in probabilistic risk assessments like the one described in this paper that consider all possible seismic events. The results of the seismic risk assessment may be used for evaluation of different seismic design codes, retrofit or mitigation options, and for emergency and recovery planning.

Building fragility and vulnerability curves may be developed either for a specific building with known structural and nonstructural characteristics, or for a generic building type representing a group of buildings with similar seismic design properties and configurations (Porter and others, 2001). In the former approach, building-specific fragility curves can be derived through rigorous analysis of the building response under various ground shaking levels. In the latter approach, buildings are categorized based on general characteristics such as their lateral force resisting system, height, and design code, and generic fragility curves are developed using generic structural properties and/or based on past performance of buildings. While building-specific fragility curves provide more accurate information for a particular structure, they are computationally intensive to develop and their applicability to nominally similar buildings is questionable. On the other hand, while being less accurate or even inapplicable for a particular building, generic fragility curves can be relatively simple to develop for a large number of building types, which allows for probabilistic seismic risk assessment on a regional level. For the mitigation policy analysis tool described in this paper, we focus on generic fragility and vulnerability curves.

The fragility and vulnerability curves for generic building used for the mitigation policy analysis tool described in this paper were computed by Karaca and Luco (2008; 2009) using the building capacity (or pushover) curves and related building parameters provided in HAZUS (Federal Emergency Management Agency, 2003). The fragility curves were developed for all of the 36 building types and 4 seismic design levels considered in HAZUS, and also for each in a range of different design ground motion intensities in order to compute fragility curves for each of five design code options considered. The resulting building fragility curves were then used to derive vulnerability curves for all combinations of building types and occupancy classes considered in HAZUS (fig. 2). Since the derived fragility and vulnerability curves are all conditioned on S_a, they can be combined with available seismic hazard data like that for Memphis in a seismic risk assessment study.

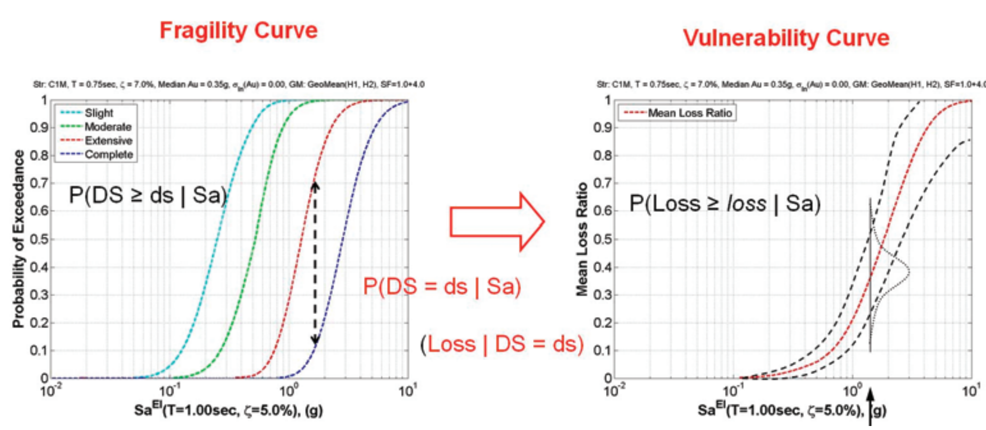

Figure 2. Structural fragility curves were combined with loss-for-a-given-damage-state estimates to produce vulnerability curves for generic building types and each of the five building code options.

Expected Losses

Expected losses per annum (equation 1) have been computed by Karaca and others, (2009) for each individual building and the five design code options by coupling the building vulnerability curves with the seismic hazard curves, all of which are described above:

$$E[L] = \sum_a E[L \mid GM = a] P[GM = a] \qquad (1)$$

where

E[L]	is the expected annual loss for an individual building with a given design option at a given location,
E[L|GM=a]	is the expected loss under a given ground motion level approximately equal to *a*, and
P[GM=a]	is the probability of the ground motion.

From these calculations, a database was populated for the DSS which contains loss estimates at the 5,145 separate vacant parcels and for the five different design code options. Full probability distributions of losses per annum have also been calculated by Karaca and Luco, but those results have not yet been incorporated into the LUPM.

Benefit-Cost Model

For benefit-cost analysis and planning, a community can utilize a net present value criterion[7] for investment decisions that incorporates the life cycle of the investment in, for example, a stricter building code (that is, the planning time period for investment), the expected losses avoided from code implementation (benefit of one code relative to another), and a one-time investment cost in mitigation as the basis for evaluating the return on investment for a loss-reduction policy. Our objective is to provide an analysis tool that incorporates a probabilistic hazard assessment to characterize the expected return on investment and decision risk associated with choosing a regional mitigation strategy. This type of analysis approach to policy evaluation can be applied in an investment portfolio risk assessment to compare alternative earthquake building codes. Different building codes may have different provisions and subsequent costs, and may perform differently under extreme conditions. The coupling of the probabilistic seismic hazard assessment with a portfolio investment approach will provide a clearly defined set of options and choices for decision makers. The first step in this type of benefit-cost analysis under uncertainty (Graham, 1981) estimates the net present value of a range of loss-reduction mitigation strategies, in this case of stricter building codes, as follows. First, the user selects the input variables, which include:

- planning horizon (time period in which the estimate is calculated),
- growth rate (number of new buildings built each year),
- discount rate[8], and
- mitigation cost (in this case relative to the current building code).

The net present value of the mitigation choice for a building at location *k* is based on both the mitigation cost and the expected annual losses avoided by the stricter construction standard or building code. The net benefit (expected losses avoided) for a single new building in each year after it is added to the building inventory is calculated using equation 2:

$$b_k = E\left[L\right]_{k,current} - E\left[L\right]_{k,proposed} \qquad (2)$$

where

$E[L]_{k,current}$ and $E[L]_{k,proposed}$ are the expected annual losses for the current and proposed (that is, stricter) building codes, respectively, which are computed as explained in the preceding section.

Next, the present value of the mitigation strategy for the building is calculated using equation 3:

$$PV_k = \sum_{t=t_k}^{T} \frac{b_k}{(1+r)^t} - \frac{c_k}{(1+r)^t} \qquad (3)$$

where

$PV_k =$	Present value of mitigation for building *k* in year zero, net of mitigation cost
$c_k =$	mitigation cost, that is, the increase in construction costs as a result of proposed stricter building code
$T =$	Planning horizon in years
$r =$	discount rate
$t_k =$	Year that building *k* is added to the building inventory (zero-based)

Next, to obtain a regional estimate of the benefit of implementing a loss-reduction policy, *B*, we sum for all the locations affected by the policy for the region (equation 4) (that is, where new buildings were constructed during the planning horizon):

$$B = \sum_{k=1}^{K} PV_k \qquad (4)$$

[7]Present value is the value on a given date of a future payment or series of future payments, discounted to reflect the time value of money and other factors such as investment risk. Present value calculations are widely used in business and economics to provide a means to compare cash flows at different times on a meaningful “like to like” basis. Net present value is defined as the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects.

[8]The discount rate is the interest rate used to discount the value of an investment in an asset from what this investment would have been worth if invested to earn interest for the length of the planning horizon.

where K is the total number of buildings built during the planning horizon. That is to say,

$$K = g \cdot T \quad (5)$$

where

g is the number of new buildings built each year, and

T is the planning horizon.

Because they are computationally intensive, the calculations of expected annual loss estimates are performed offline (Karaca and others, 2009) and a database of loss estimates is generated for use by the Web-based DSS. Once the input variables have been selected by the user, the DSS then calculates B and generates a tabular report. A schematic of this sequence is shown in figure 3.

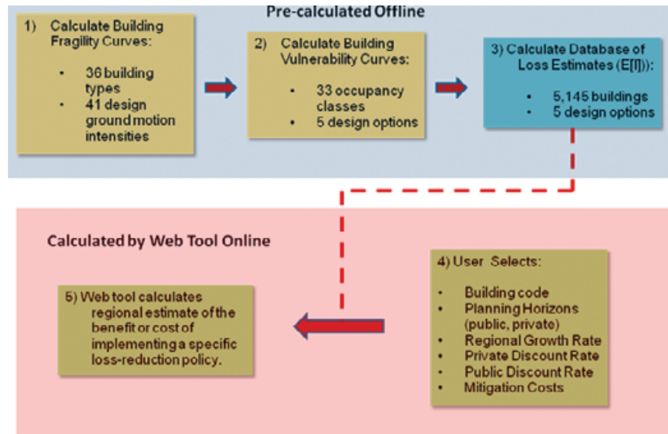

Figure 3. Schematic showing the sequence of calculations and input variables needed for regional benefit-cost estimates. A database of building loss estimates are pre-calculated offline (upper dashed box). After the user selects the input variables, the Decision Support Systems (DSS) accesses the database and calculates the regional benefit-cost estimate online (lower dashed box).

Status and Next Steps

Work is currently underway to write computer code to web-enable the benefit-cost equations, integrate these with the database of loss estimates, and design a prototype graphical user interface for the web-based DSS. An initial design for the map viewer, with hypothetical data input and run-output screens is shown in figure 4. A working prototype is expected to be completed by late 2009, followed by a period of testing, refinements, and eventual transfer of the completed DSS to cooperators in 2010.

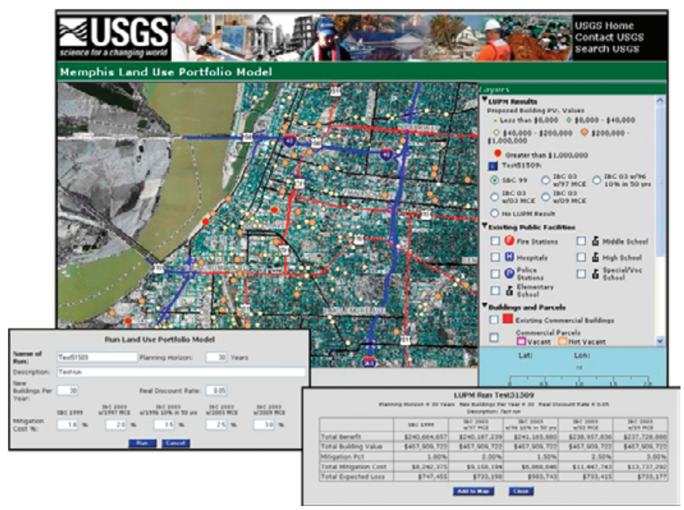

Figure 4. Initial prototype of Memphis Decision Support Systems (DSS) map viewer with sample setup and results screen.

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Missouri's Catastrophic Event Planning

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Abstract not submitted.

U.S. Army Corps of Engineers Spatial Data and Capabilities

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Abstract not submitted.

The Role of USNORTHCOM in Disaster Response

By Col. Barry Fowler

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Abstract

The United States Northern Command (USNORTHCOM) located in Colorado Springs, Colo., has geographic responsibility for the lower 48 States and Puerto Rico and US Virgin Islands for "defense support to civil authorities" (DSCA) operations. USNORTHCOM is prepared to respond to disasters, natural and manmade, when directed by the Department of Defense (DoD) in accordance with the National Response Framework. Plans and preparations are made using the "all hazards" incident response; thereby enabling response operations applicable to a wide variety of incidents such as hurricanes, wildfires, floods, and earthquakes.

The 1st Air Force, US Army North, and U.S. Fleet Forces Command are subordinate to USNORTHCOM and are vital to the accomplishment of DSCA missions. US Army North has positioned a Defense Coordinating Officer (DCO) in each of the 10 FEMA regions. The DCO normally works in direct support of FEMA and serves as the single point of contact for DoD resources during disaster response operations. During disaster response operations, the DCO reports directly to USNORTHCOM.

The New Madrid Seismic Earthquake Zone is considered a high impact incident with national consequences. The DCOs in Region VII, V, IV and VI (all adjacent to or containing the NMSZ) regularly participate in State, regional and National level exercises, planning sessions, and conferences. Region VII DCO has participated in several NMSZ events with the Missouri SEMA, National Guard, CUSEC, and has also conducted its own site visits and training exercises.

USNORTHCOM and its cadre of DCOs are committed to providing DSCA operations in support of the National Response Framework and the identified primary agency, (FEMA, for example).

FEMA Region VII Response and Recovery Operations Planning

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Abstract not submitted.

Presentation Titles and Abstracts for Thursday, August 14, 2008—Track 2: Federal and State Response and Recovery

SONS07 Overview

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Abstract not submitted.

USGS Lessons Learned from SONS07

By David Russ

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Abstract not submitted.

SEMA '07 Statewide Earthquake Exercise

By A.J. Lehmen

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Abstract not submitted.

The Role of Missouri National Guard to Civil Authorities Following a Seismic Event

By Col. Mark A. McCarter

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Abstract

The Missouri National Guard (MONG) response to an earthquake is essential to the citizens of Missouri. Preparedness through training, planning, interagency efforts, and appropriate application of military capabilities to support civil authorities are essential tenets of the MONG response. Today, the Missouri National Guard stands prepared to support the citizens of the State of Missouri in any natural/man-made disaster.

Draft National Catastrophic Earthquake Plan

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Abstract not submitted.

New Madrid Earthquake Table-Top Exercise

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(Summary by Emitt C. Witt and Krista A. Karstensen)

As part of the fact-finding theme of this conference, the Missouri State Exercise Officer for the State Emergency Management Agency developed a table-top exercise designed to be an informal discussion highlighting the needs of the response and recovery community and the gaps that the scientific community can assist in bridging. The exercise approached this topic from two fronts—1) What does the scientific community know/not know, have in possession, or are developing that can help communities prone to earthquake activity in their planning, response and recovery to an catastrophic earthquake event?; and 2) What does the community emergency management group have and need that the scientific community could provide assistance with? The table-top exercise focused on pre-event and post-event needs as related to a large magnitude event.

The Scenario

The scenario of the table-top exercise was developed by the USGS Center for Earthquake Research, Memphis, Tennessee (fig. 1). The scenario includes an M 7.7 earthquake centered near Blytheville, Missouri, at depth of 10 km around 2 pm on June 19, 2007. Estimated Mercalli Intensities indicate the most intense damage along the Mississippi River near Memphis, Tennessee, in a northeast direction to New Madrid, Missouri. In these areas shaking from the scenario event is considered violent to extreme. Structures that are capable of resisting moderate earthquakes likely sustained very heavy damage. Further away from the epicenter, the cities of Nashville, Tennessee, to the east and Little Rock, Arkansas, to the west received moderate shaking with light damage to all structures. On a regional scale, it is likely that electrical power is off, natural gas lines disrupted, and transportation infrastructure damaged.

The Exercise

The exercise was structured to bring individuals to the table that could contribute to the conversation. The State Exercise Officer pre-invited Emergency Management Directors (EMDs) from select counties in each of the State's emergency response areas (fig. 2). These EMDs along with their State Emergency Management Agency (SEMA) Area Coordinators built a set of questions related to the event that could be fielded by the science and engineering community. Likewise, during the exercise a similar set of questions were built by the scientists.

Pre-Event Concerns

The following are pre-event concerns offered by both the response and recovery and science community.

- Are currently available models good predictors of damage caused by significant earthquakes? They seem outdated and lack sufficient detail for local response communities to act upon. Also, the overall projections generated by the models are too coarse and therefore lack usefulness.

- What products are currently available from the USGS? Most of this was described during the plenary session of the conference, but some EMDs were concerned again that USGS earthquake products were too course and lack specifics that could help them at the local level.

- What surface maps are available for use by county, city planners, and the National Guard? We could use map information with more detail such as location of mines, caves, sinkholes, depth of unconsolidated material, and locations of quarry stone and/or sand deposits. These products need to be pre-staged and will be helpful during the recovery process planning.

- A list of other concerns for pre-event consideration include the effects seasonality will play on the severity of damage resulting from an earthquake; effects on water tables and wells; effects on center-pivot irrigation systems; concerns about drainage structures, and sewage systems, tributaries; concerns about bridge collapse and bridge approaches; the survivability of the fiber optic network and power sub-stations; how do we deal with pipeline rupture and HAZMAT; and what do we do about our educational facilities.

Priority concerns were categorized based on emergency response areas E, C, G, B, and I (fig. 2). Each of these areas will be impacted differently during an event and are likely to have variable roles in dealing with their citizens. Furthermore, areas that are not as heavily impacted are likely to be the responders for the areas that are more severely damaged.

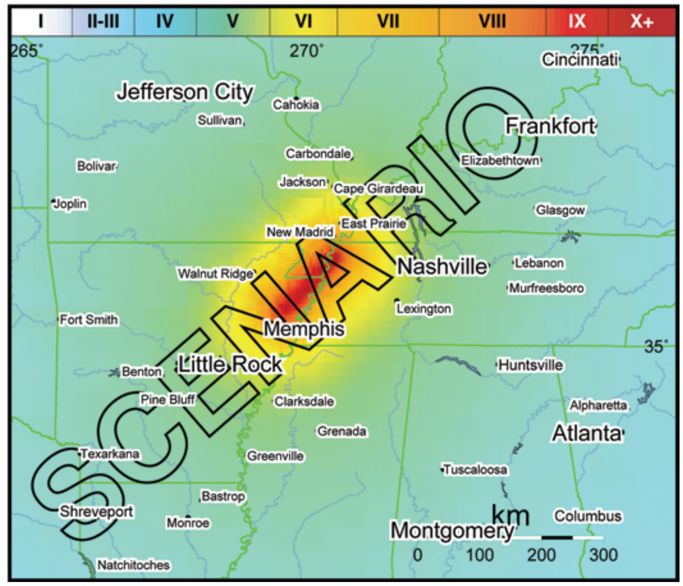


Figure 1. A depiction of a U.S. Geological Survey Shake Map showing a New Madrid Seismic Zone scenario of magnitude 7.7 centered near Blytheville, Missouri.

The following are concerns broken down by emergency management area.

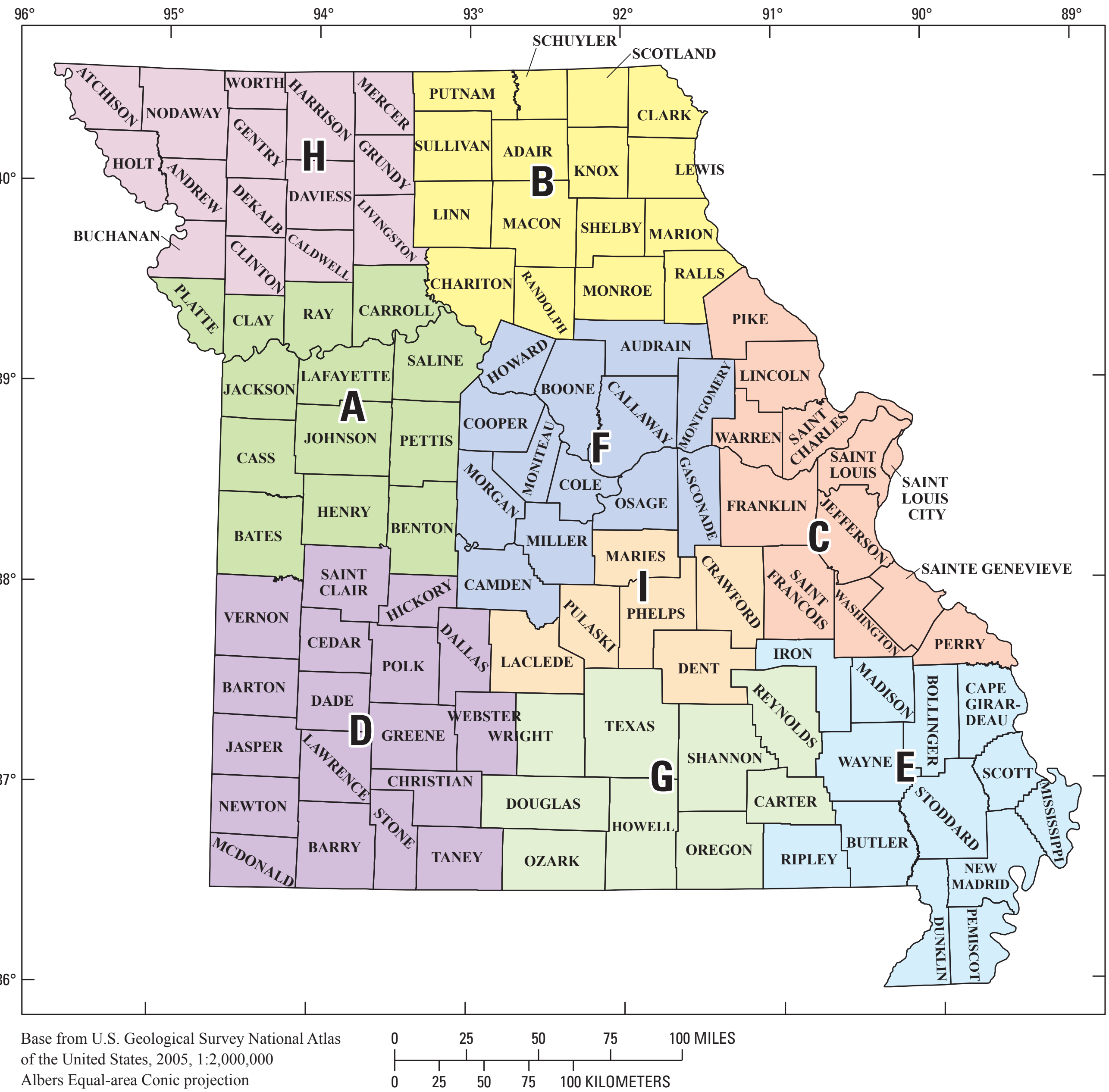
Area E

Area E is located in southeast Missouri and will be the hardest hit during a significant New Madrid event. Area E includes the 13 counties of Iron, Butler, Wayne, Ripley, New Madrid, Dunkin, Pemiscot, Stoddard, Mississippi, Scott, Madison, Bollinger, and Cape Girardeau (fig. 2). With the exception of Cape Girardeau, Area E is primarily a rural agricultural community with a heavy reliance on transportation infrastructure and community water supplies. The following are questions and concerns presented by Area E representatives:

1. The Missouri Department of Transportation exercise was canceled. This would have provided essential information about that organization's ability to respond to the State's critical infrastructure.

2. How do water tables differ and how does it effect liquefaction? The science community responded that groundwater tables will vary seasonally and with variable amounts of rainfall. The Area E representatives were very concerned about liquefaction given the evidence that it happened to a large degree during the 1811–12 earthquakes. Therefore, they wanted to know the likelihood of liquefaction and its extent.

3. There was some discussion of the need for the scientific community to do detailed soil surveys of the airports and runways. These will be important responder staging areas



Base from U.S. Geological Survey National Atlas
of the United States, 2005, 1:2,000,000
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′,
central meridian 92°30′

Figure 2. Division of Missouri into emergency response areas (Steve Bessemer, Missouri State Emergency Management Agency, written commun., 2008).

following a significant event. It was recommended that the science community perform soil borings and analysis. It was also recommended that infrastructure be assessed to identify structure sustainability and identify potential points of failure. The science community responded that doing these things becomes a matter of scale and resource availability.

Area C

Area C is located in east Central Missouri and covers 11 counties (fig. 2). These include Pike, Lincoln, Warren, St. Charles, St. Louis, Franklin, Jefferson, Washington, St. Francois, Ste. Genevieve, and Perry. Area C includes the city of St. Louis and several smaller incorporated jurisdictions surrounding the city including communities south along the Mississippi River. Seven of 11 counties have populations within the soft alluvial sediments of the river so there is concern about infrastructure failure. The scenario predicts only light to no damage for structures in this area, nevertheless, Area C representatives had the following concerns:

1. Can the scientific community provide soil overlay maps and can geotechnical maps overlay current hazard maps? The science community said yes but personnel and funding resources are the primary issue in preventing this from happening. The science community said that problems infrastructure will encounter are not solely because of liquefaction.
2. Who will arrive first? Will there be too many resources too quickly? There were no answers to these questions because they did not relate to the science community.
3. The scientific community needs to help paint a better picture of what will happen, and they need to know more clearly what areas will be affected. Also, there needs to be a better way to communicate its science to the community. Area C representatives want to know what can be expected and where is the safest place to be. The most important need is to educate communities to be self-sustaining. This is something the Central U.S. Earthquake Consortium is working on.

Area G

Area G is located to the southwest of Area E and is largely a rural forested region of Missouri (fig. 2). This area includes the counties of Wright, Texas, Shannon, Reynolds, Carter, Ripley, Oregon, Howell, Ozark, and Douglas. Geologically the area is relatively stable with respect to the potential for liquefaction, but representatives have their concerns. The Missouri evacuation plan for a significant earthquake will route people through this area to the westernmost portions of the State, so the overall theme of this area's concern is; are we prepared to deal with damaged infrastructure and overwhelmed resources?

1. Because much of Area G is located in a region of Missouri that is heavily karst, representatives were concerned about the potential problems sinkholes may pose. They wanted to know if earthquakes could trigger collapses and they wanted to know if scientists could produce detailed sinkhole maps. The Missouri Department of Natural Resources indicated that they have a sinkhole database; USGS mentioned that they are involved with karst research to develop sinkhole collapse probability maps.
2. Scientists need to hear from the response community what types of map layers would help them the most.
3. The science and first response community indicated that they must consider having common staging points during an earthquake emergency. This will facilitate effective communication between the two groups and will help provide situational awareness for mass care or the "human factor" of the event.

Area B

Area B is located in the northeastern portion of Missouri and is composed of 16 counties that include Putnam, Schuyler, Scotland, Clark, Lewis, Marion, Ralls, Monroe, Randolph, Chariton, Linn, Sullivan, Adair, Macon, Knox, and Shelby (fig. 2). Four of 16 counties border the Mississippi River and are within the severe Mercalli Intensity zone. This is largely because of the deep sediments that underlay most of the real estate along the Mississippi River flood plain. Representatives for the area indicate that infrastructure is the primary concern. They asked if the area should invest in soil surveys to identify soil properties. And, could this information help the scientific community. The response was yes.

Area I

Area I is located in the south-central portion of Missouri and is composed of six counties that include Maries, Phelps, Dent, Crawford, Pulaski, and Laclede (fig. 2). This is the closest area to the event that will sustain the least amount of damage; therefore, it is likely that Area I responders will be the first line of defense during an earthquake emergency. Resources that could be tasked to support response and recovery following a significant earthquake include the USGS offices and Missouri University of Science and Technology, Ft. Leonard Wood, two large hospitals, the Missouri Department of Natural Resources, and the National Guard. Concerns of Area I representatives include the need to identify how responders can get from one place to another, and to identify alternate routes in the case of bridge collapses, road obstructions, and so forth.

Post-Event Concerns

Following the initial earthquake event there will be a flurry of activity related to the response. The Missouri SEMA will begin implementing its earthquake response plan. This plan was developed using the principles of the National Response Framework and the National Incident Management System. While this plan focuses on the needs of the “human factor” of the event, SEMA as well as others in the response community see the potential value of having the science community at the table. The concerns the response and recovery community have include:

1. How will USGS and other science organizations be integrated at the local level? Is there a deployment plan for science that complements the response and recovery community plan?
2. Local response organizations need to know that scientists are coming to their location; what credentials will be used to identify members of the science community; will there be a plan for the locations scientists will visit; need to know arrival and departure times/dates; what disciplines will be represented; what will scientists need access to; and what is it scientists are specifically looking for.
3. Local and State response organizations want to know if data will be shared with the non-science community in a timely manner. Will there be timely comparison of actual data with pre-event data to help responders in their mission to maintain a common operating picture?
4. Are USGS personnel and other science organizations trained in the National Incident Management System?

Abstracts and Papers from Poster Session—Wednesday, August 13, 2008

Analytical and Experimental Studies on Seismic Behavior of RC Bridge Columns Subjected to Combined Loadings

By Abdeldjelil Belarbi, Suriya Prakash Shanmugam, and Young-min You

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Abstract

Reinforced concrete (RC) columns of skewed and curved bridges and bridges with unequal spans and column heights can be subjected to combined loadings including axial, flexural, shear, and torsional loadings during an earthquake. Multi-directional earthquake motions with significant vertical excitations, structural constraints because of stiff deck, movement joints, soil condition, and foundations may also lead to combined loadings. The combination of axial, bending, shear, and torsion in RC bridge columns can result in complex failure modes. Under a National Science Foundation-National Earthquake Engineering Simulation research project with objectives to understand the behavior of bridge columns under seismic loadings, experimental and analytical studies are conducted to investigate the performance of RC columns under combined loadings including torsion. The main variables being considered in the experimental study are (1) the ratio of torsion to bending moment (T/M), (2) the ratio of bending moment to shear (M/V), and (3) level of detailing for high and moderate seismicity (low or high spiral ratio). The experimental results are used to develop and calibrate the design interaction equations. Based on the experimental results, damage and ductility models that account for the combined loading effects are also being developed from design point of view. Normalized interaction diagrams for displacement and rotational ductility levels are also presented and discussed. Analytical study focuses on developing mechanical models to predict the interaction effects for RC columns under combined loadings. However, knowledge of the interaction between axial, bending, shear, and torsion in RC bridge columns is very limited. This paper presents an overall summary of the major findings and relevant results from both the experimental and analytical studies and provides new directions in the design and detailing of RC bridge columns under seismic loading.

Torsional-Flexural-Shear Interaction Characteristics of RC Bridge Columns under Simulated Seismic Loading

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Abstract

Reinforced concrete (RC) columns of skewed and curved bridges and bridges with unequal spans and column heights can be subjected to combined loadings including axial, flexural, shear, and torsional loadings during an earthquake. The combination of axial, bending, shear, and torsion in RC bridge columns can result in complex failure modes. Under an National Science Foundation-National Earthquake Engineering Simulation funded project, experimental and analytical studies are conducted to investigate the performance of RC columns under combined loadings including torsion. The main variables being considered in the experimental study are

(1) the ratio of torsion to bending moment (T/M), (2) the ratio of bending moment to shear (M/V), and (3) level of detailing for high and moderate seismicity (low or high spiral ratio). The experimental results are used to develop and calibrate the design interaction equations. Based on the experimental results, damage and ductility models that account for the combined loading effects are also being developed from design point of view. Analytical study focuses on developing mechanical models to predict the interaction effects for RC columns under combined loadings. This paper presents an overall summary of the major findings and relevant results from both the experimental and analytical studies and provides new directions in the design and detailing of RC bridge columns under seismic loading.

Introduction

RC bridge columns can be subjected to torsional moments in addition to axial, bending, and shear forces during earthquake excitations. The addition of torsion is more likely in skewed or curved bridges, bridges with unequal spans or column heights, and bridges with outrigger bents. Construction of bridges with these configurations is often unavoidable because of site constraints. In addition, multi-directional earthquake motions, significant vertical motions, structural constraints because of stiff decks, movement of joints, abutment restraints, and soil conditions may lead to combined loading effects including torsion. This combination of seismic loading and structural constraints can result in complex failure modes of these bridge columns. Very few experimental results are reported in the literature on the behavior of rectangular columns under combined loadings. Otsuka and his team (Otsuka and others, 2004) studied nine rectangular columns under pure torsion, bending/shear and different ratios of combined bending and torsional moments. The authors concluded that the pitch of the hoop lateral tie significantly affected the hysteresis loop of torsion. Later, Kawashima and his colleagues (Tirasit and others, 2005) reported tests on RC columns under three loading conditions. The authors reported that the flexural capacity of RC column decreases and the region of plastic deformation tend to move above the typical flexural plastic hinge region as the rotation-drift ratio increases. Recently, Belarbi and his team (Belarbi and others, 2008) tested a number of columns at different torsion-to-bending moment (T/M) ratios.

They observed that the effects of combined loading reduce the flexural and torsional capacities, as well as affect the failure modes and deformation characteristics. They determined that with an increase in torsion-to-bending moment (T/M) ratios, the energy dissipation capacity decreases. There are rational models available for analyzing the interaction between axial and bending loads.

The behavior of columns under bending with and without axial loadings has been extensively investigated by a number of researchers. Park and Ang (1985), Priestly and Benzoni (1996), Priestly and others (1996), and Lehman and others (1998) have all investigated and proposed various models for predicting the seismic performance behavior of columns taking into account the axial loading effect on bending capacity. Analytical models for RC columns in the past have primarily focused on inelastic flexural behavior and usually decoupled with shear and torsion. In addition to axial load, shear force, and bending moment, bridge columns can be subjected to torsional loadings. Torsional loadings can significantly affect the flow of internal forces and deformation capacity of RC columns. These in turn can affect the performance of vital components of bridges and consequently affect the daily operation of the transportation system. However, there have been no analytical models developed including the effect of flexure-shear-torsion interaction for assessment of seismic performance of RC circular bridge columns. In this direction, You and Belarbi (2008) developed a model for RC circular bridge columns under pure torsion with or without axial loading effect based on the softened truss model. The paucity of test results of RC circular columns with different reinforcement ratios under combined bending, shear and torsion loadings has hindered the development of analytical models. Therefore, the research work done in this study will be helpful not only for the enhancement of knowledge on the behavior of RC circular bridge columns under cyclic combined loadings but also for providing experimental data towards the development of rational analytical models.

Experimental Program

The main variables considered in this study are (1) the ratio of torsion-to-bending moment, (2) column aspect ratio (H/D) to simulate a flexural or shear dominant response, and (3) level of detailing for high and moderate seismicity. The aspect ratio plays an important role in determining the behavior of columns dominated by flexure or by shear. For the columns tested in single curvature, the aspect ratio is defined as the ratio of height (M/V=H) to diameter (D). The study consisted of testing circular columns at high aspect ratio (H/D=6) with low shear and at low aspect ratio (H/D=3) with moderate shear at different levels of torsion-to-bending moment ratios with two different spiral reinforcement ratios ($?_t$) as shown in table 1. The hysteretic lateral load-displacement response, torsional moment-twist response, reinforcement stress variations, and plastic hinge characteristics for the individual tested columns can be found elsewhere (Belarbi and others, 2008; Suriya Prakash and others, 2008). In particular, the effect of spiral reinforcement ratio and aspect ratio on behavior of RC circular columns under combined loadings is focused in this paper.

Test Specimen Details

The half-scale test specimens were designed to be representative of typical existing bridge columns. The column dimensions and reinforcement layout are shown in fig. 1*A*.

These RC columns had a diameter of 610 mm and clear concrete cover of 25 mm. The total height of the column for columns with aspect ratio of 6 was 4,550 mm and the effective height was 3,650 mm from the top of the footing to the centerline of the applied forces. Similarly, total height for columns with aspect ratio of 3 was 2,750 mm and the effective height was 1,850 mm from the top of the footing to the centerline of the applied loads. The axial load because of the superstructure dead weight was assumed to be 7 percent of the capacity of the columns. The longitudinal and spiral reinforcement ratios were 2.1 percent and 0.73 percent, respectively. In order to investigate the effectiveness of spiral reinforcement ratio under combined torsion and bending moments, spiral reinforcement ratio was increased from 0.73 percent to 1.32 percent. Detailed information of the material properties of the test specimens can be found elsewhere (Belarbi and others, 2008 and Suriya Prakash and others, 2008).

Table 1. Test matrix.

[Mpa, megapascal; H/D, aspect ratio; T/M, torsion to bending moment ratio]

Test columns	Compressive strength (Mpa)	Spiral ratio (percent)	Longitudinal ratio (percent)	Aspect ratio (H/D)	Torsion to bending moment ratio (T/M)
M/V(12) –T/M(0)	33.4	0.73	2.1	6	0
M/V(12)–T/M(0.1)	29.7	.73	2.1	6	0.1
M/V(12)–T/M(0.2)	26.5	.73	2.1	6	.2
M/V(12)–T/M(0.4)	25.7	.73	2.1	6	.4
M/V(12)–T/M(∞)	37.9	.73	2.1	6	∞
M/V(12)–T/M(0.2)	41.2	1.32	2.1	6	.2
M/V(12)–T/M(0.4)	41.2	1.32	2.1	6	.4
M/V(6)–T/M(0)	25.8	1.32	2.1	3	0
M/V(0)–T/M(∞)	28	1.32	2.1	3	∞
M/V(6)–T/M(0.2)	28.7	1.32	2.1	3	.2
M/V(6)–T/M(0.4)	26.8	1.32	2.1	3	.4

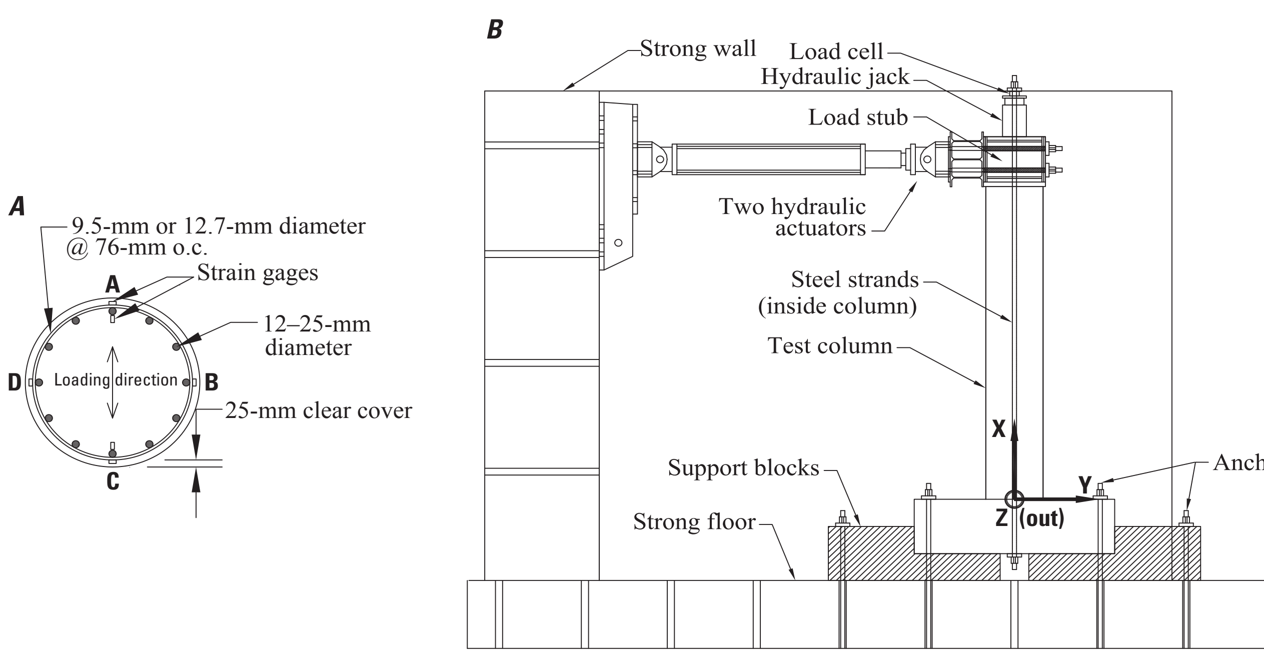

Figure 1. (*A*) Column cross sectional detail and (*B*) test setup elevation.

Effect of Transverse Spiral Reinforcement Ratio

Increase in spiral reinforcement ratio improves the shear strength and confinement of the concrete core for the columns tested under combined bending-shear. However, there is only marginal strength increase because of an increase in the spiral reinforcement ratio for the flexure dominated columns with low longitudinal reinforcement ratio and adequate confinement. Significant improvement in performance with increase in spiral reinforcement ratio can be achieved for cases under pure torsional loading. The hysteresis curves of columns with spiral reinforcement ratio of 0.73 percent and 1.32 percent are presented in the figure 2. Soon after cracking, the yielding of spirals was observed in the subsequent loading cycle of the column with spiral reinforcement ratio of 0.73 percent. This implies that the spiral ratio of 0.73 percent is in the neighborhood of the minimum design requirement for a torsional design. It is worth mentioning that 1 percent spiral ratio is a more practical value in the design of bridge columns in the United States. To offset the cracking level from yielding level, the spiral ratio was increased to 1.32 percent and again tested under pure torsion. The angle of diagonal cracks was nearly 39 to 42 degrees relative to the cross section (horizontal) of the column. The spalled region occurred near the top of the column at the completion of the test.

The torsional moment versus twist curves are approximately linear up to cracking and thereafter become nonlinear with a decrease in the torsional stiffness. The column with a spiral reinforcement ratio of 1.32 percent had a higher post-cracking stiffness. The yielding strength increased by 20 percent and the ultimate strength by 30 percent because of an increase in spiral reinforcement ratio from 0.73 percent to 1.32 percent. More importantly, significant increase in rotational ductility was achieved because of an increase in spiral reinforcement ratio. Torsion-bending moment loading curves for the columns tested under combined bending and torsional moments are shown in figure 3 As shown in the curves, all specimens reached their torsional capacity before reaching their flexural capacity. However, the longitudinal rebars yielded before the spirals. Hence, the failure sequence in all the specimens were in the order of flexural cracking, followed by shear cracking, longitudinal bar yielding, spalling, spiral yielding, and then overall failure by buckling of the longitudinal bars right after significant core degradation. Yielding of the longitudinal and spiral reinforcement occurred relatively close to each other for the columns reinforced with a spiral reinforcement ratio of 0.73 percent. By increasing the spiral reinforcement ratio, significant improvement in torsional and bending strengths was achieved. Torsion-bending moment interaction diagrams were determined at peak torsional moment (fig. 4*A*) and peak shear (fig. 4*B*) for all columns. It should be noted that the T/M ratio was maintained closely to the desired loading ratio in all columns until the peak torsional moment was attained in the unlocking direction. Soon after reaching the peak torsional strength, it was impossible to maintain the desired loading ratio as the torsional stiffness was

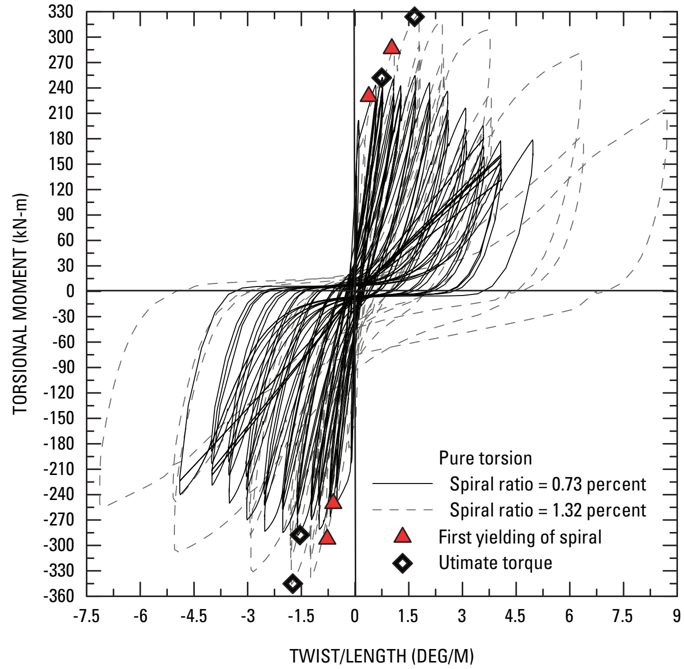

Figure 2. Torsional hysteresis under pure torsion with different spiral reinforcement ratios (?$_t$).

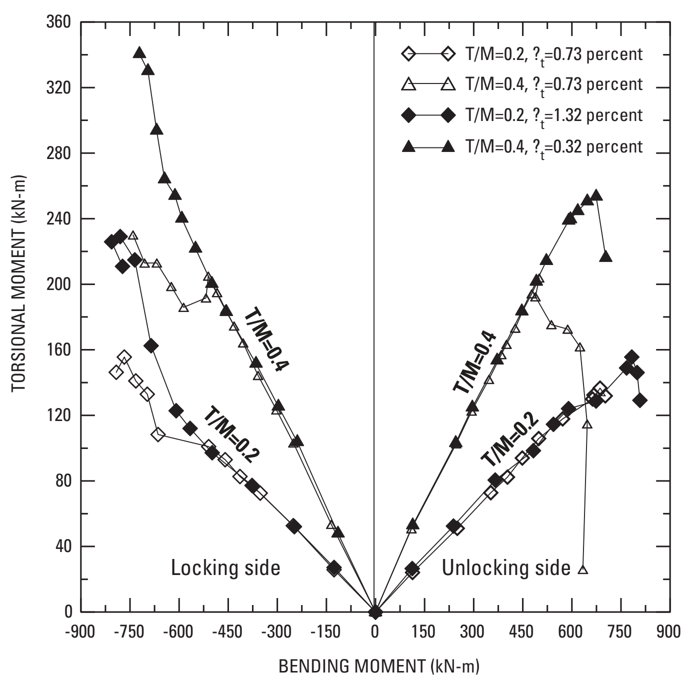

Figure 3. Comparison of torsion-bending moments curves for various combined loading ratios [?$_t$, spiral reinforcement ratio in percent].

degrading much faster in the unlocking and locking directions. However, the bending strength was degrading faster than the torsional strength in the locking direction for the columns with a spiral reinforcement ratio of 1.32 percent and hence the load ratio could not be maintained to complete the test.

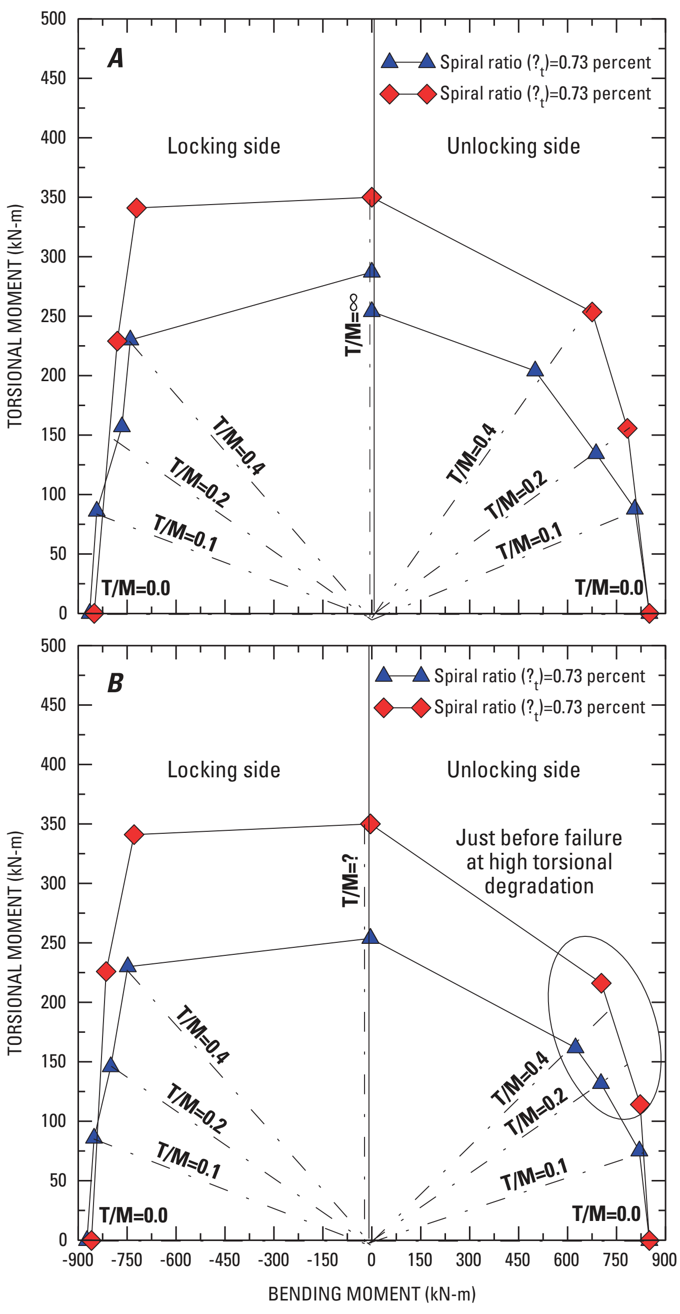

Figure 4. Torsion-bending moments interaction diagrams. (*A*) Peak shear. (*B*) Peak torsion [$?_t$, spiral reinforcement ratio in percent].

Effect of Shear Span/Aspect Ratio under Combined Loadings

The behavior of RC columns can be classified into flexure dominated or shear dominated or with significant flexure-shear interaction. The aspect ratio of the column determines the level of flexure-shear interaction. In order to adopt the plastic analysis methods in the design of RC members by assigning the plastic hinges at the weak regions, inelastic response at these regions must be assessed in the presence of combined loadings including torsion. Specifically, designers would prefer to quantify flexural response such that the dependability of flexural plastic hinges can be assessed under dominant shear/torsional loads. Test results of the six columns: one tested under cyclic pure bending (H/D=3), one column tested under cyclic pure torsion (H/D=3), and four columns tested under combined cyclic bending and torsion with different ratios of T/M such as 0.2 and 0.4 but with different shear spans (H/D=6 and 3) were used to investigate the effect of shear span under combined loadings including torsion. Analytical models were used to predict the behavior of column with aspect ratio of 6 under bending-shear and pure torsion respectively. All the columns had a spiral reinforcement ratio of 1.32 percent. Torsion-bending moment loading curves for the columns tested under combined bending and torsional moments but with two different aspect ratios are shown in figure 5. As shown in these curves, the columns with low and high aspect ratio reached their torsional and bending moment capacity almost simultaneously in the unlocking direction. However, it is somewhat different in the locking direction.

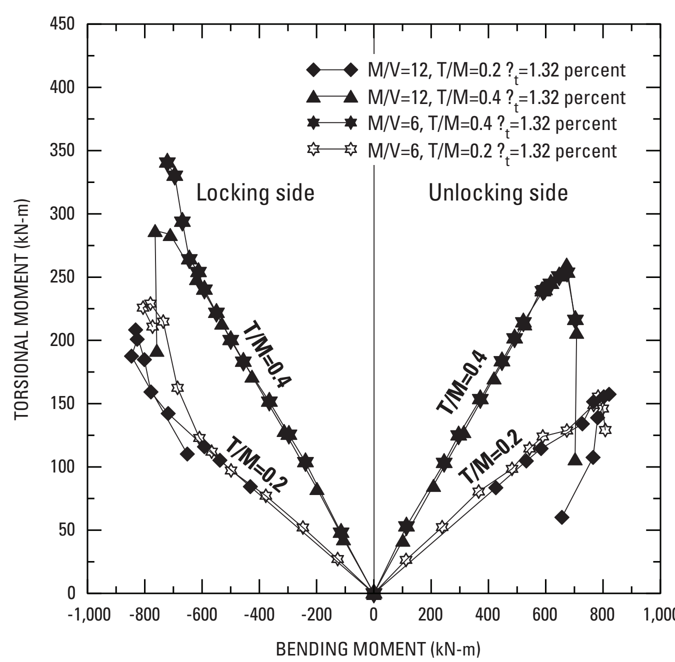

Figure 5. Comparison of torsion-bending loading curves for two different aspect ratios [$?_t$, spiral reinforment ratio in percent].

After yielding of the spiral and longitudinal reinforcement, the bending and torsional strength increased in a non-linear fashion because of the locking effect of spiral which resulted in better confinement of concrete core. Hence, the ratios were not closely maintained in the locking direction. No significant change in the torsional and bending strengths was observed with change in the aspect ratio. This is mainly because of the flexural failure mode in the columns with high and low aspect ratio. However, the effect of aspect ratio would have been more pronounced if the failure modes were in shear. Torsion-bending moment interaction diagrams were determined at peak torsional moment (fig. 6*A*) and peak shear (fig. 6*B*) for tested columns. It should be noted that the T/M ratio was not maintained closely to the desired loading ratio in the locking direction because of highly nonlinear behavior because of locking effect of spiral reinforcement. This resulted in variation of bending and torsional stiffness in a non-linear fashion after the spiral and longitudinal bar yielding.

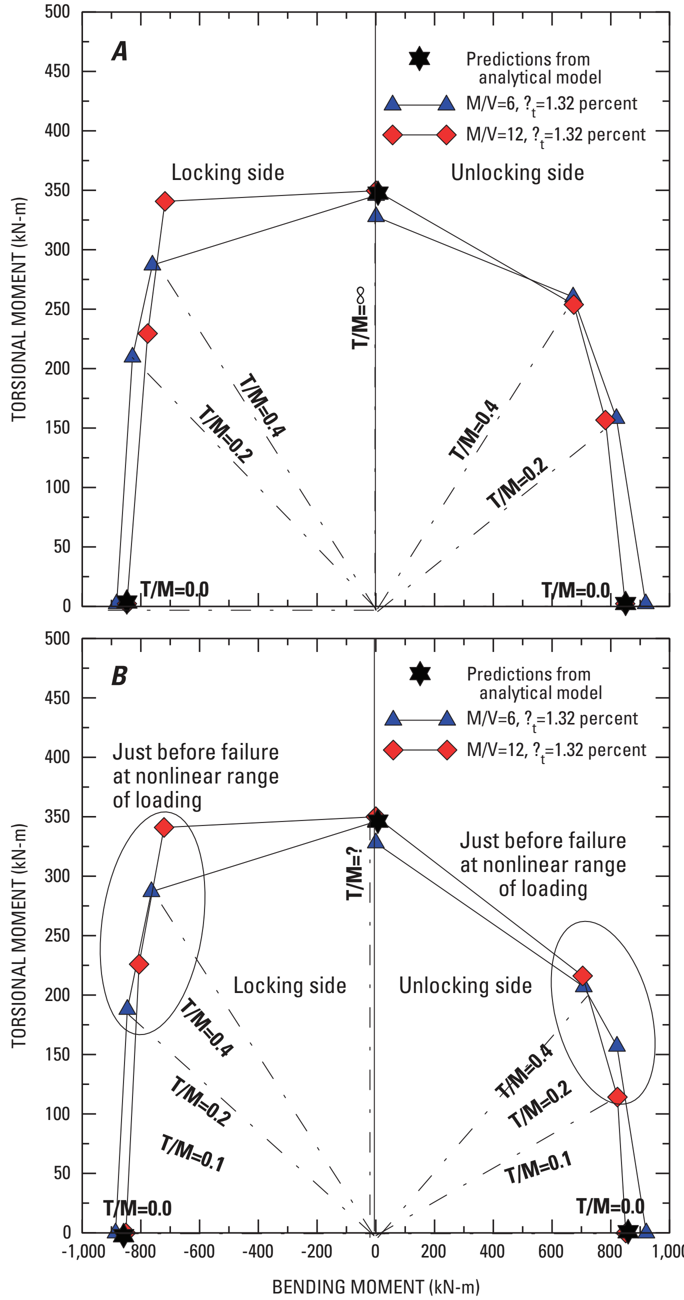

Figure 6. Torsion-bending moments interaction diagrams. (*A*) Peak torque. (*B*) Peak shear [$?_t$, spiral reinforcement ratio in percent].

Flexure-Shear-Torsion Interaction Diagrams

The test results were subsequently used to create three-dimensional interaction diagrams as shown in figure 7. Interaction curves for columns with spiral reinforcement ratios of 0.73 percent and 1.32 percent and with aspect ratio of 3 and 6 are shown in figure 7. The torsional capacity as well as bending capacity has been determined to reduce because of the effect of combined bending and torsion. The interaction between bending and torsion depends on a large number of factors, such as the amount of transverse and longitudinal reinforcement, aspect ratio of the section, and concrete strength. As explained in the previous sections, increase in the spiral reinforcement ratio resulted in a better performance. It is to be noted that there was no degradation in strength because of a change in aspect ratio or moment to shear ratio, as the columns failed predominantly in flexure. For the columns with low transverse reinforcement ratio of 0.73 percent, degradation in strength and stiffness increased with increases in torsion-to-bending moment ratios. This demonstrates that transverse reinforcement ratio of 0.73 percent which may be adequate from a flexural design point of view may not satisfy the expected design performance in the presence of torsional loadings.

Concluding Remarks

Based on this experimental and analytical investigation, the following major concluding remarks can be drawn:

- The combination of bending and torsion had the effect of reducing the torque required to cause yielding of the transverse reinforcement and the peak torsional component.
- Similarly, the combination of bending and torsion had the effect of reducing the bending moment required to cause yielding of the longitudinal reinforcement and the peak component of bending moment.
- Under combined torsion and bending, the torsional stiffness degraded more rapidly than the bending stiffness under increasing increments of displacement/rotation.
- The degradation in strength of the column under pure torsion was contained by increasing the spiral ratio.

Increasing the spiral reinforcement ratio helped to increase the torsional strength and rotational ductility by increasing deformational capacity after yielding.

- Increase in the spiral reinforcement ratio resulted in more confinement and thereby helped reducing the degradation of bending as well as torsional strength under combined bending moments and torsion.
- There was no reduction in bending and torsional strength with reduction in shear span. This was mainly because of predominant flexural failure mode because of the low longitudinal reinforcement ratio considered in this study. However, the energy dissipation under bending and torsion reduced considerably with reduction in shear span ratio.
- Energy dissipation capacity and equivalent damping ratio under combined bending and torsion increased with increases in spiral reinforcement ratio. However, they decreased with increases in torsion to bending moment ratio and reduction in shear span ratio.

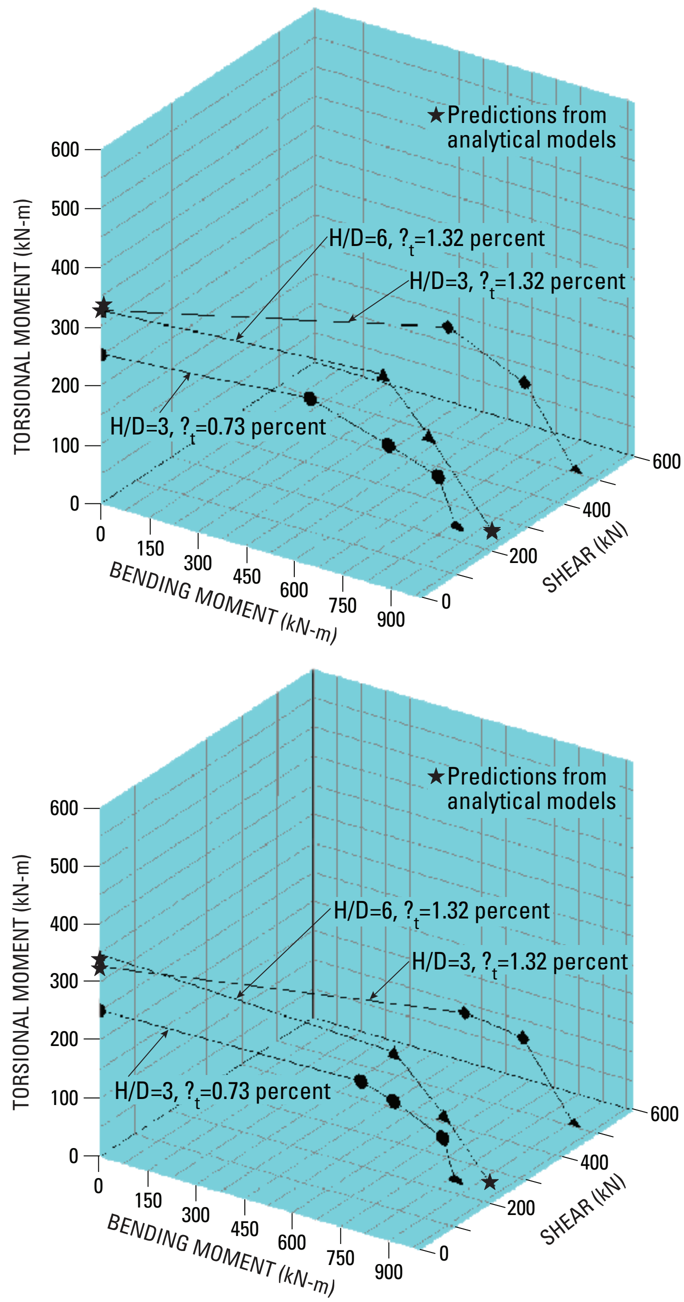

Figure 7. Three-dimensional bending-shear-torsion interaction diagrams. (*A*) Peak torque. (*B*) Peak shear.

Acknowledgments

This study was funded by NSF-NEESR, National University Transportation Center (NUTC) and Intelligent Systems Center (ISC) of Missouri University of Science and Technology. Their financial support is gratefully acknowledged.

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Hazards Assessment of St. Charles County—Earthquake and Flood

By Ronaldo Luna[9], PhD, PE, and Amy L. Morris[10]

Located on the northernmost limits of the St. Louis metropolitan area, St. Charles County has been, and continues to be, one of the fastest-growing counties in the country. Bounded by the Missouri River on the south and the Mississippi River on the north, St. Charles County is predominantly flat, low-lying terrain at great risk to periodic flooding. The county also is well within the area of influence for several local seismic zones, increasing the susceptibility to earthquake damage. Given the apparent risk to flood and earthquake, this study applied the latest version of the GIS driven software program: HAZUS-MH, to assess both hazards for St. Charles County in terms of damages, social impact, and economic losses. With this technology, it is not only possible to compare the extent of damage or losses between various scenarios but also between the different hazards. It is the intent of this research to inform St. Charles County of the possible consequences associated with each hazard scenario as well as determine which natural hazard is of most concern so that the county officials may then pursue the proper recourse.

Community and Regional Resilience Initiative: Revealing Resilience in the Memphis Area

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The six county Memphis Urban Area (MUA) serves as one of three communities of focus for Oak Ridge National Lab's Community and Regional Resilience Initiative (CARRI). In collaboration with partner organizations and community advocates the CARRI-MUA research and community engagement team is learning what resilience means to stakeholders; how that resilience is expressed at the neighborhood, community and regional scales; and what steps might be taken to enhance or reinforce resilience. This community learning will merge with that gained in the Charleston, South Carolina, and Gulfport, Mississippi, to inform a national effort to document and describe key characteristics of resilience.

Traditional and participatory research approaches are used here. Local expertise, relationships and the social fabric of place are actively integrated with hazards and risk knowledge. Strong ground motion associated with the New Madrid Seismic Zone including existing hazard assessments and related planning efforts and opportunities figure prominently in this study. Resilience in the MUA in the mind of the community team must consider the low probability, high consequence event as well as chronic disruptions. This complement of threat types is revealing insights into the characteristics of resilience at multiple scales.

Preliminary findings emphasize: communication, relationships, training and planning, identification of at-risk residents pre-disaster, and managing and informing expectations across the community. While details may be place specific the lessons learned here will inform the resilience framework for the larger CARRI program. For more information or to contribute to this work in progress please visit: *www.resilientus.org* or contact any of us.

Surface Wave Velocity Measurements in the Deep Sediments of the Mississippi Embayment

By Brent R. Rosenblad, Jonathan Bailey, and Jianhua Li

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Results are presented from surface wave velocity measurements performed in the Mississippi Embayment to develop shear wave velocity (V_S) profiles of the deep sediments in this region. Measurements were performed at eleven locations in Arkansas, Tennessee, and Missouri. Eight of the sites were located adjacent to seismic stations operated by the Center for Earthquake Research and Information (CERI) at the University of Memphis. This study utilized a unique low-frequency field vibrator that was recently developed as part of the Network for Earthquake Engineering Simulation (NEES) program. Surface wave energy was actively excited down to frequencies of less than 1 Hz, generating surface waves with wavelengths of 600 m or greater at most sites. Shear wave velocity (V_S) profiles were developed to depths of more than 200 m. The V_S values typically ranged from

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approximately 100 m/s near the surface to more than 600 m/s at the maximum profiling depths. Several distinct transitions in V_S values were observed at variable depths among the eleven sites. An average V_S developed from the eleven sites was in good agreement with V_S models that have been developed for the deep sediments of the Embayment.

Promises and Challenges of Data Collected to Aid the St. Louis Area Earthquake Hazards Mapping Project

By Conor Watkins

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St. Louis Area Earthquake Hazards Mapping Project is a cooperative effort of the U.S. Geological Survey and other public and private entities. The project includes collection of geotechnical data from other sources to assist with subsurface characterization in the project area, which encompasses approximately 3,100 square kilometers of Missouri and Illinois within the St. Louis Metro area. Sources include the U.S. Army Corps of Engineers, the Missouri Department of Transportation, and engineering firms. Interpretation of these data will aid the prediction of site response at various localities throughout the project area and the production of seismic hazards maps based on scenario earthquakes affecting the region.

The use of data from other sources provides a tremendous cost savings to the project and allows for a greater density of information in the prediction of seismic hazards. However, data from various sources arrive in a variety of formats and standards. Often, data collected for a specific project only cover a limited area. Good examples are geotechnical borings from the Missouri Department of Transportation and the U.S. Army Corps of Engineers, which tend to be restricted to the locations of highways or flood protection levees, respectively. Older data often arrive in analog formats lacking a well-defined spatial reference. Paper maps and photographs must be digitally scanned and georeferenced to existing cospatial imagery and maps. Geotechnical data contains varying levels of detail which must be accounted for when using them for subsurface characterization.

Promises and Challenges of Data Collected to Aid the St. Louis Area Earthquake Hazards Mapping Project

By Conor M. Watkins

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Abstract

The St. Louis Area Earthquake Hazards Mapping Project is a U.S. Geological Survey coordinated study of how surficial materials within a selected portion of the St. Louis metropolitan area will respond to seismic shaking. The study includes collection of geotechnical data from other sources to assist with subsurface characterization in the project area, which encompasses approximately 1,711 square miles (4,432 square kilometers) of Missouri and Illinois, in the St. Louis metropolitan area. Data sources include both public and private entities. Interpretation of this data will aid the prediction of site response to earthquakes at various localities throughout the project area and the production of seismic hazards maps based on scenario earthquakes affecting the region.

Introduction

The St. Louis Area Earthquake Hazards Mapping Project is a generalized study of how surficial materials within the St. Louis metropolitan area will respond to seismic shaking. This study, coordinated by the U.S. Geological Survey (USGS), covers 29 7.5-minute USGS quadrangles in the St. Louis area (fig. 1).

Part of the study includes the collection of geotechnical data from outside sources to assist in the subsurface characterization of materials within the project's boundaries. Data sources include the U.S. Army Corps of Engineers (USACE), the Missouri Department of Natural Resources, the Missouri Department of Transportation, municipal and county agencies, and engineering firms. Interpretation of this information will aid in the prediction of site response within the project area and the production of hazards maps relevant for scenario

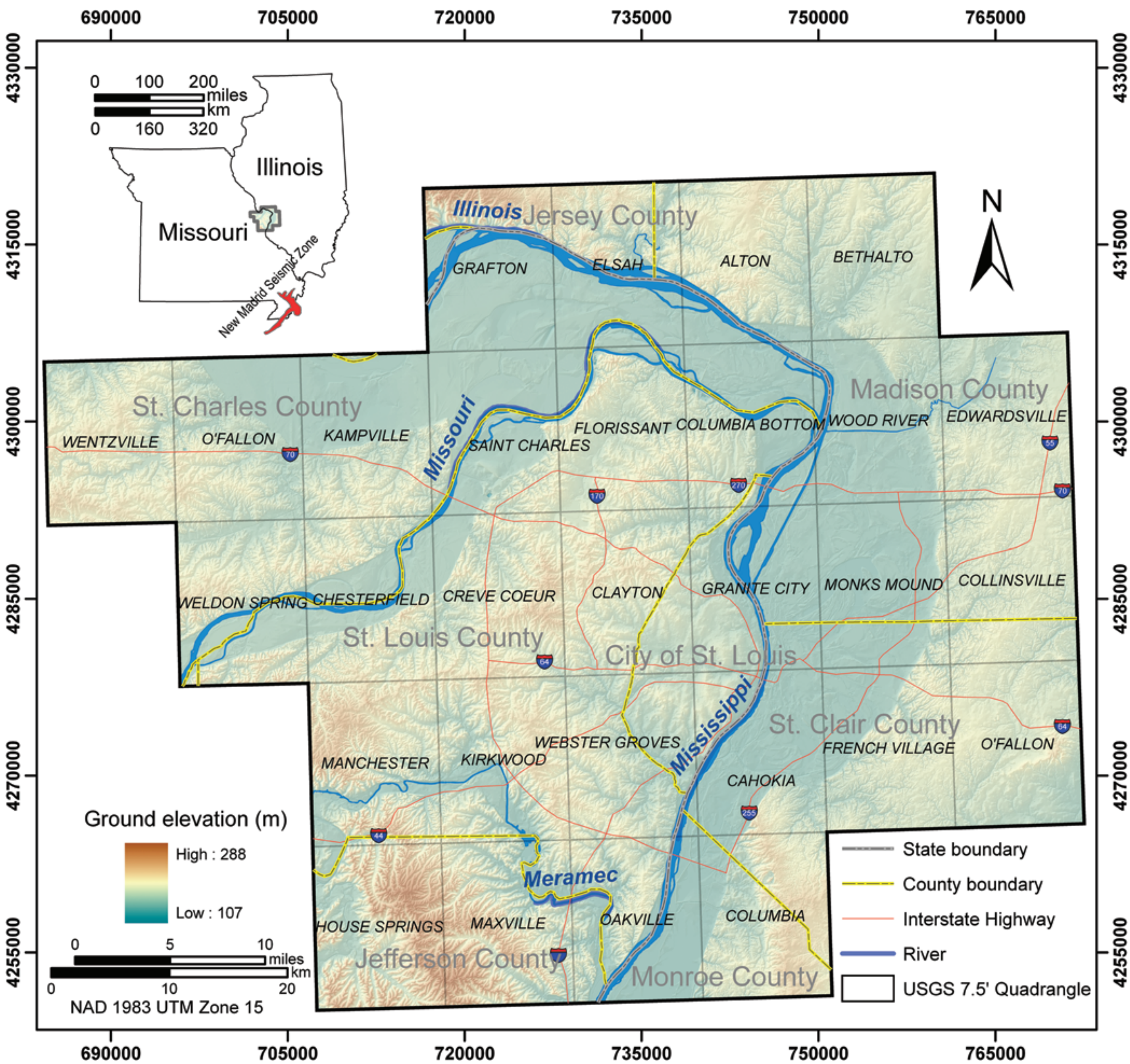

Figure 1. Extent of study area (modified from Chung, 2007).

earthquakes (earthquakes of a specific magnitude emanating from a specific location) affecting the region.

The use of data from other sources provides a tremendous cost savings to the project, allowing for a greater density of information to be collected. However, data from various sources arrive in a variety of formats and standards. Often, data collected for a specific project covers only a limited area, resulting in non-uniform densities. An example of this are geotechnical borings from the Missouri Department of Transportation and the U.S. Army Corps of Engineers which tend to be restricted to the locations of highways or flood protection levees, respectively. Historic data often arrive in analog formats lacking a spatial reference. Paper maps and photographs must be digitally scanned and georeferenced to existing cospatial imagery and maps. Geotechnical data contain varying levels of detail, depending on the source and original purpose, which must be accounted for during use for subsurface characterization.

The objective of this task is to integrate data from various sources into a uniform database so they can be used for subsurface characterization beneath the study area and to assist in creating area-wide seismic hazards maps. The project area encompasses a diverse geologic setting. Conditions vary from uplands with Paleozoic bedrock at a shallow depth to the floodplains of the Missouri and Mississippi River with 120 feet (ft) [36.6 meters (m)] or more of unconsolidated Quaternary alluvium overlying bedrock. These floodplains have a shallow water table and are subject to liquefaction. The concentration of critical infrastructure including refineries, pipelines, power plants, electrical transmission lines, highways, and railroads in these vulnerable areas makes them of particular interest.

Discussion

Data collected from the USACE and a local levee district were integrated into a GIS database. Geotechnical borings and associated plan maps for levees along the Illinois side of the Mississippi River, the St. Louis floodwall, and the Melvin Price Locks and Dam were provided by the USACE St. Louis District. None of this data were originally in electronic format and all had to be digitally scanned and georeferenced to other cospatial imagery so that it could be used in a GIS database.

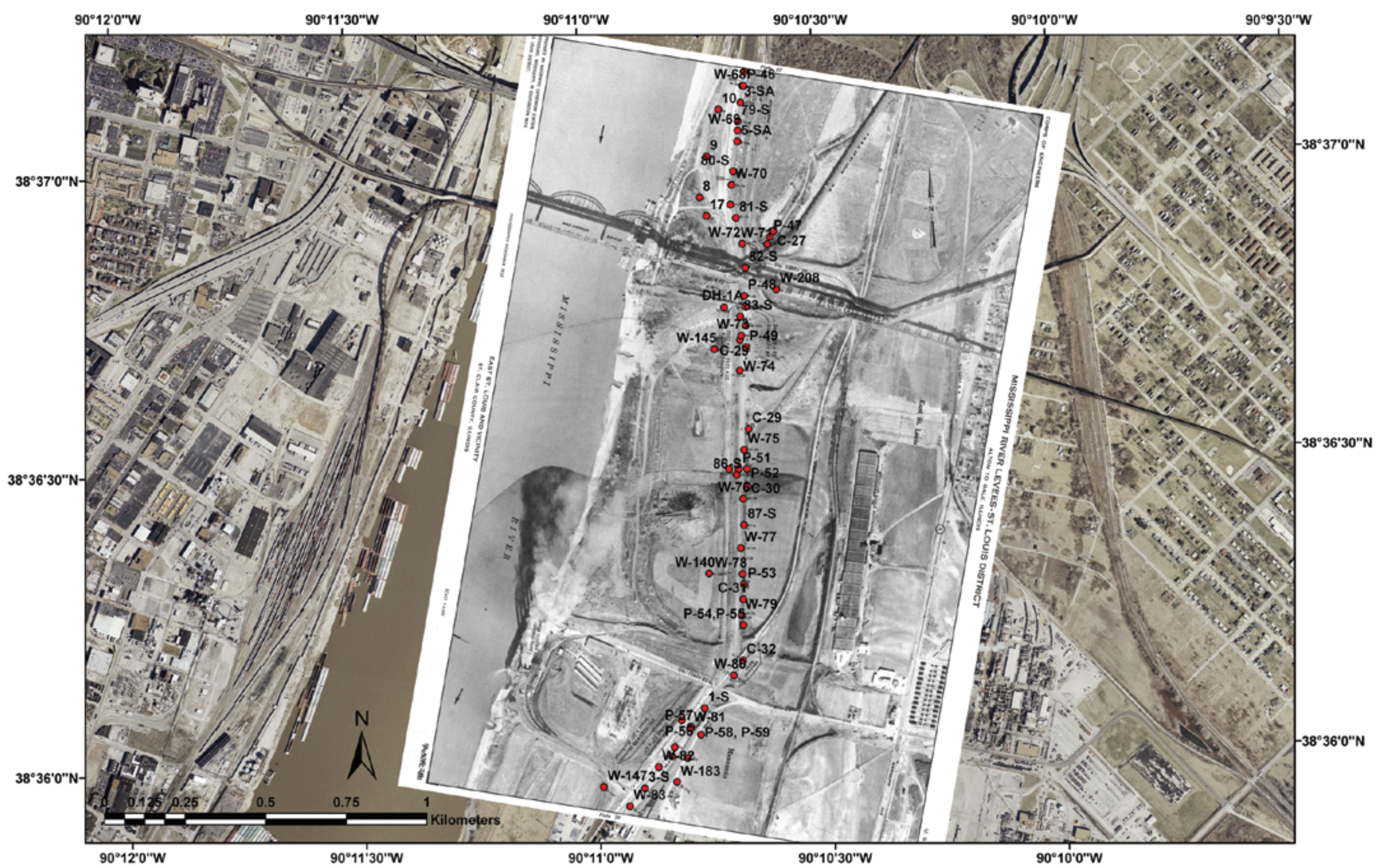

Figure 2. 1956 U.S. Army Corps of Engineers levee boring plan and locations near downtown St. Louis georeferenced according to modern aerial photography. The individually digitized points were manually entered into a vector dataset. [images adapted from U.S. Army Corps of Engineers, 1956]

The levee report (U.S. Army Corps of Engineers, 1956) was useful as it contained a high density of deep subsurface information along levees just east of the Mississippi River near St. Louis. Once the boring plan maps from the 1956 document were properly georeferenced according to modern aerial photography, individual boring locations were input as points in vector GIS datasets to be imported into the geotechnical database. This point based dataset was overlain atop the georeferenced boring plan and modern aerial imagery for convenient display (fig. 2).

An example boring log from the USACE illustrates a borehole that was advanced to a depth of around 116 ft (35.4 m) below the ground surface before encountering refusal (symbolized by R) (fig. 3) (U.S. Army Corps of Engineers, 1956). Although these borings do not provide an absolute number as to the depth to bedrock, they do provide useful information and indicate that the bedrock surface lies around 115–120 ft (35.0–36.6 m) beneath unconsolidated Quaternary alluvial floodplain deposits.

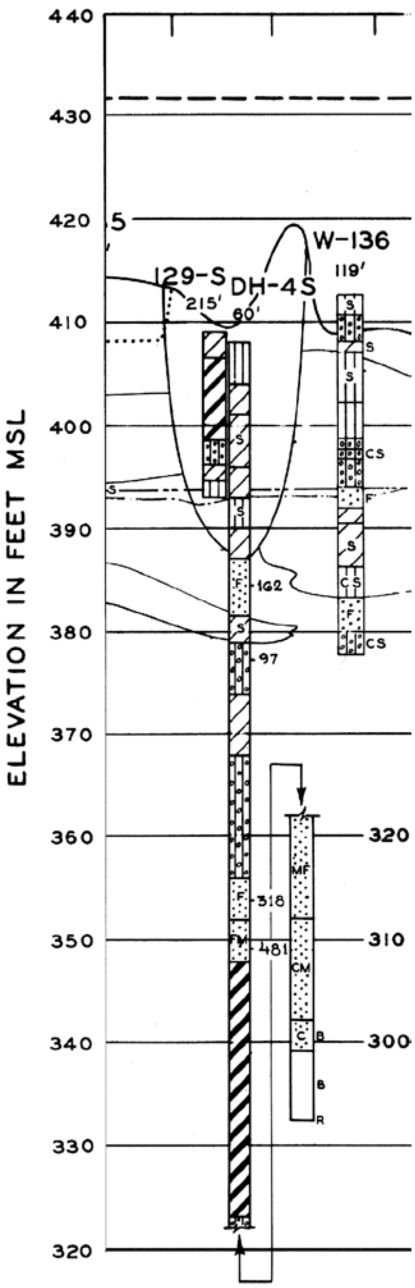

Figure 3. Example of 1956 U.S. Army Corps of Engineers levee boring showing depth to refusal (R).

A USACE boring log from 1963 at a location in the City of St. Louis north of downtown and beneath the St. Louis floodwall shows greater detail, including a core 5 ft (1.5 m) into bedrock, than the 1956 borings on the east side of the Mississippi River (fig. 4). More than 65 ft (19.8 m) of junk fill including cinders, wood, crushed concrete, steel, and underground piping were encountered before native materials were reached. Such heterogeneous fill materials make the modeling of ground response because of seismic shaking difficult because of the high variability over short distances.

A 1972 USACE boring log from the Melvin Price Locks and Dam (LD 26 Replacement) provides detailed information including depth to bedrock, Atterberg limits (where appropriate), gamma logging, standard penetration test (SPT) blow counts, electrical resistivity, and spontaneous potential (fig. 5). Such details, especially blow counts, aid in the ability to predict how such ground will respond and whether or not liquefaction will occur during an earthquake.

Data provided by the Howard Bend Levee District, a private entity in Maryland Heights, Missouri, along the Missouri River, has provided boring locations (fig. 6) and two corresponding boring logs (fig. 7*A* and 7*B*). This work was conducted according to modern sampling and testing methods as part of a project to upgrade the levee to 500-year flood protection. The recently opened (2003) Page Ave. (Mo Route 364) extension passes through the area with its main bridge over the Missouri River located in the center left and Creve Coeur Lake in the lower right of the boring plan (fig. 6), respectively.

This data arrived in digital format but lacked a spatial reference for use with GIS. The image was georeferenced to the same imagery that was used to georeference the USACE plan maps mentioned earlier.

Boring SW-9 from the Howard Bend Levee District was conducted using modern method and shows depth of bedrock at 125.6 ft (38.3 m) and includes SPT blow count data (fig. 7*A* and 7*B*). Although these logs do not core 5 ft (1.5 m) into the underlying bedrock as is done in modern USACE borings, they include standard penetration test (SPT) blowcounts and indicate that the bedrock surface lies approximately 115–125 ft (35.0–38.1 m) beneath a cover of unconsolidated Quaternary alluvium comprising the Missouri River floodplain.

Conclusion

The integration of data from unique sources into a uniform database will greatly assist with the subsurface characterization and subsequent modeling of site response because of a seismic event in the surrounding region. Use of existing

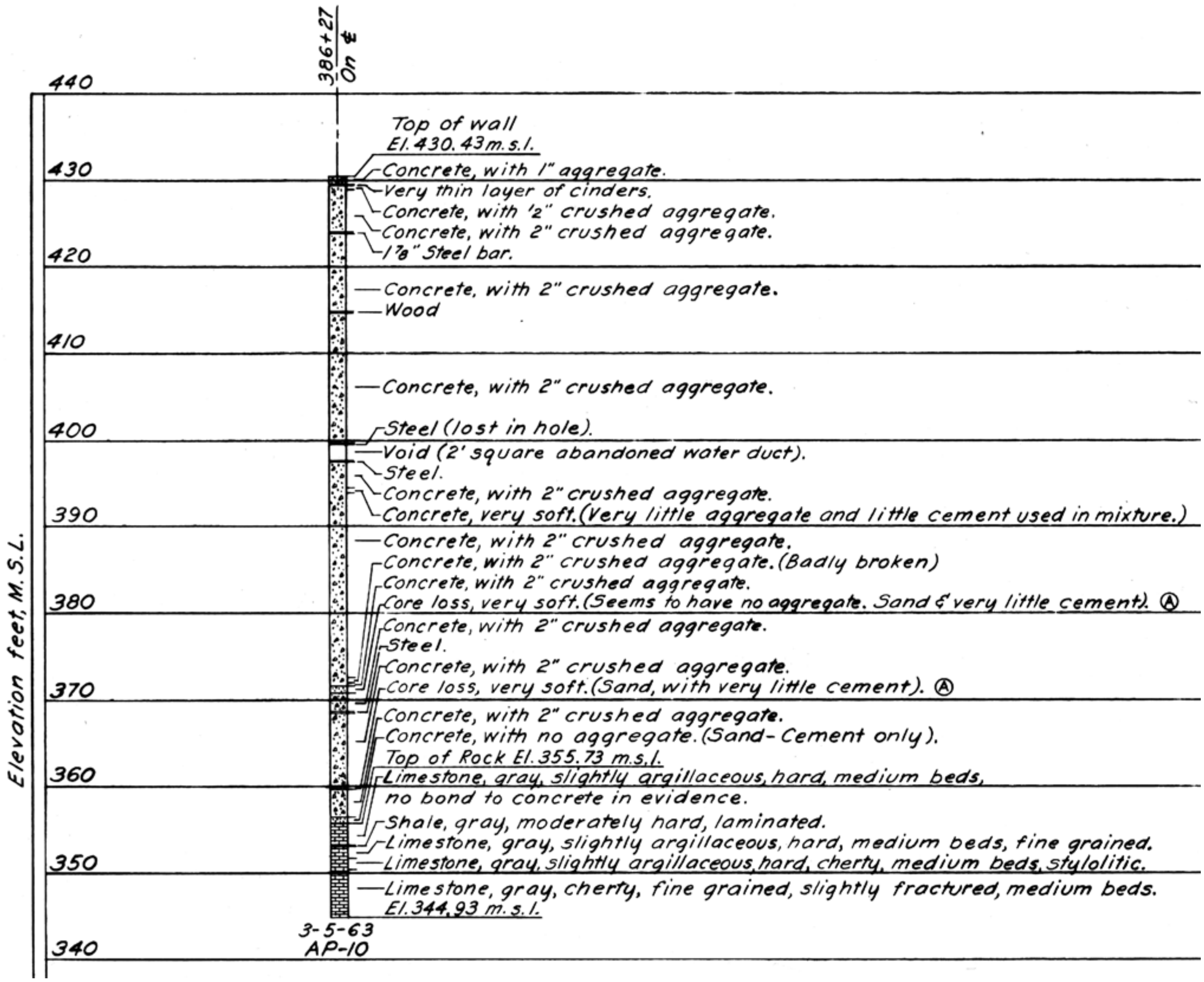

Figure 4. Example of U.S. Army Corps of Engineers boring log (from U.S. Army Corps of Engineers, 1964) illustrating more than 65 feet (19.8 meters) junk fill beneath the St. Louis floodwall.

data has the benefit of providing substantial cost savings but has its own challenges. Often, the data were collected for an entirely different purpose and formats/standards are highly variable among various sources. This information must be transformed to a uniform standard to be used in the creation of hazards maps.

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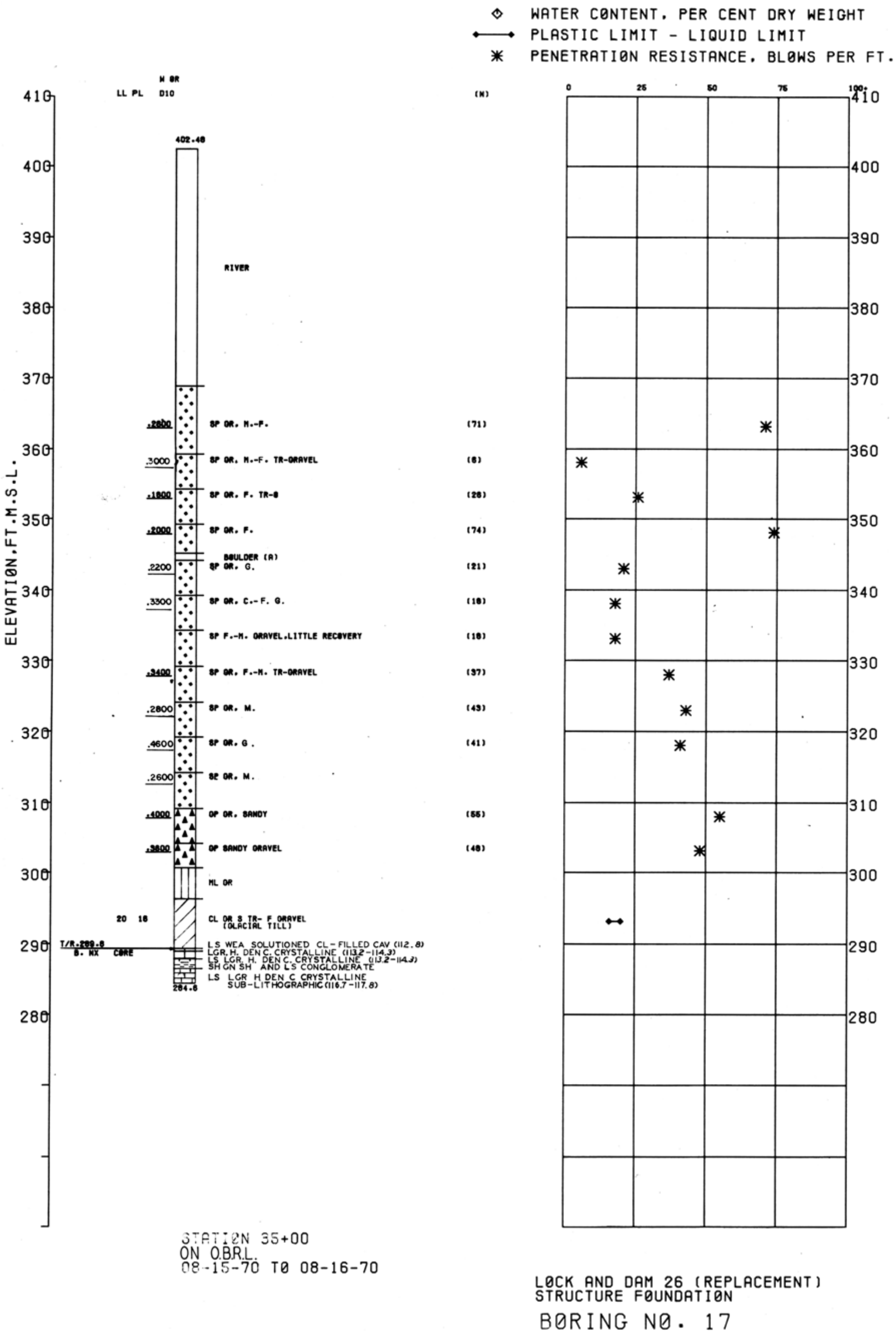

Figure 5. This boring log from U.S. Army Corps of Engineers (1972) was logged according to modern standards and shows greater amounts of detail than older standards for Corps of Engineers borings.

Figure 6. Boring plan (modified from Shannon and Wilson, 2003) illustrating the location of four borings to bedrock as provided by the Howard Bend Levee District.

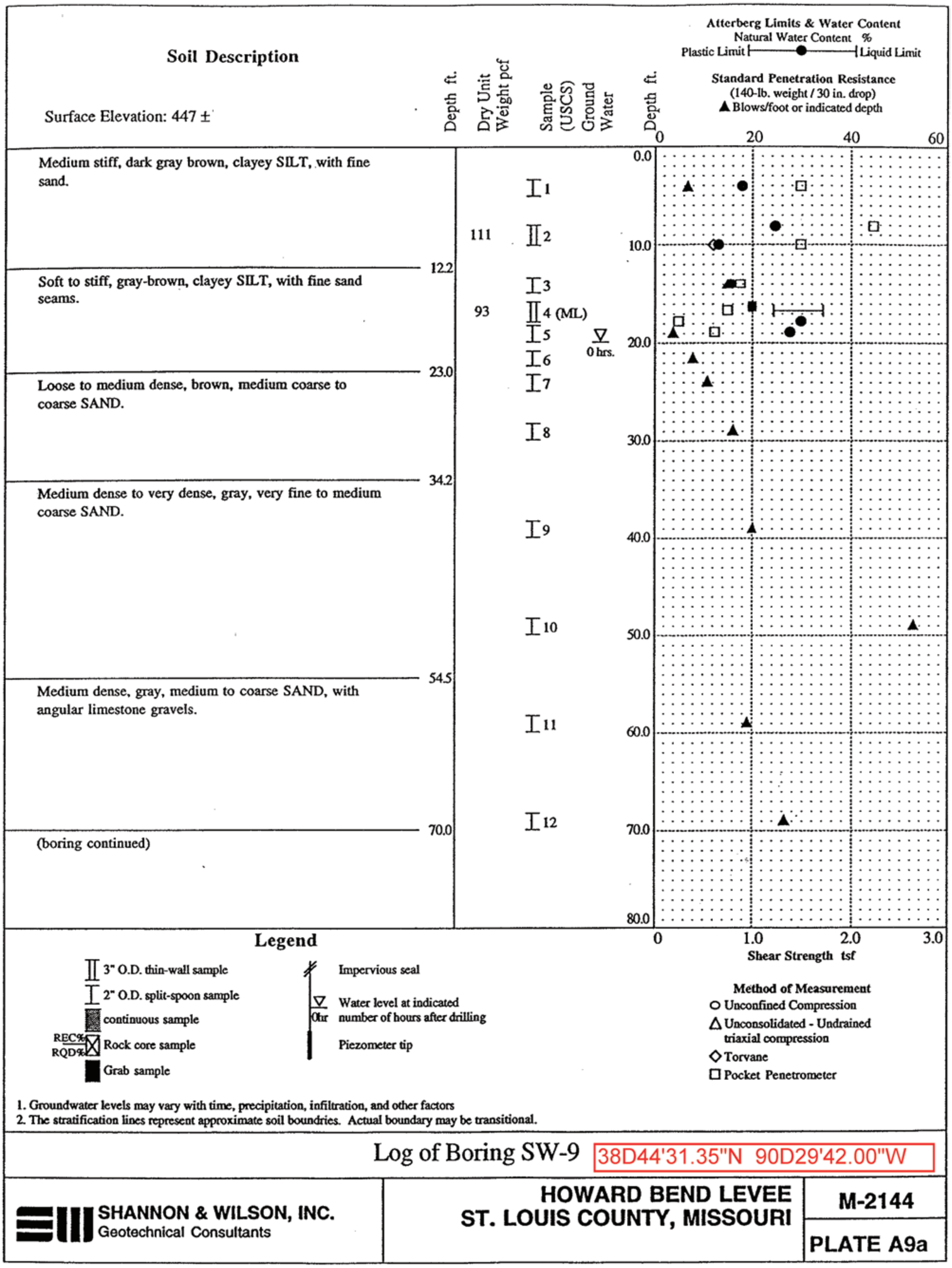

Figure 7. Boring log SW-9 from Shannon and Wilson (2003) shows depth of bedrock at 125.6 feet (38.3 meters) and includes standard penetration test (SPT) blow count data within the Howard Bend Levee District.

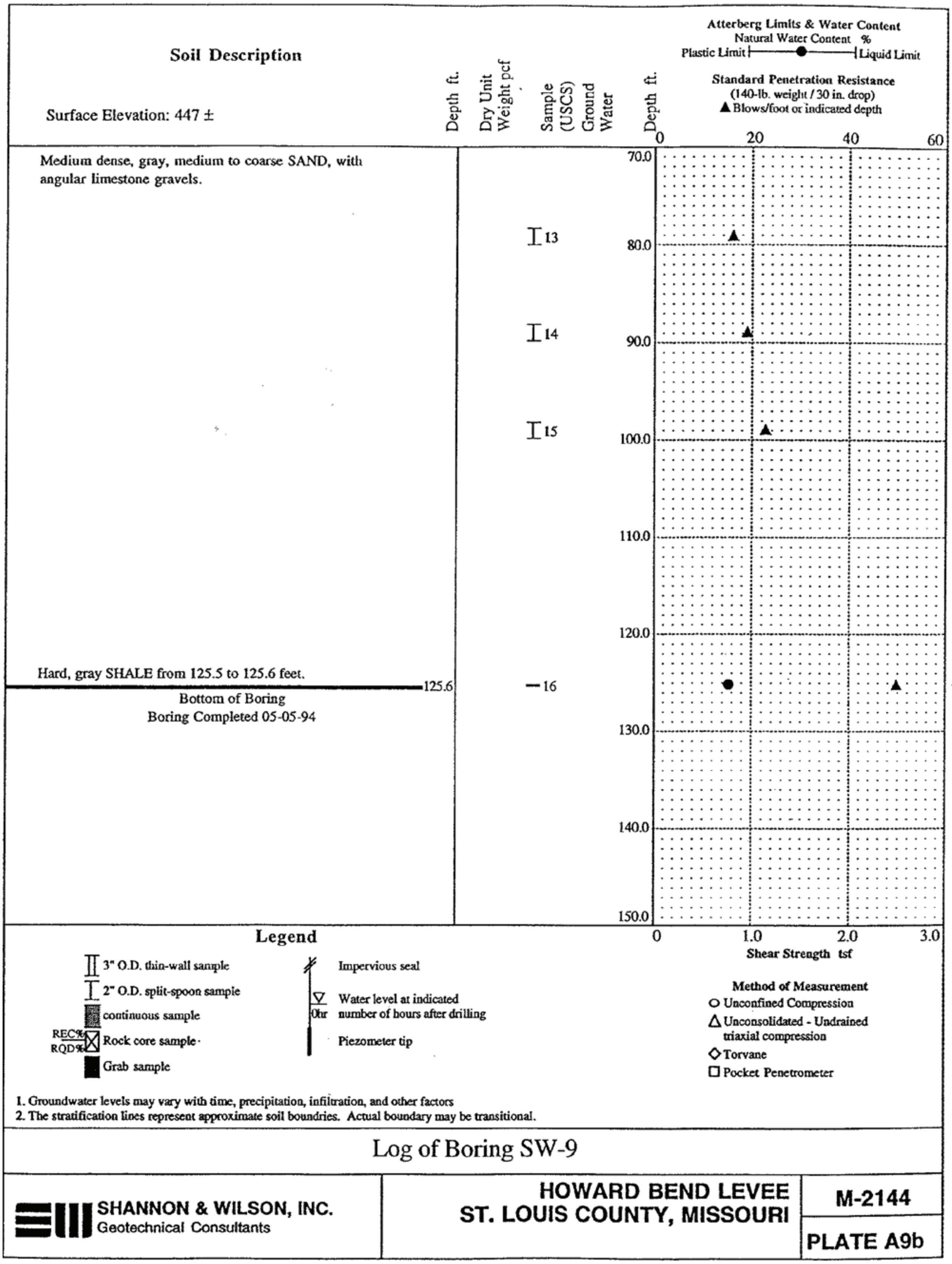

Figure 7. Boring log SW-9 from Shannon and Wilson (2003) shows depth of bedrock at 125.6 feet (38.3 meters) and includes SPT blow count data within the Howard Bend Levee District.—Continued

MoDOT Earthquake Preparedness

By Don Hillis and Rick Bennett

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Missouri Department of Transportation is a key player in nearly all emergencies and disasters. The transportation system is critical to response and recovery from events as well as the economy of the Nation.

A major earthquake in the New Madrid Seismic Zone is considered the worst-case scenario for a disaster in the State of Missouri. MoDOT has been actively planning for the earthquake scenario since 1997. In concert with numerous other agencies the MoDOT Earthquake Plan continues to be improved based on input from exercises, real events and routine reviews. Our plan is a very robust plan that is proving to mesh well with the overall State of Missouri response.

The MoDOT Earthquake Plan is part of our all-hazards "Incident Response Plan". This plan has recently been re-structured and is a true "living document". It can be updated, improved or revised at any time for any reason. MoDOT has responded to numerous real-world disasters and large-scale events in the last several years, including the recent earthquake near Mt. Carmel, Illinois, not to mention numerous winter weather events and flooding events. Each of these provides opportunities to improve our ability to respond and improve our plan.

The New Madrid Earthquake Scenario

By Greg Hempen

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Scenarios are assessments of a specific potential hazard, herein earthquakes, to determine how it would affect a community. The Earthquake Engineering Research Institute (EERI) has been a leader in creating earthquake scenarios. The New Madrid Chapter of EERI has begun development of the New Madrid Earthquake Scenario (NMES). The NMES is scheduled for completion in February 2012, the Bicentennial of the Great New Madrid Series of Earthquakes. The NMES will follow EERI's Guidelines for Developing an Earthquake Scenario (March 2006).

The NMES will provide a comprehensive impact assessment of scientifically credible earthquakes in the New Madrid Seismic Region. The Scenario will include risk-reduction recommendations for individual, public, and corporate interests from future Central U.S. earthquakes.

The Scenario is intended to provide intermediate data and products, culminating in a report in February 2012. Our interest is to reach the broad base of possible participants (reflecting EERI's broad focus from seismology to sociology) and resolve pressing seismic safety issues for the Central United States. Working groups will recommend scenario products, aid in deciding the "Scenario event," and produce their sector's portion of the New Madrid Earthquake Scenario report. One of these products is the Symposium planned for September 2008, "Seismic Sources (Hazards) in the Central United States: *Is New Madrid all there is?*" Another conference on proper Central U.S. Earthquake Time Histories is planned for May 2009. Other meetings, conferences, and products will be developed for the NMES' report, as resolved by the working groups.

Central U.S. Post Earthquake Technical Information Clearinghouse Efforts

By Jim Wilkinson, Norman C. Hester, Stephen Patrick Horton, and Theresa I. Jefferson

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In the Central United States, a Post Earthquake Technical Information Clearinghouse Plan has been developed to coordinate research activities, and to facilitate collaboration between the emergency management and research communities. Because a damaging earthquake in the Central United States will affect several States, a Multistate Technical Information Clearinghouse (MSTIC) Coordination Plan to link State technical information clearinghouses (STICs) is proposed. This paper describes beginning efforts to define the role and functions of a MSTIC as well as formalize plans with emergency management agencies to facilitate collaboration and coordination between STICs and the MSTIC.

A review of the history and functions of technical clearinghouses was conducted. The need for, structure, and roles of the MSTIC were defined. A plan for using the Post-Earthquake Information Management System, currently being developed by the National Earthquake Hazards Reduction Program (NEHRP) to share and integrate information between STICs and the MSTIC was formulated.

Using lessons learned from previous clearinghouse efforts, this study identified a number of issues that need to be addressed and resolved before the occurrence of an event in order for the MSTIC to be effective. These include: clearinghouse hosting and linkage, data collection, data organization and archival, and data dissemination.

The unique multistate impact created by an earthquake in the Central United States necessitates the need for a plan that goes beyond current standard clearinghouse plans. This paper proposes the use of a MSTIC that would enable it to collaborate and coordinate the work of multiple STICs.

ARCHER—Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance

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ARCHER is a custom-designed system of hyperspectral imaging (HSI) hardware and software, with real world applications in the areas of search and rescue, disaster impact assessment and relief, and in the area of homeland security.

ARCHER HSI executes three separate algorithms for target acquisition and detection:

- Spectral signature matching—can be programmed to look for specific colored objects.
- Anomaly detection—compares objects on the ground and identifies colors that do not "fit" in with the normal background environment.
- Change detection—executes a pixel-by-pixel comparison of current ground conditions versus ground conditions obtained in a previous examination over the same area.

HSI is a daytime, non-invasive technology, which works by analyzing an object's reflected light. It cannot detect objects at night, underwater, under dense cover, underground, under snow, or inside buildings. Optimum time to fly is at midday with the sun high in the sky. This provides maximum solar illumination and maximum reflected light. The sensor must "see" at least one square meter of the object being searched for in order to locate it. ARCHER is designed for missions optimally flown at 2,500 ft. above ground level, at a ground speed of 90–100 knots.

The U.S. Geological Survey 2008 Update to the National Seismic Hazard Maps for the Central and Eastern United States

By Oliver S. Boyd, Mark D. Petersen, Arthur D. Frankel, Stephen C. Harmsen, Charles S. Mueller, and Russell L. Wheeler

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Updated U.S. Geological Survey (USGS) National Seismic Hazard Maps of the contiguous 48 States were finalized in April of 2008. These maps, depicting ground motion values (spectral response and peak acceleration) with 2 percent, 5 percent, and 10 percent chances of being exceeded in 50 years, are used in building codes, insurance industries, and emergency preparedness. Regional and topical workshops were convened to discuss the latest understanding of source models and ground motion relationships for the United States, resulting in a consensus estimate of seismic hazard. The work presented here outlines the changes in and subsequent impacts of revisions to the USGS National Seismic Hazard Maps for the Central and Eastern United States (CEUS).

In the CEUS, the maps include improved estimates of source location and description, updated ground-motion relationships and advances in seismic hazard methodology. For example, the New Madrid source zone was fully revamped. Among the various improvements, the locations of fault traces coincide more closely with seismicity, logic trees were added to consider a longer recurrence on the northern arm, and an algorithm was adopted to account for recurrence of 1811–12 type clustered events.

Overall, the updated ground-motion relationships tend to decrease seismic hazard in the CEUS relative to hazard in the previous (2002) maps. The most unusual effect results from the clustering algorithm, for which seismic hazard increases in the center of the New Madrid Seismic Zone, decreases at its northern and southern ends, and then increases again as sites become equidistant from the three New Madrid sources.

Detailed Surficial Material Geologic Maps Over Existing Columbia Bottoms and Granite City 7.5′ Quadrangles Within the St. Louis Area Earthquake Hazard Mapping Project

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Missouri Division of Geology and Land Survey (DGLS) has produced geologic maps of surficial materials for the Missouri portion of the Columbia Bottom and Granite City 7.5-minute USGS quadrangles as part of the St. Louis Earthquake Hazard Mapping Project. Surficial materials mapping comprise the first phase of seismic hazard mapping. It serves to reduce the level of uncertainty in the three-dimensional distribution of surficial material units and their related physical properties.

Boring data from the St. Louis Surficial Materials Database, previously developed by DGLS, was used to develop three-dimensional spatial variation of surficial material units. Other available subsurface data and stratigraphic profiles was reviewed and compared with published small-scale surficial material maps and other previously developed genetic and lithostratigraphic surficial material models to facilitate mapping. These data points were used to verify surficial material type and thickness as well as generating top of bedrock elevation contours.

This analysis is necessary to assess the response of the soil column and liquefaction potential in response to different magnitude earthquakes and potential for site amplification. In addition, the accuracy and precision of earthquake hazards maps being prepared by the St. Louis Area Earthquake Hazard Mapping Project Technical Working Group will be improved.

Geotechnical Earthquake Instrumentation at the Bill E. Emerson Memorial Bridge, Cape Girardeau, Missouri

By Scott M. Olson[11], Youssef M.A. Hashash[12], and Oscar Moreno-Torres[13]

Conference Abstract

The Bill Emerson Memorial Bridge in Cape Girardeau, Missouri is located near the most seismically active region in the Central and Eastern United States, the New Madrid Seismic Zone. Because of the bridge's importance to the regional and national transportation system, Profs. Scott Olson and Youssef Hashash at the University of Illinois, via funding from the Advanced National Seismic System (ANSS) program of the United States Geological Survey (USGS), installed new geotechnical instrumentation at the bridge to substantially augment the existing instrumentation package.

The geotechnical instrumentation includes piezometers and dense downhole accelerometer/inclinometer arrays that will measure ground response in soils that are predicted to liquefy and laterally spread during future earthquakes as well as in soils that have been remediated to prevent liquefaction. The combined geotechnical and structural instrumentation will provide unprecedented opportunities to capture strong, near-field ground motions in the Central United States, observe how soils liquefy and laterally spread, and record and study soil-structure interaction for a major bridge.

Here, we describe the geotechnical instrumentation package and details of its installation, and present potential instrument responses for a number of scenario New Madrid earthquake events, including M5.5, 6.5, and 7.5 earthquakes occurring at a distance of 30 km.

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Post-Conference Paper

Geotechnical Earthquake Instrumentation at the Bill E. Emerson Memorial Bridge, Cape Girardeau, Missouri

By Scott M. Olson[14], Youssef M.A. Hashash[15], and Oscar Moreno-Torres[16]

Abstract

The Bill Emerson Memorial Bridge in Cape Girardeau, Missouri is located near the most seismically active region in the Central and Eastern United States, the New Madrid Seismic Zone. Because of the bridge's importance to the regional and national transportation system, the University of Illinois installed new geotechnical instrumentation at the bridge to significantly augment the existing instrumentation package with funding from the Advanced National Seismic System (ANSS) program of the United States Geological Survey (USGS). The geotechnical instrumentation includes piezometers and dense downhole accelerometer/inclinometer arrays that will measure ground response in soils that are predicted to liquefy and laterally spread during future earthquakes as well as in soils that have been remediated to prevent liquefaction. The combined geotechnical and structural instrumentation will provide unprecedented opportunities to capture strong, near-field ground motions in the Central United States, observe the process involved in liquefaction and laterally spreading, and record and study soil-structure interaction for a major bridge. Equivalent linear, nonlinear total stress and nonlinear effective stress site response analyses were performed to estimate the instrument response to shaking corresponding to 2 percent, 10 percent, and 50 percent probability of exceedance in 50 years hazard levels.

Introduction

Opened in 2003, the Bill Emerson Memorial Bridge over the Mississippi River from Cape Girardeau, Missouri to East Cape Girardeau, Illinois represents a significant component in the regional and national transportation system. As the only 4-lane Mississippi River crossing in 30 miles to the south (Cairo, Illinois) and 100 miles to the north (St. Louis), the bridge also is critical to emergency response and recovery. The 4-lane structure carries about 14,000 vehicles per day (VPD) (circa 2003), and by 2015 it is projected to carry about 26,000 vpd. The cable-stayed bridge structure consists

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primarily of two main towers and cables that support the bridge deck.

Located about 30 km from the New Madrid Seismic Zone (NMSZ), seismic loading and soil liquefaction were major elements of the bridge design. Nearly 80 accelerometers were installed on the structure during construction to monitor structural response to potential seismic shaking. In addition, six accelerometers were installed at or below grade in Missouri and in Illinois to monitor input seismic ground motions. Celebi (2006) provides details of the seismic structural monitoring of the Bill Emerson Memorial Bridge.

This paper describes the geotechnical instrumentation package installed as part of a U.S. Geological Survey (USGS) Advanced National Seismic Systems (ANSS) grant to monitor potential seismic liquefaction and lateral spreading, and presents predicted instrument responses for a number of scenario NMSZ events.

Site Conditions and Seismic Hazard

On the Missouri side of the river, approximately 10 to 13 m of stiff residual clays and silts overlie limestone bedrock and form a bluff overlooking the Mississippi River floodplain in Illinois. The Illinois floodplain consists of approximately 6 m of soft to medium stiff and loose to medium dense interbedded alluvial clays, silts, and sands. Below the interbedded soils, approximately 10 m of medium dense silty sands and sands with standard penetration test (SPT) blow counts (N) from about 10 to 35 are encountered. These soils are highly susceptible to liquefaction as discussed subsequently. From approximately 16 to 30 m, the sands become coarser and denser with SPT N values ranging from about 25 to more than 50. Limestone bedrock underlies the residual and alluvial soils across the site and is known to be karstic (T. Cooling, URS Corporation, written commun.). Groundwater is located about 4 m below the ground surface in the Illinois floodplain.

During the design studies (Woodward-Clyde Consultants, 1994), shear wave velocities (V_S) were measured at two locations in the overburden soils and bedrock. Additional shear wave velocity measurements were obtained (by Drs. Tom Noce and Tom Holzer of the USGS) in the Illinois alluvium during this ANSS project using seismic cone penetration tests. A representative section through the Illinois alluvium, including estimates of VS, drained friction angles, coefficient of at-rest earth pressure, and an estimate of overconsolidation ratio (OCR) is presented in figure 1.

Seismic hazard at the site is dominated at all return periods by the NMSZ, the northern end of which is about 30 km from the bridge site. The NMSZ is capable of developing M~7.5+ earthquakes and the estimated peak ground accelerations (PGA) from the USGS Seismic Hazard Map are 0.03 g, 0.28 g, and 1.11 g for 50 percent, 10 percent, and 2 percent probability of exceedance (PE) in 50 years, respectively. The latter two events are capable of triggering extensive liquefaction and lateral spreading in the medium dense sands and silty sands at the site (Woodward-Clyde Consultants, 1994).

Geotechnical Instrumentation

As part of a USGS ANSS project, the first two authors installed geotechnical instrumentation to measure ground behavior during potential liquefaction and lateral spreading, and the resulting affect on ground motion, soil-structure interaction, and embankment stability, as well as the effectiveness of ground modification performed below the Illinois approach embankment. Instruments installed at Pier 8 (UIUC–1) consisted of two strain-gage piezometers and a MEMS-based ShapeAccelArray (SAA) shown in figure 2. A similar array (UIUC–2) was installed at the toe of the approach embankment (near Pier 15; fig. 2) adjacent to ground improvement installed by the Illinois Department of Transportation. Photos of the UIUC -2 installation are shown in figure 3. The SAA is a combined downhole accelerometer array (five depths record seismic events) and in-place inclinometer manufactured by Measurand, Inc. The piezometers were installed one-third and two-thirds of the way into the liquefiable sands at depths corresponding to accelerometer depths. A third array (UIUC–3) was established adjacent to the existing "free-field" downhole accelerometer array to maximize data obtained from the existing array. At this location, two strain gage piezometers were installed in the liquefiable sands, with one piezometer adjacent to the one accelerometer installed in the alluvium. To date, the instruments have not been triggered by earthquake shaking.

The instruments are wired to an automated data acquisition system that communicates via a wireless local area network to a central data storage and processing computer located near the Missouri approach embankment. The

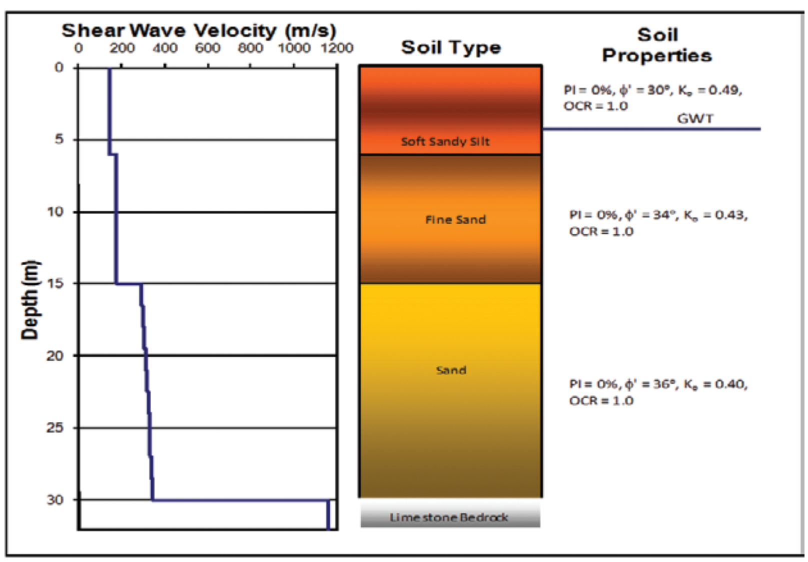

Figure 1. Representative soil profile for Mississippi River floodplain in Illinois.

enclosures for the data acquisition system and the battery storage system, the solar panels that power the system, and the wireless antenna are illustrated in figure 3*F*.

Site Response Analysis at Instrument Array UIUC–1

To examine possible instrument response for various earthquake scenarios, we performed one-dimensional (1D) site response analyses using equivalent linear, nonlinear total stress, and nonlinear effective stress methods using DEEP-SOIL v3.5 (Hashash and others, 2008). We also compared the nonlinear effective stress site response analysis results to simplified methods for estimating liquefaction triggering and excess porewater pressure (PWP) generation. As large earthquakes have not been recorded in the Central and Eastern United States (CEUS), we preliminarily used synthetic bedrock motions (for Site Class B) generated by SMSIM (Atkinson and Boore, 1995) for the site response analyses. For this study, input motions were generated that correspond to 2 percent, 10 percent, and 50 percent PE in 50 years and propagated through the representative profile presented in figure 1. This profile corresponds closely to the subsurface conditions encountered at array UIUC–1.

A sample set of bedrock and surface acceleration time histories computed in the nonlinear effective stress analysis for the 2 percent PE in 50 years hazard level is presented in figure 4. These results exhibit distinct ground motion incoherency 2 to 3 seconds after the start of shaking. The ground motion incoherency and long period motion observed 3 seconds after the start of shaking are consistent with seismic liquefaction occurring early during ground shaking (Youd and Carter, 2005). Similar results were observed for other synthetic ground motions corresponding to a 2 percent PE in 50 years hazard level. Triggering of liquefaction was less severe for synthetic ground motions corresponding to a 10 percent PE in 50 years hazard level, and liquefaction was not predicted for synthetic motions corresponding to a 50 percent PE in 50 years hazard.

Simplified liquefaction potential analyses were performed using the cyclic stress method (Seed and Idriss, 1971; Whitman, 1971) as last updated by Youd and others (2001). Cyclic resistance ratios (CRR) were estimated using the SPT-based method updated by Youd and others (2001) and using the V_S-based method proposed by Andrus and others (2004). Cyclic stress ratio (CSR) was computed using the PGA computed at the surface from the nonlinear total stress

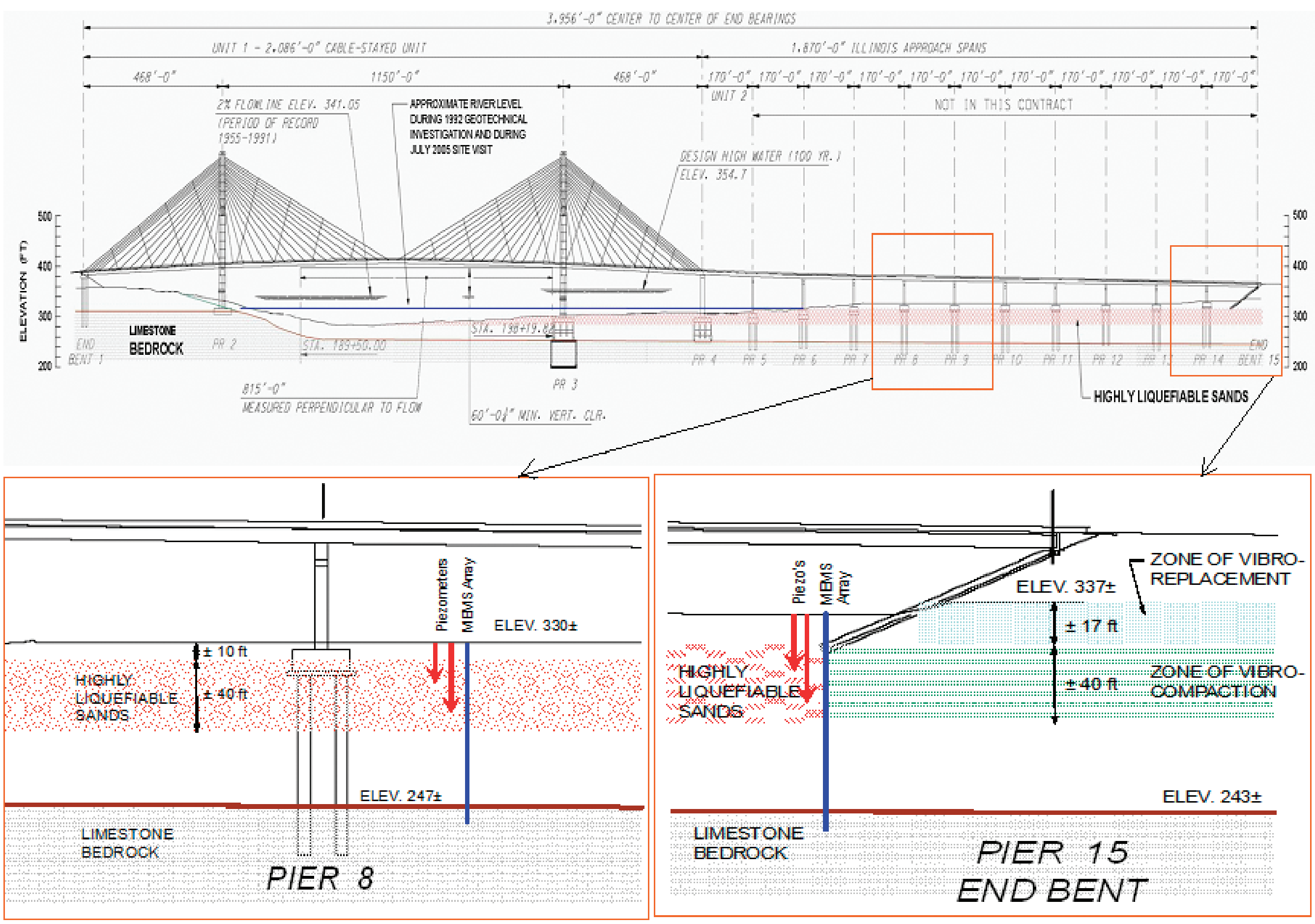

Figure 2. Locations of geotechnical instrumentation arrays UIUC–1 and UIUC–2.

Figure 3. Geotechnical instrumentation, installation, and data acquisition in Illinois.

analyses, then r_d was used to calculate the cyclic stress ratio variation with depth. All other procedures described by Youd and others (2001) were used. The factor of safety against triggering level-ground liquefaction is:

$$FS_{liq} = \frac{CRR}{CSR} \qquad (1)$$

Marcuson and Hynes (1990) proposed correlations between excess PWP ratio, r_u, and FS_{liq} for sands and gravels, where r_u is defined as:

$$r_u = \frac{u_x}{\sigma'_{vo}} \qquad (2)$$

where

u_x = excess PWP and

σ'_{vo} = initial vertical effective stress.

An r_u value equal to unity corresponds to the triggering of liquefaction.

A comparison of maximum ru profiles computed using the simplified method (equations 6 and 7) and using nonlinear effective stress site response analyses for synthetic ground motions corresponding to each hazard level (2 percent, 10 percent, and 50 percent PE in 50 years) is shown in figure 5. The simplified method predicts liquefaction throughout the medium dense sands from about 4 m to 16 m below grade, as well as in the dense sands from 21 m to 26 m and from 29 m to 30 m (fig. 5*A*). In contrast, the nonlinear effective stress site response analyses shows less severe liquefaction, predicting liquefaction around 5 m and from about 13 to 15 m below grade. The sands between 5 and 13 m are predicted to experience PWP increases, but not liquefaction. Below 21 m, small r_u values are predicted, but at levels well below that corresponding to liquefaction.

Comparisons for a sample ground motion corresponding to the 10 percent and 50 percent PE in 50 years, respectively, are illustrated in figures 5*B* and 5*C*. As illustrated in figure 5*B* for the 10 percent PE in 50 years, the simplified method predicts significantly higher r_u values than the nonlinear effective stress site response analysis, although the zones of sand that exhibit PWP increase are similar. For the 50 percent PE in 50 years example, neither the simplified method nor the nonlinear effective stress site response analysis predicted excess PWP generation.

Conclusions

As part of a USGS ANSS project, the first two authors installed geotechnical instrumentation at the Bill E. Emerson

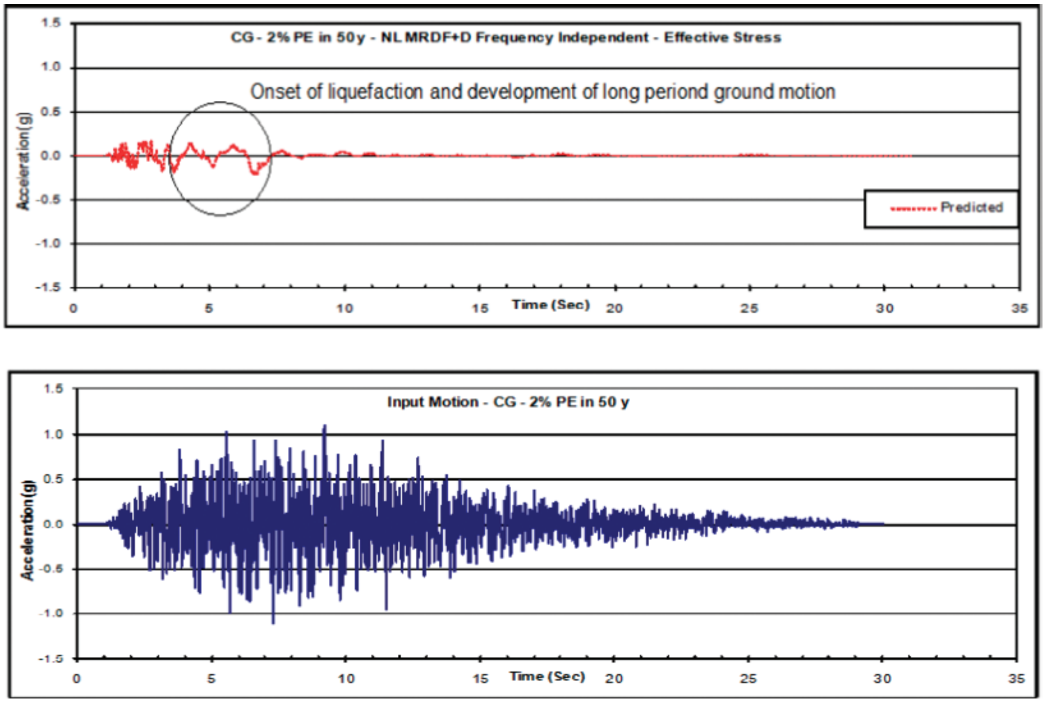

Figure 4. Ground motion incoherency predicted by nonlinear effective stress site response analysis.

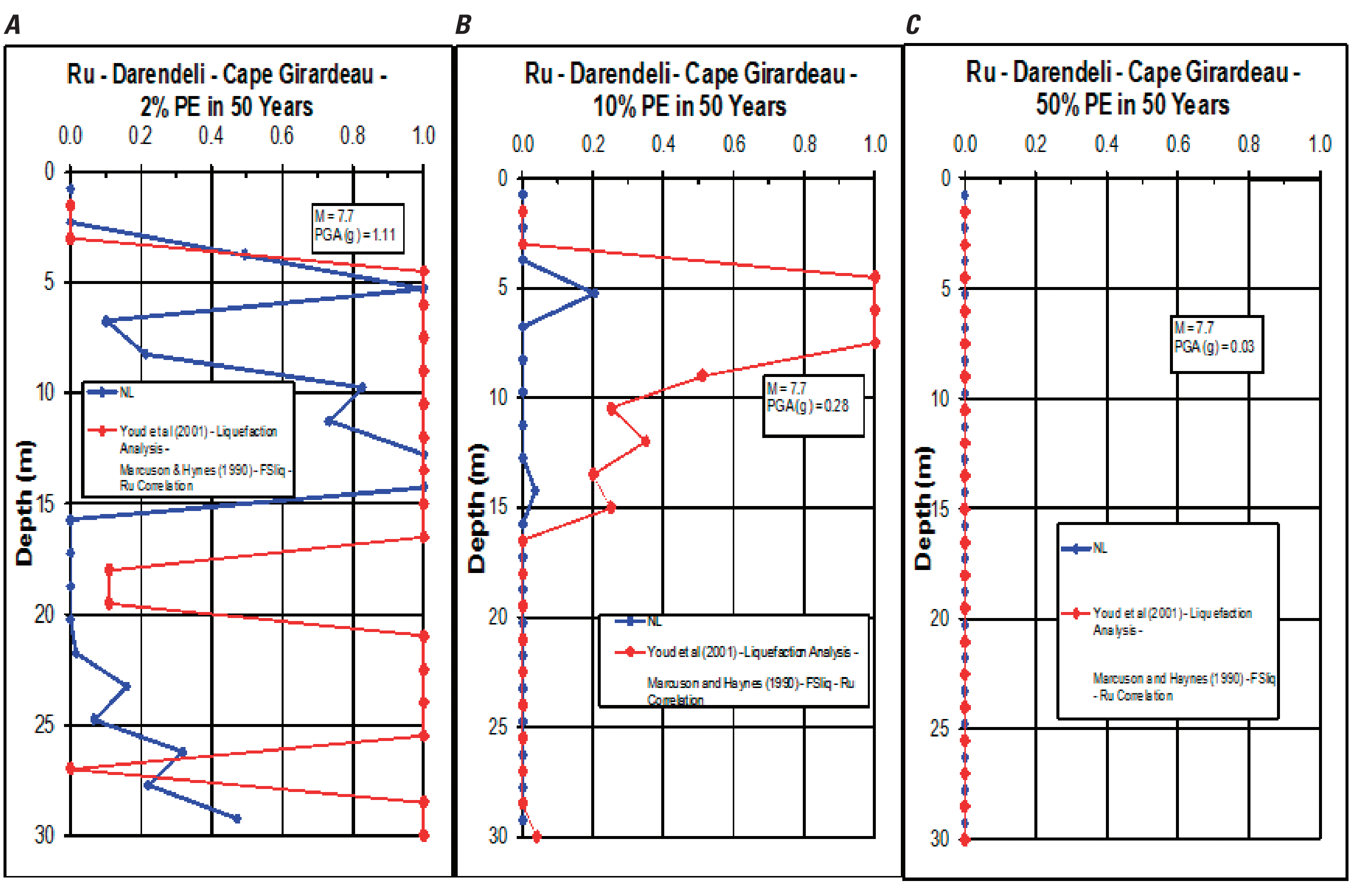

Figure 5. Example comparisons of excess porewater pressure ratios predicted by nonlinear effective stress site response analysis and simplified liquefaction analysis. (*A*) 2 percent probability of exceedence (PE) in 50-year ground motion, (*B*) 10 percent PE in 50-year ground motion, and (*C*) 50 percent PE in 50-year ground motion.

Memorial Bridge to significantly augment the existing structural instrumentation on the bridge. The geotechnical instruments will measure ground response in soils that are predicted to liquefy and laterally spread during strong earthquakes. The combined geotechnical and structural instrumentation provides unprecedented opportunities to capture strong, near-field ground motions in the Central United States.

Predictions of instrument responses for scenario New Madrid earthquakes were made using equivalent linear, nonlinear total stress, and nonlinear effective stress site response analyses. The nonlinear effective stress results predicted significant ground motion incoherency at the 2 percent PE in 50 years hazard level. These analyses also predicted less severe porewater pressure generation for the 2 percent and 10 percent PE in 50 years hazard levels than simplified empirical methods. No excess porewater pressure generation was predicted for the 50 percent PE in 50 years hazard level using either the site response analyses or the simplified method.

Acknowledgments

This work was supported in part by U.S. Geological Survey, Department of the Interior, under USGS Agreement No. 06CRGR0006 under the guidance of Drs. Woody Savage and Bill Leath of the USGS. Dr. Mehmet Celebi (USGS) provided information on the existing structural instrumentation. Mr. Bryan Heartnagel (Missouri Department of Transportation, MoDOT) provided bridge plans and served as a point of contact for MoDOT. Mr. Greg Smothers (Illinois Department of Transportation, IDOT) served as a point of contact for IDOT. Mr. Joe Zdankiewicz (IDOT) provided geotechnical reports for the Illinois approach. Their input is gratefully acknowledged. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either express or implied, of the U.S. Government or the individuals mentioned above.

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Development of Composite Dispersion Curves for the Determination of Shear Wave Velocity Profiles

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Spectral analysis of surface waves (SASW) and refraction micro-tremors (ReMi) are two non-intrusive methods used for determining in situ shear-wave velocities. While both methods applied individually have been shown to produce reasonable results, both suffer from poor resolution for specific frequency ranges. The SASW method produces good results in the upper 30 meters controlled by frequencies above 5 Hz where signal to noise ratios are acceptable. The ReMi method produces good results in the frequency range of 2 to 15 Hz but suffers from lack of high frequency ambient noise and spatial aliasing. By combining the two methods, we can produce a composite dispersion curve with higher accuracy in both low and high frequency ranges resulting in a better determination of shear wave velocity profile.

Communicating Earthquake Mitigation with the Health/Hospital Community: Moving from Information to Action and Closing the Loop

By Sue L. Evers and Cathleen Carlisle

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Under the National Earthquake Hazards Reduction Program, roles of the Federal Emergency Management Agency (FEMA) include guidance development, building codes and standards, training, outreach, State and local coordination, and partnerships. To achieve the technology transfer, FEMA has produced many publications, moving the research findings into technical documents, then into training and outreach. The challenge has been to move from providing information to achieving action from recipients of the information. This project will discuss how we are moving to close the loop. Since January of 2005, there have been more than 200 earthquakes along the New Madrid Seismic Zone, many of which were widely felt throughout the region. When and where the next one will occur, and how large it will be, are questions that are difficult, if not impossible, to answer with any certainty, but reducing the vulnerability from damages is possible.

Hospitals have unique nonstructural components, including special equipment and unique infrastructure systems. Even during smaller-sized earthquakes, nonstructural components of hospitals can cause injury and/or varying amounts of damage. Furthermore, hospitals must remain operational during and after an earthquake. By using sound, cost effective mitigation techniques, operations can be maintained and losses can be reduced, and in some cases eliminated. With our partners, we took the segments most critical to hospital functionality following an earthquake and packaged the information in plain language with photos of hospital earthquake damage and the mitigation fixes. Our plan is to follow up with class participants and report back on the actual implementation.

The St. Louis Area Regional Response System (STARRS) and its sponsoring partners hosted two one-day workshops on earthquake mitigation for hospitals. Some of the topics covered included the earthquake hazard, State earthquake program overview, FEMA existing buildings program, and nonstructural mitigation for hospital facilities.

Determining Social Impacts and Needs Assessments based upon HAZUS-MH Damage and Loss Estimates

By Theresa I. Jefferson, John Harrald, and Frank Fiedrich

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A FEMA funded catastrophic planning and preparedness project is focusing on utilizing essential scientific and technical modeling results to predict potential physical and human consequences should a New Madrid Seismic Zone (NMSZ) earthquake occur. The software program, HAZUS-MH, a public-domain application, is being utilized to produce damage and loss estimates based on a scientifically defendable scenario. This paper describes the methodology developed to translate the damage and loss estimates into a variety of social impacts and needs assessments.

Through interviews with various emergency response organizations, an inventory of the most valuable information necessary for making decisions regarding planning and response was compiled. This data was used to determine the various social impacts and needs assessments to be modeled.

A methodology was developed for utilizing HAZUS outputs to determine the following:

- “At risk” populations.
- Sheltering and commodities requirements.
- Chronic illnesses requiring medical support.
- Pet sheltering.
- Sheltering analysis.
- Vulnerability analysis.
- Emergency fuel requirements.
- Security issues—prison populations.

HAZUS-MH was originally designed as a mitigation tool. This is the first large scale effort to adapt the modeling results to a planning and preparedness environment. By translating the outputs of HAZUS into information describing social impacts and needs assessments it is possible to provide the emergency management community with the information they need to develop effective response strategies and to determine the capabilities and capacity required for response to a catastrophic event.

Multistate Technical Information Clearinghouse

By Jim Wilkinson and Theresa I. Jefferson

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Natural disasters occur infrequently, limiting our ability to develop an inclusive knowledge base concerning such events. The ability to study, interpret, and document findings immediately following a damaging seismic event, is a critical step in furthering our understanding of events, allowing for effective awareness, mitigation, response, and recovery efforts. In the Central United States, a Post Earthquake Technical Information Clearinghouse (PETIC) Plan has been developed to coordinate research activities, and to facilitate collaboration between the emergency management and research communities. Because a damaging earthquake in the Central United States will affect several States, a Multistate Technical Information Clearinghouse (MSTIC) Coordination Plan to link State technical information clearinghouses (STICs) is proposed. This paper describes initial efforts to define the role and functions of a MSTIC as well as formalize plans with emergency management agencies to facilitate collaboration and coordination between STICs and the MSTIC.

Seismic Hazard, Risk, and Mitigation Policy in the New Madrid Seismic Zone

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Large earthquakes of about M7.5 that are similar to those that occurred during 1811–12 in the New Madrid Seismic Zone are of great concern for the communities in the Central United States, particularly in northeastern Arkansas, western Kentucky, southeastern Missouri, and northwestern Tennessee. It has been determined that these large earthquakes occurred several times in the past few thousands of years with an average recurrence interval of 500 to 1,000 years. It has also been determined that these large earthquakes concentrated along the New Madrid faults coincide with present-day seismicity. All these indicate that the communities in the Central United States are facing significant seismic hazards. In terms of magnitude, the seismic hazard can be measured as an M7.5 earthquake, with an average recurrence interval of 500 to 1,000 years. The median peak ground accelerations (PGA) are estimated to be about 0.25 g in Memphis and 0.1 g in St. Louis, respectively. Therefore, in terms of ground motion at a specific site, the seismic hazard can be measured as a 0.25 g PGA in Memphis or 0.1 g PGA in St. Louis with recurrence interval of 500 to 1,000 years, respectively. A PGA of 0.3 g with a recurrence interval of 500 to 1,000 years can also be estimated in Paducah, Kentucky. These are estimated seismic hazards based on the current scientific understanding of the New Madrid Seismic Zone. These hazard estimates, however, may not be enough for making mitigation policy because a policy decision is based more on seismic risk than on seismic hazard.

Seismic hazard and risk are two fundamentally different concepts, and the definition of seismic risk is broad and subjective. In a general term, risk is the probability (chance) of harm if someone or something (vulnerability) is exposed to a hazard. In a quantitative term, risk is defined by three parameters: probability, a level of hazard, and exposure (time and asset). Therefore, seismic risk is generally defined as the probability of experiencing a level of seismic hazard or loss for a given exposure (time and asset), for example, 5–10 percent probability of exceedance of a M7.5 earthquake in 50 years, 5–10 percent probability of exceedance of 0.25 g in 50 years in Memphis, and 0.1 g in St. Louis. These risk estimates are based on 1) time-independent (Poisson) model that could be used to describe the occurrences of earthquakes; 2) an exposure such as a building or bridge with a life of 50 years. If the fragility curve (a relation between damage potential and ground motion level) for a building or bridge is known, seismic risk in terms of economic loss can also be estimated. For example, if a PGA of 0.1 g could cause $10,000 damage to a building in St. Louis, the estimated seismic risk for the building is 5–10 percent probability of exceedance of $10,000 in 50 years.

These are estimated seismic hazards and risks posed by the large earthquakes in the New Madrid Seismic Zone. These risk estimates should be the bases for any mitigation policy consideration.

Publishing support provided by:
Rolla and Denver Publishing Service Centers

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Witt—Proceedings of Preparing for a Significant Central United States Earthquake—Science Needs of the Response and Recovery Community—SIR 2010–5173

ISBN 978-1-4113-2983-6
9 781411 329836

Printed on recycled paper