UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PROCEEDINGS OF CONFERENCE XXIII

A WORKSHOP ON "CONTINUING ACTIONS TO REDUCE POTENTIAL LOSSES FROM FUTURE EARTHQUAKES IN ARKANSAS AND NEARBY STATES"

SEPTEMBER 20-22, 1983

NORTH LITTLE ROCK, ARKANSAS

Reston, Virginia
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CONVENED UNDER AUSPICES OF
NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

SPONSORED BY

U.S. GEOLOGICAL SURVEY,
THE FEDERAL EMERGENCY MANAGEMENT AGENCY, AND
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CONVENOR AND CHAIRMAN OF THE STEERING COMMITTEE

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1983

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by

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INTRODUCTION

The workshop, "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States," was held in North Little Rock, Arkansas, on September 20-22, 1983. The U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), and the Arkansas Office of Emergency Services cosponsored the meeting.

This workshop was the twenty third in a series of workshops and conferences that USGS has sponsored since 1977, usually in cooperation with one or more other agencies or institutions. Each workshop and conference has the general goal of improving knowledge utilization by bringing together knowledge producers and users. For each workshop or conference, a steering committee is created to tailor the objectives to the geographic region and to foster a process that counteracts the criticism that much of the knowledge produced through research is not fully utilized. Inadequate utilization of research occurs because of either the lack of a process which links knowledge producers and users, sometimes referred to as a network, or because of inefficient use of a network.

Seventy-five people having varied backgrounds in earth science, social science, architecture, engineering, and emergency management participated in the workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States." They represented local, State, and Federal Government, industry, architectural and engineering firms, academia, and voluntary agencies. Most came from the Eastern United States (see Appendix A of the report for a list of participants).

HISTORICAL SEISMICITY IN ARKANSAS

Most of the 130 significant earthquakes known to have occurred in Arkansas since 1699 have been centered in the northeastern corner of the State, in the New Madrid seismic zone. Earthquakes have also been recorded in most other parts of the State except the far south and northwest corner of the State. The strongest earthquake recorded in Arkansas occurred December 16, 1911. It was centered near the Cross-Crittenden County line north of Norvell and Parkin. This earthquake was one of the three great earthquakes that occurred in the New Madrid seismic zone in late 1811 and early 1812. (The two in 1812 were centered in southeast Missouri.) The 1811-1812 sequence, which had epicentral intensities of XI - XII on the Modified Mercalli intensity scale, caused extensive deformation of the land surface of the surrounding area and were felt as far away as Canada, the Atlantic Coast, and the Gulf Coast (see Figure 1). Casualties and damage to man made structures were not extensive; however, the area was sparsely inhabited at the time. Aftershocks followed

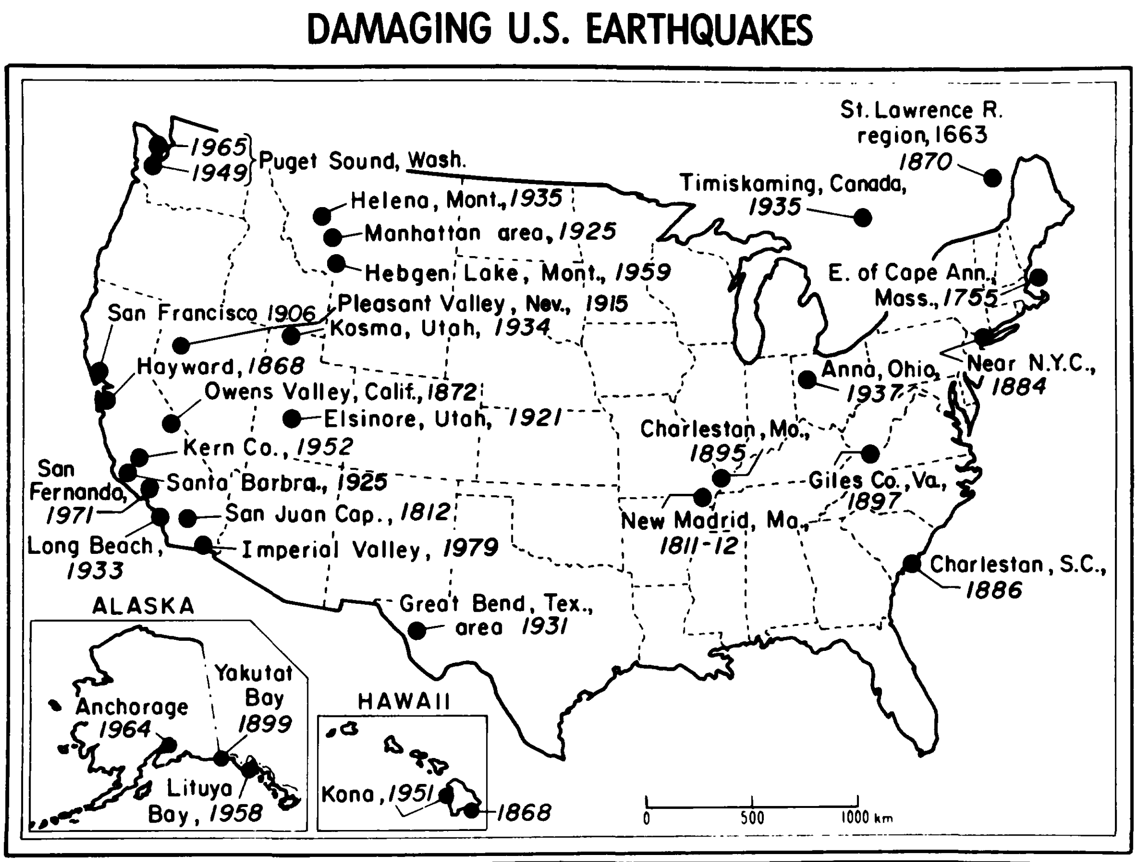


Figure 1.--Map showing location of notable earthquakes in the United States.

each earthquake for several years. The two earthquakes having the highest value of epicentral intensity (Modified Mercalli VII) in the 20th century occurred October 28, 1983, north of the epicenter of the 1811 earthquake, and May 7, 1927, in Craighead County, a few miles south of Jonesboro. The earthquake that occurred December 19, 1965, at Blytheville was recorded instrumentally and assigned a magnitude of 5.3. The 1982-1983 earthquake swarm near Enola is the most significant recent earthquake activity.

OBJECTIVES OF THE WORKSHOP

This workshop is the fifth in a subseries specifically designed to define the earthquake threat in the Eastern United States and to improve earthquake preparedness. The four prior workshops on earthquake preparedness were sponsored by USGS and FEMA and brought together producers and users of hazard information with the goal of fostering partnerships.

The first workshop, "Preparing for and Responding to a Damaging Earthquake in the Eastern United States," was held in Knoxville, Tennessee, in September 1981. The Knoxville workshop (described in USGS Open-File Report 82-220) demonstrated that policymakers and members of the scientific-engineering community can assimilate a great deal of technical information about earthquake hazards and work together to devise practical work plans. The workshop resulted in the creation of a draft 5-year work plan to improve the state-of-earthquake-preparedness in the Eastern United States and marked the birth of the South Carolina Seismic Safety Consortium.

The second workshop, "Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area," was held in St. Louis, Missouri, in May 1982. It resulted in the identification of specific actions with a high potential for reducing losses that could be implemented immediately and the formation of the Governor's of Kentucky Task Force on Earthquake Hazards and Safety. The results of the workshop (described in USGS Open-File Report 83-157) reaffirmed that pratical work plans can be created efficiently by a diverse group.

The third workshop, "The 1886 Charleston, South Carolina, Earthquake and its Implications for Today," was held in Charleston, South Carolina in May 1983.

The Charleston workshop had multiple objectives involving the discussion of scientific information and its use in the siting of critical facilities and preparedness.

The fourth workshop, "Continuing Actions to Reduce Potential Losses from Future Earthquakes in the Northeastern United States," was held at Massachusetts Institute of Technology, Cambridge, Massachusetts, on June 13-15, 1983. The Boston workshop was designed to define the earthquake threat. It was designed to accelerate the ongoing work of the Arkansas Office of Emergency Services, providing a forum for discussion of their activities to prepare for and respond to the earthquake hazard.

RECENT SEISMIC STUDIES IN THE CENTRAL UNITED STATES

Since the early 1970's major advances have been made towards understanding the nature of earthquake hazards in the Central United States. Below is a discussion of some of the more notable studies. The National Earthquake Hazards Reduction program stimulated many of the studies. These and other studies are discussed in more detail in other sections of the proceedings.

Investigation of the New Madrid, Missouri, Earthquake Region, Geological Survey Professional Paper 1236

This comprehensive report describes geological, geophysical, and geochemical investigations in New Madrid, Missouri, and contiguous regions. The studies contained in the report cite major advances made since 1973 toward understanding the nature of earthquakes and earthquake hazards in the stable interior of a continent. Many of these advances are the product of the seismic network which operates throughout the region (see Figure 2).

National Ground-Shaking Hazard Maps

The USGS increased its research activities in the Central United States following the Earthquake Hazards Reduction Act in 1977. One of the studies involved the preparation of national ground-shaking hazard maps (Algermissen and others, 1982). These maps (and the predecessor map (Figure 3) produced by Algermissen and Perkins, 1976) are being used by the Applied Technology Council (ATC).

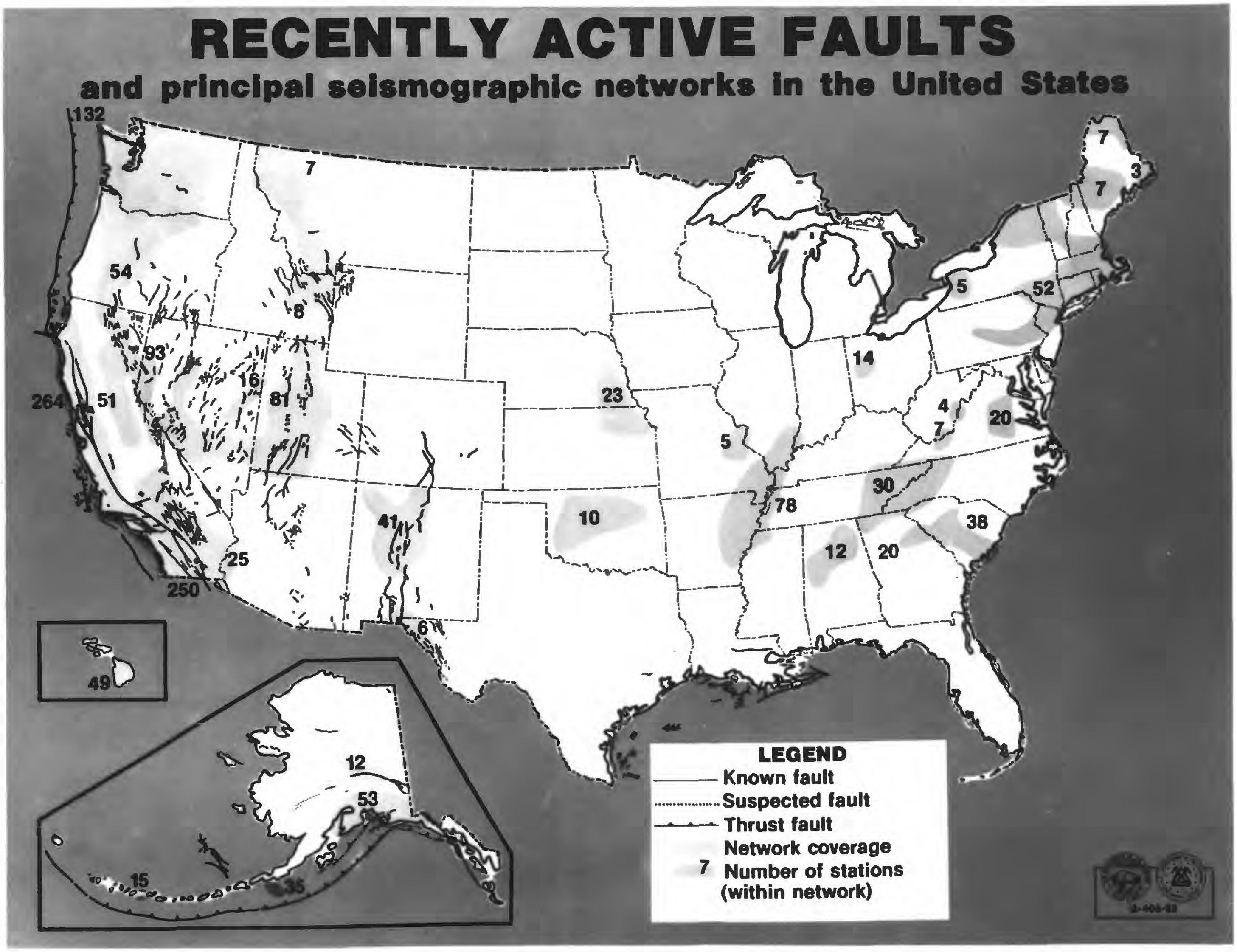


Figure 2.--Recently active faults and the principal seismographic networks in the United States.

The ATC, organized by the Structural Engineers Association of California in 1971, completed a draft report entitled "Tentative Provisions for the Development of Seismic Regulations for Buildings," in 1978. This report contains ground motion maps of effective peak acceleration and effective peak velocity for bedrock sites. These maps show the estimated ground motion in a 50 year period with a 90 percent probability of not being exceeded, and provide a realistic basis for comparing the relative severity of ground shaking throughout the United States (see Figure 4). In the New Madrid seismic zone, the value of effective peak acceleration for sites underlain by bedrock can be greater than 0.2 g locally. The recommendations contained in the ATC report are currently being tested in trial designs at a number of locations throughout the United States by the Building Seismic Safety Council, a program funded by FEMA.

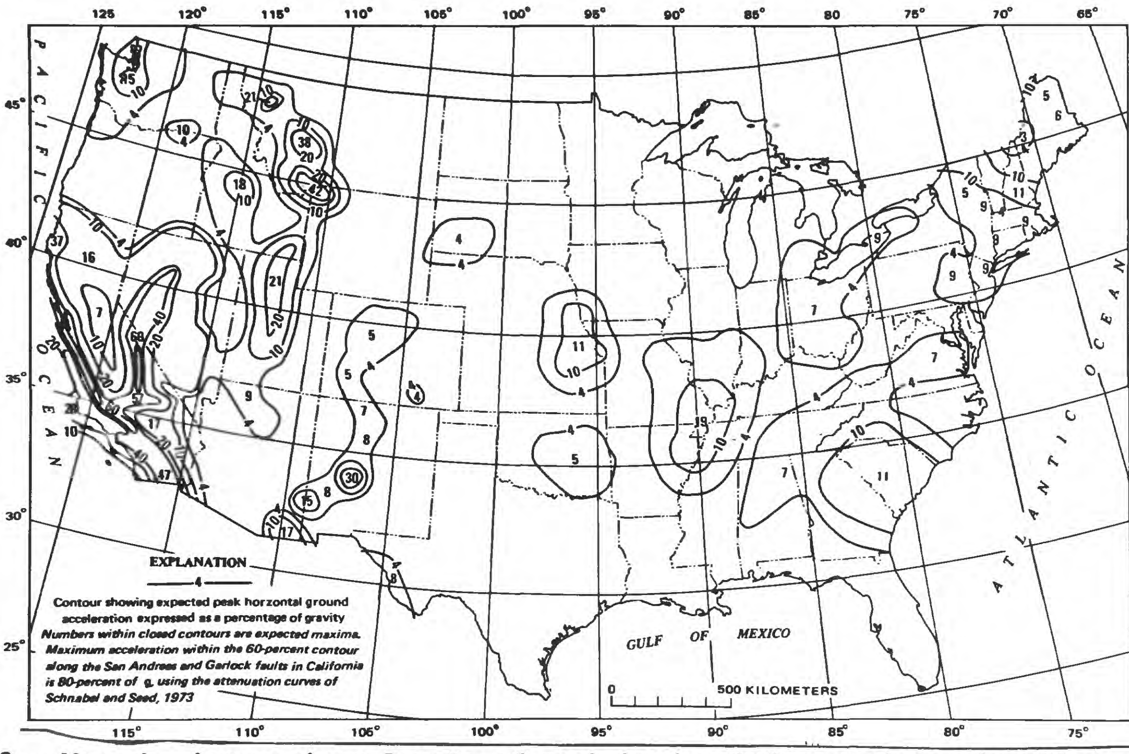


Figure 3.--Map showing maximum levels of peak horizontal ground acceleration at rock sites in the United States in a 50 year period, (Algermissen and Perkins, 1976). The contoured values of acceleration represent the 90 percent probability level; that is, there is a 90 percent chance that these values will not be exceeded within a 50 year period.

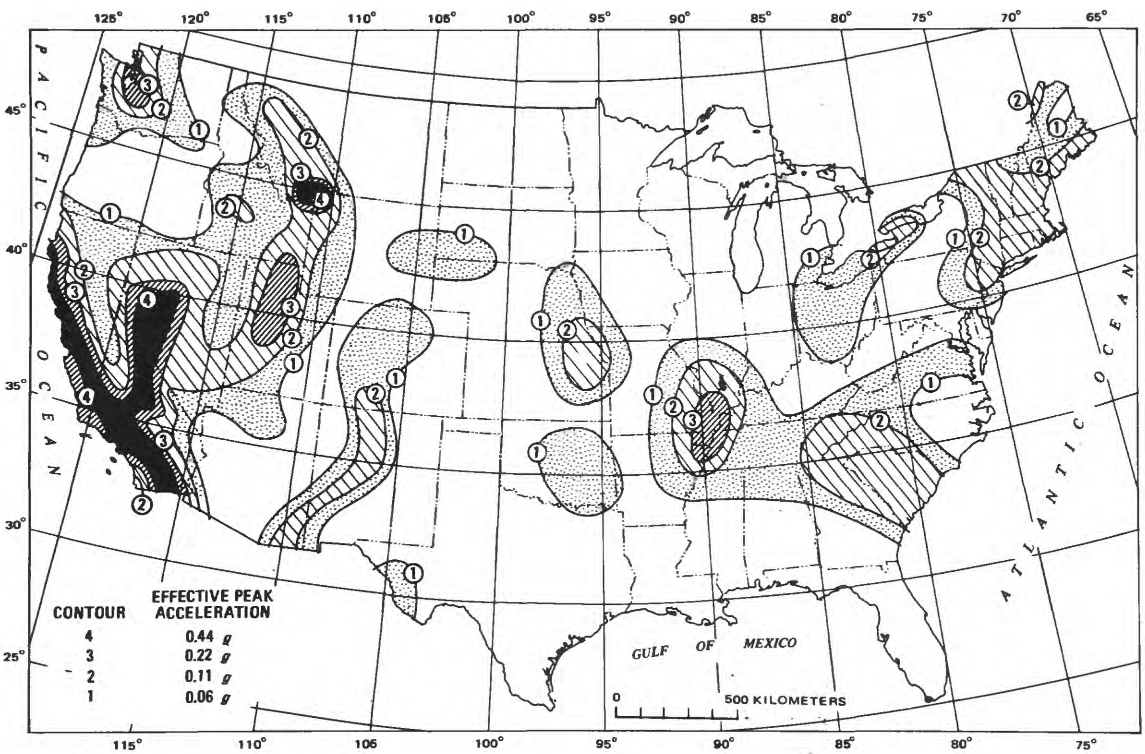


Figure 4.--Map showing preliminary seismic zones proposed by the Applied Technology Council (1978). Contours connect area having equal values of peak acceleration. The New Madrid seismic zone falls mainly in zones 1, 2, and 3.

1982-1983 Enola Swarm

The Tennessee Earthquake Information Center has operated a net of portable seismic instruments in the region of Enola, Arkansas, throughout the 20 months in which it has experienced a swarm of 25,000 earthquakes with the largest earthquake recorded at M 4.5 and the thousands of "ultra-micro earthquakes with -3 to -4 magnitudes. The swarm of earthquakes has caused a rethinking of current ideas about midplate seismic activity and raised fascinating seismological questions.

"Estimation of Earthquake Effects Associated With A Great Earthquake In The New Madrid Seismic Zone, USGS Open File Report 83-179"

The estimates of the effects of a great earthquake are based on the distribution of intensities associated with the earthquakes of 1811-12, 1843, and 1895. Specific intensity maps were developed for 6 cities near the epicentral region taking into account the most likely distribution of site response in each city.

"Central United States Earthquake Prepardness Project: Six City Report"

The report will present an assessment of the expected casualties, damage, and disruption expected to occur in the six Central United States cities as a result of the hypothetical occurrence of a great earthquake anywhere in the Mississippi Valley. The consulting firm of Allen and Hoshall, Inc. are preparing this study for the Federal Emergency Management Agency

WORKSHOP PROCEDURES

The procedures used in the workshop were designed to enhance the interaction between all participants and to facilitate achievement of the objectives. The following procedures were used:

PROCEDURE 1: Research reports and preliminary technical papers of the participants were distributed at the workshop and used as basic references.

The technical papers of the participants were finalized after the workshop and are contained in this publication.

PROCEDURE 2: Scientists, social scientists, engineers, and emergency management specialists gave oral presentation in ten plenary sessions.

The objectives were to integrate research--hazard awareness--preparedness knowledge and to define the problem indicated by the session theme, clarifying what is known about the New Madrid earthquakes and what knowledge is still needed. These presentations served as a summary of the state-of-knowledge and gave a multidisciplinary perspective.

PROCEDURE 3: The participants responded to the presentations of the speakers and panelists, using questions posed to focus the discussion.

PROCEDURE 4: Discussion groups were convened following the plenary sessions to generate recommendations for future research and mitigation actions.

PROCEDURE 5: Ad hoc discussions on topics not addressed during the plenary and small group discussions added a spontaneous dimension to the workshop.

PLENARY SESSIONS

The overall theme of the workshop was developed in six plenary sessions. The themes, objectives, and speakers for each session are described below:

SESSION I: THE NATURE AND EXTENT OF EARTHQUAKE HAZARDS IN A ʺANSAS

OBJECTIVE: Presentations giving an overview of the current status of knowledge gained from geologic and seismological research in the New Madrid seismic zone.

SPEAKERS: Otto Nuttli
David Russ
Arch Johnston

SESSION II: PRELIMINARY RESULTS OF THE FEMA EARTHQUAKE VULNERABILITY STUDY IN THE CENTRAL UNITED STATES

OBJECTIVE: Presentation describing the preparation of isoseismal maps, the development of fragility curves for estimation of earthquake-induced damage, and a preliminary assessment of the potential vulnerability.

SPEAKERS: Margaret Hopper
Mike Banker
Martin McCann

SESSION III: AWARENESS AND CONCERN ABOUT EARTHQUAKE HAZARDS IN THE CENTRAL UNITED STATES

OBJECTIVE: Presentations describing current social science research findings.

SPEAKERS: Joanne Nigg
Alvin Mushkatel

SESSION IV: RESPONDING TO A HYPOTHETICAL EARTHQUAKE IN ARKANSAS

OJBECTIVE: A presentation giving a plausible scenario which described some of the technical-societal-political issues that could result from a major earthquake in the New Madrid seismic zone and in Arkansas.

SPEAKER: Charles Thiel

SESSION V: RESPONDING TO THE EARTHQUAKE THREAT

OBJECTIVE: Presentations giving the concept of integrated emergency management planning and an assessment of the current-state-of-preparedness in Arkansas.

SPEAKERS: Leon McGoogan
Edward Stallcup
Gary McClure
Ugo Morelli
Burton Zavelo
Richard English
Roy Popkin
Reo Hosman
Maurice Robinson
Mike Means

SESSION VI: FORMULATING PLANS TO DEAL WITH EARTHQUAKE HAZARDS IN ARKANSAS AND NEARBY STATES

OJBECTIVE: Presentations describing architectural and engineering strategies and local, State, and Federal plans for improving the capability to deal with earthquake hazards.

SPEAKERS: Henry Lagorio
Clarke Mann
Gary McClure
Mary Ellen Stemper
Ugo Morelli
Norman Williams
Walter Hays
Ed Stallcup
Leon McGoogan

DISCUSSION GROUPS

The following subjects were discussed in a small group setting. The goal was to achieve personal identification with both the problem and its solution. The topics include:

1) Solving in a "crisis environment" technical-societal-political issues that could arise following a major earthquake in the New Madrid seismic zone.

2) The state-of-earthquake-preparedness in Arkansas and Arkansas' earthquake response plan.

3) Steps or activities which individuals can take to increase earthquake awareness and concern in their community, workplace, professional and service organizations, and home.

CONCLUSIONS AND RECOMMENDATIONS

The participants of the Workshops on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States," concluded that no area in the Mississippi Valley including Arkansas is adequately prepared to cope with a catastrophic earthquake, and that the multidisciplinary cooperative efforts by the USGS, FEMA, the State of Arkansas and others must be continued.

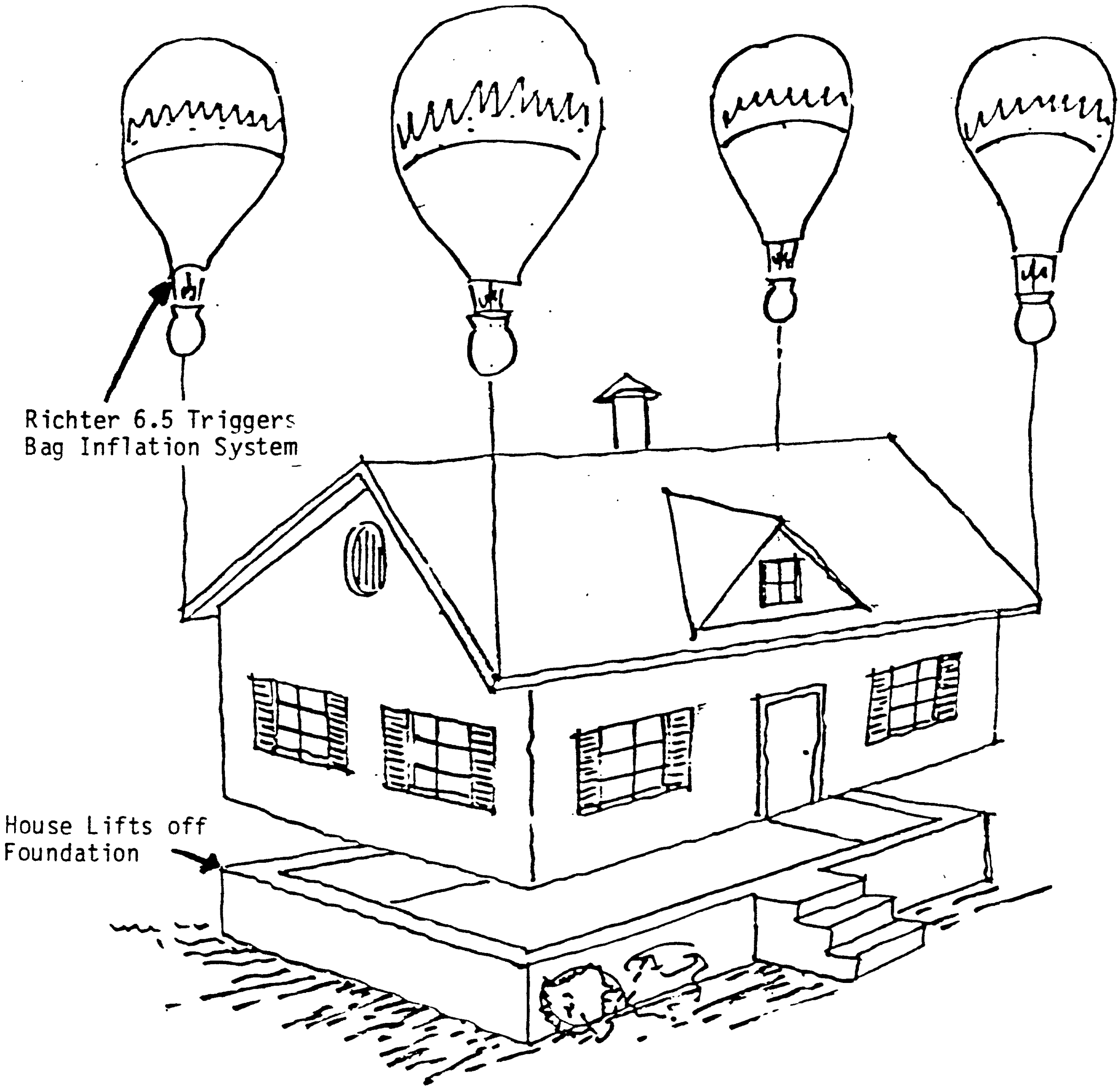
On the basis of the plenary sessions and the discussion groups, the participants proposed the following actions to improve the level of earthquake preparedness in Arkansas:

1) Individuals in Arkansas should adopt personal measures to increase earthquake preparedness including:

   a) making their homes earthquake proof (See Figure 5),
   b) formulating family response plans,
   c) enlisting emergency preparedness workers to set an example in their communities.

Figure 5

TREMOR HOT-AIR BALLOON SYSTEM



(Have not yet figured how to get it down?)

2) Vulnerability analyses of the Central United States and Arkansas must be refined so that the Arkansas Office of Emergency Services and local governments can formulate more specific response plans.

3) The State Office of Emergency Services needs to coordinate earthquake preparedness planning with local governments, business, and industry in the State.

4) The Office of Emergency Services in cooperation with the Federal Emergency Management Agency needs to produce training and educational materials on earthquake preparedness and response.

5) The USGS, the Arkansas Geological Survey, and universities need to continue their efforts to understand seismicity in the Central United States and Arkansas in particular.

ACKNOWLEDGMENTS

A special note of appreciation is extended to each of the following individuals for their contributions:

1) The Steering Committee of Leon McGoogan, Arkansas Office of Emergency Services, Otto Nuttli, St. Louis University, Richard Sanderson, FEMA, Susan Tubbesing, National Hazards and Research Information Center, Paula Gori, USGS, and Walter Hays, USGS, who planned and organized the workshop.

2) The participants who joined in the plenary sessions and the discussion groups were the key to the success of the workshop. Their vigorous and healthy exchange of ideas made the workshop practical and interesting.

3) Leon McGoogan and Ed Stallcup provided valuable assistance in providing logistical support.

4) Carla Kitzmiller, Sherrill Moser, Joyce Costello, Cheryl Miles, Susan Kibler, Lynn Downer, Wanda Fuller, Peggy Randalow, and Imogene Pearce provided strong and capable administrative support.

REFERENCES

Algermissen, S. T., and Perkins, D. M., (1976), A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States: U.S. Geological Survey Open-File Report 76-416, 46 p.

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bender, B. L., (1982), Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States: U.S. Geological Survey Open-File Report 82-1033.

Allen and Hoshall, Inc. (1983), Central United States Earthquake Preparedness Project: An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from a Great Earthquake in the New Madrid Seismic Zone, (REVIEW DRAFT): Report prepared for the Federal Emergency Management Agency, 345 p.

Applied Technology Council, (1978), Tentative Provisions for Development of Seismic Regulations for Buildings: National Science Foundation, National Bureau of Standards, ATC 3-06, NBS SP 510, NSF 78-8, 514 p.

Hopper, M. G., Algermissen, S. T., and Dobrovolny, E. E., (1983), Estimation of Earthquake Effects Associated with a Great Earthquake in the New Madrid Seismic Zone: U.S. Geological Survey Open-File Report 83-179, 80 p.

McKeown, F. A., and Pakiser, L. C., (1982), Investigations of the New Madrid, Missouri, Earthquake Region: U.S. Geological Survey Professional Paper 1236, 201 p.

EVALUATION OF THE WORKSHOP ON "CONTINUING ACTION TO REDUCE LOSSES FROM EARTHQUAKES IN ARKANSAS AND NEARBY STATES"

by

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At the conclusion of the two-and-a-half day gathering, participants were asked to evaluate the success of the workshop in reaching its goals, to rate various activities, and to estimate possible changes in awareness and concern as a result of having taken part. The workshop was designed to define the earthquake threat in Arkansas, describe current capabilities for responding to an earthquake in Arkansas, develop strategies to increase awareness and concern, and recommend future research.

Responses were elicited on a five-point scale, 1 and 2 representing the lowest level of agreement, 3 moderate agreement, and 4 and 5 highest agreement, or a "yes" response (see Figure 1). Since not all respondents answered all the questions, percentages are based only on those who submitted evaluations (see Figure 2).

Evaluations returned by 40 participants indicate that the workshop was successful in meeting its goals. Ninety-five percent of the evaluators thought the workshop did a moderate to good job of defining the earthquake threat in Arkansas. Over 85% also felt that the workshop did a more than adequate job when it came to providing information dealing with current response capabilities. Respondents were similarly impressed with the workshop's role in developing strategies to increase awareness and concern. Response was only slightly less enthusiastic when evaluating the success of the workshop in recommending future research. Nearly one-half found it quite successful, another 20% thought it moderately helpful and fewer than 20% viewed the workshop as only slightly helpful in this regard.

FIGURE 1

Evaluations of the Workshop by Individual Participants

	Low 1	2	3	4	High 5
1. Did you find the conference to be useful for:					
a. defining the earthquake threat in Arkansas?	0	2	6	13	19*
b. describing the current capabilities of responding to an earthquake in Arkansas?	1	3	14	13	8
c. developing strategies to increase earthquake awareness, concern, and preparedness?	0	3	13	15	6
d. recommending future research?	1	6	8	11	6
2. Did the conference benefit you or your organization by:					
a. providing new sources of information and expertise you might want to utilize in the future?	0	3	7	11	18
b. establishing better understanding of the problems faced by decisionmakers?	0	1	10	14	14
3. Did you find the following activities useful:					
a. formal presentation?	0	0	6	13	20
b. discussions following the formal presentations?	0	1	8	13	19
c. earthquake scenario and discussion group exercise	1	4	7	14	14
d. small discussion groups?	0	1	9	13	14
e. informal discussions during coffee breaks, lunches, and after hours?	0	0	11	12	15
f. notebook and abstracts?	1	1	9	17	11
4. If the clock were turned back and the decision to attend the workshop were given you again, would you want to attend?	0	0	5	5	30
5. Should future workshops be planned to continue the work initiated at this meeting?	1	0	4	11	24
6. Prior to attending this workshop, I would rate my <u>awareness</u> of the earthquake threat in Arkansas as?	3	6	13	8	10
7. Prior to attending this workshop, I would rate my <u>concern</u> about the state-of-earthquake preparedness in Arkansas as?	3	10	12	4	11
8. I now rate my awareness as	0	0	3	13	22
9. I now rate my concern as	0	1	3	16	18

*Evaluations were completed by forty participants. Totals vary as not all respondents completed all questions.

FIGURE 2

Evaluations of the Workshop by Percentages of Participants

	Low 1&2	3	High 4&5*
1. Did you find the conference to be useful for:			
a. defining the earthquake threat in Arkansas?	5%	15%	80%
b. describing the current capabilities of responding to an earthquake in Arkansas?	10%	35%	52%
c. developing strategies to increase earthquake awareness, concern, and preparedness?	8%	33%	52%
d. recommending future research?	17%	20%	42%
2. Did the conference benefit you or your organization by:			
a. providing new sources of information and expertise you might want to utilize in the future?	8%	17%	72%
b. establishing better understanding of the problems faced by decisionmakers?	2%	25%	70%
3. Did you find the following activities useful:			
a. formal presentation?	--	15%	82%
b. discussions following the formal presentations?	2%	20%	77%
c. earthquake scenario and discussion group exercise...	12%	17%	70%
d. small discussion groups?	2%	22%	67%
e. informal discussions during coffee breaks, lunches, and after hours?	--	27%	67%
f. notebook and abstracts?	5%	22%	70%
4. If the clock were turned back and the decision to attend the workshop were given you again, would you want to attend?	--	12%	87%
5. Should future workshops be planned to continue the work initiated at this meeting?	2%	10%	87%
6. Prior to attending this workshop, I would rate my <u>awareness</u> of the earthquake threat in Arkansas as?	22%	33%	45%
7. Prior to attending this workshop, I would rate my <u>concern</u> about the state-of-earthquake preparedness in Arkansas as?	33%	30%	37%
8. I now rate my awareness as	--	8%	87%
9. I now rate my concern as	2%	8%	85%

*Percentages do not total 100% as not all respondents completed all questions.

In order to determine in what specific ways the meeting was useful to participants, questions addressed sources of information and how they provided a better understanding of the seismic problem in Arkansas and nearby states.

Over 70% of the respondents gave the workshop high marks for providing new sources of information or expertise, and another 17% were at least moderately happy with new sources suggested by the workshop.

Certainly a major achievement of the workshop was the extent to which it gave participants an appreciation of the problems faced by decisionmakers. Seventy percent said that the workshop was very successful in providing a better understanding of problems faced by decisionmakers, and 25% said that it was at least moderately successful.

To indicate which activities were viewed as the most useful, participants were asked to rate formal presentations, follow-up discussions, the earthquake scenario exercise, small group discussions, informal discussions, and materials such as notebooks and abstracts. Formal presentations received the most enthusiastic evaluation; 82% of the respondents judged them to be highly useful. Follow-up discussions and small group discussions were also seen to be valuable. Discussions following the formal presentations were judged highly successful by nearly 80% of the respondents. Small discussion groups were judged by more than three-fifths of the group to be very useful and by roughly one-fifth to be at least moderately useful. The earthquake scenario exercise was well received, with 87% of the respondents giving it moderate to high marks. Informal discussions and materials were seen to be valuable parts of the meeting as well (see Figure 2).

The importance attached to this workshop is shown in the response of 87% of those submitting evaluations that they would, knowing now what to expect, most definitely wish to attend. Not one person indicated a reluctance to take part in similar future gatherings. Only one respondent failed to see the need for future meetings which would continue work initiated at this gathering (see Figure 1).

The most interesting and significant impact of the workshop has been its influence on heightening levels of awareness and concern. Significant numbers of participants (22%) reported their levels of awareness prior to the workshop would have been described as low. Thirty-three percent rated their levels of awareness as moderate, and 45% rated them as high before the workshop.

Following the workshop, however, no participant felt his or her awareness was low; only 8% considered their awareness moderate, while 87% judged their awareness to be high. Similarly, levels of concern were heightened significantly by participation. Before the workshop, concern was judged to have been low by nearly one-third of the respondents, with 30% registering moderate concern and only 37% high concern. After the workshop, participants revised their perceptions of concern significantly; only 2% defined their levels of concern as low, 8% said they were moderate, and 85% said they were highly concerned about the seismic hazard potential in the Arkansas.

Looking at individual responses, it can be seen that only five people registered a decline in level of awareness or concern after participating in the workshop, and 18 of the 40 respondents registered no post-workshop changes in levels of awareness or concern. Of these 18, eleven identified themselves prior to the workshop as already possessed of great awareness or concern, and they remained in those categories. The remaining responses showed increases in level of awareness or concern or both after taking part in the workshop.

Another important judgment of the success or failure of a workshop can be made by looking beyond the impacts it had on attitudes, to ways in which it may have affected behavior. In order to determine whether the workshop had any long-term effect on the behavior of participants, the final question on the evaluation sheet asked respondents to consider actions they might take to improve the awareness and concern of others or to implement mitigation activities in the Central United States. Response from 28 participants to this question was varied.

Most of these participants indicated plans to get earthquake information out to the public through a variety of means. A few were going to take steps to make themselves and their neighbors less vulnerable to earthquake damage. Participants envisioned teacher training, incorporation of earthquake hazard information into school and college curricula, broadening the knowledge of co-workers and encouraging state earthquake policy and programs as areas of future action. It is evident from their responses that the workshop provided enough new information to cause participants to begin thinking of ways to pass on their expanded knowledge of the earthquake threat in Arkansas.

HISTORICAL OVERVIEW, CURRENT STATUS OF KNOWLEDGE AND SEISMOLOGICAL RESEARCH IN THE NEW MADRID SEISMIC ZONE

by

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INTRODUCTION

The New Madrid seismic zone is a classic example of a low-probability, high-risk phenomenon. Moderately large earthquakes will affect an area the size of one or several States, and great earthquakes, such as those of the winter of 1811-1812, will disrupt to various degrees, the lives of approximately half the population of the United States. Because these earthquakes occur infrequently, they pose some unique problems to those responsible for hazard mitigation and disaster response, as will be discussed throughout this Workshop. The purpose of this paper is to present a non-technical summary of the historical and present-day earthquake activity, and to describe briefly some of the seismological research that relates to the objectives of the Workshop.

HISTORIC OVERVIEW

The 1811-1812, earthquakes have the distinction of being the greatest sequence of earthquakes in the history of the United States. It is difficult to imagine that, in a three-month period, there were three earthquakes of M_s (surface-wave magnitude) 8.5 or greater, five more of M_s 7.8, another ten of M_s 7.0 (all eighteen earthquakes were felt in Washington, D.C.) and at least 1850 additional earthquakes that were felt at Louisville, 250 to 300 miles from the epicenters. The energy released by these earthquakes exceeded that released by all other earthquakes in the United States and Canada east of the Rocky Mountains from the time of settlement to the present.

As best as can be determined from historical accounts, the first of these great earthquakes occurred around 2:15 a.m. on December 16, 1811, in Mississippi County, Arkansas. The land was badly ravaged, with the ground rising or dropping by as much as 10 to 20 feet in various locations. The nearest settlement, at Little Prairie, Missouri, (now called Caruthersville) was seriously damaged. There were massive landslides along the banks of the Mississippi River as far south as Natchez, and also along the White and St. Francis Rivers in Arkansas. Cracks in the ground were so deep and wide that it was reported to be impossible to travel from Cape Girardeau, Missouri, to Little Rock on horseback. Unfortunately, I have been unable to find any written accounts of the damage at Little Rock, itself. The damage from the sequence of large earthquakes extended over a huge area. I estimated the area of structural damange to be approximately 50,000 square miles and of non-strucutral, or architectural damage, to be about 600,000 square miles. By comparison, the non-structural damage area of the 1906 San Francisco earthquake was only about 40,000 square miles.

The aftershocks of these earthquakes continued through at least 1817, but by that time the inhabitants of the area were so accustomed to them that they did not consider them newsworthy. In fact, a reliable record of the number of aftershocks ends at March 15, 1812. The aftershock activity probably ended by 1820.

Even if the 1811-1812 earthquakes had not occurred, the historical earthquake record from 1833 through 1972, would have marked the central Mississippi Valley as being an active earthquake zone. Standard statistical methods for obtaining the recurrence rate of earthquakes, when applied to these data, indicate that an M_s 8.5 earthquake occurs on average every 500 to 700 years in the area.

After 1812, the largest earthquakes in the New Madrid seismic zone was the January 1843, event of M_s about 6.3 and the October 1895, event of M_s about 6.7. The 1843 earthquake had its epicenter near Marked Tree, Arkansas, and caused damage in eastern Arkansas, western Tennessee, and northwestern Mississippi. The 1895 event occurred at Charleston, Missouri, and did damage in eastern Missouri, southern Illinois, southern Indiana, and western Kentucky. It was felt as far away as the Atlantic and Gulf Coasts.

PRESENT-DAY EARTHQUAKE ACTIVITY

Studies of the seismicity of the New Madrid zone were notably improved when Saint Louis University began to operate a regional network of seismographs in July 1974, with financial support provided by the U.S. Geological Survey and later also by the U.S. Nuclear Regulatory Commission. Since then over 2000 small earthquakes have been detected and located by the network. The epicenters of these earthquakes, which range in size from m_b (body-wave magnitude) 1.0 to 5.0, define a zone approximately 15 miles wide that extends from a point in Arkansas about 25 miles northwest of Memphis to the Reelfoot Lake area of western Tennessee, then makes a north-northwesterly jog to New Madrid, Missouri, and again resumes its north-eastwardly course to southern Illinois. Its overall length is about 200 miles. Geological studies indicate that the rift structure, in which the New Madrid seismic zone is located, is broader, extends farther both to the southwest and northeast, and has another arm extending from New Madrid to St. Louis. However, the rate of earthquake activity is not uniform throughout this broader region. It is more intense in the smaller zone previously described, which I define as the New Madrid seismic zone. I prefer to associate the earthquakes outside this zone with other source regions, such as the Wabash Valley, Illinois Basin, St. Francois Uplift and Ouachita-Wichita Mountains. It is my belief that these latter source zones are capable of producing large, but not great, earthquakes.

CURRENT RESEARCH

Focal-mechanism studies of New Madrid zone earthquakes by R. B. Herrmann of Saint Louis University show right-lateral strike-slip faulting on the two NE trending branches of the fault system, and reverse faulting on the NNW trending central branch of the fault. These motions can be explained by a regional E-W trending field of compressive stress.

The question most frequently asked about the New Madrid seismic zone concerns the probability of occurrence of future large earthquakes. It is a difficult question to address, for the commonly used methods for making such estimates assume that earthquakes occur randomly in time. This assumption is legitimate if one is talking about time periods many times longer than the average recurrence time for the largest earthquakes. But it is unsatisfactory for small time intervals. After a great earthquake or earthquakes, such as in 1811-1812, essentially all of the strain energy previously stored in the rock masses has been released, and it will take an appreciable amount of time until another large earthquake can be produced. This means that the assumption of random time distrubtion of very large earthquakes is invalid. It also serves to explain why the New Madrid seismic zone has been relatively quiet since 1812, for it takes time to store up enough energy to produce large earthquakes. Therefore, we should not let this hiatus of large earthquakes since 1812 lull us into a false sense of security. For the New Madrid seismic zone an assumption of random time distribution likely is valid for earthquakes of M_S no greater than 6, because their energy release is trivial compared to that of the great earthquakes.

If my studies of spectral scaling relations can be applied to the New Madrid seismic zone, there has been about five feet of strain deformation since 1812 along the fault. If that energy were to be released in the near future, it would result in an M_S 7.6 earthquake, a very large earthquake that would be damaging over a wide area of the Central United States. Unfortunately, we do not know when the fault will rupture to produce the next great earthquake. It may not happen for decades, or for centuries. The longer it takes, the larger its magnitude will be. Furthermore, we can be fairly certain that the next century will show more of the moderate magnitude earthquakes than the last century, as the rock masses will be in a higher state of strain. This is a cause for concern, for even these moderate-sized earthquakes can injure and kill, if they are located near centers of population.

GEOLOGIC STUDIES IN THE NEW MADRID SEISMIC ZONE

by

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The New Madrid earthquake of 1811-12 was unusual in at least three important respects: the felt area and the region of damage were anomalously large, even for a great earthquake; the earthquake was followed by an extended period of large aftershocks, lasting more than a year; and the earthquake occurred in the interior of one of the Earth's major crustal plates where large seismic events are generally uncommon. In recent years a substantial effort has been made to understand the geologic setting and seismic characteristics of the lower and central Mississippi Valley in order to evaluate the potential for future great earthquakes and to formulate plans that will help to mitigate the associated hazards. The integrated set of geological and geophysical studies that have been made have examined surface, near subsurface, and deep-crustal features and have resulted in the identification of major geologic structures that represent the source zones of the region's seismicity. The studies have also provided an increased understanding of the cause and nature of large intra-plate earthquakes.

GEOLOGIC SETTING AND TECTONIC EVOLUTION

The New Madrid seismic zone is located in the center of the northern part of the Mississippi Embayment, a spoon-shaped sediment-filled trough that indents the southern margin of the North American craton. Geological and geophysical research reveals that the embayment began to form during the middle of the Mesozoic Era, about 150 million years ago. The location and geometry of the embayment was largely controlled by even older and more deeply buried structures whose nature and significance have recently been delineated by gravity, magnetic, and seismic studies. Hildenbrand and others (1982) have convincingly shown that the primary structure in the region is a northeast-trending, buried rift (Reelfoot rift) that extends northeasterly from Arkansas into western Kentucky (Figure 1). The rift is approximately 75 Km wide and has the shape of a shallow depression with 1.5-2.5 Km of relief. Large positive magnetic and gravity anomalies occur along the flanks of the rift and are inferred to be late Mesozoic plutons composed of complex assemblages of mafic rocks. Igneous intrusions (some inferred to be as young as post-middle Eocene) also lie along the axis of the rift, where they occur as dikes, laccoliths, and broad, regional ring structures.

Burke and Dewey (1973) hypothesized that Reelfoot rift formed as a failed arm of a triple plate junction that extended into the North American Craton from the ancient, rifted continental margin. Recent seismic refraction studies by Mooney and others (1983) confirm the presence of the rift and help to define its character and origin. Their studies show the presence of a "pillow"-shaped zone of anomalous velocity (Vp=7.3 Km/sec) rocks that lies between the lower crust and the mantle. It is believed that the "pillow" formed during active rifting when mantle-derived magma was injected into the lower crust. The thickness of the pillow systematically increases to the northeast suggesting that the rift formed over a mantle hot spot rather than as a failed arm of a triple junction.

Faults within and near Reelfoot rift have been identified primarily from the analysis of seismic reflection profiles (Zoback and others, 1980; Hamilton and Zoback, 1982). The profiles show that Paleozoic rocks within the rift and along its flanks are abundantly faulted, but that very few faults vertically offset the buried Paleozoic surface and younger rocks by more than 10m. The rocks that lie along the axis of the rift, however, have been uplifted (in places as much as 1-2 Km), intruded by dikes and laccoliths, and pervasively faulted. The highly deformed nature of this area is most likely the result of upper crustal weakening caused by stretching and thinning of the lithosphere during the rifting process. Several large faults show evidence of reversal of movement, indicating that faults in the rift have been reactivated, at times under an extensional stress field and at times under a compressional stress field. Detailed geomorphologic and high-resolution seismic studies indicate that very few tectonic faults offset the surface of the Mississippi Valley flood plain. Those that do are located along the eastern edge of the Lake County uplift, a complex late-Holocene dome-like feature that hydrological evidence suggests is currently undergoing continued uplift. The lack of significant vertical offsets on post-Paleozoic faults is clear evidence that vertical faulting has not been a major process in the Mississippi Embayment in the past 150 million years. Epeirogenic movements such as those that gradually uplifted the Ozark Plateau and downwarped the Mississippi Embayment have predominated.

RELATION OF GEOLOGIC STRUCTURE TO EARTHQUAKE OCCURRENCE

The large New Madrid earthquake of 1811-12 and most earthquakes of M_b>5.0 occurring in the Central United States since the New Madrid series are located in the Reelfoot rift. Since 1974, St. Louis University has operated a seismic network in the area. Recordings from the network show that microearthquakes are relatively common within the rift and that they occur in distinct linear zones at depths less than 15 km. (Figure 1). The longest of the zones lies along the rift axis, nearly parallel to and just west of the Mississippi River between Marked Tree, Arkansas, and Caruthersville, Missouri. A shorter zone extends to the northeast along the rift flank from New Madrid to near Cairo, Illinois, where the Mississippi and Ohio Rivers converge. A diffuse northwesterly seismic trend between New Madrid and Dyersburg, Tennessee, connects the two northeasterly seismic zones, defining an overall seismic pattern that, although geometrically en echelon, appears to be continuous. The northwest-trending seismic zone cuts across the rift in an area where the Mississippi Valley flood plain and underlying rocks have been tectonically uplifted during the late Holocene (Lake County Uplift). A minimum of 10 m of uplift has occurred in the last 2000 years, producing modifications in the course of the Mississippi River.

A tectonic model has been developed that interrelates the patterns of seismicity, rift structure, Holocene uplift, and sense of fault movement (Russ, 1982). In this model, great earthquakes (M_s>7.5) are associated with a source zone that is largely coincident with the area of structural complexity along the axis of Reelfoot rift. The area extends from just south of Marked Tree to Caruthersville. Focal plane mechanisms derived for recent microearthquakes (Herrmann, 1979, Herrmann and Canas, 1978) indicate that both of the linear northeast-trending seismic zones are best represented as right-lateral strike-slip faults. It has been proposed (Russ, 1982) that the strike-slip movement along these zones produces compression in the left-stepping offset between the two zones, causing thrusting and vertical strain that results in uplift (Lake Country uplift) and earthquakes. Reverse fault focal plane mechanisms and reverse faults identified on seismic reflection profiles support this model.

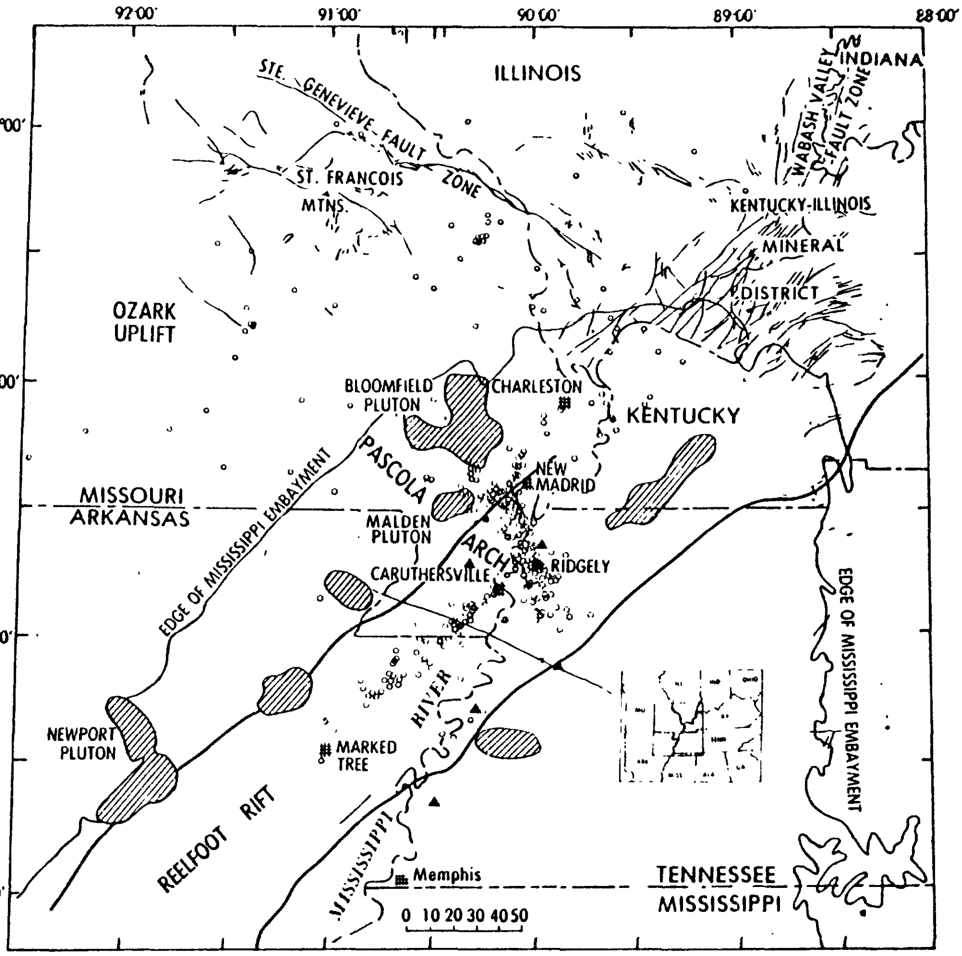
From the evidence, it is apparent that damaging earthquakes in the Mississippi Embayment occur along ancient reactivated faults that originally formed when Reelfoot rift was created. The significance of the model is that it identifies the source zones for damaging earthquakes and suggests that the northeasterly and southwesterly limits of great New Madrid-type earthquakes may be limited to the area of structural complexity along part of the rift axis.

To increase our understanding of the detailed structure of the rift and of its tectonic evolution, the U.S. Geological Survey is purchasing approximately 200 miles of selected commercial seismic reflection profiles. Analysis of these profiles should facilitate a definitive characterization of Reelfoot rift and further refine our knowledge of the seismic source zone.

FUTURE EARTHQUAKES IN THE NEW MADRID SEISMIC ZONE

An analysis of historic seismic data (Nuttli and others, 1978; Johnson, 1982) and geologic data (Russ, 1979) indicates that great earthquakes (M_b>7.5) recur every 600-700 years in the New Madrid seismic zone. Because only 171 years have elapsed since the New Madrid earthquake of 1811-12 we are probably several hundred years away from a repetition of this devastating event. Smaller, but still damaging earthquakes, however, occur much more frequently. Eighty-eight years have passed since an earthquake large enough to cause significant building damage and widespread ground liquefaction has occurred in the New Madrid area. The last event of this size took place in 1895 near Charleston, Missouri, at the northern end of the seismic zone and was felt over an area of 2,500,000 square kilometers. Sandblows were reported in a number of communities near Charleston and a new lake was formed (Hopper and Algermissen, 1980). Magnitude-frequency relations (Nuttli and others, 1978; Johnson, 1982) suggest that Charleston, Missouri-sized earthquakes (M_b=6.2) have a recurrence interval of 90-100 years in the New Madrid area. Thus, it would be prudent to conclude that a magnitude $M_b \sim 6.2$ earthquake might occur in the region in the near future. Within the region, the probable location of the earthquake is completely unknown. Such an earthquake, however, would reasonably be expected to produce effects similar to those that accompanied the recent Coalinga, California, earthquake which was of the identical magnitude. Moderate building damage, injuries, cracked oil and gas pipelines, and downed power lines would occur. Geologic effects, such as widespread ground liquefaction, and cracking, minor flooding, debris flows and landslides would have the potential to seriously disrupt the economy and normal daily activities of the area for a considerable period of time.

To better evaluate the timing of the next damaging earthquake and of the potential consequences to the local populace and their property, a number of geoscience studies are currently underway in the New Madrid area. Exploratory trenching and high resolution seismic reflection surveying are being done to identify active faults and to determine the rate at which they move. These data will then be used to calculate the rate of earthquake recurrence. Geomorphologic, geodetic, and strain-monitoring studies are being carried out to identify areas of modern tectonic deformation and to calculate the rate of accumulation of elastic strain energy. Sandblows and landslides generated by previous earthquakes are being investigated to calculate the area and degree of future ground-failure susceptibility. The results of all of these studies will provide valuable input to the mitigation of seismic hazards in the New Madrid seismic zone.



EXPLANATION

Northern limit of Mississippi Embayment coastal-plain sediments

Mafic or ultramafic intrusion within the Mississippi Embayment—Identified in drill cores and cuttings

Mafic or ultramafic intrusion within the Mississippi Embayment interpreted from the magnetic field— Approximate boundary of intrusion determined from zero contour of associated anomaly on the second vertical derivative map

Fault

Earthquake epicenter

Boundary of inferred subsurface Reelfoot rift

Figure 1

REFERENCES CITED

Burke, K., and Dewey, J. F., 1973, Plume-generated triple junctions: Key indicators in applying plate tectonics to old rocks: Journal of Geology, v. 81, p. 406-433.

Hamilton, R. M., and Zoback, M. D., 1982, Tectonic features of the New Madrid seismic zone from seismic reflection profiles: U.S. Geological Survey Professional Paper 1236-F, p. 55-82.

Herrmann, R. B., 1979, Surface wave focal mechanisms for eastern North American earthquakes with tectonic implications: Journal of Geophysical Research, v. 84, no. B7, p. 3543-3552.

Herrmann, R. B., and Canas, J. A., 1978, Focal mechanism studies in the New Madrid seismic zone: Bulletin of the Seismological Society of America, v. 68, no. 4, p. 1095-1102.

Hildenbrand, T. G., Kane, M. F., and Hendricks, J. D., 1982, Magnetic basement in the upper Mississippi embayment region--A preliminary report: U.S. Geological Survey Professional paper 1236-E, p. 39-53.

Hopper, M. G., and Algermissen, S. T., 1980, An evaluation of the effects of the October 31, 1895, Charleston, Missouri, earthquake: U.S. Geological Survey Open-File Report 80-778, 43 p.

Johnston, A. C., 1982, A major earthquake zone on the Mississippi: Scientific American, v. 246, no. 4, p. 60-68.

Mooney, W. D., Andrews, M. C., Ginzburg, A., Peters, D. A., and Hamilton, R. M., 1983, Crustal structure of the northern Mississippi embayment and a comparison with other continental rift zones: Tectonophysics, v. 94, p. 327-348.

Nuttli, O. W., and Herrmann, R. B., 1978, Credible earthquakes for the central United States, in State-of-the-art for assessing earthquake hazards in the United States, Report 12: U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Miscellaneous Paper S-73-1, 99 p.

Russ, D..P., 1979, Late Holocene faulting and earthquake recurrence in the Reelfoot Lake area, northwestern Tennessee: Geological Society of America Bulletin, pt. 1, v. 90, p. 1013-1018.

Russ, D. P., 1982, Style and significance of surface deformation in the vicinity of New Madrid, Missouri: U.S. Geological Survey Professional Paper 1236-H, p. 95-114.

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P.. McKeown, F. A., and Brockman, S. R., 1980, Recurrent intraplate tectonism in the New Madrid seismic zone: Science, v. 209, no. 4460, p. 971-976.

ESTIMATION OF EARTHQUAKE EFFECTS
ASSOCIATED WITH A GREAT EARTHQUAKE IN THE NEW MADRID SEISMIC ZONE

By

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ABSTRACT

Estimates have been made of the effects of a large M_S = 8.6, I_o = XI earthquake hypothesized to occur anywhere in the New Madrid seismic zone. The estimates are based on the distributions of intensities associated with the earthquakes of 1811-12, 1843 and 1895 although the effects of other historical shocks are also considered. The resulting composite type intensity map for a maximum intensity XI is believed to represent the upper level of shaking likely to occur. Specific intensity maps have been developed for six cities near the epicentral region taking into account the most likely distribution of site response in each city. Intensities found are: IX for Carbondale, IL; VIII and IX for Evansville, IN; VI and VIII for Little Rock, AR; IX and X for Memphis, TN; VIII, IX, and X for Paducah, KY; and VIII and X for Poplar Bluff, MO. On a regional scale, intensities are found to attenuate from the New Madrid seismic zone most rapidly to the west and southwest sides of the zone, most slowly to the northwest along the Mississippi River, on the northeast along the Ohio River, and on the southeast toward Georgia and South Carolina. Intensities attenuate toward the north, east, and south in a more normal fashion. Known liquefaction effects are documented but much more research is needed to define the liquefaction potential.

INTRODUCTION

The New Madrid seismic zone is the site of some of the largest historical earthquakes in the conterminous United States, the 1811-1812 series. It is also the most seismically active area in the Central United States. Since an earthquake with a maximum Modified Mercalli (M.M.) intensity greater than IX has not occurred in the area since 1895 (see Appendix 1 for a description of the Modified Mercalli intensity scale), and not one equivalent to the 1811-1812 sequence since 1812, the people of the region are neither expecting nor prepared for such a disaster. There are many older buildings of unreinforced brick that are known from experience in areas of frequent earthquakes to represent a considerable risk. If these structures were located in an area with more frequent large earthquakes, they would have been damaged long ago and perhaps removed. Many people in the Midwest are unaware of the damage potential of a large earthquake. Although the occurrence of the New Madrid earthquakes is widely known, they are regarded only as interesting curiosities.

The New Madrid seismic zone has been the focus of a considerable amount of scientific research in recent years. Important publications with particular relevance to this study include a number of papers by Nuttli (1973, 1974, 1979, 1981, and 1982) the U.S. Geological Survey Professional Paper in the New Madrid region (McKeown and Pakiser, 1982), the MATCOG (Mississippi-Arkansas-Tennessee Coucil of Governments) study (M & H Engineering and Memphis State University, 1974), and the recent book on earthquake risk for the New Madrid region by Liu (1981). Studies on ground effects during the New Madrid earthquakes include those by Russ (1979) and Obermeier (unpub. data). Considerable research has been done in the city of Memphis, including the MATCOG report mentioned above, a study by Sharma and Kovacs (1980) of Purdue University, and by Nowak and Morrison (1982) of the University of Michigan.

The objectives of the present study are:

1) to estimate the magnitude, probability of occurrence, and location of an 1811-type earthquake,

2) to estimate the levels of damaging ground motion (in terms of Modified Mercalli intensities) throughout the Midwest resulting from this simulated earthquake,

3) to estimate the intensities at each of the six representative cities studied individually (see figure 1),

4) to assess the potential for liquefaction in the area of intensity IX and above,

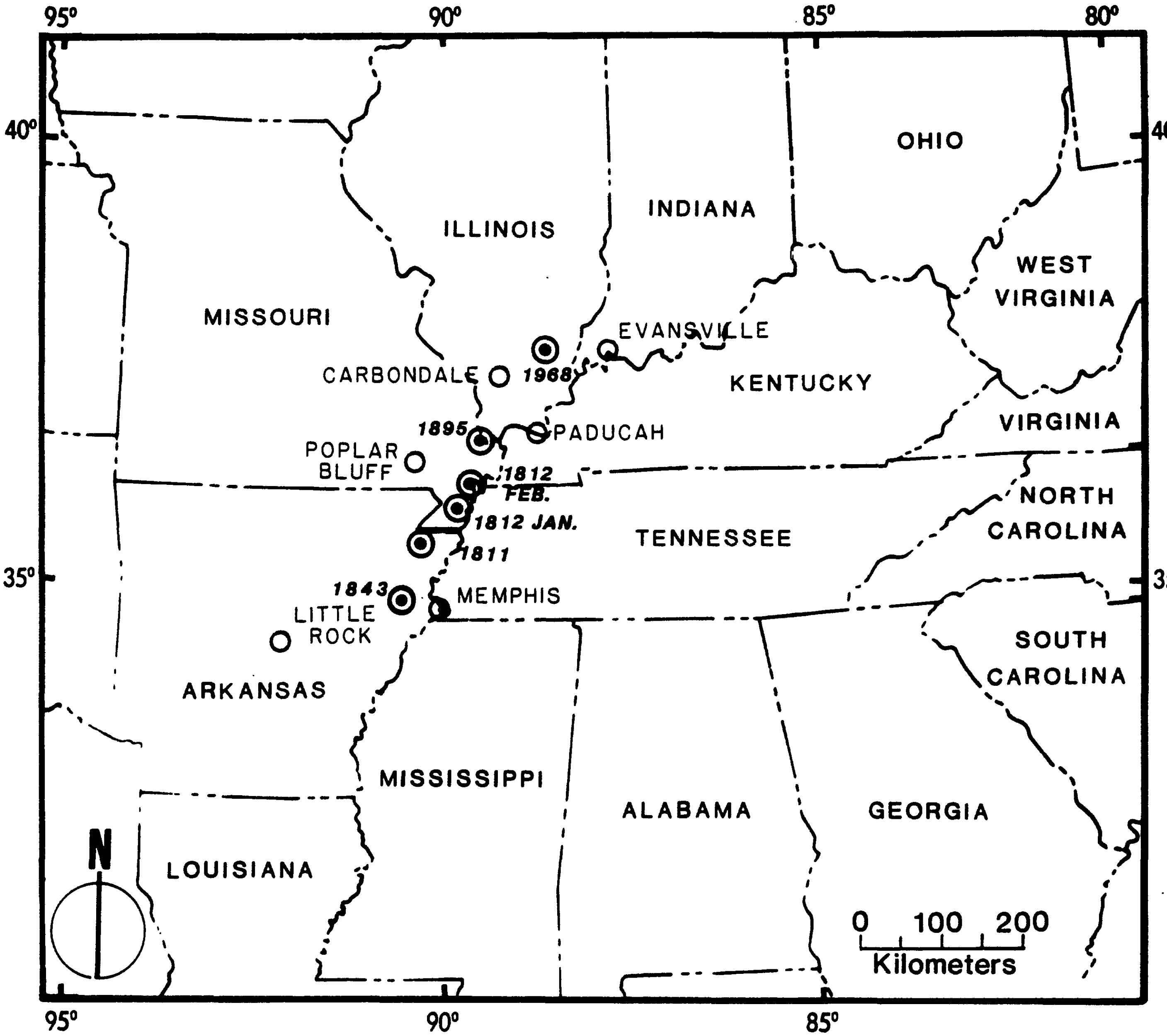

Figure 1.__Map showing the six cities evaluated in this report. Also shown (circles with dots) are localities of the epicenters of the large historical earthquakes discussed in this report.

5) to review pertinent aerial photography to find the distribution of sand blows, and

6) to find areas of lower intensities, both regional and in the six cities, based on damage patterns of previous earthquakes and on local geology.

Similar studies in other areas have been prepared for FEMA and its predecessor agencies. They include reports on San Francisco (Algermissen and others, 1972), Los Angeles (Algermissen and others, 1973), Puget Sound (Hopper and others, 1975), and Salt Lake City (Rogers and others, 1976). While this report is similar in purpose and design to those studies, in method and scope it is necessarily different. The method varies from the previous reports because of the different geologic and seismic setting, particularly the low attenuation of seismic energy in the midcontinent, which results in unusually large damage areas. This report does not include damage estimates, as did the earlier studies.

EARTHQUAKES OF 1811-1812

During the winter of 1811-1812 three great earthquakes occurred in the Mississippi Valley each having magnitude m_b[1] above 7.1 (see table 1 and figure 2). There have been no other earthquakes larger than these within the

[1] "Magnitude" is a measure of the size of an earthquake, or of the total amount of energy released by the earthquake. Several different magnitudes may be calculated from the amplitudes of the seismic vibrations recorded by a seismograph. The two most common ones are m_b, derived from the body-wave vibrations, and M_s, derived from the surface-wave vibrations. In this report magnitudes will always be given as m_b; in addition, M_s will bve given for the largest shocks. "Intensity" refers to the effects of an earthquake on people, structures, and ground. The intensity value is denoted by a Roman numeral in the Modified Mercalli Intensity Scale (see Appendix 1). The maximum intensity, I_o, is the most severe of these effects, and occurs, usually, near the instrumental epicenter. For old, pre-instrumental earthquakes, magnitudes are usually estimatied from I_o, or from contoured maps of intensity data (isoseismal maps) using either the total felt area (largest isoseismal) or the attenuation or weakening of the intensities with distance.

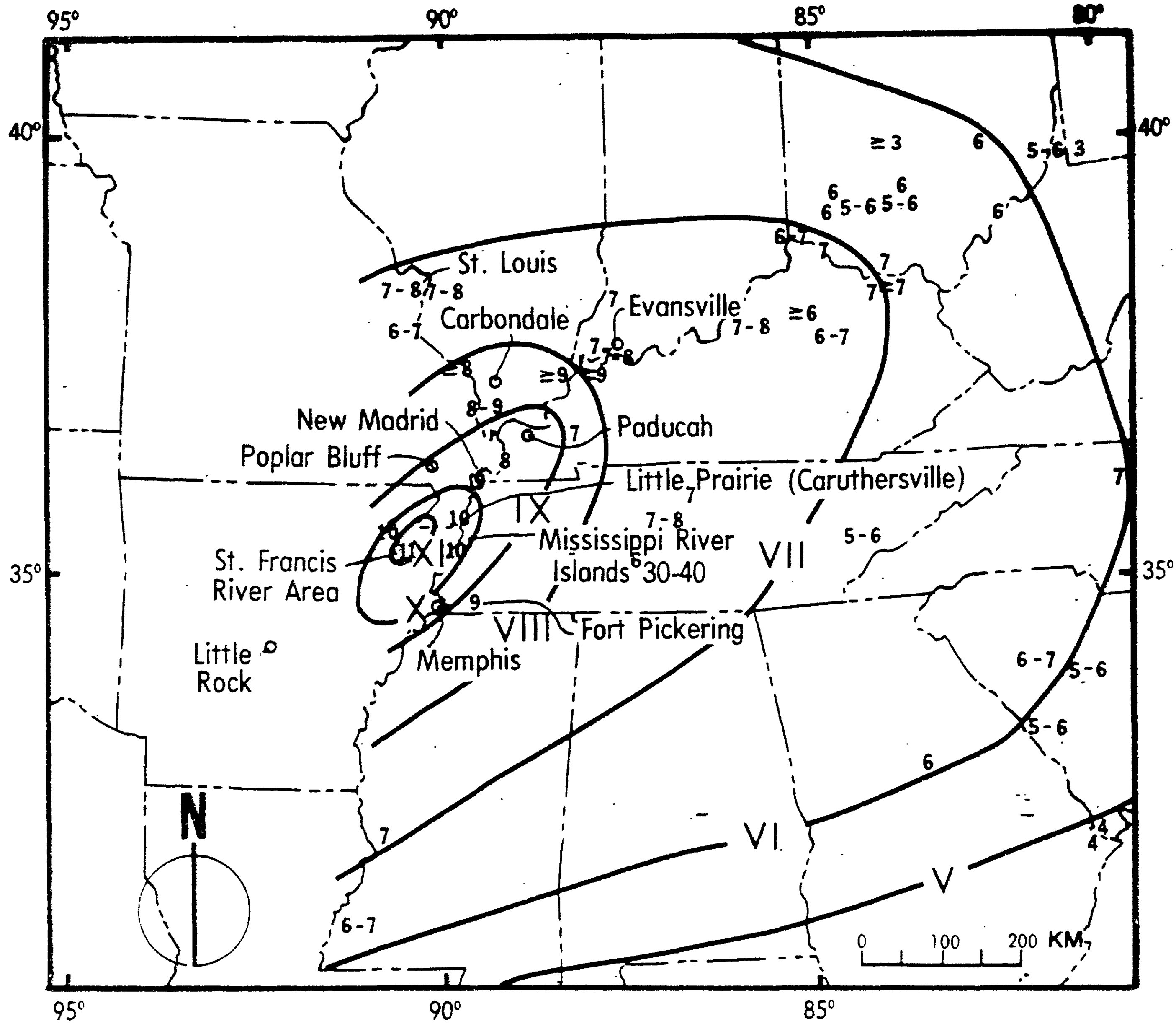

Figure 2. Isoseismal map of the December 16, 1811, earthquake, in northeast Arkansas (first major shock of the New Madrid series). After Nuttli (1981). Arabic numbers represent assigned Modified Mercalli intensities for individual locations; Roman numerals, the intensities for the isoseismals. Maximum intensity for this earthquake is XI. No information is available with which to complete the isoseismals on the west side. There are no assigned intensities for any of the six cities in this study except the IX at Fort Pickering near what is now Memphis. Since the isoseismal lines are not very well constrained by the data, they give only an approximation of the intensity at any given place. Within the IX isoseismal lie Memphis, Paducah, and Poplar Bluff; within the VIII, Carbondale and perhaps Little Rock; within the VII, Evansville.

TABLE 1.--RELATIVE SIZES OF THE 1811-1812 EARTHQUAKES. INTENSITY AND MAGNITUDE ESTIMATES FROM NUTTLI (1981). EPICENTER ESTIMATES FROM DAVID P. RUSS (PERSONAL COMMUNICATION)

	I_o	M_s	m_b	Epicenter Lat.	Epicenter Long.
1811 Dec 16	XI	8.6	7.2	35.8°N	90.3°W
1812 Jan 23	X-XI	8.4	7.1	36.2°N	89.8°W
1812 Feb 7	XI-XII	8.7	7.3	36.5°N	89.6°W

conterminous United States during historical times. Their magnitudes are comparable to those of the largest California earthquakes, and, because of the low attenuation of seismic intensities in the eastern and Central United States, their felt areas are much larger than similar magnitude California shocks. These earthquakes were felt with intensity greater than or equal to V M.M. (that is, enough to cause alarm) over approximately 2,500,000 km^2, which includes the entire eastern United States (Nuttli, 1973). The area of intensity VII (mainly architectural damage) and greater covers parts of Illinois, Indiana, Ohio, Kentucky, Tennessee, Alabama, Mississippi, Louisiana, Arkansas, and Missouri. Because of the low population density in 1811, the effects of these earthquakes west of the Mississippi River are not known, but they can be estimated. From this study and others it is clear that large parts of Kansas, Oklahoma, and Texas were shaken at the intensity-VII level.

The maximum intensities of the three 1811-1812 earthquakes range from XI to XII (see table 1). In the epicentral area of the first shock (December 16, 1811), the St. Francis River area of northeastern Arkansas, a lake was uplifted and drained, while other places subsided as much as 12 feet (3.7 m) (see figures 2 and 3). Sand and other materials were thrown from fissures or cracks in the swampland. The greatest disturbance occurred along the Mississippi River between Islands 30 and 40 along the Tennessee-Arkansas border north of Memphis (Nuttli, 1973). According to Fuller (1912, p. 10), "Great waves were created, which overwhelmed many boats and washed others high upon the shore, the return current breaking off thousands of trees and carrying them out into the river. High banks caved and were precipitated into the river, sand bars and points of land gave way, and whole islands disappeared." Uplifted areas caused ponding or waterfalls along the Mississippi. Landslides were extensive along the river banks as far up the Ohio River as Indiana, but particularly severe along the Chickasaw Bluffs on the Mississippi River north of Memphis. The roads between New Madrid and Arkansas were made impassable by the earthquake. The area of marked earth disturbances extended from Cairo to Memphis and from Crowley's Ridge to Chickasaw Bluffs.

The people in the epicentral area in 1811-1812 were able to survive as well as they did only because of their lifestyle. There were only about 5000 people living in the area of intensity X and greater, and they occupied light, wood-frame structures, the kind least susceptible to earthquake damage. Transportation was by horse, boat, and foot, and most escaped on foot; the small population was able to feed itself after the earthquake by hunting wild geese (Nuttli, 1981).

In addition to the three main shocks, there were numerous aftershocks, fifteen of them quite strong (table 2). All 18 of the above shocks were strong enough to be felt at Washington, D.C., and awaken sleepers when at night (Nuttli, 1981). Moreover, Jared Brooks of Louisville, 200 miles (320 km) from the epicentral area, counted 1,874 shocks felt at Louisville from December 16, 1811 until March 15, 1812 (Nuttli, 1973 and Fuller, 1913 p. 33).

TABLE 2.—AFTERSHOCKS OF THE 1811-1812 NEW MADRID EARTHQUAKES. NUMBERS AND M_S MAGNITUDES ARE FROM NUTTLI (1981). CONVERSION TO m_b FROM A FIGURE IN NUTTLI (1982).

I_o	M_S	m_b	Number
X-XII	≥ 8	≥ 6.8	3
IX-X	7-8	6.3-6.8	5
VIII-IX	6-7	5.8-6.3	10

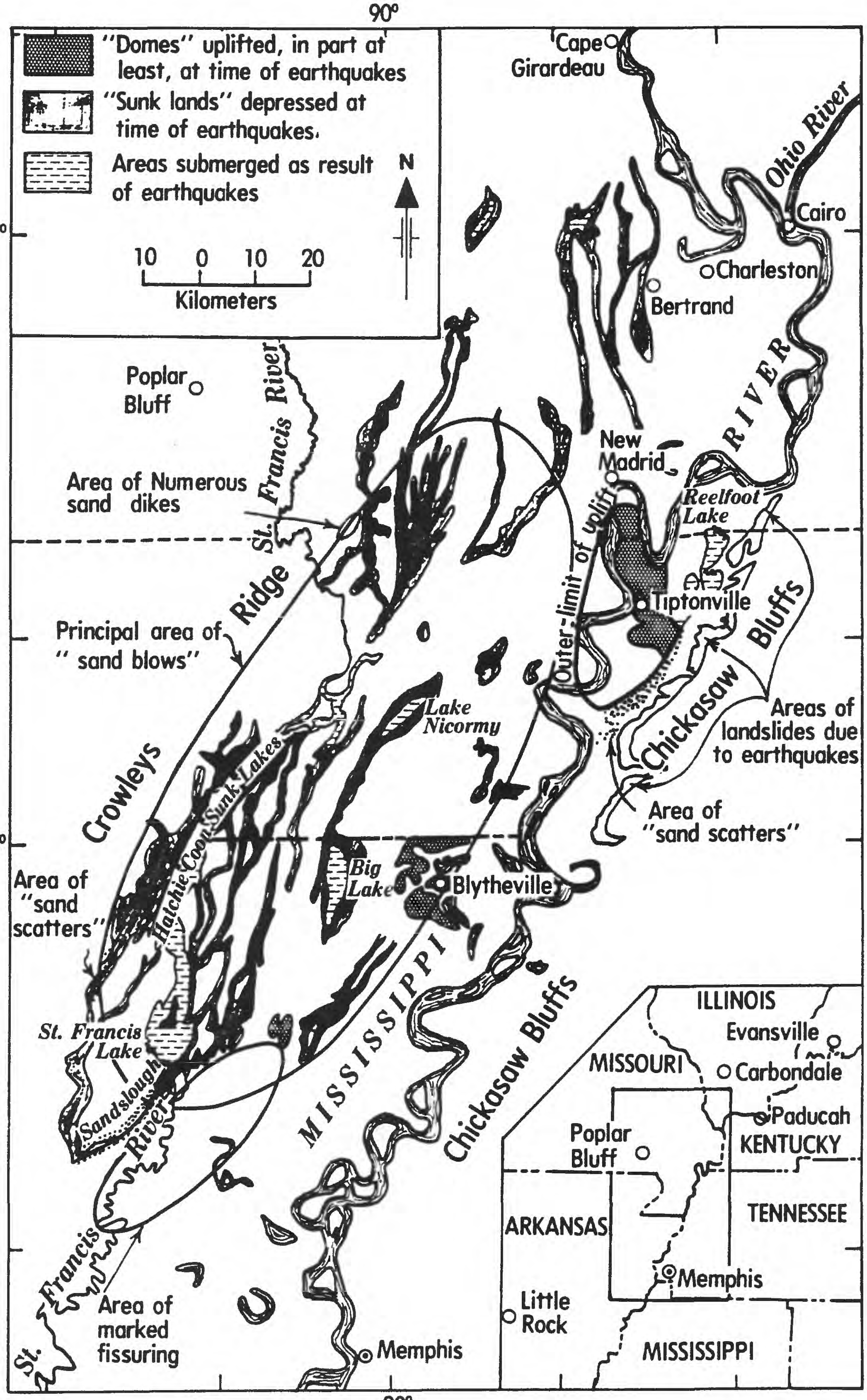

Figure 3. Map of the ground effects of the New Madrid district. After Fuller (1912).

There is little available information on the 1811-1812 series for the six cities in this study. Using Nuttli's (1981) map of the 1811 earthquake (see figure 2), Carbondale is in the VIII area; Evansville, the VII area; Little Rock, off the map; Memphis, the IX area; Paducah, the IX area; and Poplar Bluff, the IX area. Nuttli (1973) assigned a IX at Fort Pickering, near what is now Memphis.

The isoseismals for the 1811 earthquake, figure 2, are quite smooth and generalized. This is a result of the limited amount of historical data for this earthquake and its distribution over the eastern United States. No information at all is available for west of the Mississippi River. Even less is known about the distribution of effects of the two 1812 shocks in the sequence; Nuttli (1973) lists only 13 locations having assigned intensities for each of these earthquakes and does not attempt to make an isoseismal map from them. In order to estimate what the distribution of intensities for such large shocks might have been, another source of intensity information is necessary.

OTHER LARGE EARTHQUAKES IN THE REGION

Significant information is available for three other Central U.S. shocks, which are all smaller than the three large shocks of the 1811 series, but have magnitudes (m_b) greater than 5.5 (see table 3). All three were damaging earthquakes. These earthquakes supply more detailed information in areas where there is little or no 1811 data. Their isoseismal maps are shown in figures 4, 5, and 6.

TABLE 3.--RELATIVE SIZES OF LARGE EARTHQUAKES IN THE AREA. ESTIMATES FROM HOPPER AND ALGERMISSEN (1980 AND UNPUB. DATA), COFFMAN AND CLOUD (1970), AND NUTTLI (1981).

	I_o	m_b	Epicenter
1843 Jan 05	VIII	6.0	Near Memphis, Tennessee
1895 Oct 31	IX	6.2	Charleston, Missouri
1968 Nov 09	VII	5.5	South-central Illinois

The two largest of these earthquakes, those in 1843 and 1895, were chosen as the basis for the simulated earthquake developed in this study. They occurred near the south and north ends of the New Madrid seismic zone, respectively. Since it is assumed that the simulated earthquake in this study might occur anywhere in the New Madrid seismic zone, the locations of these two shocks are ideal for the simulation. Moreover, the greater availability of intensity data for the 1843 and 1895 earthquakes, compared to the 1811-1812 sequence, makes possible the more detailed isoseismals that are necessary for the simulation. The 1968 earthquake, although smaller than the 1843 and 1895 shocks, and located north of the New Madrid seismic zone, is also discussed here because of its excellent data set, including assigned intensities at all six of the cities considered in this report.

The information available for each of the six cities considered in this study for the 1811-1812, 1843, 1895, and 1968 earthquakes is summarized in table 4. The table shows the distances from the epicenters to each city and the assigned intensities in the cities when that information exists. Since there are no records from any of these cities in 1811-1812 (most of the cities didn't yet exist, except for Fort Pickering near Memphis), the isoseismal area within which a city lies is noted instead of an intensity value assigned on the basis of actual earthquake effects. Intensities near the cities are also noted for some of the 1811 locations. Isoseismal areas, rather than assigned intensities, are also given when necessary for the other earthquakes in table 4.

The three large earthquakes for which there is much available information will now be considered in more detail. They are: 1) January 5, 1843, near Memphis, Tennessee (figure 4), 2) October 31, 1895, Charleston, Missouri (figure 5), and 3) November 9, 1968, southern Illinois (figure 6). Their effects on the six cities studied in this report are discussed below. More detailed information can be found in Appendices 2-7 at the end of this report.

January 5, 1843

The 1843 earthquake (figure 4) is the third largest historical earthquake (or series) in the central Mississippi valley. Only the 1811-1812 and the 1895 earthquakes were larger. Moreover, it is the closest of the large Mississippi

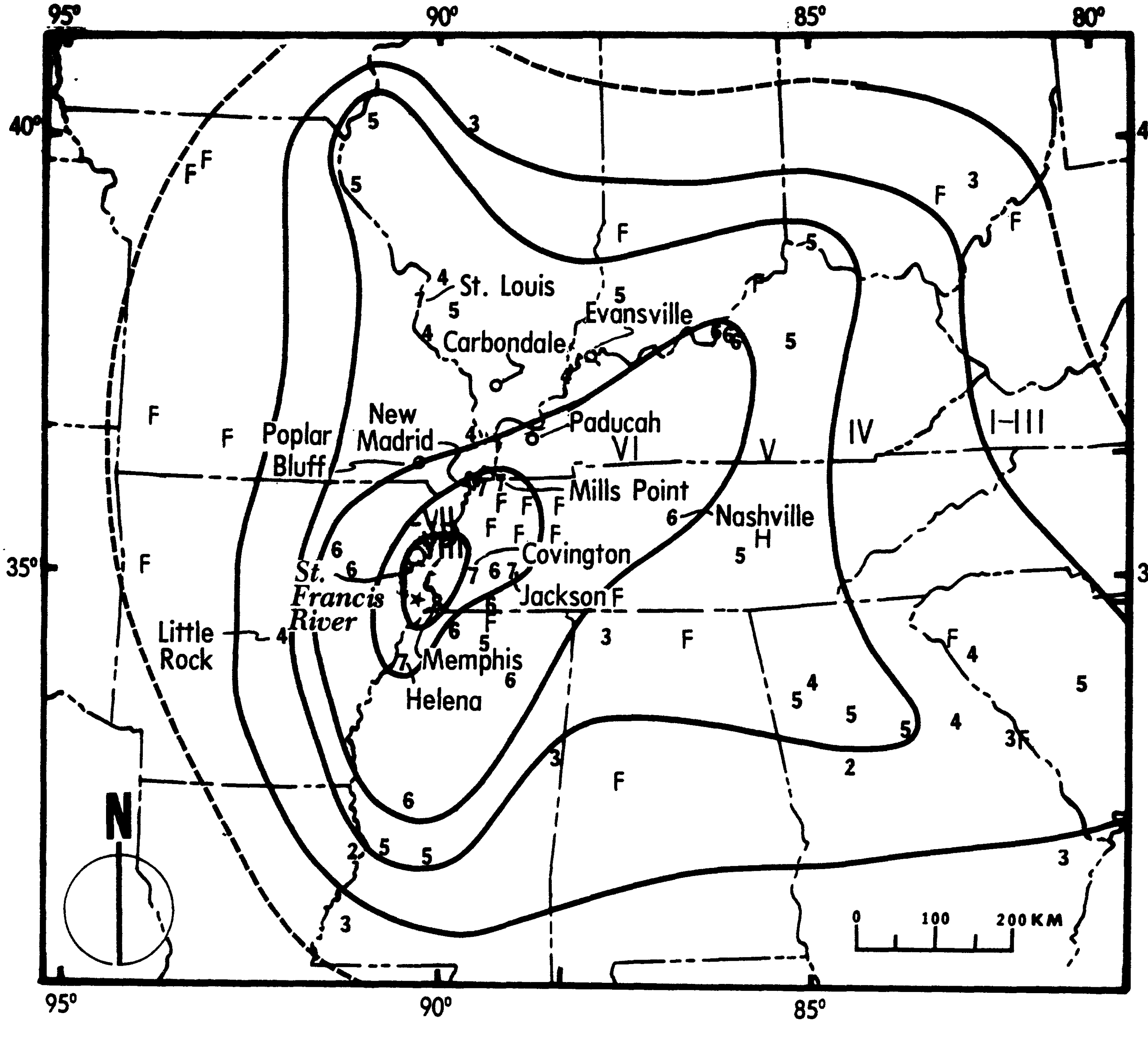

Figure 4.__Isoseismal map of the January 5, 1843, earthquake near Memphis, Tennessee. After Hopper and Algermissen (unpub. data). Arabic numbers represent assigned Modified Mercalli intensities for individual locations; F, H, and O are used for Felt, Heavy, and Liquefaction, respectively. Star is at the epicenter. Of the six cities in this study there are assigned intensities for two: IV at Little Rock and VIII at Memphis. There are no assigned intensity values for the other four cities, but Carbondale and Evansville lie within the intensity V isoseismal; Paducah and Poplar Bluff, the VI isoseismal.

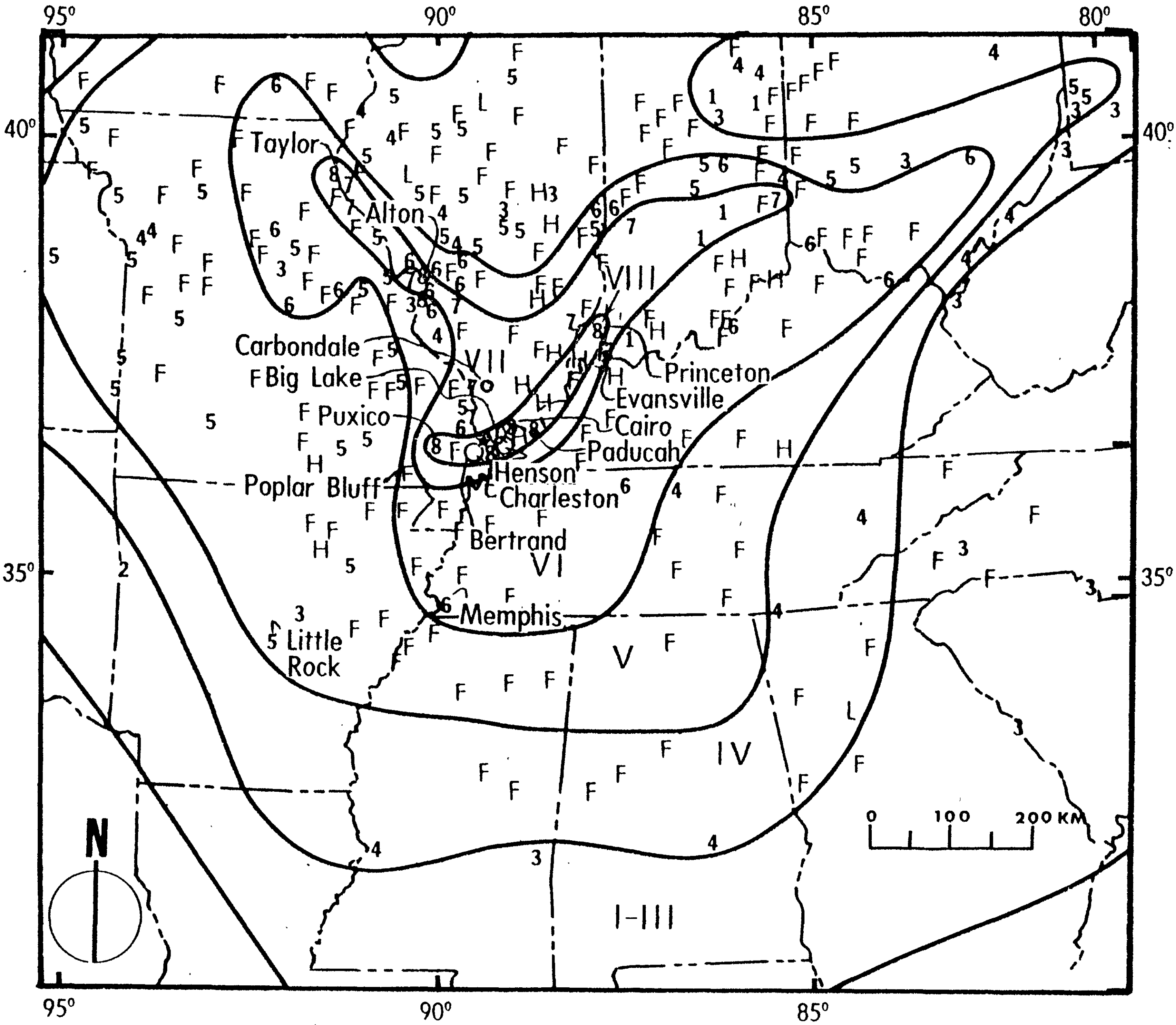

Figure 5. Isoseismal map of the October 31, 1895, earthquake near Charleston, Missouri. After Hopper and Algermissen (1980). Arabic numbers represent assigned Modified Mercalli intensities for individual locations; F, H, L, and O are used for Felt, Heavy, Light, and Liquefaction, respectively. Star is at the epicenter. Of the six cities in this study there are assigned intensities for five: Felt at Evansville, V at Little Rock, VI at Memphis, VIII at Paducah, and felt at Poplar Bluff. Carbondale has no assigned intensity but lies within the intensity-VII isoseismal.

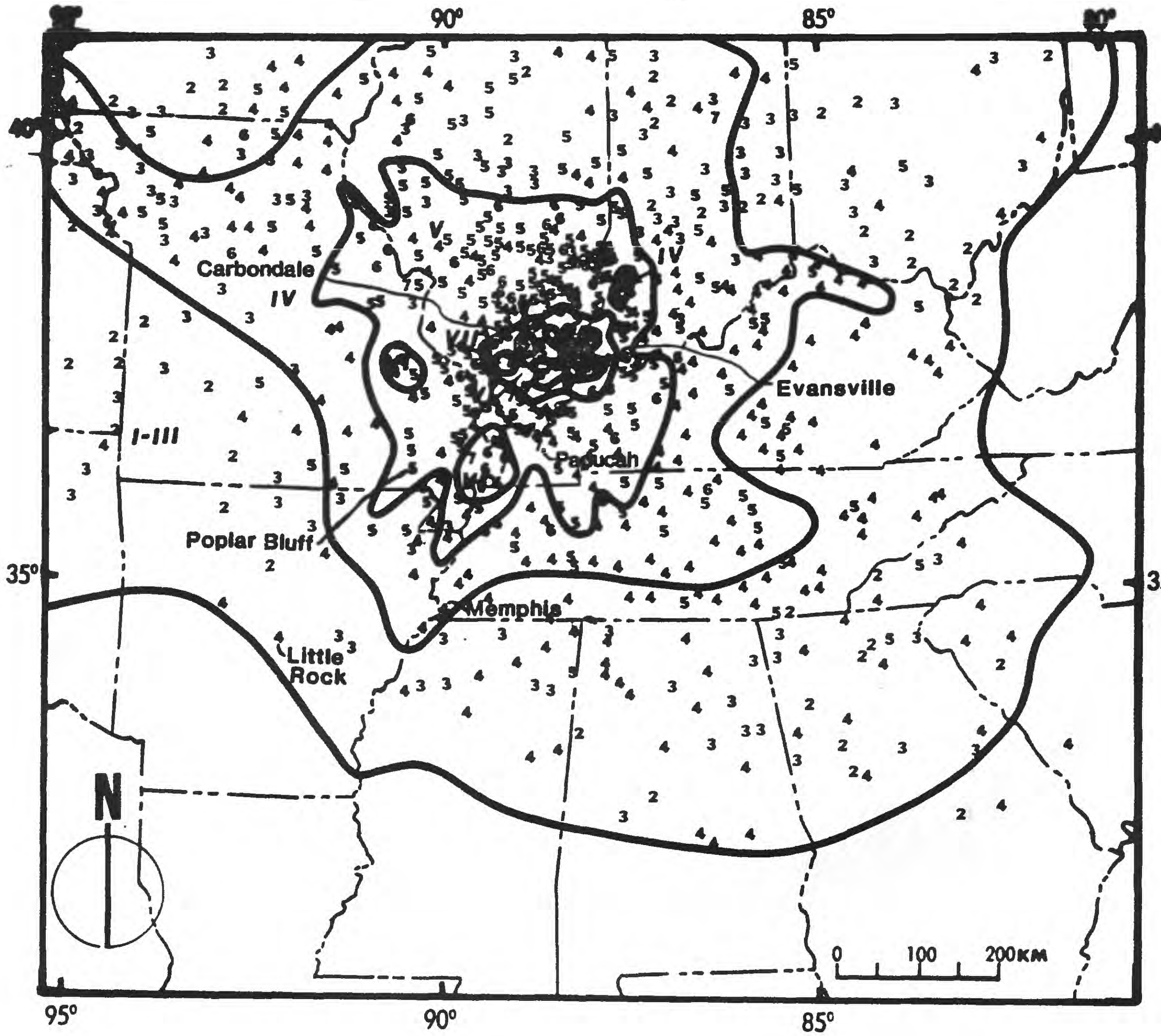

Figure 6. Isoseismal map of the November 9, 1968, earthquake in south-central Illinois. After Gordon and others (1970). Arabic numbers represent assigned Modified Mercalli intensities for individual locations. Star is at the epicenter. Assigned intensities at the six cities in this study are: VI at Carbondale, VI at Evansville, I-VI at Little Rock, I-V at Memphis, VI at Paducah, and V at Poplar Bluff.

valley earthquakes to the epicenter of the 1811 earthquake. More intensity data are available for 1843, and therefore its isoseismals show greater detail than those of the 1811 earthquake.

The maximum intensity for the 1843 shock is VIII M.M. The epicentral area appears to be the area of northeast Arkansas west of Memphis, Tennessee.

TABLE 4. EPICENTER-CITY DISTANCES AND CITY INTENSITIES. WHERE THERE ARE NO ASSIGNED CITY INTENSITIES, THE ISOSEISMAL AREA IN WHICH THE CITY LIES IS GIVEN INSTEAD. INTENSITIES AT NEARBY LOCATIONS ARE NOTED WHERE RELEVANT. THERE IS INSUFFICIENT INFORMATION TO CONTOUR ISOSEISMALS FOR THE 1812 EARTHQUAKES, SO THE CITIES' ISOSEISMAL AREAS ARE UNKNOWN FOR THOSE SHOCKS. LATITUDE (°W) AND LONGITUDE (°N) ARE SHOWN BELOW EACH DATE AND EACH CITY AND EACH EARTHQUAKE DATE.

DATE AND EPI-CEN-TER	CARBON-DALE IL 37.7° 89.2°	EVANS-VILLE IN 38.0° 87.6°	LITTLE ROCK AR 34.7° 92.3°	MEMPHIS TN 35.1° 90.1°	PADUCAH KY 37.1° 88.6°	POPLAR BLUFF MO 36.8° 90.4°
1811 Dec. 16 35.8° 90.3°	238km In VIII AREA.	336km in VII AREA OFF MAP.	212km in VII AREA?	80km IX at FORT PICKER-ING	205km in IX AREA	104km in IX AREA
1812 Jan. 23 36.2° 89.8°	178km	280km	274km	120km	145km	87km
1812 Feb. 07 36.5° 89.6°	142km	241km	311km	160km	102km	82km
1843 Jan. 05 35.2° 90.5°	307km in V AREA	402km in V AREA	170km IV	32km VIII	269km in VI AREA	179km in VI AREA
1895 Oct. 31 37.0° 89.4°	81km in VII AREA	192km FELT. in VII AREA	362km V	223km VI	81km VIII	94km FELT. in V AREA
1968 Nov. 09 38.0° 88.5°	69km VI	81km VI	498km I-IV	350km I-IV	105km VI	218km V

Nuttli (1974) noted that no reports are available from this area, which was lightly populated in 1843, but the maximum intensity there "probably would have been VIII or slightly greater." He found m_b = 6.0 based on intensity attenuation with distance and m_b = 6.1 based on the felt area. Total felt area is about 1,500,000 km^2, or about the same as the 1968 southern Illinois earthquake (Hopper and Algermissen, unpub. data). Reports of damage include fallen chimneys and cracked brick walls at Memphis (Heinrich, 1941); damaged chimneys at Covington, Jackson, and Nashville in Tennessee, at Helena in Arkansas, at Mills Point [now Hickman] in Kentucky, and at New Madrid and Saint Louis in Missouri. In the St. Francis River area of northeastern Arkansas a hunter reported that a deep lake had been formed by the earth's sinking on the river. (<u>The Daily National Intelligencer</u>, Washington, D.C., Jan. 30, 1843).

The following is the available information, taken from Hopper and Algermissen (unpub. data), for the 1843 earthquake for each of the six cities in this study:

<u>Carbondale, Illinois:</u>

No report is available from Carbondale for the 1843 earthquake, but the city is within the intensity-V isoseismal. No reports exist within a 50-km radius of Carbondale. The closest avalable intensity data are three IV's at distances of 75, 95, and 120 kilometers from Carbondale, and one V at 115 kilometers.

<u>Evansville, Indiana:</u>

No report is available from Evansville for the 1843 earthquake. The city is within the intensity-V isoseismal but no reports are located within a 50-kilometer radius of Evansville. The nearest report is a IV from a location about 60 km downstream along the Ohio River.

<u>Little Rock, Arkansas:</u>

The <u>Little Rock State Gazette</u> describes "the rattling of windows, glasses, and cupboards, and the creaking of our wooden houses....The shaking of the earth...seemed to indicate a vibratory motion from N.E. to S.W., and continued for about the space of one minute." This report is assigned intensity IV.

Memphis, Tennessee:

Several newspapers give accounts of the earthquake at Memphis. The American Eagle of January 6, 1843, says, "We were in our office..., in the second story of a new block of brick buildings. The commencement of the jarring we conceived to proceed from the violent undertaking of some person to shake open a door beneath us. But in a moment afterwards, the agitation seized the brick walls surrounding us, shaking and reeling them, to such an extent, as to knock down particles of brick and plaster, jarring the roof and whole buildings so as to impress us with the fear of the buildings's falling....We hastily fled into the street for safety....In the street there was still a violent rocking of the earth, and a rattling and rumbling noise. People fled into the streets.

The shock lasted about two minutes, and reached its most agitation period at the end of the first half minute, when it gradually died away in a dismal rumbling sound, apparently moving to the south-east, and proceeded from the north-west....

The tops of several chimneys were shaken down, the bricks falling inside....A great many brick walls are seriously cracked and sunk, windows broken, and a cotton shed, naturally crazy, fell down shortly after the shock."

Memphis is assigned an intensity of VIII. It is the only intensity VIII assigned for the shock. The epicenter is assumed to be about 30 km west of Memphis.

Paducah, Kentucky:

No report is available from Paducah in 1843. The city is within the intensity-VI isoseismal with no reports within a 50-km radius. The closest reports are a IV at 85 km from Paducah and two VII's at 75 and 100 km from Paducah. The two VII's are about 90 km closer to the epicenter than Paducah.

Poplar Bluff, Missouri:

No report is available for Poplar Bluff for 1843. The city is on the line between the intensity-V and VI areas. No other reports are located within a 50-km radius of Poplar Bluff, and the closest report is the intensity-VII at New Madrid, about 80 km away from Poplar Bluff.

OCTOBER 31, 1895

The 1895 earthquake (figure 5) is the largest historical earthquake in southeast Missouri, except for the 1811-1812 sequence. It is therefore of particular interest to this study because its effects were much better observed than those of 1811 and 1812. The numbers of people and structures in the area by 1895 provided more numerous and better distributed reports than were available in 1811. This allows much better defined isoseismals, which can be used to estimate the shaking west of the Mississippi River that must have occurred as a result of the 1811 earthquake.

The maximum M.M. intensity is at least VIII, and probably IX; VIII is assigned at seven places by Hopper and Algermissen (1980). Heinrich (1941) notes that at Charleston "every building in the commercial block was damaged...and many walls were cracked." At Cairo "the number of chimneys shaken down in the city probably runs into the hundreds" (Marvin, 1895). Sandblows, or spouts of water and sand, were reported near Bertrand, Big Lake, and Charleston, Missouri, and a new lake was formed south of Henson Lake, Missouri; these places are all within the VIII contour, but this evidence of liquefaction is not used to assign intensities in figure 5. Rather, the liquefaction locations (for example, Bertrand, Missouri) are denoted on figure 5 by "Q", when no other information is available on which to assign a Modified Mercalli intensity. (Note that, similarly, brief, non-definitive reports are denoted on figure 4 by "F" (felt), "H" (heavy), and "L" (light).) Nuttli (1974) assigned a maximum intensity of IX to the Bertrand report and VIII-IX at Charleston. He derived $m_b = 6.2$ based on the intensity fall-off with distance. The epicenter is placed near Charleston at 37.0^oN, 89.4^oW by both Nuttli and other researchers. It is marked on figure 5 with a star. The felt area is estimated to be about 2,500,000 km^2 (Hopper and Algermissen, 1980).

The following is the available information, taken from Hopper and Algermissen (1980), for the 1895 earthquake for each of the six cities in this study:

Carbondale, Illinois:

No report is available from Carbondale in 1895. The city is within the intensity-VII isoseismal, and there are intensity-VII reports from two other locations within a 50-km radius of Carbondale.

Evansville, Indiana:

Marvin (1895) reports the 1895 earthquake felt at Evansville. The city is within the intensity-VII isoseismal, and there are assigned intensities of VIII and VII, plus two others simply denoted as "heavy", within a 50-km radius of Evansville.

Little Rock, Arkansas:

At Little Rock, Marvin (1895) says, "Distinct earthquake, the vibrations being east and west and lasting about one minute." Little Rock is assigned intensity V and is within the intensity-V isoseismal.

Memphis, Tennessee:

Marvin (1895) notes that in Memphis "there was no damage done...except to two chimneys in the suburbs, which were shaken down." Memphis is assigned an intensity of VI for 1895 and is inside the intensity-VI isoseismal. The closest other reports are all "felt"s.

Paducah, Kentucky:

Paducah is assigned an intensity of VIII (Hopper and Algermissen, 1980) and is within the VIII isoseismal. The Saint Louis Post-Dispatch says, "Houses sw ayed to and fro, a number of chimneys fell and several walls were cracked." Within 50 km of Paducah are another VIII and two "heavy" locations.

Poplar Bluff, Missouri:

Of Poplar Bluff Heinrich (1941) said, "The movement was described as rocking and seemed to be east-west. A noise "like a cyclone" preceded the shock." Poplar

Bluff is inside the intensity-VI isoseismal and within 50 km of locations assigned VIII, V, and "felt." Poplar Bluff is assigned "felt" rather than a specific intensity.

NOVEMBER 9, 1968

The November 9, 1968 earthquake (figure 6) is the largest earthquake to occur in the Central United States since 1895. Stauder and Nuttli (1970) located it at 37.95°N, and 88.48°W with a depth of 25 km. They found a body-wave magnitude of $m_b = 5.54 \pm 0.44$ using stations at teleseismic distance (beyond 25°) or $m_b = 5.44 \pm 0.29$ using Evernden's (1967) formula. Stauder and Nuttli (1970) suggested that the earthquake is probably closely related to the Wabash Valley fault system in southern Illinois. Gordon and others (1970) found that the strongest shaking, VII M.M., took place in the Wabash and Ohio River Valleys and adjacent lowlands of south-central Illinois. They observed that damage consisted primarily of bricks thrown from chimneys, broken windows, toppled TV antennas, and cracked plaster. In the epicentral area they found cracks in foundations, chimneys thrown down, and scattered instances of collapsed parapets and overturned tombstones. Their survey showed 15 percent of the chimneys within 25 miles (40 km) of the epicenter had sustained damage. The felt area included 580,000 mi^2 (1,500,000 km^2) of the Central United States including all or portions of 23 states.

The following are the reports from the six cities included in this study:

Carbondale, Illinois:

In United States Earthquakes, 1968 (Coffman and Cloud, 1970) intensity VI is assigned at Carbondale, where there were reports of a crack in the putty on a window, a cracked sidewalk, and overturned oil tanks. Carbondale is within the intensity-VI isoseismal.

Evansville, Indiana:

In United States Earthquakes, 1968 (Coffman and Cloud, 1970) intensity VI is assigned at Evansville, where there were reports that plaster fell throughout the city, a chimney on an old house fell, and bricks were loosened on an old church so that the wall threatened to collapse. Evansville is within the VI isoseismal.

Little Rock, Arkansas:

In United States Earthquakes, 1968 (Coffman and Cloud, 1970) intensity I-IV is assigned at Little Rock. Little Rock is in their I-III area.

Memphis, Tennessee:

In United States Earthquakes, 1968 (Coffman and Cloud, 1970) intensity I-IV is assigned at Memphis. Memphis is within their IV isoseismal.

Paducah, Kentucky:

In United States Earthquakes, 1968 (Coffman and Cloud, 1970) intensity VI is assigned at Paducah, where a few bricks fell from chimneys. Paducah is within the VI isoseismal.

Poplar Bluff, Missouri:

In United States Earthquakes, 1968 (Coffman and Cloud, 1970) intensity V is assigned at Poplar Bluff. Poplar Bluff is within the intensity-V area. There is a VI nearby on the east and V's to the north.

SEISMICITY OF THE NEW MADRID SEISMIC ZONE

Large earthquakes of the New Madrid seismic zone are shown in figure 7. It includes the three 1811-1812 earthquakes with Io $\geq$ XI M.M., the 1843 and 1895 earthquakes with Io's of VIII and IX respectively, and all other shocks with Io $\geq$ VI-VII. Intensities $\leq$VI are indicated by small circles.

There are numerous smaller earthquakes in the study region in addition to the three large earthquakes of 1811-1812 discussed above. The New Madrid seismic zone (figure 8) is the most active seismic area in the Central and Eastern United States (Zoback and others, 1980). The zone has recently been well defined as a result of a regional seismic network, which was established in 1974 (Stauder, 1982) and through seismic reflection profiling (Zoback and others, 1980). Seismic reflection profiling is a method for determining the locations and xttitude of strata beneath the surface by recording artifically induced vibrations.

Epicenters determined using the recordings obtained by the seismic network from 1974 to 1981 are shown in figure 8. They are plotted from a computer tape of epicenter locations made available by Robert B. Herrmann of Saint Louis University. These instrumentally recorded microearthquakes, for the most part not felt, give sharp definition to the location of the New Madrid seismic zone. Precise definition of the zone prior to the installation of the seismographic network in 1974 was impossible because of the scatter in the historical epicenters (figure 7) which are for the most part located by intensity data, rather than by instrumental data.

Note that, while the recent seismicity defines the zone, it does so only for the interval 1974-1981. Activity may have occurred elsewhere in the zone prior to 1974. The epicenters of the 1843 and 1895 shocks, although poorly located themselves, appear to be somewhat south and north, respectively, of the clustered epicenters shown in figure 8.

ESTIMATION OF MAGNITUDE AND PROBABILITY OF OCCURRENCE OF LARGE DAMAGING EARTHQUAKES IN THE MISSISSIPPI VALLEY

Earthquake Of Maximum Magnitude

Nuttli (1981) has assigned the largest shock of the 1811-1812 a M_s (surface wave magnitude) of 8.7, equivalent to an m_b (body wave magnitude) of 7.3. These magnitudes are at the upper limits of both magnitude scales, which means, from a practical point of view, that the M_s and m_b magnitude scales saturate at these levels. Saturation of the scales means that the amplitudes of P-waves and surface waves with periods of one second and 20 seconds respectively reach limiting amplitudes for body wave magnitudes of about 7.5 and surface wave magnitudes of about 8.7. The m_b magnitude is derived from the amplitude of P-waves at about one second period. The M_s magnitude is derived from the amplitude of surface waves with periods of 20 seconds. Larger earthquakes (earthquakes

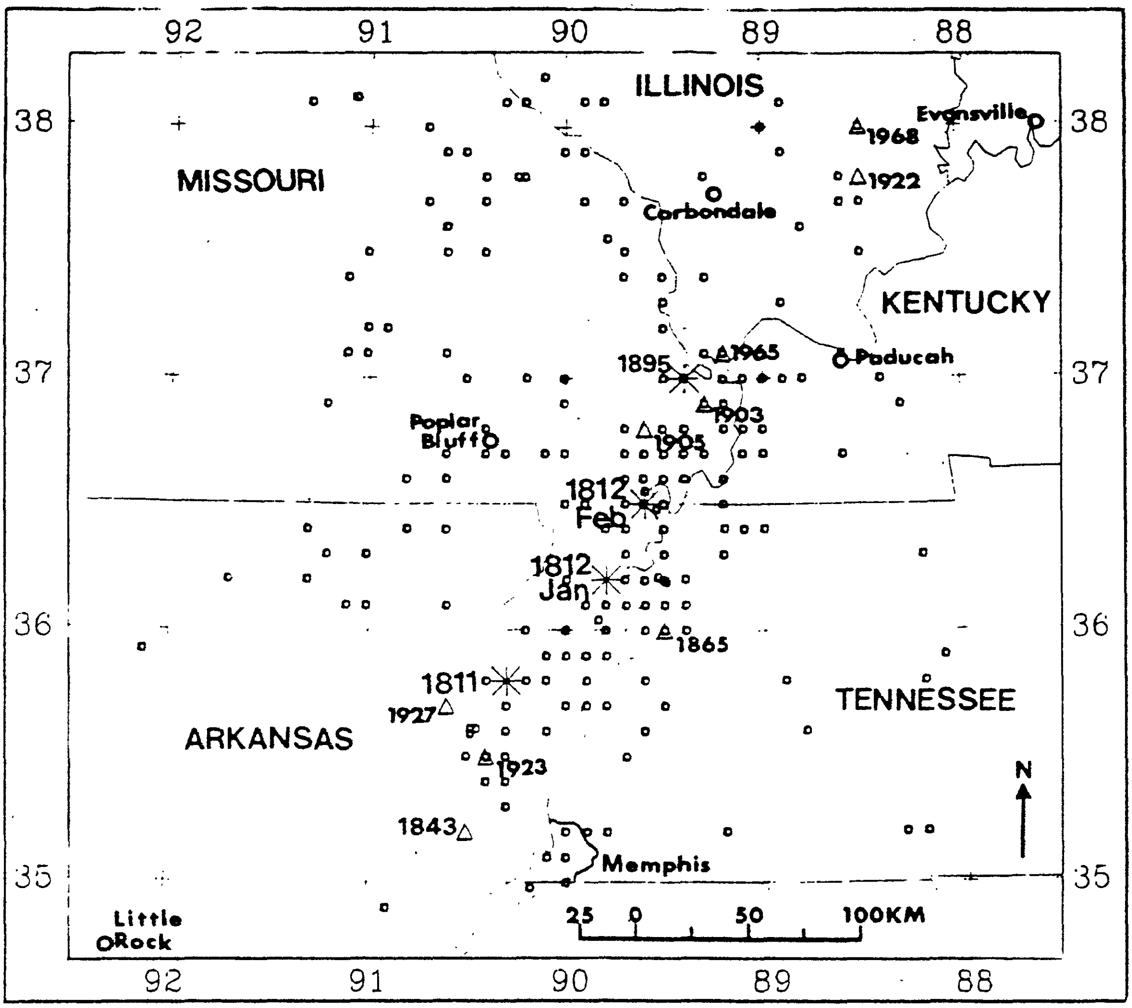

Figure 7. Historical seismicity of the New Madrid seismic zone and surrounding areas, 1800-1982. Plotted from Algermissen and Askew, unpublished listings. Epicenters for intensities IX and above are indicated by astericks; VI-VII, VII, and VIII by triangles; and VI and below by small circles. Epicenters for the 1811-1812 shocks are from David P. Russ (oral communication, 1982).

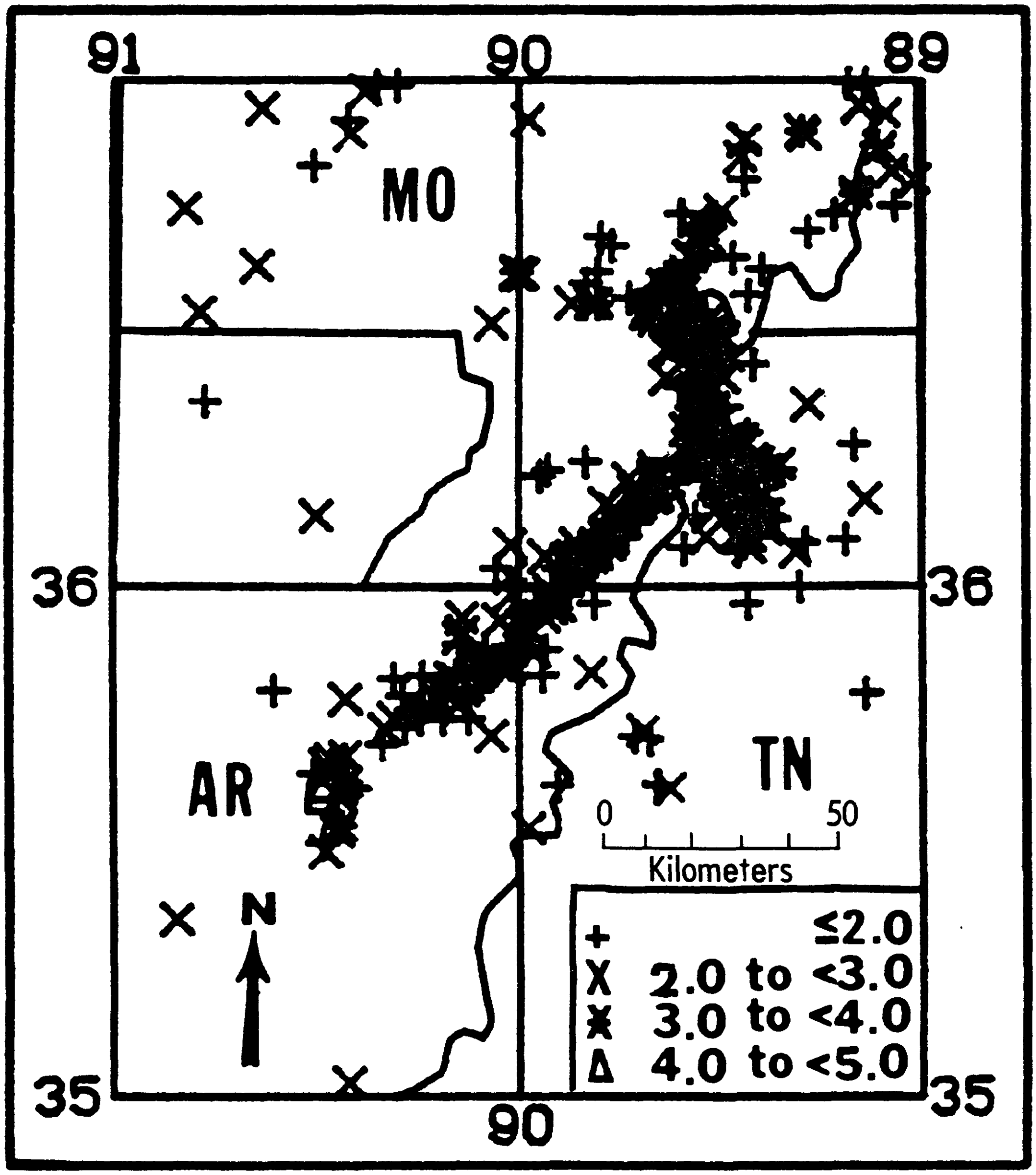

Figure 8.__Microseismicity of the New Madrid seismic zone, 1974-1981. Plotted from tape obtained from Robert B. Herrmann of Saint Louis University.

releasing more energy than earthquakes with m_bf7.3 and M_sf8.7) are known to have occurred (for example, in Alaska in 1964) and their magnitude can be scaled by use of the moment magnitude M_w (Kanamori, 1977). Earthquakes with large moment magnitudes for which both the M_s and m_b scales are saturated are not likely to produce significantly larger amplitude ground motions than M_s = 8.7 (m_b = 7.3) earthquakes out to distances of the order of 100 km. At greater distances, earthquakes with large moment magnitudes may produce significantly larger amplitude ground motion at longer periods. Earthquakes will shake increasingly larger areas (as M_w increases) at damaging levels.

The entire length of the New Madrid zone is only about 240 km which suggests that the stress drop in the 1811-1812 earthquakes may have been higher than for earthquakes along plate boundaries such as occur in California.

A number of investigations have developed magnitude-fault rupture length relationships using various data sets (for a summary see Slemmons, 1977). Based upon a length of about 240 km for the New Madrid Zone, most of these relationships would predict smaller maximum magnitudes than are known to have occurred in the zone although the dispersion of the data sets is very large. Because of the uncertainty in the stress drop associated with earthquakes in the Midwest and the large dispersion of the magnitude-fault length data sets, fault length does not offer a very high resolution method of estimating maximum magnitude events in the Midwest.

Because of the large magnitudes of the three principal shocks of the 1811-1812 sequence and since these are the largest shocks known to have occurred in historical times in North America (exclusive of Alaska), it is at least reasonable to assume that repetition of the 1811-1812 series in the Mississippi Valley represents an adequately conservative model for disaster planning and response. This assumption is made in the present study.

Recurrence of Large Shocks

The average recurrence rates of large earthquakes can be estimated reasonably well from the historical record of earthquake occurrence provided that the area is not too small, that is, the area is sufficiently large that a number of large shocks have been known to have occurred historically. The seismicity of the midwestern United States is relatively low and the 1811-1812 series of large shocks is unique although some archeological evidence and certain native American legends suggest earlier large earthquake occurrence. A number of estimates have been made of the average recurrence rate for large earthquakes in the Mississippi Valley. Since significant seismogenic faults (and consequently fault slips) have not been positively identified in the Mississippi Valley, estimates of the recurrence times of large shocks has been based on the historical earthquake data. Table 5 summarizes some of the estimates. The important conclusion from table 5 is that there is general agreement among a wide range of investigations on the average recurrence interval for large shocks when the recurrence rate is estimated from the historical seismicity. In the absence of geologic (fault slip) or other confirmatory data, it is not easy to estimate the reliability of the estimates of the recurrence rates of large shocks based on the historical data.

TABLE 5.--ESTIMATES OF AVERAGE RECURRENCE TIMES FOR LARGE EARTHQUAKES IN THE MISSISSIPPI VALLEY

Source	Magnitude or Maximum MM Intensity	Estimated Recurrence (years)	Method Used
Nuttli (1974)	7.0 - 7.4 (m_b) 7.0 - 7.4 (m_b)	510 710	Maximum likelihood Weighted least squares
Algermissen (1973)	XI (m_b f 7.2)	500	Least squares (1811-1812 events included)
McClain and Myers (1970)	X	175	
Mann and Howe (1973)	7.7 (M_s) X	600-700	
Algermissen (1972)	XI (m_b f 7.2)	500-600	Extreme value analysis

ESTIMATION OF DAMAGING GROUND MOTION IN TERMS OF MODIFIED MERCALLI INTENSITIES

The ground shaking (reported in Modified Mercalli intensities) at a site depends primarily on three factors:

1) the size of the earthquake, that is, the amount of energy released by the earthquake,

2) the attenuation, or weakening of seismic waves, along the path between the epicenter and the site, and

3) geologic conditions at the site itself. The size of the earthquake has already been discussed. For the purposes of this study it is assumed to be a magnitude m_b = 7.2, Io = XI M.M. earthquake located in the New Madrid seismic zone. This agrees with the size of the December, 1811, earthquake as estimated by Nuttli (1981).

Variations in intensity patterns of three large regional earthquakes are used to develop a composite regional intensity map for a large earthquake that might occur anywhere along the zone. The method used and the resulting map (figure 9) are discussed in the next section. From this regional intensity map, projected intensities at each of the six cities in this study have been determined. Seismic zonation at the scale of an individual city requires some knowledge of geologic conditions at each site. Site conditions important for the evaluation of intensity include topographic slope, geologic materials, and water saturation. These conditions determine the potential for higher or lower than average shaking, and the potential for such geologic effects as liquefaction, flooding, and landsliding. The section on site geology deals with these conditions for each of the six cities studied.

SEISMIC INTENSITIES

Causes of intensity pattern variations

The intensity patterns of two large earthquakes with epicenters close together are frequently similar. For example, higher intensities are usually experienced

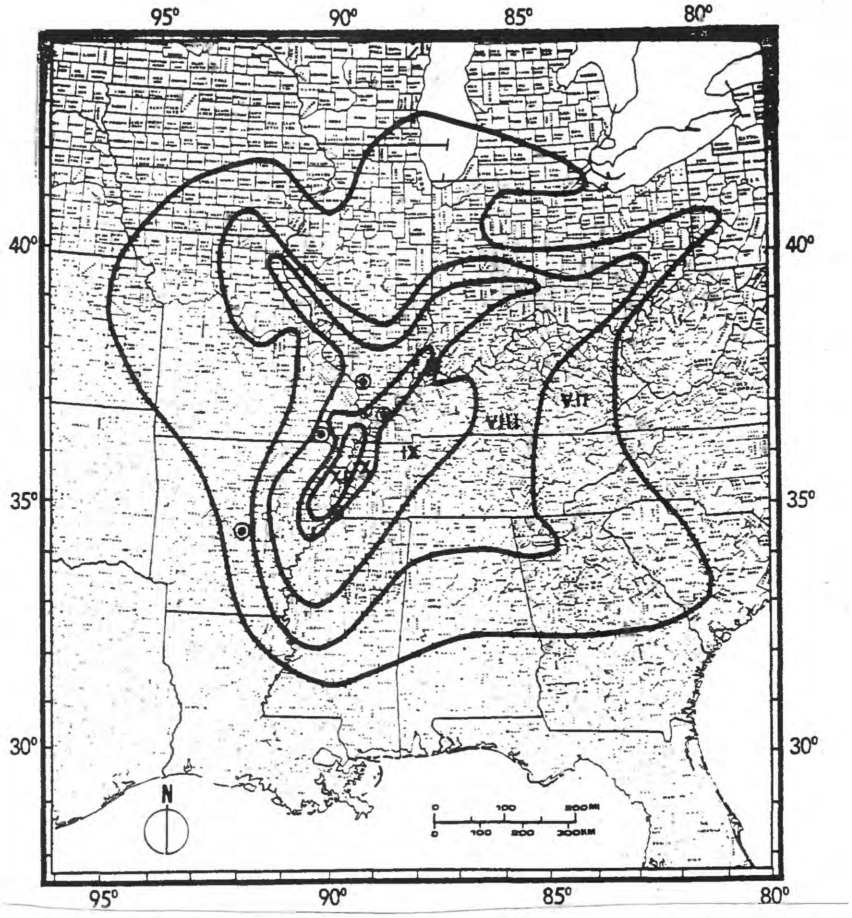

Figure 9.--Hypothetical regional intensity map for an 1811-size earthquake having an epicenter anywhere along the New Madrid seismic zone. Dots show the location of the six cities in this study. The contours on this map are used to assign the county intensities shown in Figure 16. The intensities mapped in this illustration are for disaster prepredness and mitigation planning only and represent the maximum intensity from an ensemble of possible large earthquakes. The intensities mapped here are not likely to occur everywhere in the area mapped at each intensity level.

in alluvial river valleys, lower intensities on bedrock. Some other localities with unusually high or low intensities are more difficult to explain. The intensity scale is an attempt to quantify a qualitative type of information, and in the process the scale greatly simplifies a very complex phenomenon. Factors which are thought to affect the resulting intensity at a given site include: earthquake magnitude and depth; focal mechanism; epicentral distance; acceleration, velocity, amplitude, period, and wavelength of the seismic waves; duration of strong shaking; type of ground; geologic structure; slope of ground, ground water and natural period of structures and sites. In addition, assignment of intensity values to observed effects should include consideration of type of construction, quality, and workmanship. Much of the preceding list is from Barosh (1969).

Comparison of the intensity patterns of the four earthquakes shown in figures 2, 4, 5, and 6 reveals some similarities. For the data-scarce 1811 earthquake.(figure 2) the patterns are mostly smooth curves, nearly circular. There is a slight hint of higher attenuation to the south, lower to the northeast, but too few data occur on the map to give much confidence in the exact locations of the isoseismals. For the 1843 earthquake, figure 4, the situation is improved. The attenuation is definitely higher on the southwest, lower on the northeast along the Ohio River, on the northwest along the Mississippi River, and on the southeast. The 1895 earthquake, figure 5, with epicenter farther north, shows similar low attenuation northeast and northwest. The 1968 earthquake, figure 6, though a smaller earthquake located north of the New Madrid seismic zone and north of the other earthquakes considered, has an excellent data set allowing detailed contouring of isoseismals. Note that it shows low attenuation along all the river valleys, higher attenuation to the south and south-southwest. Figure 6 also clearly shows that within a given isoseismal area, the intensities are not uniform. For example, in the IV area there are a number of III's and V's, and even VI's. Isoseismals are normally constructed to outline the predominant intensity in an area, that is, the highest intensity which is common in an area.

As discussed above, intensity may not attenuate uniformly in all directions. When data are sufficient isoseismals are seldom circles, but rather extend farther along certain courses (for example, river valleys) and have reentrants, or lower intensity regions, in other areas. To preserve these patterns of unusually high or low intensity areas, the isoseismals of the 1843 and 1895 earthquakes have been used as the basis of the regional map (figure 9) developed in this study.

Hypothetical regional isoseismal map

The 1843 and 1895 isoseismal maps have been used as the basis of the hypothetical regional map because they are the largest earthquakes in the New Madrid seismic zone for which sufficient data are available to make reasonably detailed isoseismal maps. The shaking levels associated with each of these two earthquakes have been extrapolated to the level of an 1811-size earthquake; the 1895 earthquake is raised two intensity levels from a low maximum intensity of IX to XI. The maximum intensity of the 1843 shock has been raised 2.5 levels from mid-VIII to XI. The results are two 1811 type maps, one for the northern end of the New Madrid seismic zone and one for the southern end, which taken together show the attenuation patterns for large earthquakes likely to occur throughout the New Madrid zone. These two maps have been combined graphically by taking the maximum intensity at every point to yield the hypothetical regional intensity map (figure 9).

The effect of this method is simply to increase the intensity levels shown on the 1895 and 1843 isoseismal maps, figures 5 and 4. This may be done because graphs of intensity attenuation (plots of intensity versus distance from the epicenter) for earthquakes of lower I_o are assumed to be parallel to similar graphs for earthquakes of higher I_o. Thus the attenuation curve for a smaller earthquake may be raised in order to simulate an attenuation curve for a larger earthquake, and the map isoseismals may be raised.

One additional modification was necessary to complete figure 9. Since the hypothetical map is based on earthquakes at the north and south ends of the seismic zone, a gap is produced between the areas of intensity XI resulting from the 1895 epicentral area on the north and the area of XI resulting from the 1843 epicentral area on the south. In this gap the X's produced by the method above have been arbitrarily changed to XI's along the length of the New Madrid seismic zone. This is necessary since large earthquakes are assumed to be possible anywhere along the zone. The lack of an earthquake located near the center of the seismic zone to be used as a third basis for the hypothetical regional map has only a small effect on the outer contours. By the same reasoning, if only one hypothetical earthquake occurred at the north (south) end of the seismic zone, cities near the south (north) end would experience lower intensities than those shown on figure 9, but cities far away from the zone would experience about the intensities shown, no matter in which section of the seismic zone the earthquake occurred.

The map in figure 16 shows the same information as figure 9, but has been generalized to show the predominant intensity in each affected county. In figure 16, a particular county has been judged to be either within or outside a particular intensity area. As with contouring intensty data, the rule used is that of the highest predominant intensity in a given county. Counties more or less evenly divided between two (or more) intensities are usually included in the higher category. This map will be of assistance to planning efforts by individual cities and counties. It must be stressed that every point in a county will not experience the intensity shown on figure 16. If for example, the county of intereat is on the north side of the area of figure 16, and the earthquake which actually occurs on the north end of the New Madrid seismic zone, some parts of the county are expected to experience the intensities shown on figure 16. There might also be a few isolated instances of intensity one unit higher, as well as many areas that will have lower intensities, perhaps several intensity levels lower. The processes producing simple intensities are very complicated and can result in structural damage to one building while a similar building nearby sustains little or no damage. Also, note that, for an earthquake at the south end of the New Madrid seismic zone, a county on the north side of the area of figure 16 will probably be at least one intensity unit lower than shown, and vice versa. Discussion of the application of figure 16 to specific locations follows the next section.

Liquefaction and landsliding

Liquefaction occurs when earthquake shaking causes a water-saturated, unconsolidated sand at depth to loose all its shear strength and become fluid. This mechanism produced the sandblows that were so prevalent during the 1811-1812 earthquakes.

Liquefaction can cause a loss of bearing capacity of any structure in the liquefied region. In Niigata, Japan, in 1964, many structures settled more than 1 m, often with severe tilting. One apartment building tilted 80 degrees from the vertical but remained structurally intact. Some buried structures floated to the surface (Seed and Idriss, 1967).

Liquefaction can also cause landslides. Several severe landslides were caused by liquefaction in Anchorage, Alaska, during the 1964 earthquake. Failure occurred in sand lenses overlain by clay; the sand failed and caused blocks of earth to move along a nearly horizontal surface toward a free face, or bluff, and then to collapse in wedge-shaped masses (Eckel, 1970).

Similar conditions likely to result in liquefaction exist in the Mississippi embayment. Liu (1981) described the conditions there: A few feet of clay and silt overlie a massive sand and gravel substratum, 50-100 feet (15-30 meters) thick. During earthquake shaking, the saturated cohesionless materials compact, causing an increase in pore water pressure in the soil and the upward flow of the water to the surface. This in turn causes flooding. Liu also pointed out that natural levees interbedded with lenses of cohesionless sand may fail by liquefaction, form flow slides into the watercourses, and cause flooding. Also, collapse of the man-made dikes in the New Madrid area into the drainage canals would cause widespread flooding (Liu, 1981).

One particular site that Liu notes, where the liquefaction potential has been investigated, is the Patoka Dam site in Indiana. Results indicate the foundation at the dam site to be subject to liquefaction from a magnitude-6.5 earthquake (Liu, 1981).

Geologic evidence of sandblows associated with the 1811-1812 and earlier earthquakes is still visible at the surface today. Detailed mapping of these sands in the Saint Francis basin has recently been completed by Obermeier (unpub. data). The potential for liquefaction may well exist beyond the Saint Francis basin, however. More work needs to be done in this region by examination of areal photographs to find the farthest extent of previous liquefaction evidence.

Youd and Perkins (1978) suggested that an opportunity exists for liquefaction, in sediments susceptible to liquefaction, as far as 150 km from the epicenter of a great earthquake. Since all six of the cities studied in this report are within this distance range of some segment of the New Madrid seismic zone, the potential for liquefaction must be assumed to exist in all of them that are underlain by liquefiable sediments. In each case, this is the area shown as the highest intensity on figures 11-15. Carbondale (fig. 10), though close enough to an epicenter located on the northern part of the seismic zone for liquefaction to occur, is not thought to have geologic conditions conducive to liquefaction.

STUDIES OF SIX CITIES

Maps of the six cities studied individually are shown in figures 10-15. The intensity in general in the area of a city can be determined from the map of hypothetical regional intensities, figure 16. But to zone a city in greater detail it is necessary to have some knowledge of the local geologic conditions. For this purpose, field investigations were made for each of the six cities in this study.

The assigned intensities on each city map are intended to be the maximum intensities likely--that is, those that would occur if the assumed 1811-size earthquake occurred on the part of the New Madrid seismic zone nearest that city. All of the cities would not experience these worst-case intensities at the same time. For example, if the assumed earthquake occurred near the south end of the zone, Memphis would in fact experience the IX's and X's shown in figure 16, but Evansville, which is north of the zone, and which is projected in figure 11 and figure 16 to have a maximum intensity of IX, would likely experience only intensity VIII effects. Similarly, if the earthquake were at the north end of the aeismic zone, Evansville would have the IX shown, while Memphis would probably experience only intensity VIII-IX effects. However, since in the 1811-1812 series three great shocks all occurred within a short period of time (December 16, 1811 to February 7, 1812), it is possible that the cities might all experience the maximum intensities more or less contemporaneously.

The intensities shown on figures 10-15 take into account both the regional map intensity (figure 16) and the local geologic conditions at each city. The regional map gives the highest common intensity for each city, but it is the local geologic conditions that determine the actual differences in intensities within each city. For example, one city (Carbondale, figure 10) has so little significant geologic variation as to be assigned only one intensity throughout, IX. Paducah (figure 14), on the other hand, has conditions likely to produce most severe damage along the river and sucessively lower intensities, in areas with different conditions, away from the river; the most stable locations in Paducah are thought to be two intensity levels lower than the area along the river. Thus three intensity levels are shown for Paducah. Poplar Bluff and Little Rock (figures 15 and 12) are also thought to have differences of two intensity levels, but with no intermediate-level intensity. Thus at Poplar Bluff the intensity drops abruptly at the edge of the bluff along the Black River from X in the Mississippi River alluvial plain to VIII on the uplands. Finally, geologic conditions at Evansville and Memphis suggest a difference of one intensity level.

Each of the six cities is discussed in more detail below.

Carbondale, Illinois

Physiographic description:

Carbondale is situated in the till plains of the Central lowland province (Fenneman, 1938) in an area of very low topographic relief.

Underlying material:

The northern part of the city is underlain by lake deposits consisting of well-bedded silt and some clay; the southern part is underlain by hard, silty, sandy, and clayey till with some sand and gravel (Lineback, 1974). These deposits are probably at least 50 feet (15 m)

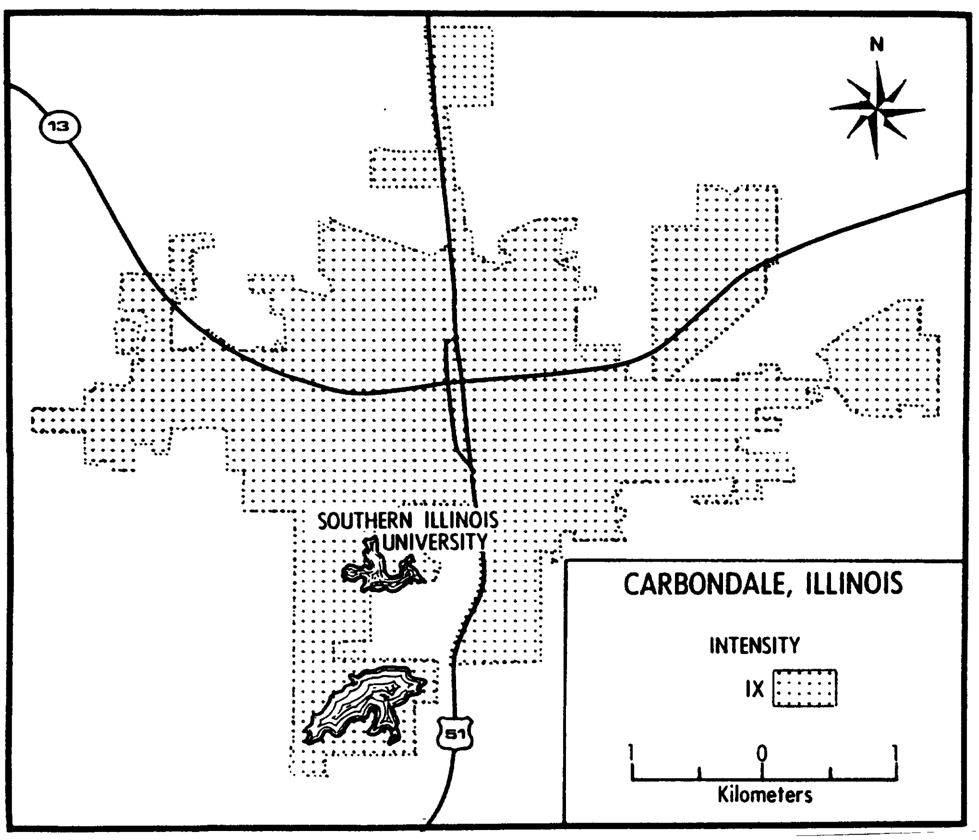

Figure 10.--Hypothetical intensity map for Carbondale, Illinois. For an earthquake near the north end of the New Madrid seismic zone, the intensity for Carbondale is IX for the entire city. For an earthquake near the south end of the new Madrid seismic zone, the intensity at Carbondale would be lower.

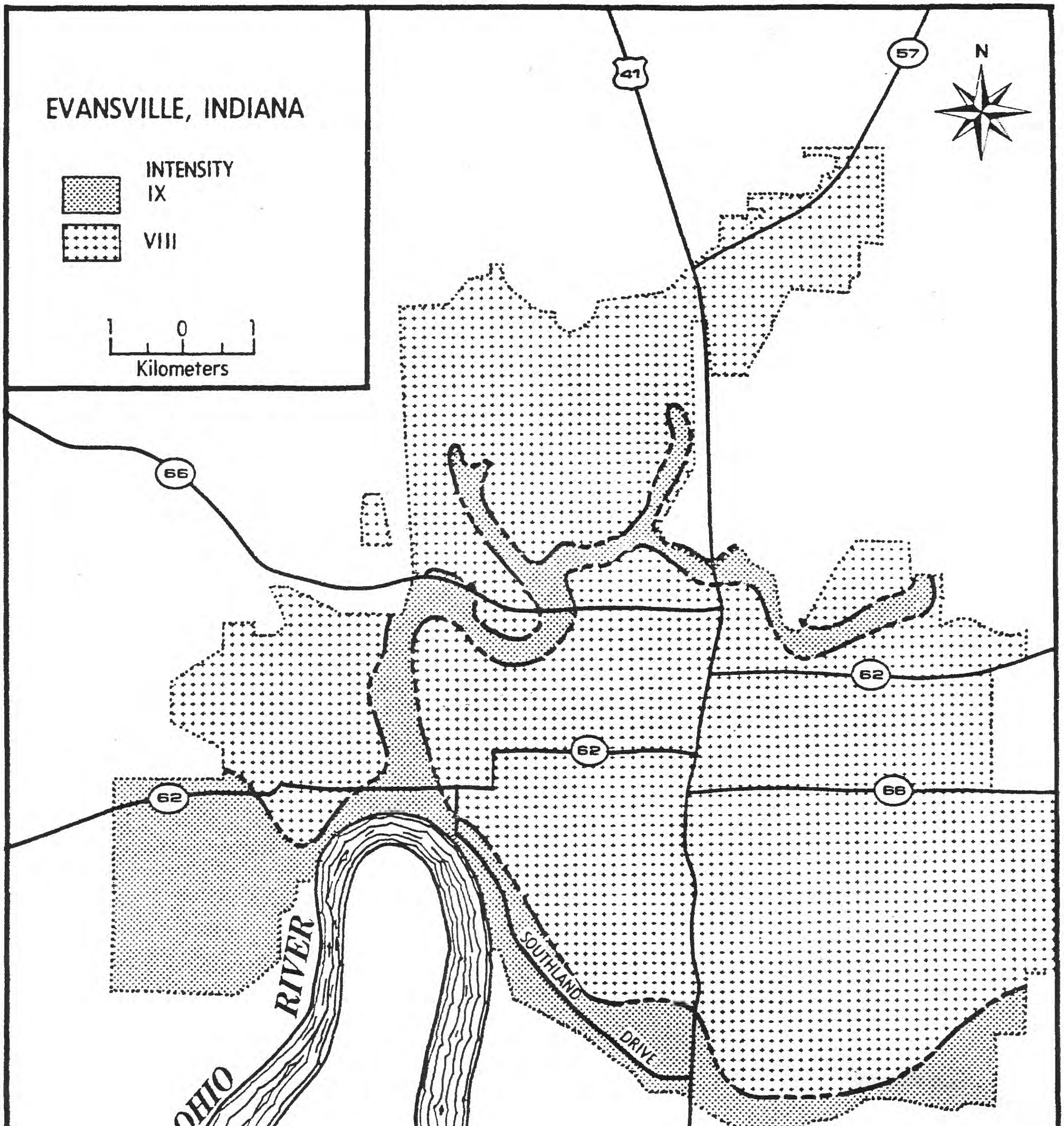

Figure 11. Hypothetical intensity map for Evansville, Indiana. For an earthquake near the north end of the New Madrid seismic zone, intensities projected for Evansville are: IX along the Ohio River flood plain and its tributary and VIII for the lacustrine sediments of the rest of the city. For an earthquake near the south end of the New Madrid seismic zone, the intensity at Evansville would be lower.

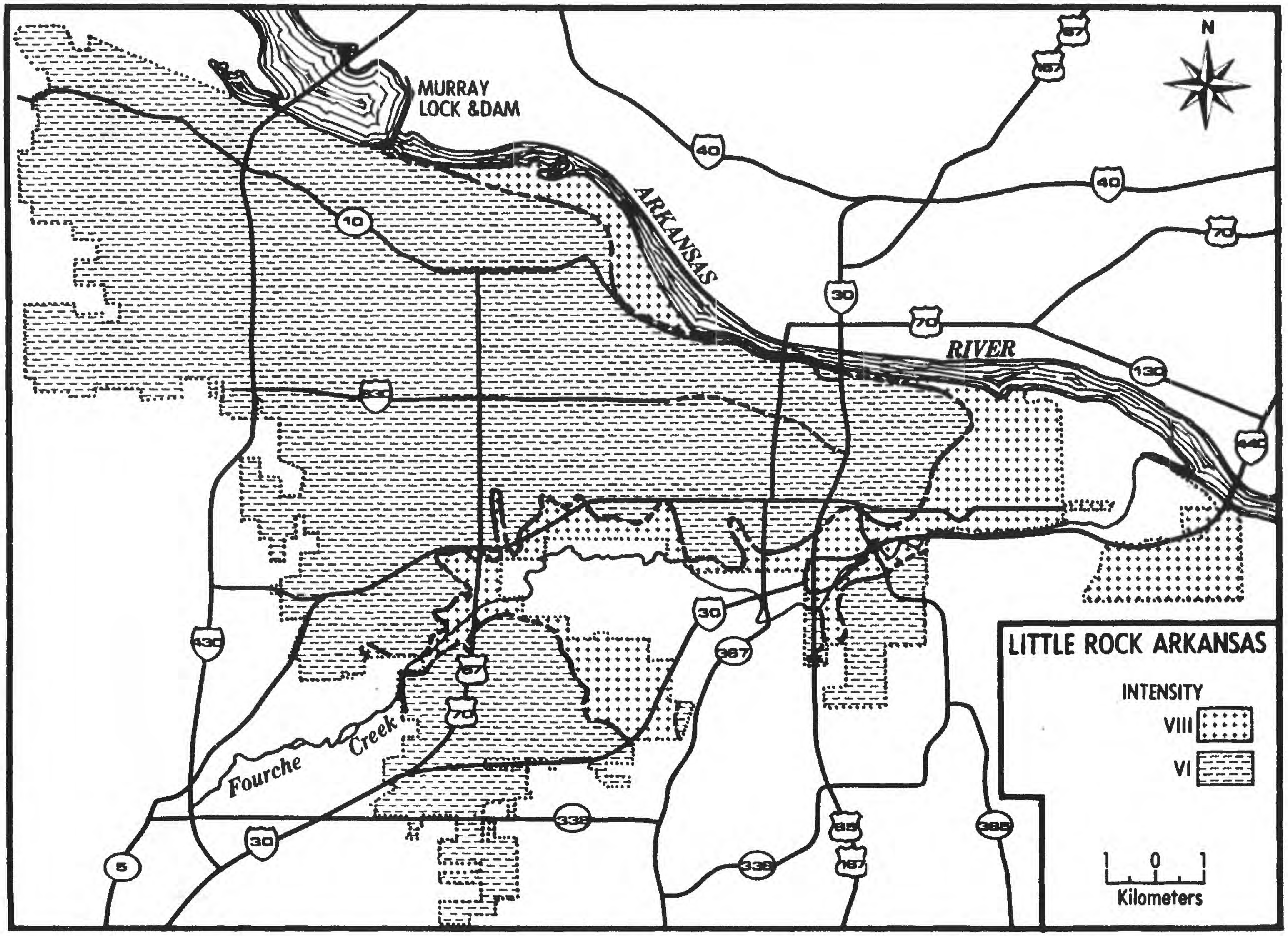

Figure 12.__Hypothetical intensity map for Little Rock, Arkansas. For an earthquake near the south end of the New Madrid seismic zone, intensities projected for Little Rock are: VIII on the river alluvium, but only VI on the sandstones, shales, and limestones of the hills. For an earthquake near the north end of the New Madrid seismic zone, the intensities at Little Rock would be lower.

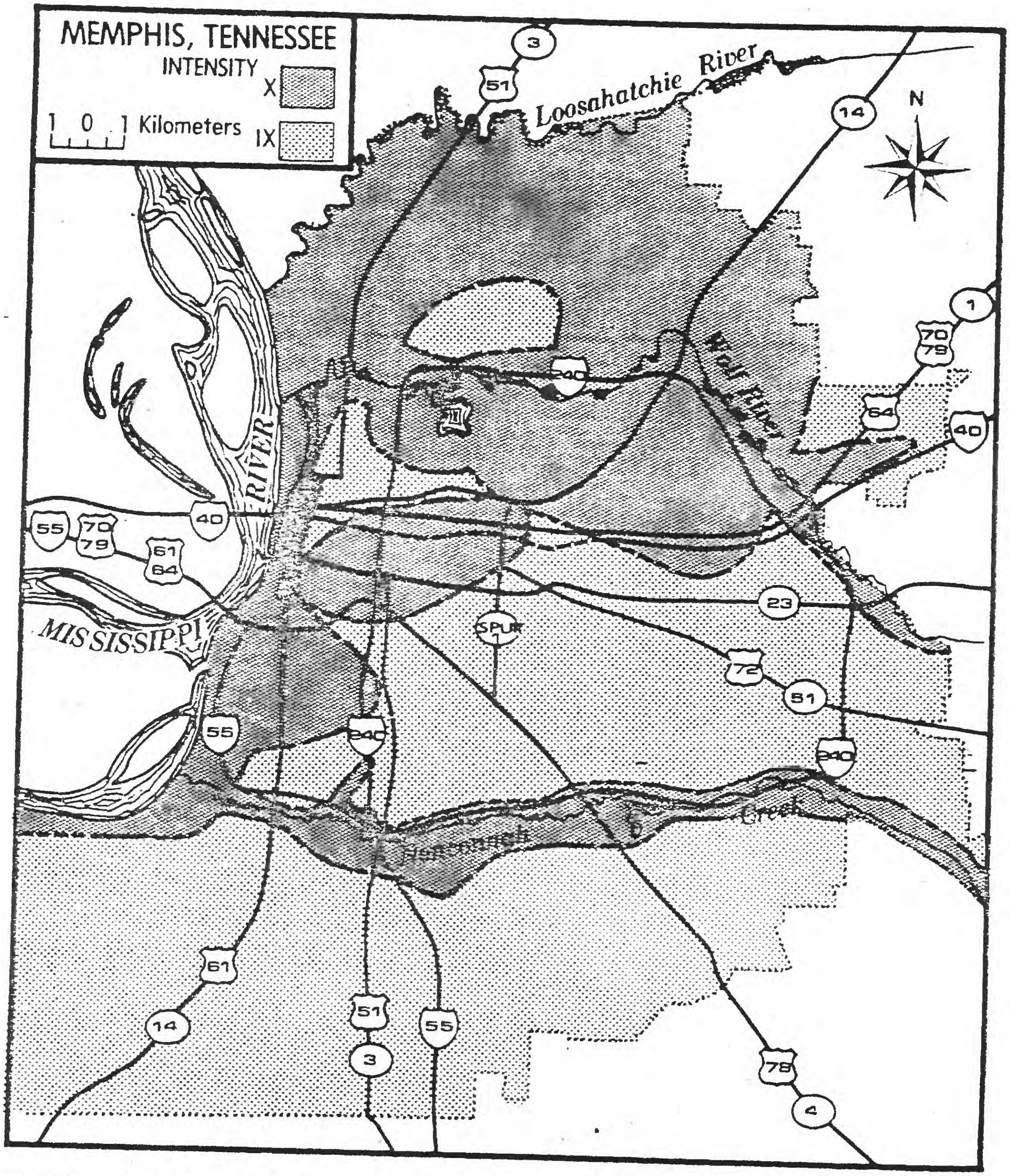

Figure 13.__Hypothetical intensity map for Memphis, Tennessee. For an earthquake near the south end of the New Madrid seismic zone, intensities projected for Memphis are: X in the alluvial valleys and in the areas found by Sharma and Kovacs (1980) to have high amplification factors (figure 20) or to be susceptible to liquefaction (figure 19), and IX in the rest of the city. For an earthquake near the north end of the New Madrid seismic zone, the intensities at Memphis would be lower.

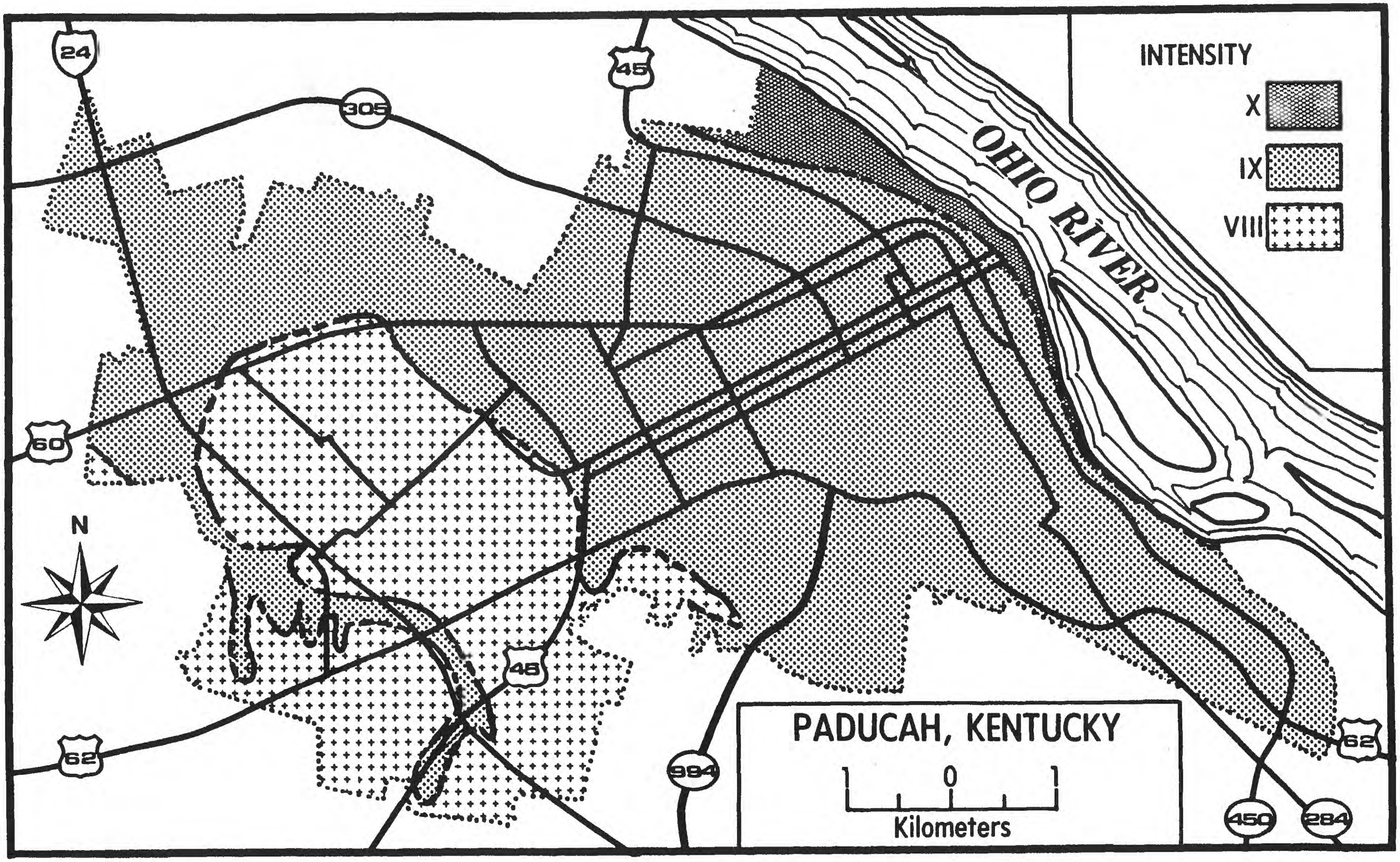

Figure 14.__Hypothetical intensity map for Paducah, Kentucky. For an earthquake near the north end of the New Madrid seismic zone, intensities projected for Paducah are: X on the river alluvium, IX on the lacustrine deposits underlying most of the city, and VIII in the hills southwest of the city. For an earthquake near the south end of the New Madrid seismic zone, the intensities at Paducah would be lower.

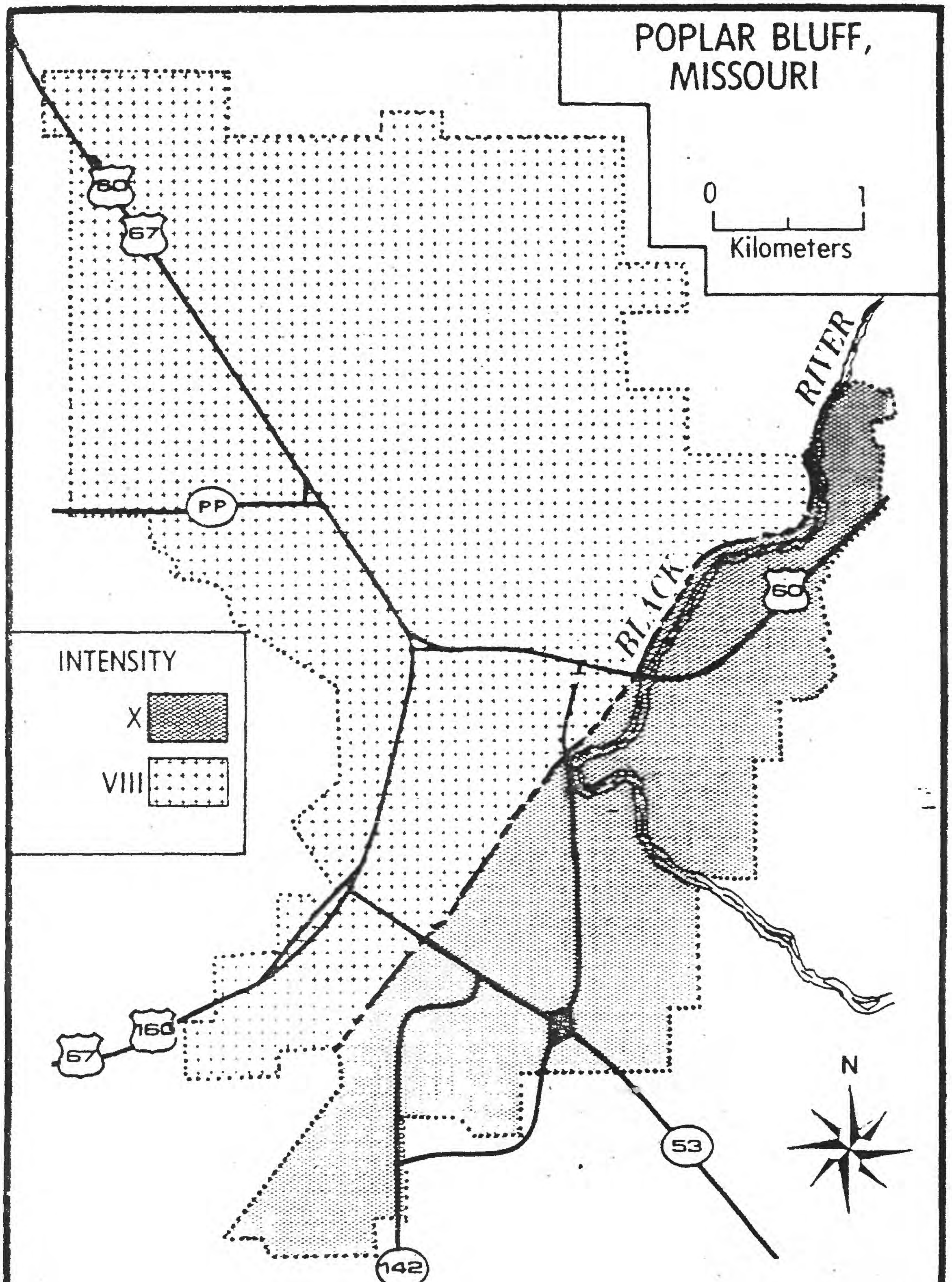

Figure 15.__Hypothetical intensity map for Poplar Bluff, Missouri. For an earthquake near the north end of the New Madrid seismic zone, intensities projected for Poplar Bluff are: X on the Mississippi flood plain southeast of the city, but only VIII on the uplands to the northwest. For an earthquake near the south end of the New Madrid seismic zone, the intensities at Poplar Bluff would be lower.

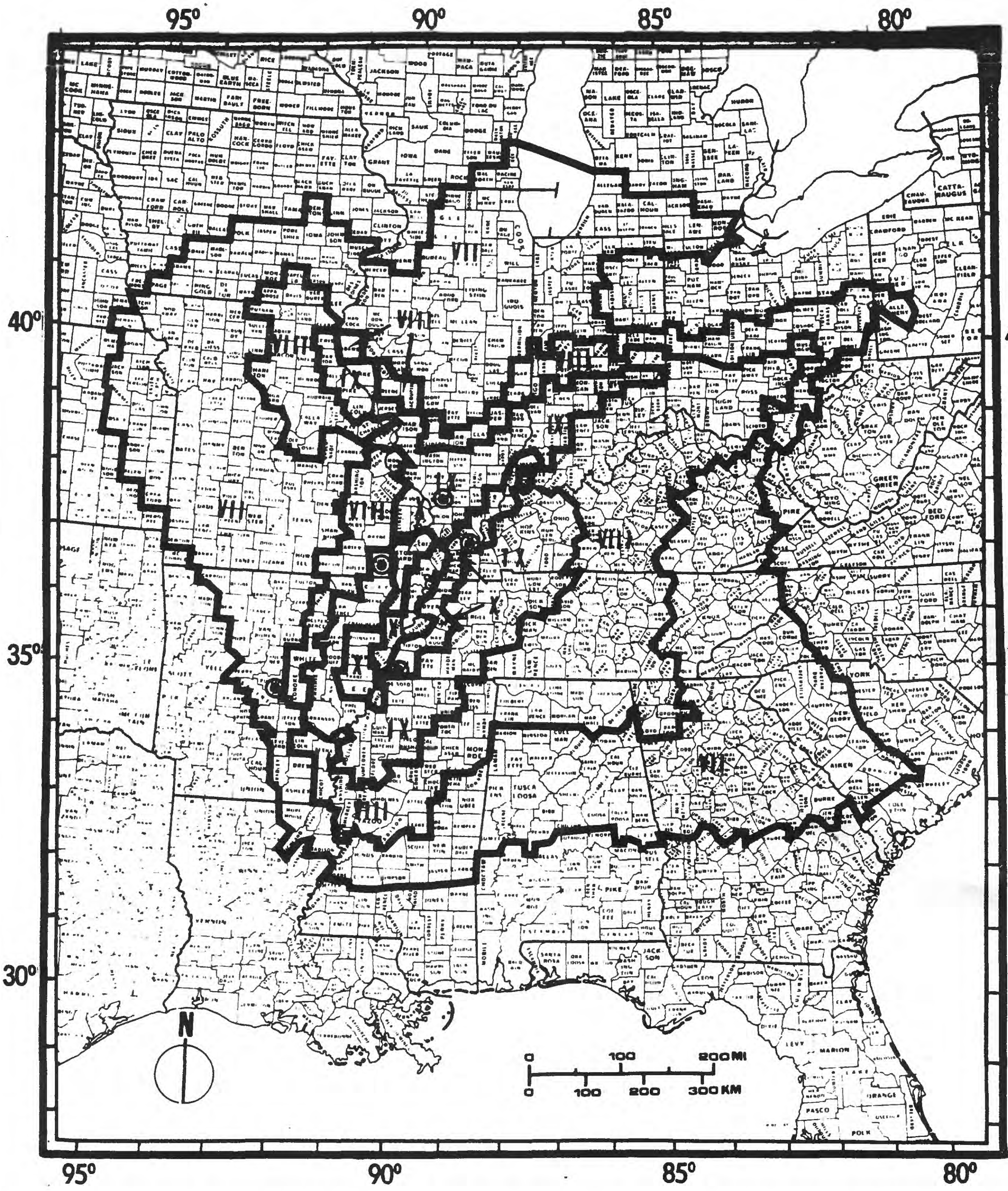

Figure 16.—Hypothetical regional intensity map by county. Assumes an 1811-size earthquake having an epicenter anywhere along the New Madrid seismic zone. Dots show the locations of the six cities in this study. The intensities mapped in this illustration are for disaster preparedness and mitigation planning only and represent the maximum intensity from an ensemble of possible large earthquakes. The intensities mapped here are not likely to occur everywhere in the area mapped at each intensity level. See text for more detailed information.

thick and overlie interbedded sandstone, shale, limestone and coal of Pennsylvanian age (Williams and others, 1967).

Physical property tests and other information:

Selected standard penetration tests (18 inch drop of a 4n-1b hammer) show N values that range from 9 blows/foot near the surface to 40 at depths of 50 feet (15 m) (Pulley, Gary, Assistant Soils Engineer, Illinois Department of Transportation, Carbondale, Illinois, oral communication, September 15, 1982). (In shallow alluvium N values are generally about 10; in denser materials N values are higher. Liquefaction potential is highest at low N values.)

Potential for landslides, liquefaction, and other geologic effects:

Landslides--Landslides in response to strong earthquakes are unlikely.

Liquefaction--The liquefaction potential is low.

Hypothetical intensity map for Carbondale:

The highest projected intensity at Carbondale is IX M.M, from the regional map (figure 16). This intensity would occur for an 1811-size earthquake anywhere near the north end of the New Madrid seismic zone. Carbondale would experience only intensity VIII for an 1811-size earthquake near the south end of the seismic zone. The 1895 epicenter (on which the hypothetical intensities are based) is only 81 km from Carbondale (see table 4 and Appendix 2), accounting for the high intensity projected there; there is no information about what happened in Carbondale in 1895. Although the 1968 earthquake is closer (69 km) to Carbondale, and overturned oil tanks in Carbondale (Coffman and Cloud, 1970), it is not in the New Madrid seismic zone, and an earthquake of the size studied in this report is not deemed likely at the 1968 epicenter.

The seismic zonation of Carbondale is based primarily on the site geologic conditions. Although different geologic units can be differentiated at the surface, they are not deemed significantly different with respect to intensity values. Nor are landslides or liquefaction effects particularly likely at Carbondale. Thus the map of Carbondale shows only one M.M. intensity value, IX. Again note that this is the highest projected intensity, and that every building in Carbondale is not expected to be damaged at the intensity-IX level. Some buildings may not be damaged at all. Rather, the predominant part of the most important damage will be at this level.

Evansville, Indiana

Physiographic description:

Evansville is situated along the Ohio River in the Interior Low Plateaus province (Fenneman, 1938). Topographic relief within the city proper is low; some of the banks along the Ohio River are steep.

Underlying material:

Much of the city is underlain by lake deposits consisting of clay, silt, and sand that are Pleistocene in age (Gray and others, 1970); Recent alluvium occurs along the flood plain of the Ohio River; thickness of these materials was not given in the data reviewed, but is inferred to be in the tens of feet rather than in the hundreds of feet. Beneath these surficial materials are well indurated shale, sandstone, limestone and some coal belonging to the McLeansboro Group of Pennsylvanian age.

Physical property tests and other information:

Specific test data were not available as of this writing. However, test data is available in the files of private consulting firms. According to Richard Eifler, City Engineer, landslides are not a problem throughout most of the city; however, along the river bluff near Reitz School oversteepening of a side hill cut during railroad and highway construction caused a landslide.

Potential for landslides, liquefaction, and other geologic effects:

Landslides--A strong earthquake probably would not cause landslides throughout most of the city; however, landslides probably would occur along the steeper bluffs adjacent to the Ohio River. Some compaction and differential settlement of flood plain alluvium probably would also occur.

Liquefaction--While a liquefaction potential exists throughout much of the city, it is low and would be localized; the liquefaction potential in the alluvium along the Ohio River flood plain is probably high.

Hypothetical intensity map for Evansville:

Intensities projected at Evansville are VIII and IX M.M., for an earthquake near the north end of the New Madrid seismic zone (figure 16). An earthquake near the south end of the seismic zone would produce only VII and VIII at Evansville. Evansville is approximately 200-400 km away from earthquakes located along the New Madrid seismic zone (table 4 and Appendix 3), and there are no reports for Evansville from any of the larger earthquakes in the zone, except that the 1895 earthquake was felt. Also, there was slight damage (VI) from the nearby (81 km) 1968 earthquake north of the New Madrid seismic zone.

The higher of the two projected intensities at Evansville follows the alluvium of the Ohio River flood plain and its tributary. In this area liquefaction is a strong possibility in the event of an earthquake along the northern end of the New Madrid seismic zone. Also in this area, landslides might occur along the bluffs overlooking the Ohio River. The potential for liquefaction and landslides, as well as for vibration damage, is less on the lake sediments of the rest of the city, the area shown on figure 11 as VIII.

Little Rock, Arkansas

Physiographic deacription:

Little Rock is situated on the border between the Ouachita province and the Mississippi Alluvial Plain (Fenneman, 1938). Most of the city is located south of the Arkansas River, west of the Mississippi Alluvial Plain, and north of Fourche Creek in the subdued Ouachita Mountains. Within the city area these mountains have a maximum total difference in topographic relief of about 150 feet (46 m) above the Arkansas River. By comparison the Mississippi Alluvial Plain and the Arkansas River flood plain exhibit little topographic relief.

Underlying material:

Most of the city is underlain by the Jackfork Sandstone of Pennsylvanian age (Haley and others, 1976); some shale is interbedded with the sandstone and a fairly thick shale bed is present at the base of the bluff along the Arkansas River near the Murry Lock and Dam. These rocks have been intricately thrust faulted; the faults are inactive; most of them trend east-southeast and the attitudes of the beds vary over short distances.

A part of the city north of Fourche Creek is underlain by Tertiary age interbedded sand, calcareous clay, limestone, silty clay, and silt of the Midway and Wilcox Groups (Haley and others, 1976, and Gordon and others, 1958); these materials are here about 65 feet (20 m) thick.

Along the Arkansas River and where it passes into the Mississippi alluvial plain the underlying material generally consists of dense silty sand, sand, silty clay, and gravel.

Residual soils developed on the Jackfork Sandstone are a gravelly silt loam, shallow to fairly deep, and moderately permeable; soils developed on the Wilcox and Midway Groups are a silty to sandy loam, shallow to fairly deep, and slowly to moderately permeable (Haley, Bickner, and Festervand, 1975, and Soil Conservation Service, 1967).

Physical property tests and other information:

Well logs of three test hole borings were provided by Mr. Jake Clements, Engineer with the Materials and Tests Division, Arkansas

Highway Department, Little Rock. Two logs at the Arkansas River crossing of I-440 indicate that the material consists mainly of silty sand in the upper 20 to 30 feet (6 to 9 m) and sand and gravel below that to the depths of the holes, which terminated at 62 feet (18.9 m) and 110 feet (33.5 m); the material is non-plastic, and N values for standard penetration tests range from about 10 in the upper part to 32 and 52 in the lower parts. The log in alluvium along Fourche Creek east of the intersection with U.S. highway 65 consists mainly of silty clay, and sand and gravel near the bottom of the hole at a depth of 55-60 feet (17-18 m); N values are variable; they range from 5 to 10 in the upper part and 41 in the lower 5 feet (1.5 m) of the test section.

According to Mr. William Bush, Geologist, Arkansas Geological Commission, landslides are a minor problem in the vicinity of Little Rock. A landslide occurred at the south end of High Street north of the Chicago, Rock Island and Pacific railroad tracks; it was caused by oversteepening of an artificial cut (Michael Batie, City Engineer, Little Rock, oral communication, 1982). There is also evidence of sloughing and minor landsliding in the bluff along the Arkansas River near the Murry Lock and Dam.

Geologic mapping in the vicinity of Little Rock has not revealed any surficial features that could be attributed to liquefaction (Boyd Haley and William Bush, oral communication, 1982).

Potential for landslides, liquefaction, and other geologic effects:

Landslides--Landslides in response to strong earthquake vibrations are unlikely throughout most of the city. However, sloughing and small landslides could occur along some of the steeper bluffs.

Liquefaction--The liquefaction potential is very low for the part of the city underlain by the Jackfork Sandstone and by units of the Midway and Wilcox Groups. The liquefaction potential is probably low to moderate for the part of the city underlain by flood plain deposits of the Arkansas River and the Mississippi Alluvial Plain.

Hypothetical intensity map for Little Rock:

Intensity VII M.M. is projected at Little Rock on the regional map (figure 16) for an epicenter near the south end of the New Madrid seismic zone. Little Rock is 170-360 km away from earthquakes in the New Madrid seismic zone, and experienced intensities of IV, V, and I-IV in 1843, 1895, and 1968 (table 4 and Appendix 4).

At Little Rock the hypothetical intensities change from VIII for river and stream alluvium to VI for the neighboring sandstone, shale, and limestone hills of the rest of the city. Landslides are unlikely for most of the city, but a few small landslides might occur along some of the steeper bluffs. There is a moderate potential for liquefaction in the flood plain deposits (area shown as VIII in figure 12), although no geologic evidence of previous liquefaction in the area has been found.

Memphis, Tennessee

Physiographic description:

Memphis is situated in the Coastal Plain Province along the border between the East Gulf Coastal Plain and the Mississippi Alluvial Plain. The locally steep bluffs adjacent to the Mississippi River along the west edge of the city are 60 to 100 feet (18 to 30 m) high. Most of the city is located south of Wolf River and north of Nonconnah Creek, an area of low topographic relief.

Underlying material:

A generalized description of the underlying materials in Memphis and vicinity is given in table 6 and an east-west geologic cross section through Memphis in figure 17. Both are from M & H Engineering and Memphis State University (1974).

Physical property tests and other information:

The general locations for boreholes from which Sharma and Kovacs (1980) collected data are shown in figure 18. To protect confidentiality of the sources, exact locations of bore holes are omitted. By calculating relative density and shear strength from standard penetration resistance and using other factors, Sharma and Kovacs concluded that there are three zones likely to be susceptible to liquefaction (see figure 19).

Terzaghi (1931) describes a landslide that occurred at Memphis in 1926 and attributes the failure to movement of ground water. Mr, Richard Hoffman, Acting City Engineer, City of Memphis, said that during the last several years there have been no significant problems with landslides, but that they had minor problems with differential settlement along parts of Riverside Drive where it is located on an old fill that was not placed according to present day engineering practice (oral communication, 1982).

Fuller (1982) describes landslides along Chickasaw Bluff, 50 to 100 miles (80 to 160 km) north of Memphis along the east side of the Mississippi River (see figure 3) that could be classified as horizontal block glides, and implies that they were caused by the earthquake seouence of 1811-1812. Information useful in reaching a conclusion about the possibility of the occurrence of horizontal block glide landslides is meager and inconclusive.

Potential for landslides, liquefaction, and other geologic effects:

Landslides--Depending upon ground water conditions, smaller landslides will probably occur along the Mississippi River bluffs in response to strong earthquake vibrations, and differential compaction will take place over many areas of artificial fill. The occurrence of horizontal block glide landslides cannot be ruled out entirely.

Liquefaction--Areas of potential liquefaction within the city of Memphis are shown in figure 19, (from Sharma and Kovacs, 1980). The liquefaction potential is probably high for the area underlain by Mississippi River flood plain deposits.

Hypothetical intensity map for Memphis:

The highest projected intensities at Memphis are IX-X M,M, from the regional map (figure 16). These intensities would occur in the event of the assumed 1811-size earthquake at the south end of the New Madrid seismic zone, if the assumed earthquake occurred at the north end of the seismic zone, intensities at Memphis would range from VIII to IX. However, the worst case assumes an earthquake at the 1843 epicenter (on which the southern part of the hypothetical map is based), just 32 km away (table 4 and Appendix 5). That earthquake produced fallen chimneys and cracked brick walls at Memphis, and hundreds of people ran into the streets. The much larger 1811 earthquake, 80 km from Memphis, resulted in a IX at Fort Pickering near Memphis.

Zonation of intensities in Memphis takes into account three kinds of data:

Local geologic conditions,

Amplification of seismic waves over bedrock ground motion, as defined by Sharma and Kovacs (1980), and

Areas potentially susceptible to liquefaction, also from Sharma and Kovacs (1980).

The alluvial valleys of the Mississippi, Loosahatchie, and Wolf Rivers and Nonconnah Creek are thought to represent slightly more hazardous geologic conditions than the rest of the city. All have upper alluvial strata resting on loose, fine-to-medium grained sands, which could liquefy at intensity IX or greater (M & H Engineering and Memphis State University, 1974). Also, areas of artificial fill, especially old, poorly engineered fill, are somewhat more likely to have damage. Finally, the bluffs along the Mississippi River are susceptible to landslides in the event of the large, nearby earthquake assumed for this study. A particularly critical area for landslides

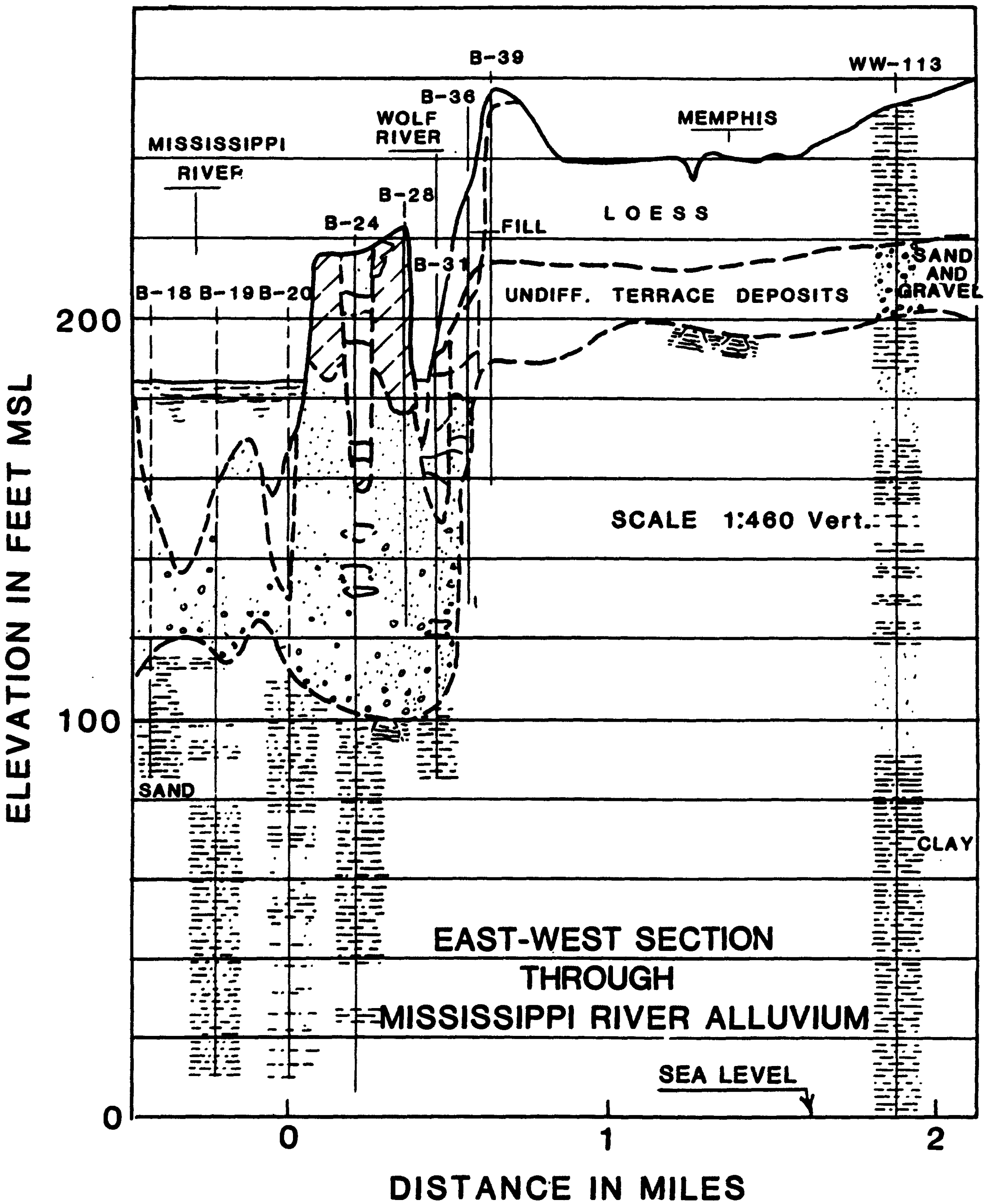

Figure 17. East-west geologic cross section beneath Memphis, Tennessee. After Sharma and Kovacs (1980), who quote M. & H. Engineering and Memphis State University (1974).

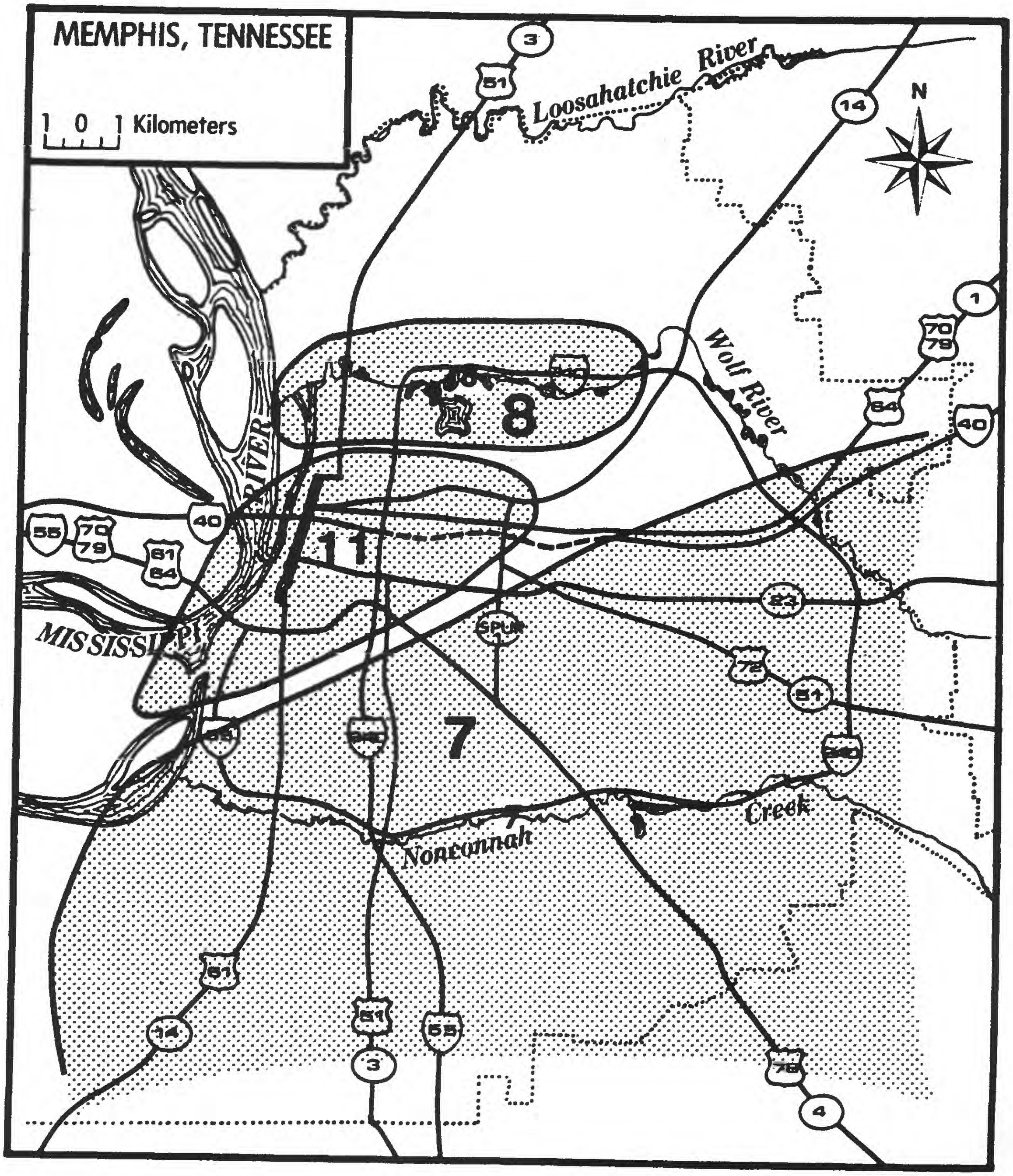

Figure 18.__Map of Memphis, Tennessee. After Sharma and Kovacs (1980). Figures within shaded areas indicate the number of sites investigated for Sharma and Kovacs' study within each shaded area.

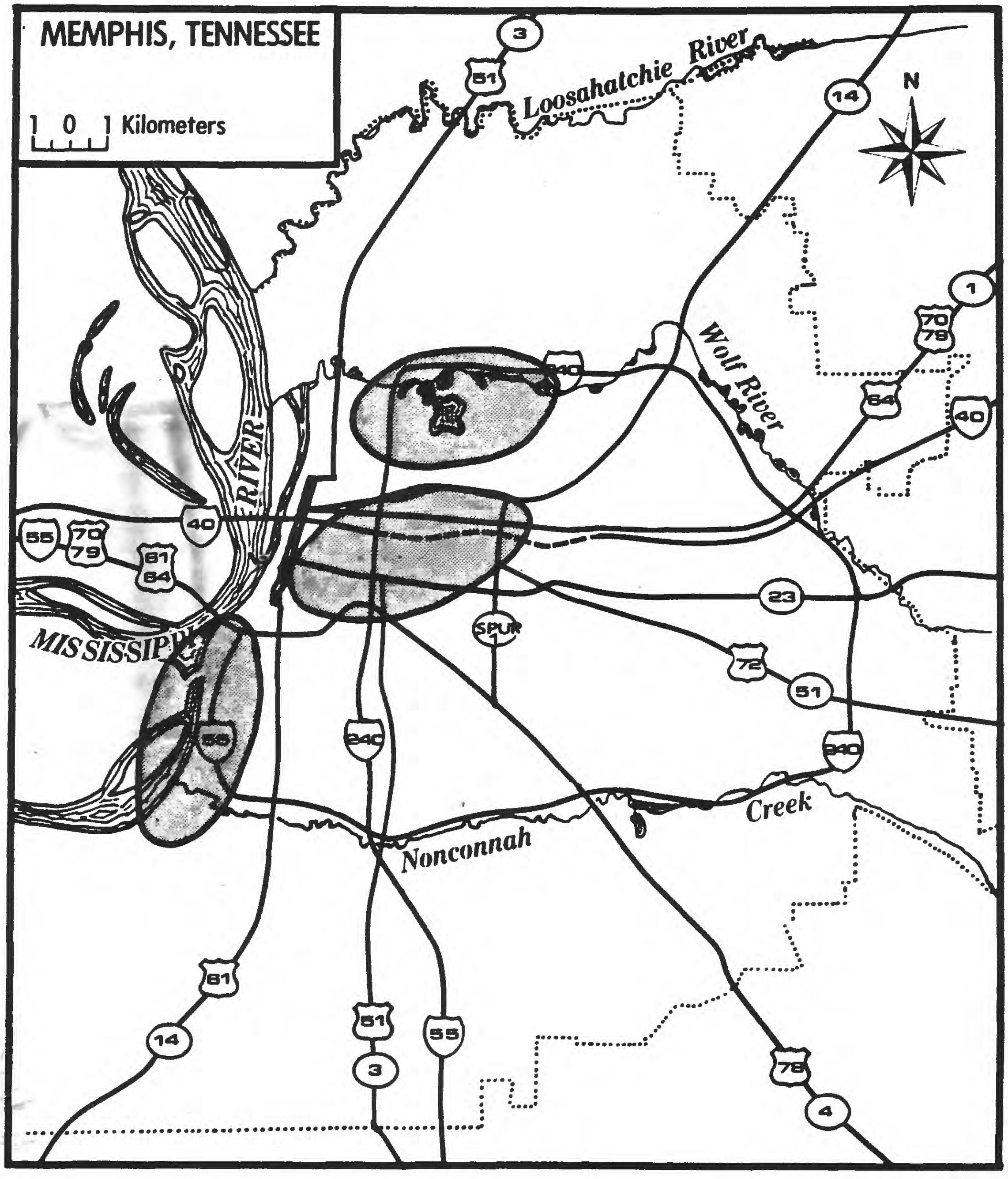

Figure 19. Map of Memphis, Tennessee. After Sharma and Kovacs (1980). Shaded areas indicate zones where soils may be susceptible to liquefaction for earthquakes with Modified Mercalli intensity greater than VII.

TABLE 6. STRATIGRAPHIC SECTION. SECTION AT MEMPHIS, TENNESSEE, FROM M & H ENGINEERING AND MEMPHIS STATE UNIVERSITY (1974).

Series	Subdivision	Range of Thickness - meters	Description
Holocene	Redeposited Loess	0-10	Generally water-logged silts or silty clays with a 1-2m. crust in dry weather.
	Alluvial sands and gravels	0-6	Gray, fine to medium sands with occasional gravel, low to medium relative density.
Pleistocene	Loess	0-16	Wind-deposited clayey silts and silty clays.
	Sandy clay	0-3	Very stiff silty clay, possibly old erosional surface.
	Terrace sand	0-60	Fluviatile medium grained and gravels sands and gravels, very dense, generally brown or red frequently iron-oxide -cemented.
Eocene	Jackson(?) Group	0-150	Hard, fat clays interbedded toward east and south with fine, very dense white sands.

is the east bank of the Mississippi River from about I-55 to about I-40 (figure 13) (M & H Engineering and Memphis State University). This was the site of the 1926 landslide.

Sharma and Kovacs (1980) developed synthetic accelerograms for a potential earthquake of magnitude mb = 7.0 located at 50, 100, and 200 km from Memphis. They found that attenuation for their 50-km-away shock would produce at Memphis intensity IX, a bedrock acceleration of 18% g, a predominant period of about 0.35 seconds, and a duration above 5% g of about 19 seconds. Using borehole data (proprietary) and local sources of information (figure 18), they computed selective amplification factors for various parts of Memphis (figure 20). They found higher amplifications in assumed looser materials close to the Mississippi and Wolf rivers; pockets of stiff clays showed very small amplifications. They suggest that the amplification diminishes toward the southeast because of a lower water table and denser soils away from the rivers. Their maps for the earthquakes at 100 and 200 km are similar to figure 20, but the 200-km map shows somewhat higher amplification toward the southeast. Although their 200-km-away earthquake only produces bedrock accelerations of 11% g and intensities of VII-VIII at Memphis, it has a predominant period of 0.67 seconds and a duration above 5% g of 25 seconds. Sharma and Kovacs therefore suggest that the higher amplifications for the 200-km-away earthquake are due to its longer duration and to its longer period content which is in the 0.7 to 1.0 second range of the natural period of the soils. They also point out that an even more distant earthquake, having a predominant period of 1 second at Memphis, would cause even greater amplifications, but because of the attenuation of acceleration with distance, the surface accelerations would be comparable to their design earthquakes. Moreover, because of the predominant periods generated, they conclude that the 50-km-away earthquake is likely to be more damaging to structures of 3-4 stories, while the 100-and 200-km-away earthquakes will be more hazardous to 9-10-story structures.

Structural damage may occur not only from the strength of the vibrations, but also because of loss of the bearing capacity due to liquefaction. Sharma and Kovacs (1980) also investigated the

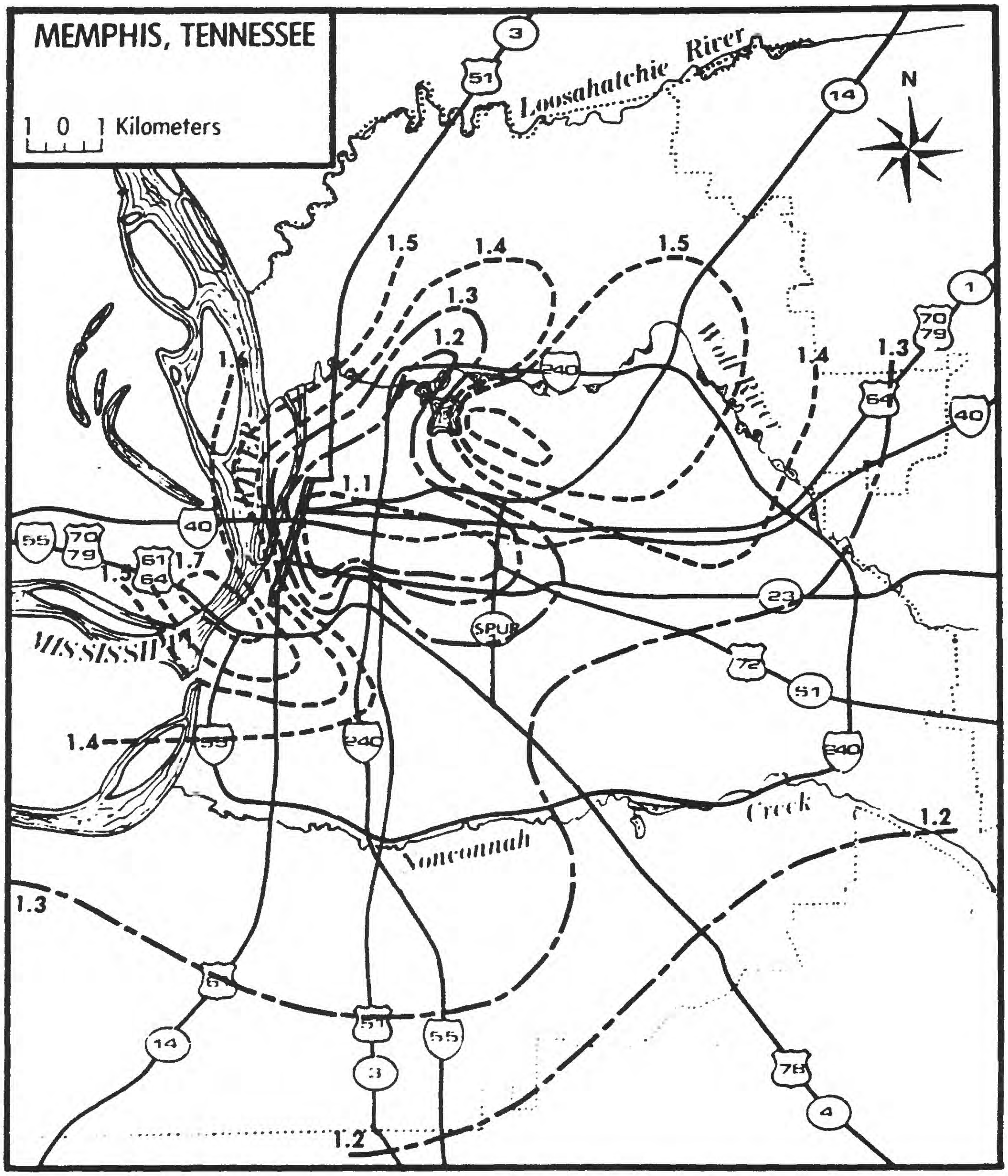

Figure 20.__Map of Memphis, Tennessee. After Sharma and Kovacs (1980). Contours are for amplification factors above assumed bedrock acceleration of 18% g at Memphis from a magnitude m_b=7.0 earthquake 50 km away from Memphis in the New Madrid seismic zone.

liquefaction potential of several of the layers from data available for Memphis. Their findings are shown in figure 19, and the number of boreholes from which they obtained their input data in figure 18.

They assumed that sands with a relative density greater than 75% would not liquefy for a sufficient time period to initiate loss of bearing capacity.

All three of these factors (geology, amplification, liquefaction) were considered in the development of the Memphis map, figure 13. The slightly higher intensity on the alluvium can be seen in the areas of X along the Mississippi, Loosahatchie, and Wolf Rivers and Nonconnah Creek. Some of these areas correspond to the areas of high amplification (shown in figure 20) on the north and west sides of the city. Two of the three areas of potential liquefaction (shown in figure 19) are also included in the high amplification areas, but the central one from figure 19 can be distinguished as a separate area of potential X in figure 13. In addition, there are areas throughout the city on old, poorly engineered, artificial fill, where differential settlement may occur. Finally, landslides are likely along the Mississippi River bluffs.

Paducah, Kentucky

Physiographic description:

Paducah is situated in the upper part of the Mississippi Embayment that is also called the East Gulf Coastal Plain (Fenneman, 1938) and near the confluence of the Tennessee and Ohio Rivers. Topographic relief is low for most of the city; total difference between the Ohio River and outlying suburbs is about 150 feet (46 m).

Underlying material:

Most of the city proper is underlain by a Pleistocene and recent sequence consisting of silt, clay, and some sand.

Physical property tests and other information:

Standard penetration tests were not available at the time of this writing. However, other tests indicate that the material has the following engineering characteristics (Nichols, 1968):

1) percolation is slow to moderate,

2) generally the moisture content is high,

3) cut slopes will stand in 20-foot (6-m) high, nearly vertical slopes when dry, but decrease greatly with increase of moisture content,

4) compressive strength is moderate when dry, but decreases rapidly as moisture content increases,

5) easily moved with hand or power equipment in most places,

6) erodes rapidly, and

7) susceptible to frost heave.

Potential for landslides, liquefaction, and other geologic effects:

Landslides--On slopes where soil-moisture content is high, landslides should be expected in response to strong earthquake ground motion (Nichols, 1968).

Liquefaction--Much of the ground underlying Paducah would be susceptible to compaction, high amplitude ground motion, and possible liquefaction in response to strong earthquake shaking (Nichols, 1968).

Hypothetical intensity map at Paducah:

The highest projected intensities at Paducah are VIII-X M.M, from the regional map (figure 16). This range of intensities would occur for an 1811 size earthquake near the northern end of the New Madrid seismic zone. The range would be somewhat lower for an epicenter farther south. Paducah is only 81 km away from the epicenter of the 1895 earthquake and experienced an intensity of VIII during that shock; a number of chimneys fell and several walls were cracked (table 4 and Appendix 6). Also, a few bricks fell from chimneys, resulting in intensity VI in 1968.

Intensities projected at Paducah decrease from the X in the alluvium along the river to IX in the lacustrine deposits on which most of the city is situated, to VIII in the hills in the southwest part of the city. Landslides are possible on slopes with high moisture content, and liquefaction is a possibility, especially along the river in the area shown as intensity X.

Poplar Bluff, Missouri

Physiographic description:

Poplar Bluff is situated on the border between the Ozark Plateaus and the Mississippi Alluvial Plain (Fenneman, 1938). Most of the city is located on the mildly dissected uplands of the Ozark Plateaus west of the Black River; a small part of the city occupies the flat Mississippi Alluvial Plain east of Black River.

Underlying materials:

The surface is underlain by sandstone, chert, and interbedded fine-grained dolomite which comprises the Roubidoux Formation of Ordovician age (McCracken, 1961). Deep residual weathering of these materials has produced the surficial soils on which most of the city is constructed. The soils are somewhat compact, medium stiff, dense, and consist of silty clay, sand and soil gravel. East of Black River the underlying materials are typical river alluvium, sand, silt, gravel and clay.

Physical property tests and other information:

A test bore hole at the Veterans Administration Hospital is typical of several others located in the city west of Black River (Smith, Sam, City Engineer and head of the Sam Smith Engineering Consulting firm, Poplar Bluff, Missouri, oral communication, September, 1982). The test hole penetrated residual soils to a depth of 57 feet (17 m) where a cherty dolomite was encountered; the residual soils consist of silt, clay, sand and gravel. N values for standard penetration gradually increase from 12 at 38 feet (11,6 m) to 78 at 54 feet (16.5 m).

Test hole data in the alluvium west of Black River was not observed. However, the silty sands and clays in the alluvium have low plasticity, and at one bridge location the material consists of a clean sand at a depth of 20 feet (6 m) (Malloy, nan, Engineer of Soils and Geology, member of the Sam Smith Engineering Consulting firm, Poplar Bluff, Missouri, oral communication, September, 1982). Also, bridge pile driving caused heaving in adjacent sidewalks.

Potential for landslides, liquefaction, and other geologic effects:

Landslides--In response to strong seismic shock small landslides wouldprobably occur locally along the steep bluff just west of Black River and in steep artificial slopes.

Liquefaction--The liquefaction potential is probably low in the part of the city west of Black River. East of Black River the liquefaction potential is high.

Hypothetical intensity map for Poplar Bluff:

From the regional map (figure 16) intensity IX is projected at Poplar Bluff. Much higher intensities (IX and X) are projected in the Mississippi flood plain southeast of the town than on the uplands to the west and northwest (VII-IX). The difference is judged to be at least two intensity levels at Poplar Bluff, with X below in the river alluvium and VIII above on the uplands. The projected intensity values are so high because of the assumption of an epicenter at the north end of the New Madrid seismic zone. The epicenter of the 1895 earthquake, which dominates the northern part of the regional map (figure 16), is only 94 km from Poplar Bluff (table 4 and Appendix 7), and the presumed epicenter of the February, 1812, earthquake only about 80 km away. There is no information on the 1812 effects at Poplar Bluff, but the 1895 earthquake was felt there, causing a noise like a cyclone. Also, the 1968 earthquake resulted in intensity V at Poplar Bluff.

AREAS OF PROJECTED MINIMAL DAMAGE

The attenuation of intensity is not uniform in all directions from an epicenter; in some directions intensity diminishes much more rapidly than in other directions, causing areas of relatively low intensity. Such areas of lower than average intensity may readily be picked out on the hypothetical regional intensity map, figure 16--for example, the area of of intensity VII in south-central Missouri. It may be seen by inspection of figure 16 that the intensities attenuate much more rapidly on the west and southwest than anywhere else. To the northwest (along the Mississippi River), to the northeast (along the Ohio River), and to the southeast (into Georgia), the intensities attenuate much more slowly than elsewhere. To the north, east, and south, the intensities attenuate in a more normal fashion, neither unusually high or low.

It is assumed that, for disaster planning purposes an area of intensity VIII (structural damage) would not be considered an area of minimal damage even if relatively low compared to nearby areas of IX or greater. Moreover, areas of intensity VII (architectural damage) and VI (threshold of any type of damage) are areas of minimal damage even if they are not relatively low. Thus the areas of minimal damage are those areas shown as VII, VI, and $\leq$VI in figure 16 and on the maps of the six cities. Regionally, their nearest occurrence to the epicentral area is on the west and southwest, but they also occur, slightly farther away, on the north, east, and south.

If figure 16 is to be used by, say, a county administrator, to plan for emergency procedures before, during, and after an earthquake, the following points should be kept in mind:

1) The intensity shown on figure 16 for his county is a guide to the highest level of intensity projected to be prevalent in some part of

his county. Every point in the county will not experience this intensity; some places within the county will be lower, even in the part of the county where this guide intensity occurs often.

2) The guide intensity itself will be lower for an epicenter at the farthest part of the New Madrid seismic zone from his county.

3) The same guide intensity in two counties at very different epicentral distances will result in different kinds of damage. The damage will be similar in level of destructiveness, but not in type. A county closer to the epicenter (assumed limited to be somewhere within the New Madrid seismic zone) and experiencing an intensity of, say, VIII, will have damage to low-rise, rigid structures, caused by the short-period, high-acceleration vibrations. It may also have ground effects, such as liquefaction in its alluvial areas and landslides on its bluffs. A county at a greater distance from the epicenter, also with a guide intensity of VIII, may have damage to its high-rise structures, but little or none to its low-rises, and less or no liquefaction. This is the result of the longer period surface waves predominant at farther distances from the epicenter, periods closer to the resonant periods of high rises. This is discussed more fully in the section on predomiant periods below.

4) Buildings that are expected to be used for relief purposes after an earthquake must be selected on the basis of structural soundness and probable ground response at that site. Assume that the guide intensity may actually occur to a number of buildings sited in the alluvial river valleys, where vibrations are often amplified. If the guide intensity is VIII or more, also assume that liquefaction may occur in such alluvial areas and that landslides are likely, especially on steep, water-saturated bluffs. Since damage at a given intensity level also depends on the strength of the structures themselves, type and quality of the buildings should be considered. Beyond the immediate epicentral area, local site conditions, including both the ground and the type and quality of any structure on it, are more important for estimating the potential damage at that site or building than anything else.

PREDOMINANT PERIODS

Particular consideration needs to be given to the effects caused by the longer-period seismic waves at large distances from great earthquakes, especially for earthquakes occurring in the Central United States. Two topics of particular importance for this study will be discussed:

1) effects on tall buildings, and

2) effects on ground and water.

The moderate-size (mb = 5.5) 1968 earthquake in southern Illinois is reported to have done slight damage and frightened people in Chicago skyscrapers, 430 km away from the epicenter; to have been felt on the twelth floor of a 16-story building at M.I.T. in Cambridge, Massachusetts, 1,500 km away; and to have been felt in tall buildings in southern Ontario, Canada (Necioglu and Nuttli, 1974). Such effects are a consequence of the similarity of the predominant periods exhibited by the earthquake at those distances to the natural periods of the buildings. In the epicentral region damage is caused by the short-period, high-acceleration vibrations predominant there; farther away, the longer-period waves, having low ground acceleration for relatively large ground displacements, begin to predominate (Nuttli, 1979). The anomalously low attenuation of these waves in the Central United States makes them potentially destructive over large distances. This low attenuation together with the dispersion, or variation in velocity of different wavelengths of surface waves, results in a prolonged duration of shaking at distant points (Nuttli, 1979).

The long-period waves that extend to larger distances from a great earthquake may also produce ground and water effects. Ground effects caused by long-period waves include landslides, settling, and slumping. This may cause damage to foundations of buildings and bridges, break buried pipes and crack road surfaces. Landslides, too can be triggered in susceptible places at large epicentral distances from a great earthquake. Seiches and oscillations in surface water may occur out to hundreds of kilometers from the epicenter.

CONCLUSIONS

An earthquake the size of the 1811 shock, in spite of the long recurrence time, muat be considered an event which might reasonably be expected to occur in the New Madrid seismic zone. In no other location in the Midwest is such a large earthquake deemed likely. Therefore, the earthquake chosen for simulation in this study is an Io = XI, mb = 7.2 shock anywhere along the New Madrid seismic zone. Its potential regional distrihution of Modified Mercalli effects is shown in figure 16. Note that the map in figure 16 does not represent a single earthquake, but rather a composite of earthquakes along the New Madrid seismic zone. Thus, the intensity at any given site is the maximum expected, but higher than that which would likely occur if the epicenter happened to be at the far end of the seismic zone from the site. The zone, for example of intensity X M.M., would probably be shorter for a single shock. However, in 1811-1812 there were three major shocks and hundreds of aftershocks, many of them large enough to cause damage, especially in structures already damaged by the first main shock. The 1811-1812 shocks are thought to have begun at the southern end of the seismic zone and moved toward the northern end with each successive major earthquake from December 16 to February 7 (see table 1 and figure 1). Thus it is possible that all the areas of figure 16 would be exposed to the heavy damages more or less contemporaneously.

At the time of the largest shock or shocks, there would be geological effects such as liquefaction, flooding, and landsliding. Liquefaction and flooding are particularly a problem in the low-lying alluvial areas along the major watercourses. Landslides are most likely on the bluffs along these same watercourses, but also can occur on hills with susceptible geologic conditions anywhere.

Possible areas of intensities lower than those in nearby regions can be picked out on figure 16. The closest such area to the epicentral region is in south-central Arkansas. In general, the intensities tend to attenuate most rapidly on the southwest side of the New Madrid seismic zone. Within any county, areas of lower intensity than suggested on figure 16 can be found. The simulated intensites are for the worst conditions prevalent in a county. Intensity may be as much as several intensity levels lower in less susceptible areas of a county. Planners wishing to avoid the more high-risk areas should consult a local geologist and follow the examples provided by the separate studies of the six cities in this report.

The six cities studied represent a range in population and industrial development, but all are near the epicentral region and are likely to experience intensities of VIII or greater. Development of the city intensity maps, figures 10-15, assumes the epicenter to be at the nearest point of the New Madrid seismic zone to each city. Actual level of intensity is determined from the regional map, figure 16, but within a city, distribution of effects and range of intensities is determined solely by local geologic conditions. A city with fairly uniform geologic conditions, such as Carbondale, is assigned a single intensity value (IX) throughout the town. A city like Poplar Bluff, with a radical difference in the geologic conditions below and above the bluff, is assigned two intensity values (X and VIII) with a difference of two intensity levels. Results for the other cities are: Evansville, IX and VIII; Little Rock, VIII and VI; Memphis, X and IX; and Paducah, X, IX, and VIII.

Long-period effects from such an earthquake are expected to cause isolated instances of damage in susceptible locations at large epicentral distances. For example, Chicago, in the intensity-VII area of figure 16, may have some damage to tall buildings due to the period of the seismic waves at that distance being at or near the resonant period of the buildings. Much smaller earthquakes in or near the New Madrid seismic zone have been felt in tall buildings in Chicago.

APPENDIX 1

MODIFIED MERCALLI INTENSITY SCALE OF 1931*

I

Not felt-or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt:

I sometimes birds, animals, reported uneasy or disturbed;
R.F.** sometimes dizziness or nausea experienced;
sometimes trees, structures, liquids, bodies of water, may sway-doors may swing, very slowly.

II

Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons.
Also, as in grade I, but often more noticeably:
I sometimes hanging objects may swing, especially when delicately
to suspended;
II sometimes trees, structures, liquids, bodies of water, may sway,
R.F. doors may swing, very slowly;
sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced.

III

Felt indoors by several, motion usually rapid vibration.
Sometimes not recognized to be an earthquake at first.
Duration estimated in some cases.
III Vibration like that due to passing of light, or lightly loaded trucks, or
R.F. heavy trucks some distance away.
Hanging objects may swing slightly.
Movements may be appreciable on upper levels of tall structures.
Rocked standing motor cars slightly.

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*Wood, H. O., and Neumann, F., 1931, Modified Mercalli Intensity Scale of 1931, Bulletin Seismological Society of America, v. 21, pp. 277-283.

**Indicates corresponding degree of intensity in the Rossi-Forel scale, an intensity scale widely used in the United States before the publication of the Modified Mercalli Scale in 1931. Intensity scales used in other parts of the world are discussed in Barosh (1969). An amplified version of the Modified Mercalli scale is given by Richter (1958).

IV

Felt indoors by many, outdoors by few.
Awakened few, especially light sleepers.
Frightened no one, unless apprehensive from previous experience.
Vibration like that due to passing of heavy, or heavily loaded trucks.
IV Sensation like heavy body striking building, or falling of heavy objects
to inside.
V Rattling of dishes, windows, doors; glassware and crockery clink
R.F. and clash.
Creaking of walls, frame, especially in the upper range of this grade.
Hanging objects swung, in numerous instances.
Disturbed liquids in open vessels slightly.
Rocked standing motor cars noticeably.

V

Felt indoors by practically all, outdoors by many or most; outdoors direction estimated.
Awakened many, or most.
Frightened few-slight excitement, a few ran outdoors.
Building trembled throughout.
Broke dishes, glassware, to some extent.
V Cracked windows-in some cases, but not generally.
to Overturned vases, small or unstable objects, in many instances,
VI with occasional fall.
R.F. Hanging objects, doors, swing generally or considerable.
Knocked pictures against walls, or swung them out of place.
Opened, or closed, doors, shutters, abruptly.
Pendulum clocks stopped, started, or ran fast, or slow.
Moved small objects, furnishings, the latter to slight extent.
Spilled liquids in small amounts from well-filled open containers.
Trees, bushes, shaken slightly.

VI

Felt by all, indoors and outdoors.
Frightened many, excitement general, some alarm, many ran outdoors.
Awakened all.
VI Persons made to move unsteadily.
to Trees, bushes, shaken slightly to moderately.
VII Liquid set in strong motion.
R.F. Small bells rang-church, chapel, school, etc.
Damage slight in poorly built buildings.
Fall of plaster in small amount.
Cracked plaster somewhat, especially fine cracks chimneys in some instances.
Broke dishes, glassware, in considerable quantity, also some windows.
Fall of knick-knacks, books, pictures.
Overturned furniture in many instances.
Moved furnishings of moderately heavy kind.

VII

Frightened all-general alarm, all ran outdoors.
Some, or many, found it difficult to stand.
Noticed by persons driving motor cars.
Trees and bushes shaken moderately to strongly.
Waves on ponds, lakes, and running water.
Water turbid from mud stirred up.
Incaving to some extent of sand or gravel stream banks.
Rang large church bells, etc.
Suspended objects made to quiver.
VIII- Damage negligible in buildings of good design and construction, slight
R.F. to moderate in well-built ordinary buildings, considerable in poorly
built or badly designed buildings, adobe houses, old walls (especially
where laid up without mortar), spires, etc.
Cracked chimneys to considerable extent, walls to some extent.
Fall of plaster in considerable to large amount, also some stucco.
Broke numerous windows, furniture to some extent.
Shook down loosened brickwork and tiles.
Broke weak chimneys at the roof-line (sometimes damaging roofs).
Fall of cornices from towers and high buildings.
Dislodged bricks and stones.
Overturned heavy furniture, with damage from breaking.
Damage considerable to concrete irrigation ditches.

VIII

Fright general-alarm approaches panic.
Disturbed persons driving motor cars.
Trees shaken strongly-branches, trunks, broken off, especially palm trees.
Ejected sand and mud in small amounts.
Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
Damage slight in structures (brick) built especially to withstand earth-
VIII+ quakes.
to Considerable in ordinary substantial buildings, partial collapse:
IX- racked, tumbled down, wooden houses in some cases; threw out
R.F. panel walls in frame structures, broke off decayed piling.
Fall of walls.
Cracked, broke, solid stone walls seriously.
Wet ground to some extent, also ground on steep slopes.
Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers,
Moved conspicuously, overturned, very heavy furniture.

IX

Panic general.
Cracked ground conspicuously.
Damage considerable in (masonry) structures built especially to withstand earthquakes:
IX+ threw out of plumb some wood-frame houses built especially to with-
R.F. stand earthquakes;
great in substantial (masonry) buildings, some collapse in large part;
or wholly shifted frame buildings off foundations, racked frames;
serious to reservoirs; underground pipes sometimes broken.

X

Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks.
Landslides considerable from river banks and steep coasts.
Shifted sand and mud horizontally on beaches and flat land.
X Changed level of water in wells.
R.F. Threw water on banks of canals, lakes, rivers, etc.
Damage serious to dams, dikes, embankments.
Severe to well-built wooden structures and bridges, some destroyed.
Developed dangerous cracks in excellent brick walls.
Destroyed most masonry and frame structures, also their foundations.
Bent railroad rails slightly.
Tore apart, or crushed endwise, pipe lines buried in earth.
Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI

Disturbances in ground many and widespread, varying with ground material.
Broad fissures, earth slumps, and land slips in soft, wet ground.
Ejected water in large amount charged with sand and mud.
Caused sea-waves ("tidal" waves) of significant magnitude.
Damage severe to wood-frame structures, especially near shock centers.
Great to dams, dikes, embankments, often for long distances.
Few, if any (masonry), structures remained standing.
Destroyed large well-built bridges by the wrecking of supporting piers, or pillars.
Affected yielding wooden bridges less.
Bent railroad rails greatly, and thrust them endwise.
Put pipe lines buried in earth completely out of service.

XII

Damage total-practically all works of construction damaged greatly or destroyed.
Disturbances in ground great and varied, numerous shearing cracks.
Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.
Wrenched loose, tore off, large rock masses.
Fault slips in firm rock, with notable horizontal and vertical offset displacements.
Water channels, surface and underground disturbed and modified greatly.
Dammed lakes, produced waterfalls, deflected rivers, etc.
Waves seen on ground surfaces (actually seen, probably, in some cases).
Distorted lines of sight and level.
Threw objects upward in the air.

APPENDIX 2

EFFECTS OF THE 1811-12, 1843, 1895, AND 1968 EARTHQUAKES AT LITTLE ROCK, ARKANSAS

1811 December 16 (212 km from Little Rock)

No information on Little Rock. Little Rock is off the west edge of the area of Nuttli's (1981) isoseismal map for the 1811 earthquake, but extension of his isoseismals would probably place it in the VII or VIII area.

1812 January 23 (274 km from Little Rock)

No information on Little Rock. The only intensity information in the Midwest is two points: an VIII at Cape Girardeau and a IX at New Madrid (Nuttli, 1973).

1812 February 7 (311 km from Little Rock)

No information on Little Rock. No intensity information within a 300-km radius of Little Rock. No information south or west of the epicenter except the V at New Orleans (Nuttli, 1973), over 700 km from the epicenter. Saint Louis at 251 km epicentral distance is an VIII-IX.

1843 January 5 (170 km from Little Rock)

An intensity IV is assigned at Little Rock by Hopper and Algermissen (unpub. data). From the Arkansas State Gazette, Little Rock, AR, January 11, 1843: "Earthquake. - On the fourth instant about half past eight o'clock, P.M., a quaking of the earth was very sensibly felt here, attended by the rattling of windows, glasses, and cupboards, and the creaking of our wooden houses....The shaking of the earth in this instance seemed to indicate a vibratory motion from N.E. to S.W., and continued for about the space of one minute."

1895 October 31 (362 km from Little Rock)

Intensity V is assigned at Little Rock by Hopper and Algermissen (1980). From Marvin (1895): "Distinct earthquake, the vibrations being east and west and lasting about one minute, occurred at 6:15 a.m. Shock was also felt at Forrest City, Helena, Brinkley, and several other points in eastern Arkansas."

1968 November 9 (498 km from Little Rock)

United States Earthquakes, 1968 (Coffman and Cloud, 1970) assigns intensity I-IV at Little Rock.

APPENDIX 3

EFFECTS OF THE 1811-12, 1843, 1895, AND 1968 EARTHQUAKES AT CARBONDALE, ILLINOIS

1811 December 16 (238 km from Carbondale)

No information on Carbondale. The nearest points for which there is information are Cape Girardeau, 40 km away from Carbondale, on the Mississippi River and a >IX 90 km away on the Ohio River. Carbondale is within the VIII isoseismal (Nuttli, 1981).

1812 January 23 (178 km from Carbondale)

No information on Carbondale. The only intensity information in the Midwest is two points: an VIII at Cape Girardeau and a IX at New Madrid (Nuttli, 1973).

1812 February 7 (142 km from Carbondale)

No information on Carbondale. Nuttli (1973) assigned IX at Cape Girardeau, 40 km from Carbondale and 103 km from the epicenter. He also assigned VIII-IX at Saint Louis and IX at Cahokia, each about 140 km from Carbondale and 250 km from the epicenter.

1843 January 5 (307 km from Carbondale)

No information on Carbondale. Carbondale lies within the intensity-V area on the isoseismal map of Hopper and Algermissen (unpub. data, 1983). Within a 100-km radius of Carbondale are two intensity-IV locations.

1895 October 31 (81 km from Carbondale)

No information on Carbondale. Within a 60-km radius of Carbondale are two VII's, one V, one Felt and one Heavy on Hopper and Algermissen' (1980) isoseismal map. Carbondale lies within the VII isoseismal.

1968 November 9 (69 km from Carbondale)

From United States Earthquakes, 1968 (Coffman and Cloud, 1970): "Carbondale.--Felt by all and frightened many. Putty cracked around picture windows of trailer. North-south crack in cement walk. Some oil tanks overturned, all oriented with long axis north-south. Small objects fell to the west. Television shifted slightly. Water in fish tank was splashed out on the west side. Trailer's blocks sank into mud on the northwest corner and had to be releveled after quake. Walking was difficult. Damage slight." They assigned intensity VI.

APPENDIX 4

EFFECTS OF THE 1811-12, 1843, 1895, AND 1968 EARTHQUAKES AT EVANSVILLE, INDIANA

1811 December 16 (336 km from Evansville)

No information on Evansville. It is within the intensity- VII isoseismal on Nuttli's (1981) map and there is a VII location very nearby (within less than 20 km of Evansville). Across the Ohio River on the Kentucky side are a VII-VIII location at 25 km from Evansville, and a $\geq$IX at 30 km.

1812 January 23 (280 km from Evansville)

No information on Evansville. The only intensity information in the Midwest is two points: an VIII at Cape Girardeau and a IX at New Madrid (Nuttli, 1973).

1812 February 7 (241 km from Evansville)

No information on Evansville. The nearest location having intensity information is the IX at Cape Girardeau (Nuttli, 1973), 180 km from Evansville, and much closer to the epicenter at 103 km. At approximately the same epicentral distance as Evansville are the IX at Cahokia and the VIII-IX at Saint Louis, about 240 km from Evansville and 250 km from the epicenter.

1843 January 5 (402 km from Evansville)

No information on Evansville. Evansville lies within the intensity-V area on the isoseismal map of Hopper and Algermissen (unpub. data). Within a 100-km radius of Evansville there are one intensity-V and one intensity-IV location.

1895 October 31 (192 km from Evansville)

Marvin (1895) records the earthquake as felt at Evansville. Within a 60-km radius of Evansville there are one VIII, two VII's, three Heavy's, and one felt on Hopper and Algermissen's (1980) map. Evansville lies within the VII isoseismal and near the edge of the VIII isoseismal on that map.

1968 November 9 (81 km from Evansville)

From United States Earthquakes, 1968 (Coffman and Cloud, 1970): "Evansville (Federal Building).--Felt by all. Two ornament columns on building dislodged. About 4 square feet 0.4 m^2 of plaster fell from third floor ceiling. Small objects fell. Loud earth noises. Damage slight. Press reported a chimney fell on old house, and that plaster cracked and broke throughout the city. Bricks loosened on an old church building, and wall threatened to collapse." They assigned intensity VI.

APPENDIX 5

EFFECTS OF THE 1811-12, 1843, 1895, AND 1968 EARTHQUAKES AT PADUCAH, KENTUCKY

1811 December 16 (205 km from Paducah)

No information on Paducah. Nuttli's (1981) map shows it in the intensity-IX area with an intensity VII assigned to a location within 40 km of Paducah.

1812 January 23 (145 km from Paducah)

No information on Paducah. The only intensity information in the Midwest is two points: an VIII at Cape Girardeau and a IX at New Madrid (Nuttli, 1973).

1812 February 7 (102 km from Paducah)

No information on Paducah. The nearest location having intensity information is the X-XI at New Madrid (Nuttli, 1973) only 21 epicentral distance as Paducah is the IX at Cape Girardeau, 90 km from Paducah and 103 km from the epicenter.

1843 January 5 (269 km from Paducah)

No information on Paducah. On Hopper and Algermissen's (unpub. data) isoseismal map there are two VII's, two IV's, and three felt's within a 100-km radius of Paducah; none of these points is within 75 km of Paducah.

1895 October 31 (81 km from Paducah)

Intensity VIII assigned by Hopper and Algermissen (1980).

From The Saint Louis Post-Dispatch, Saint Louis, MO, October 31, 1895: "PADUCAH, Ky., Oct. 31.--At 5:10 o'clock this morning a severe shock of earthquake was felt all over town. Houses swayed to and fro, a number of chimneys fell and several walls were cracked."

1968 November 9 (105 km from Paducah)

From United States Earthquakes, 1968 (Coffman and Cloud, 1970): "Paducah.--Few bricks fell from chimneys (press)." They assigned intensity VI.

APPENDIX 6

EFFECTS OF THE 1811-12, 1843, 1895, AND 1968 EARTHQUAKES AT POPLAR BLUFF, MISSOURI

1811 December 16 (104 km from Poplar Bluff)

No information on Poplar Bluff. Nuttli's (1981) map shows it near the outer edge of the intensity-IX area, but there are no locations with assigned intensity values within an 80-km radius of Poplar Bluff; nearby intensity values include X at Little Prairie (Caruthersville), 90 km from Poplar Bluff; X at 85 km; IX at New Madrid at 80 km; and VIII-IX at Cape Girardeau at 110 km. These locations are all along the Mississippi River. The only locations near Poplar Bluff that are not on the river and that have assigned intensities are a X and an XI in northeastern Arkansas at 95 and 120 km from Poplar Bluff and closer to the epicenter. The XI is on the Saint Francis River.

1812 January 23 (87 km from Poplar Bluff)

No information on Poplar Bluff. The only intensity information in the Midwest is two points: an VIII at Cape Girardeau and a IX at New Madrid (Nuttli, 1973).

1812 February 7 (82 km from Poplar Bluff)

No information on Poplar Bluff. The nearest locations having intensity information are the X-XI at New Madrid (Nuttli, 1973), 80 km from Poplar Bluff and 21 km from the epicenter, and the IX at Cape Girardeau 110 km from Poplar Bluff and 103 km from the epicenter.

1843 January 5 (179 km from Poplar Bluff)

No information of Poplar Bluff. On Hopper and Algermissen's (unpub. data) isoseismal map there are one VII (at New Madrid) and one IV within a 100-km radius of Poplar Bluff. Both points are on the Mississippi River and are over 75 km away from Poplar Bluff. Poplar Bluff is on the edge of the VI isoseismal.

1895 October 31 (94 km from Poplar Bluff)

Poplar Bluff lies within the intensity-VI isoseismal, and near the edge of the VII isoseismal on Hopper and Algermissen's (1980) map for the 1895 earthquake. Within a 30-km radius of Poplar Bluff are intensities of VIII and V. Poplar Bluff itself is assigned Felt.

From Heinrich (1941): "At Poplar Bluff the movement was described as rocking and seemed to be east-west. A noise "like a cyclone" preceded the shock."

1968 November 9 (218 km from Poplar Bluff)

United States Earthquakes, 1968 (Coffman and Cloud, 1970) assigns intensity V at Poplar Bluff.

APPENDIX 7

EFFECTS OF THE 1811-12, 1843, 1895, AND 1968 EARTHQUAKES AT MEMPHIS, TENNESSEE

1811 December 16 (80 km from Memphis)

Intensity IX at Fort Pickering, TN, near Memphis (Nuttli, 1973). Memphis is within the intensity-IX area on Nuttli's 1981 isoseismal map. The next nearest location having intensity information is between Mississippi River islands 30 and 40, which Nuttli assigned X; their location is 70 km north of Memphis along the river and 45 km from the epicenter.

1812 January 23 (120 km from Memphis)

No information on Memphis. The nearest intensity information, IX (Nuttli, 1973), is from New Madrid, MO, 180 km from Memphis and 59 km from the epicenter.

1812 February 7 (160 km from Memphis)

No information on Memphis. The nearest intensity information, X-XI (Nuttli, 1973), is from New Madrid, MO, 180 km from Memphis and 21 km from the epicenter.

1843 January 5 (32 km from Memphis)

Intensity VIII assigned by Hopper and Algermissen, unpub. data.

From The Daily Picayune, New Orleans, LA, January 10, 1843: "Courier reports of Memphis newspaper--hundreds run into streets, in fear houses would tumble down. No damage done, unless it be to crockery ware. The vibrations of the earth lasted in all two minutes and were accompanied by a heavy rumbling sound."

From The Weekly Picayune, New Orleans, LA, January 16, 1843: "The Memphis papers of the 5th instant give the particulars of one of the greatest earthquakes which has occurred there since 1811. The paroxysm commenced about twenty minutes before 9 o'clock, on the evening of the 4th instant, and lasted about half a minute during which time, says the Enquirer, the firm-set earth did "reel to and fro as a drunken man," so violently indeed as to make hundreds run into the streets from fear that the houses they were in were about to tumble down. No damage, however, was done, unless it be to crockery-ware, which we should think it likely have suffered some where placed loosely on shelves. The vibrations of the earth might have lasted in all nearly two minutes, and were accompanied by a heavy rumbling sound as if some seventeen hundred and fifty heavy loaded wagons had been driving briskly along the street.

There was quite a rush at the theatre, and indeed everywhere else, to get out of doors, and the shrieks of females were heard in different quarters of the town. The Editor of the Enquirer closes his account of the earthquake with, "We shall not be surprised to hear of considerable damage being done at Mills Point, New Madrid, etc."

From The Memphis Appeal, Memphis, TN, January 13, 1843: "...It was preceded and accompanied with a rumbling sound, as of rumbling thunder. Opinions are various as to that period of duration--some supposing half a minute, and some as much as two minutes--but all agree that it was a rather alarming affair, and by far the severest since 1811. But little damage has been done to buildings. The coping of some chimneys has been removed, and we have heard of the prostration of a cotton shed."

From The American Eagle, Memphis, TN, January 6, 1843: "At about half past 8 o'clock yesterday evening our City was visited by one of those awful throes of Nature, so convulsive and terrible, as to spread almost universal alarm over the city. The firmest buildings trembled and cracked, and the earth reeled and rocked under a most terrific excitement...

We were in our office at the moment, in the second story of a new block of brick buildings. The commencement of the jarring we conceived to proceed from the violent undertaking of some person to shake open a door beneath us. But in a moment afterwards, the agitation seized the brick walls surrounding us, shaking and reeling them, to such an extent, as to knock down particles of brick and plaster, jarring the roof and whole building so as to impress us with the fear of the building's falling. Sensible of the appalling cause of the agitation, we hastily fled into the street for safety....In the street was still a violent rocking of the earth, and a rattling and rumbling noise. People fled into the streets, and cries, and lamentations of many horror-stricken men and women were heard to fill the air.

The shock lasted about two minutes, and reached its most agitation period at the end of the first half minute, when it gradually died away in a dismal rumbling sound, apparently moving to the south-east, and proceeded from the north-west...

The tops of several chimneys were shaken down, the bricks falling inside, and with the reeling of the houses and quaking of the earth, frightfully alarming the inhabitants. A great many brick walls are seriously cracked and sunk, windows broken, and a cotton shed, naturally crazy, fell down shortly after the shock. At our auction houses, which were filled with people, so alarming and precipitate was the rush into the street that many people were crushed and trampled upon by the affrightened crowd."

From Heinrich (1941): "Destructive at Memphis, Tennessee, where chimneys fell and brick walls cracked. One building reputedly collapsed."

1895 October 31 (223 km from Memphis)

Intensity VI assigned by Hopper and Algermissen (1980).

From The Telegraph Herald, Dubuque, IA, November 1, 1895: "Memphis, Tenn., Oct. 31.--A violent earthquake shook Memphis Thursday morning at 5:08. The shock lasted not over a minute. It was preceded by a roar."

From The Saint Louis Post-Dispatch, Saint Louis, MO, October 31, 1895: "MEMPHIS, Tenn., Oct. 31.--A heavy shock of earthquake was felt here this morning at 5:08. The vibration was from east to west. Houses rocked and people were almost spilled out of bed. The shock lasted about a minute, and was preceded by a rumbling sound."

From Heinrich (1941): "Several chimneys were reported thrown down in the suburbs of Memphis, Tennessee."

From Marvin (1895): "An earthquake shock of considerable severity was felt in this city this morning shortly after 6 o'clock. A careful comparison of time by a number of competent observers shows that the vibrations from the first shock ceased at 6 hr. 07 min. 30 sec. a.m., having lasted about thirty seconds. A secondary shock or vibration was observed at 6 hr. 14 min. 00sec. by a number of reliable observers, though not by all. There was no damage done in this city, except to two chimneys in the suburbs, which were shaken down."

From Moneymaker (1954): "At...Memphis, Tennessee, several chimneys were thrown down."

1968 November 9 (350 km from Memphis)

United States Earthquakes, 1968 (Coffman and Cloud, 1970) assigns intensity I-IV at Memphis.

APPENDIX 8

GLOSSARY

ATTENUATION OF INTENSITY--The fall-off of seismic intensity with distance from the epicenter.

BODY WAVES--Seismic waves that travel through the earth. There are two kinds of body waves, P waves and S waves. The P waves, sometimes called the "primary wave" because it travels fastest and arrives first, is a compression-rarefaction vibrating in the direction of propagation. The S wave, sometimes called the "secondary wave" because it arrives after the P wave, is a shear wave vibrating at right angles to the direction of propagation.

EPICENTER--The location on the earth's surface directly above the focus.

EPICENTRAL AREA--Area surrounding the epicenter, usually the isoseismal of highest intensity.

FAULT--A fracture or fracture zone in the earth. Earthquakes are caused by ruptures along faults.

FELT AREA--The entire area over which an earthquake is reported felt. See also "isoseismal map".

FOCAL DEPTH--The depth of focus of the earthquake beneath the surface of the earth.

FOCUS--The center, or source, of an earthquake below the surface. Also called the hypocenter.

HYPOCENTER--The focus.

INSTRUMENTAL EARTHQUAKE--An earthquake whose vibrations were recorded by instruments, or seismographs.

INSTRUMENTAL EPICENTER--The epicenter derived from seismograms. It usually corresponds to the area of highest intensity.

INTENSITY SCALE--An arbitrary ranking of the effects produced by an earthquake on people, structures, and the ground. The intensity value is denoted by a Roman numeral in the Modified Mercalli Intensity Scale (See Appendix 1). The maximum intensity I_0, is the most severe of these effects, and occurs, usually, near the instrumental epicenter.

ISOSEISMAL MAP--A map on which assigned intensities for a single earthquake have been plotted and contoured. Examples are figures 2, 4, 5, and 6. The contour lines are called "isoseismals". The innermost contour (highest isoseismal) is the epicentral area, and usually includes the instrumental epicenter. Epicenters for pre-instrumental earthquakes are usually placed at the location of the highest known intensity report. The outermost isoseismal encloses the "felt area" of the earthquake.

LIQUEFACTION--The sudden transformation of soil into a fluid. Repeated earthquake vibrations can cause a loose, water-saturated sand to suddenly loose all of its shear strength or internal friction resistance and collapse. If the released water can find an outlet to the surface, continuing vibrations can then pump water and sand out of the ground. When this water and sand spouts from a single hole it is called a "sand blow"; it may also seep out of the ground along long fractures or cracks. This phenomenon was widespread in the central Mississippi Valley during the 1811-1812 New Madrid earthquake (figure 3), and the sand deposited at that time may still be seen in aerial photographs.

m_b--Body-wave magnitude. See "magnitude".

M_S--Surface-wave magnitude. See "magnitude".

MAGNITUDE--An instrumental measure of the size of an earthquake, or of the total amount of energy released at the source of the earthquake. Several different magnitudes may be calculated from the amplitudes of the seismic vibrations recorded by a seismograph. The two most common ones are m_b, derived from the body-wave vibrations, and M_S, derived from the surface-wave vibrations. Magnitude is popularly referred to as "Richter magnitude" because the first magnitude scale was developed by Charles F. Richter.

PRE-INSTRUMENTAL EARTHQUAKE--Any historical earthquake that occurred before the development of seismographs. Epicenters for such earthquakes are usually placed at the site of the highest known intensity report, or on the trace of an active fault near that report (when such a fault is known). Magnitudes of pre-instrumental earthquakes are usually estimated from: 1) the maximum intensity, I_o; 2) the felt area; or 3) the attenuation of intensity with distance as determined from an isoseismal map.

SAND BLOW--See "liquefaction".

SEICHE--A wave created on the surface of an enclosed body of water. Seiches caused by seismic waves may occur hundreds of kilometers from the epicenter.

SEISMICITY--The distribution of historical earthquakes. Figure 7 shows the geographical distribution of the historical seismicity of the Mississippi Valley. The catalog of these events also gives their distribution in time.

SEISMIC WAVES--The disturbances propagated outward from the focus of an earthquake. They cause the vibrating or rolling or swaying motions observed at sites far from the epicenter. Seismic waves that travel through the earth are called "body waves". Those that travel along the earth's surface are called "surface waves".

SEISMIC ZONE--An area of intense local seismicity. The microseismicity of the New Madrid seismic zone (figure 8) implies the location of the buried fault.

SEISMOGRAM--An instrumental record of earthquake vibrations. Information obtained from seismograms includes arrival times, amplitudes, and periods of seismic waves. These measurements are used to calculate the magnitude of the earthquake and the location of the hypocenter.

SEISMOGRAPH--An instrument to record earthquake vibrations. The record of the vibrations is a "seismogram".

SURFACE WAVES-- Seismic waves that travel only along the surface of the earth.

WAVE AMPLITUDE--Height of a wave crest above the base line.

WAVE LENGTH--Distance between succeeding wave crests.

WAVE PERIOD--Time for the passage of one complete wave cycle.

REFERENCES

Algermissen, S. T., 1972, The seismic risk map of the United States, Development, use, and plans for future refinement in Algermissen, S. T., ed., Conference on seismic risk assessment for building standards, March 16, 1972, Washington, D. C., p. 11-16.

Algermissen, S. T., 1973, The problem of seismic zoning in Building practices for disaster mitigation: Bldg. Sci. Ser. 46, U.S. Dept. of Commerce, Bureau of Standards, p. 112-124.

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bender, B. L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey, Open-file Report 82-1033, 99 p., 6 plates.

Algermissen, S. T., (principal investigator), Rinehart, W. A., Dewey, J., Steinbrugge, K. V. (principal consultant), Lagorio, H. J., Degenkolb, H. J., Cluff, L. S., McClure, F. E., Scott, S., and Gordon, R. F., 1972, A study of earthquake losses in the San Francisco Bay Area--A report prepared for the Office of Emergency Preparedness: U. S. Dept. Commerce, NOAA, Environmental Research Laboratories, 220 p.

Algermissen, S. T. (principal investigator), Steinbrugge, K. V. (principal consultant), Hopper, M., Campbell, K., Rinehart, W. A., Perkins, D., Lagorio, H. J., Moran, D. F., Cluff, L. S., Degenkolb, H. J., Duke, C. M., Gates, G. O., Jacobson, D. W., and Olson, R. A., 1973, A study of earthquake losses in the Los Angeles, California area--A report prepared for the Federal Disaster Assistance Administration, Department of Housing and Urban Development: U. S. Dept. Commerce, NOAA, Environmental Research Laboratories, 331 p.

Barosh, 1969, Use of seismic intensity data to predict the effects of earthquakes and underground nuclear explosions in various geologic settings: U.S. Geological Survey Bull. 1279, 93p.

Coffman, J. L., and Cloud, W. K., 1970, United States Earthquakes, 1968: U.S. Dept. Commerce, 111 p.

Eckel, Edwin, B., 1970, The Alaska earthquake, March 27, 1964: Lessons and conclusions: U.S. Geol. Survey Prof. Paper 546, 57 p.

Evernden, J. F., 1967, Magnitude determination at regional and near-regional distances in the United States: Seismological Soc. America Bull. 57, p. 591-639.

Fenneman, N. M., 1938, Physiography of the eastern United States: McGraw-Hill, New York.

Fuller, M. L., 1912, The New Madrid Earthquake: U. S. Geological Survey, Bull. 494, 119 p.

Gordon, D. W., Bennett, T. J., Hermann, R. B., and Rogers, A. M., 1970, The south-central Illinois earthquake of November 9, 1968: Macroseismic studies: Seismological Soc. America Bull. 60, p.953-971.

Gordon, M., Jr., Tracey, J. I., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U. S. Geolgical Survey Prof. Paper 299, 268p.

Gore, W. A., Brown, J. H., and Fielder, R. T., 1978, Soil survey of Lawrence County, Arkansas: U.S. Soil Conservation Service, 79 p.

Gray, H. H., Williams, J. W., and Wier, C. E., 1970, Geologic map of the 1 degree x 2 degree Vincennes Quadrangle and parts of adjoining quadrangles, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Geological Survey, 1:250,000.

Haley, B. R., Glick, E. E., Bush, W. V., Clardy, B. F., Stone, C. G., Woodward, M. B., and Zachry, D. L., 1976, Geologic map of Arkansas: Arkansas Geological Commission and U.S. Geological Survey, scale 1:500,000.

Haley, G. J., Buckner, R. O., Festervand, D. F., 1975, Soil Survey of Pulaski County, Arkansas: U. S. Dept. Agriculture Soil Conservation Service and Arkansas Agricultural Experiment Station, 65 p., 65 plates.

Heinrich, R. R., 1941, A contribution to the seismic history of Missouri: Seismological Soc. America Bull. 31, p.187-224.

Hopper, M. G., and Algermissen, S. T., 1980, An evaluation of the effects of the October 31, 1895, Charleston, Missouri, earthquake: U. S. Geological Survey Open-File Report 80-778.

Hopper, M. G., Langer, C. J., Spence, W. J., Rogers, A. M., and Algermissen S. T., Olsen, B. C., Lagorio, H. J., and Steinbrugge, K. V., 1975 A study of earthquake losses in the Puget Sound, Washington, area: U.S. Geological Survey Open-File Report 75-375, 298p.

Kanamori, H., 1977, The energy release in great earthquakes: Journal of Geophysical Research, v. 82, p. 2981-2987.

Lineback, J. A., 1979, Quaternary deposits of Illinois: Illinois State Geol. Survey, 1:500,000.

Liu, Ben-chieh, 1981, Earthquake risk and damage functions: application to New Madrid: Westview Press, Boulder, Colorado, 297 p.

Logan, W. N., 1932, Geological map of Indiana: Indiana Dept. of Conservation, Publication No. 112.

M & H Engineering and Memphis State University, 1974, Regional earthquake risk study: Mississippi-Arkansas-Tennessee Council of Governments/Memphis Delta Development District (MATCOG/MDDD)

Mann, O. C., and Howe., W., 1973, Regional earthquake risk study: Progress Report No. 2, M & H Engineering, Memphis, Tennessee.

Marvin, C. F., 1895, Report on the earthquake of October 31, 1895: Monthly Weather Review 23, p. 374-379.

McClain, W. C., and Myers, D. H., 1970, Seismic history and seismicity of the Southeastern region of the United States: Report No. ORNL-4582, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

McCracken, M. H., 1961, Geologic map of Missouri: Missouri Geological Survey, 1:500,000.

McKeown, F. A., and Pakiser, L. C., 1982, ed., Investigations of the New Madrid, Missouri, earthquake region: U.S. Geological Survey Prof. Paper 1236, 201 p.

Moneymaker, B. C., 1954, Some early earthquakes in Tennessee and adjacent states (1699 to 1850): Journal of Tennessee Academy of Science, v. 29, no. 3, p. 224-233.

Necioglu, A., and Nuttli, O. W., 1974, Some ground motion and intensity relations for the central United States: Earthquake Engineering and Structural Dynamics 3, p.111-119.

Nichols, T. C., 1968, Engineering geology of the Paducah East Quadrangle in Kentucky: U. S. Geological Survey Bulletin 1258-A, 13 p.

Nowak, A. S., and Morrison, E. L. R., 1982, Earthquake hazard analysis for commercial buildings in Memphis: Univ. of Michigan, UMEE 82R2, 151 p.

Nuttli, O. W., 1973, The Mississippi Valley earthquakes of 1811 and 1812: Intensities, ground motion and magnitudes: Seismological Soc. America Bull. 63, p.227-248.

Nuttli, O. W., 1974, Magnitude-recurrence relation for central Mississippi valley earthquakes: Seismological Soc. America Bull. 64, p. 1189-1207.

Nuttli, O. W., 1979, Seismicity of the central United States: Geological Soc. America Reviews in Engineering Geology IV, p. 67-93.

Nuttli, O. W., 1980, Seismic hazard associated with the New Madrid faulted zone: <u>In</u> Technical papers, fiftieth annual international meeting, Society of Exploration Geophysicist, v. 6, p. 3469-3484.

Nuttli, O. W., 1981, Evaluation of past studies and identification of needed studies of the effects of major earthquakes occurring in the New Madrid fault zone: A report submitted to Federal Emergency Management Agency Region VII, Kansas City, Missouri, 28 p.

Nuttli, O. W., 1982, Empirical magnitude and spectral scaling relations for mid-plate and plate-margin earthquakes: Paper presented at meeting of International Assoc. of Seismology and Physics of the Earth's Interior, London, Canada.

Nuttli, O. W., and Herrmann, R. B., 1978, State-of-the-art for assessing earthquake hazards in the United States, Report 12, Credible earthquakes for central United States: U.S. Army Engineer Waterways Experiment Station, 98 p.

Richter, Charles F., 1958, Elementary seismology: W. H. Freeman and Company, San Francisco, 768 p.

Rogers, A. M., Algermissen, S. T., Hays, W. W., and Perkins, D. M., (geological and seismological portion); Van Strein, D. O., Hughes, H. C., Hughes, R. C., Lagorio, H. J., and Steinbrugge, K. V. (engineering analysis portion), 1976, A study of earthquake losses in the Salt Lake City, Utah area: U.S. Geological Survey Open-File 76-89, 357 p.

Russ, D. P., 1979, Late Holocene faulting and earthquake recurrence in the Reelfoot Lake area, northwestern Tennessee: Geol. Soc. America Bull., v. 90, p. 1013-1018.

Seed, H., Bolton, and Idriss, I. M., 1967, Analysis of soil liquefaction, Niigata earthquake: J. Soil Mech. American Soc. Civ. Eng., v. 93, p. 83-108.

Sharma, S., and Kovacs, W. D., 1980, The microzonation of the Memphis, Tennessee, area: U. S. Geological Survey Open-File Report 80-914, 129 p.

Slemmons, D. B., 1977, State-of-the-art for assessing earthquake hazards in the United States, Report 6, Faults and earthquake magnitude: U.S. Army Engineer Waterways Experiment Station, 129 p.

Soil Conservation Service, U. S. Dept. Agriculture, 1967, Soil Association map, state of Arkansas: Soil Conservation Service, U. S. Dept. Agriculture and Univ. Arkansas Div. of Agriculture, 3M-6-79R.

Stauder, W., 1982, Present day seismicity and identification of active faults of the New Madrid seismic zone in McKeown, F. A. and Pakiser, L. C., ed., Investigations of the New Madrid, Missouri, earthquake region: U. S. Geological Survey Prof. Paper 1236, chapter C.

Stauder, W., and Nuttli, O. W., 1970, Seismic studies: South central Illinois earthquake of November 9, 1968: Seismological Soc. America Bull. 60, p. 973-981.

Terzaghi, K., 1931, Earth slips and subsidences from underground erosion: Engineering News-Record, p. 90-92.

Williams, H. B., and others, compilers, 1967, Geologic map of Illinois: Illinois Department of Registration and Education, Illinois Geological Survey, 1:500,000.

Wood, H. O., and Neumann, F., 1931, Modified Mercalli intensity scale of 1931: Seismol. Soc. America Bull. 21, p. 277-283.

Youd, L. T., and Perkins, D. M., 1978, Mapping liquefaction-induced ground failure potential: Journal of the Geotechnical Engineering Div., ASCE, v. 104, no. GT4, Proc. Paper 13659, p. 433-446.

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., McKeown, F. A., and Brockman, S. R., 1980, Recurrent intraplate tectonism in the New Madrid seismic zone: Science, v. 209, p. 971-976.

AN ASSESSMENT OF DAMAGE & CASUALTIES FOR SIX CITIES IN THE CENTRAL UNITED STATED RESULTING FROM A GREATEARTHQUAKE IN THE NEW MADRID SEISMIC ZONE

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INRODUCTION

This presentation is a brief review of the status of this Central United States Earthquake Prepardness Project (CUSEPP) report, hereafter referred to as the "Six City Report". As this report is in draft form, it is under review and is, therefore, subject to revision prior to release to the public, no specific findings or numbers will be released or discussed at this time. Discussions will be offered as to the methodology used and general comments pertaining to the report's findings.

BACKGROUND

Due to the growing knowledge and concern on the part of seismic experts concerning earthquake risk in the New Madrid Seismic Zone, the CUSEPP was developed and initiated by the Federal Government in response to this developing situation. The Six City Report is one of that project's outputs, to be used by national, regional, and local emergency managers and planners to assess disaster magnitudes and to begin the development of response plans for the occurrence of significant earthquakes in the Central United States region. This report (The Six City Report) will present an assessment of the expected casualties, damage and disruption expected to occur in the six Central United States cities as a result of the hypothetical occurrence of a "great" earthquake anywhere along the New Madrid Seismic Zone. These cities are Memphis, Tennessee, Little Rock, Arkansas, Evansville, Indiana, Paducah, Kentucky, Carbondale, Illinois, and Poplar Bluff, Missouri.

The severity of ground shaking expected for the hypothetical earthquake was estimated by the U.S. Geological Survey (USGS), for both the Central United

States Region in general, and individually for the six project cities. Field teams from the Federal Emergency Management Agency (FEMA), with local assistance, collected an inventory, using a variety of techniques, of the structural characteristics of virtually all of the structures in the six project cities. Allen and Hoshall, Inc., along with its subcontractors, developed and applied methodology which provided for computer input and manipulation of inventory data, damage assessment and casualty estimation. System experts on the project team assessed damage and disruption to vital city systems, such as medical and emergency services, utility systems, transportation networks, and other vital entities.

METHODOLOGY

Generally, the Six City Report embodies a three phase approach. Initially, the USGS, in a project documented in another CUSEPP report, provided estimates of ground shaking for the hypothetical project earthquake. A "great" earthquake, of approximate Richter magnitude 8.5, was selected. This represented an earthquake of the same general strength as one of three great earthquakes which occurred in the New Madrid Seismic Zone in 1811-1812, and resulted in the formation of Reelfoot Lake. This event was chosen as a realistic maximum-level earthquake, for planning and emergency management purposes. Isoseismal maps were prepared for the general Central United States region, and specifically for the six project cities, using the Modified Mercalli intensity (MMI) scale. Areas within a city which could be expected to experience poor soil behavior and possible soil liquefaction, were accounted for by assigning these zones a higher MMI rating. These regional and city maps were provided to the project team and were used to indicate ground shaking intensities with which to assess damage to structures and resulting casualties.

The second major activity was the collection, by FEMA, using various techniques, of descriptive structural information for all structural types found within the six project cities. Some of this data resulted from the individual surveying of critical facilities such as medical facilities, schools, power plants, etc. For others, a grouping or aggregate concept was utilized, to allow for general surveys of very large numbers of similar structures, such as residential, industrial and other structures. This and other city specific information, along with the ground shaking estimates, were given to the project team for analysis.

The third phase of the project was to prepare estimates of damage, casualty and disruption in the six project cities based upon the previously prepared ground shaking estimates and structural inventory. This was accomplished by the Allen and Hoshall project team, which included as subcontractors Systan, Inc., who are responsible for casualty estimation and for assessment of damage to transportation systems, and Jack R. Benjamin & Associates (JBA), who developed the damage estimation methodology. Work began by entering the large quantity of structural information into the Allen and Hoshall computer system. Then JBA developed the methodology to be used to assess damage to structures within the six cities. This method, utilizing "fragility curve" procedures, was applied in this project to estimate damage to groups of structures having similar structural characteristics. Fragility curves were prepared for 16 categories of structures. These are listed in Table I. This method of damage assessment predicts the expected damage state to be equalled or exceeded, to a population of given structural types, when exposed to certain levels of ground shaking. An example curve and the damage categories are shown in Figure I and Table II, respectively.

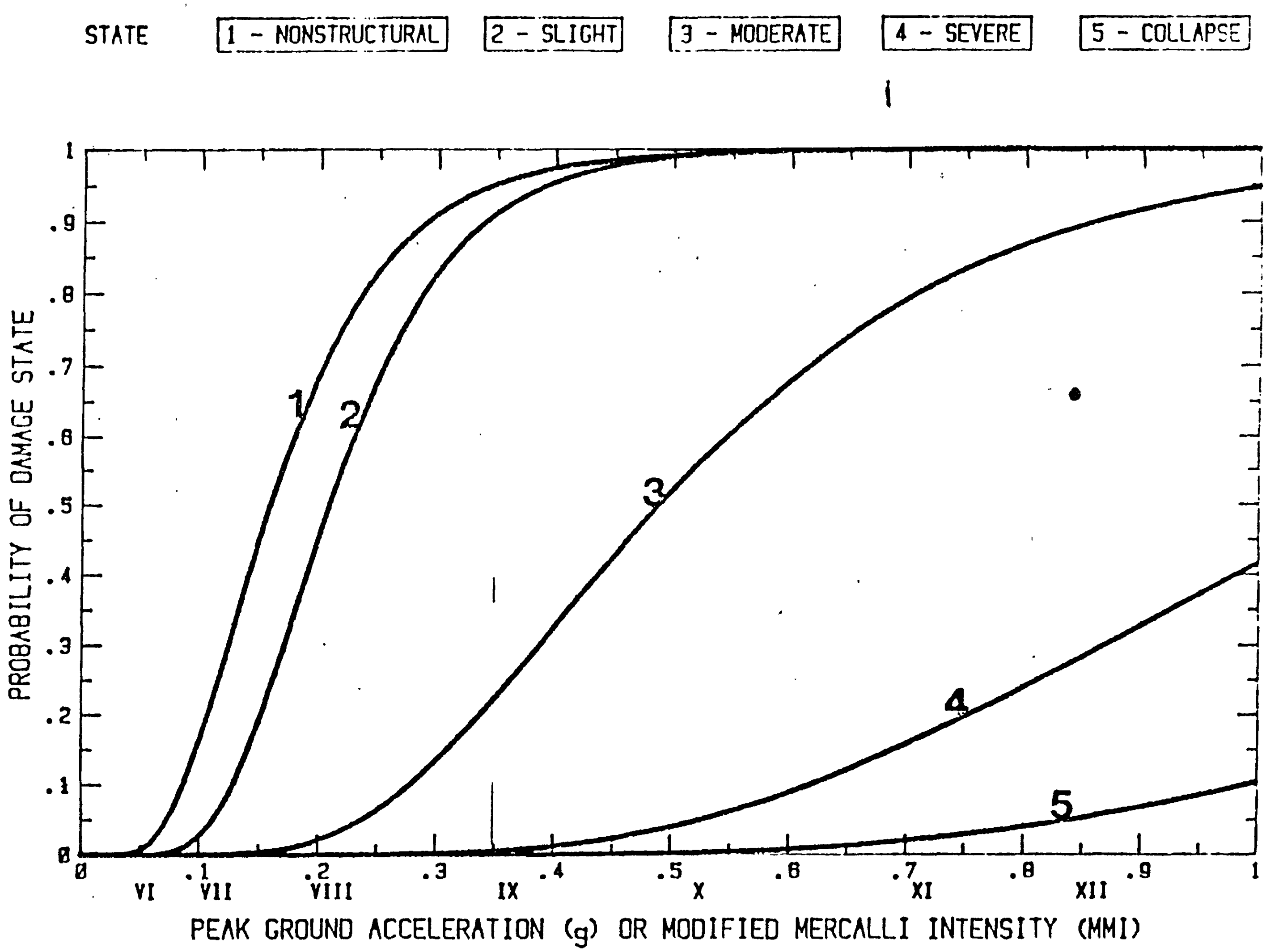
TABLE I - STRUCTURE TYPES

1-5/Story shear wall buildings	6/Story shear wall buildings
Bearing wall buildings	Wood frame buildings
Pre-engineered metal buildings	Tilt-up buildings
Pre-cast buildings	Electrical switchyard equipment
Emergency power units	Water/sewage plants
Power plants	Earth dams
Highway bridges	Major bridges
Cylindrical storage tanks	Elevated tanks

Project team engineers used the fragility curves, along with their experience and familiarity with urban systems and the behavior of structures under earthquake conditions, to produce estimates of expected damage to structures and services in the project cities. SYSTAN, INC., similarly used the fragility curve method to assess damage to rail and highway links in and around the project cities, and to prepare estimates of persons killed and seriously injured as a result of damage to occupied structures within the project cities.

PROJECT FINDINGS - GENERAL COMMENTS

In general, casualties, damage and disruption to essential services will be extensive in the six project cities following the occurrence of the project earthquake. Damage and disruption experienced by the six project cities will



STRUCTURE TYPE: XXXX

vary primarily as a function of their proximity to the New Madrid Seismic Zone. That is, cities closer to the zone will experience greater damage, as reflected in their higher estimated MMI ground shaking levels cities farther away will experience less severe conditions.

Damage to and loss of electrical utilities, primarily due to the susceptibility of power plants and sub-stations to earthquake-caused damage, will work great hardship on all project cities, causing or contributing to the loss of some or

TABLE II

DAMAGE CATEGORIES[1]

Response Level		Damage Category	Extent of Damage in General	Suggested Post-Earthquake Actions
	0	No Damage	No Damage	No Action Required
Elastic	I	Slight Non-structural Damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Building need not be vacated. Only architectural repairs needed.
Inelastic (yielding of some elements)	II	Slight Structural Damage	Small cracks, in walls, falling of plaster in large bits over large areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Architectural repairs required to achieve durability.
Inelastic (general yielding)	III	Moderate Structural Damage	Large and deep cracks in walls; widespread crack of walls, columns, piers and tilting or falling of chimneys. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated, to be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening are necessary after which architectural treatment may be carried out.
Inelastic (ultimate of some elements)	IV	Severe Structural Damage	Gaps occur in walls; inner or outer walls collapse; failure of ties to separate parts of buildings. Approximately 50% of the main structural elements fail. The building takes a dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation.
Inelastic (ultimate all main elements)	V	Collapse	A large part of whole of the building collapse.	Clearing the site and reconstruction.

1. from: Basic Concepts of Building Codes, Vol. I, International Association of Earthquake Engineering, Toyko, Japan, 1980

all other major utility networks. Water systems and sewers systems frequently rely heavily upon electricity to provide pumping for water distribution and sewage lifting facilities. These systems will probably be unavailable in most or all the project cities following an occurrence of the project earthquake. The implications of the loss of a water system are obvious. Natural gas systems in the six project cities are expected to suffer damage; in any case, they will almost certainly be shut down immediately for inspection and repair, and thus will be unavailable.

Medical and other emergency services will be disrupted according to the severity of ground shaking in the individual cities. Another important factor is the type of structure involved. Cities closest to the zone will experience serious disruption to these services; those farther away are expected to have significantly less damage. Facilities located in damage-prone structures, such as those constructed of unreinforced masonry, are expected to suffer much greater damage than those in reinforced frame structures.

Transportation links will be similarly affected. Cities closest to the fault zone are expected to be seriously hampered due to loss of key bridges on their major rail and highway links. Cities farther away are expected to suffer less isolation. Major airports are expected to have at least partial availability of runways, but electrical systems, including lighting and navigational aides, are prone to loss. River port facilities are expected to be generally unavailable throughout the zone.

CONCLUSION

The findings of the six city report, when released, will depict general estimates of casualties, damage and disruptions resulting from the project earthquake in the six project cities. Wherever possible, information as to expected system availability and expected number of available structures will be presented in tabular form, on a general summary basis, and on a city-specific basis, to provide for maximum utilization by all interested users. It is hoped that this report, and the methods developed and implemented during its completion, will serve as prototypes for significant and useful future work in this worthwhile project.

DEVELOPMENT OF FRAGILITY CURVES FOR ESTIMATION OF EARTHQUAKE-INDUCED DAMAGE

by

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INTRODUCTION

In order to assess emergency management needs immediately after a major earthquake, it is necessary to make some determination of the potential number of casualties, the availability of major life-line systems (such as highways, communication networks, and water supply systems), the availability of emergency services (such as hospitals), and the consequences of possible secondary disasters (such as seismically-induced dam failures). Management planning also requires an assessment of the expected long-term needs for restoration of damaged facilities. Therefore, a methodology is required that will, for example, assess the likelihood and degree that hospital services will be available after an earthquake, as well as estimate the expected value of hospital losses. Such a procedure was developed for the Central United States Earthquake Preparedness Project (CUSEPP). This procedure is described in subsequent paragraphs.

Although earthquake-induced damage and failure of a structure may result from a variety of mechanisms: foundation failure due to liquefaction, foundation displacement caused by fault break or landslide, etc., damage is principally due to ground shaking. As a result of ground shaking, vibration is developed in a structure. Due to the inherent dynamic characteristics of structures, the level of vibration in most structures is significantly greater than the level of shaking in the ground. For small levels of vibration in a structure, damage is minor or does not occur at all. At larger levels of vibration, damage becomes more significant and failure more likely.

The actual damage that will be inflicted on a structure by a particular level of ground shaking is uncertain because of (1) design and construction irregularities, (2) variability in material properties, (3) uncertainty in structural response to earthquake-induced shaking, and (4) uncertainty in the level of ground shaking that will cause a structure to fail. However, it is possible to define a range of ground shaking over which failure can occur. Within this range, the assessment of the likelihood of failure increases from a probability of zero (i.e., no chance of failure) to a probability of one (e.g., certain failure).

The relationship which describes the probability of failure at various levels of ground shaking is known as a fragility curve. For the purpose of emergency management planning, fragility curves can be used in conjunction with estimates of the severity of ground motion intensity, to predict the probability that a structure will fail and the degree of damage that it is liable to sustain. The level of ground shaking is most commonly expressed in terms of the peak ground acceleration (PGA); however, Modified Mercalli intensity (MMI) can be used as well.

Peak ground acceleration is the maximum value of ground shaking recorded by an instrument known as an accelerograph. It is preferred by engineers to describe seismic loads and is the most commonly used parameter to characterize ground shaking. Modified Mercalli Intensity, on the other hand, is a subjective measure of the level of ground shaking that ranges numerically from I to XII. Each value on the MMI scale corresponds to observations of damage and sensations experienced as a result of the earthquake. For earthquakes with recordings of PGA and MMI, a correlation between these parameters has been observed. Table 1 provides a description of the Modified Mercalli Intensity scale and a range of PGA values for each intensity. For the CUSEPP project, maps of the ground motion intensity (MMI) corresponding to a New Madrid earthquake were provided by the U.S. Geological Survey.

FRAGILITY CURVE DESCRIPTION

A fragility curve can be used to represent failure of a specific structural system, or a generic structure type. For the CUSEPP project, fragility curves

TABLE 1
MODIFIED MERCALLI INTENSITY SCALE

Intensity	Description	PGA Interval [1] (g units)
I.	Not felt except by a few under specially favorable conditions.	< 0.03
II.	Felt only by persons at rest in places such as upper floors of buildings. Delicately suspended objects swing.	< 0.03
III.	Felt by many persons in places such as upper floors of buildings but of a degree that most persons do not recognize it as an earthquake. Standing automobiles may rock slightly as if from vibration caused by a passing truck. Duration may be measured.	< 0.03
IV.	In daytime, felt by many indoors but by only a few outdoors. Dishes, windows, doors disturbed, and walls creak. Sensation like a heavy truck striking a building. Standing automobiles rocked considerably.	< 0.03
V.	Felt by all, many awakened. Some dishes and window glasses broken, wall plaster may crack. Unstable objects overturned. Disturbance of telephone poles, trees and other tall objects sometimes noticed. Pendulum clocks stopped.	0.03-0.08
VI.	People are frightened and run outdoors. Heavy furniture may be moved; some instances of fallen plaster and toppling of chimneys. Slight damage.	0.09-0.15
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in ordinary structures, and considerable in poorly built or badly designed structures. Chimneys broken. Felt in moving automobiles.	0.16-0.25

TABLE 1 (CONTINUED)
MODIFIED MERCALLI INTENSITY SCALE

Intensity	Description	PGA Interval [1] (g units)
VIII.	Some damage even in buildings of good design and construction. Considerable damage in ordinary buildings, with some collapsing. Great damage in poorly constructed buildings. Panel walls thrown out of frame structures. Falling of houses and factory chimneys, columns, monuments and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Hinders driving of automobiles.	0.26-0.45
IX.	Damage considerable in buildings of good design and construction. Structures thrown out of alignment with foundations. Ground cracked conspicuously. Underground pipes damaged.	0.46-0.60
X.	Wooden houses of good design and construction collapse. Most masonry and frame structures destroyed together with foundations. Ground cracked causing damage. Rails bent. Slopes and embankments slide. Water surface rises.	0.61-0.80
XI.	Almost all masonry structures collapse. Bridges destroyed. Fissures over entire surface of ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent prominently.	0.81-0.90
XII.	Damage total. Waves seen transmitted at ground surface. Topography changed. Objects thrown into air.	$\geq$ 0.91

[1] Acceleration ranges taken from Reference 1.

were developed for the 16-structure types (or structural systems) listed in Table 2. Further, the fragility curves were prepared in two basic formats: one format which describes the probability of failure for "all" structures of a given type (e.g., all bearing wall buildings), and a second format which delineates the probability of failure for "good" structures, "average" structures, and "bad" structures of a given type (e.g., good bearing wall building, average bearing wall building, or bad bearing wall building).

Thus, if a specific structure or group of structures could be distinguished as either good (i.e., significantly better than average), average, or bad (i.e., significantly worse than average) in terms of anticipated seismic performance, then the corresponding "good," "average," or "bad" fragility curves were used to determine the likelihood of failure. On the other hand, if a structure of a given type could not be distinguished as good, average or bad in terms of anticipated seismic performance, then the "all"-structure fragility curve was used to determine the likelihood of failure.

Traditionally, fragility curves assume a structure to be in one of two possible states: completely failed or not failed. For some structure types, such as electrical switchyard equipment, two-state modeling accurately represents observed failure patterns. However, for most structures, and especially buildings, damage is observed to occur in varying degrees from no damage to collapse.

To describe multiple damage states for buildings (and other structure types), fragility curves were developed which quantify the probability of reaching one of five damage states: nonstructural, slight, moderate and severe structural damage, and collapse. These five damage states are described in Table 3. For structures such as bridges, tanks, etc., only the moderate, severe and collapse damage states were used since nonstructural and slight structural damage is not of interest for emergency planning purposes. As mentioned previously, for structures such as electrical switchyard equipment, which respond with either no damage or complete failure, a single damage state (i.e., collapse) was used.

TABLE 2

STRUCTURE TYPES USED FOR

CUSEPP SIX-CITY STUDY

1-5/Story shear wall buildings
6/Story shear wall buildings
Bearing wall buildings
Wood frame buildings
Pre-engineered metal buildings
Tilt-up buildings
Pre-cast buildings
Electrical switchyard equipment
Emergency power units
Water/sewage plants
Power plants
Earth dams
Highway bridges
Major bridges
Cylindrical storage tanks
Elevated tanks

TABLE 3
DAMAGE CATEGORIES[1]

Response Level		Damage Category	Extent of Damage in General	Suggested Post-Earthquake Actions
	0	No Damage	No Damage	No Action Required
Elastic	I	Slight Non-structural Damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Building need not be vacated. Only architectural repairs needed.
Inelastic (yielding of some elements)	II	Slight Structural Damage	Small cracks, in walls, falling of plaster in large bits over large areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Architectural repairs required to achieve durability.
Inelastic (general yielding)	III	Moderate Structural Damage	Large and deep cracks in walls; widespread crack of walls, columns, piers and tilting or falling of chimneys. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated, to be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening are necessary after which architectural treatment may be carried out.
Ineleastic (ultimate of some elements)	IV	Severe Structural Damage	Gaps occur in walls; inner or outer walls collapse; failure of ties to separate parts of buildings. Approximately 50% of the main structural elements fail. The building takes a dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation.
Inelastic (ultimate all main elements)	V	Collapse	A large part of whole of the building collapse.	Clear the site and rebuild.

[1] Damage Categories taken from Reference 2.

The function of each fragility curve is the quantification of the likelihood of reaching or exceeding a particular damage state, given the severity of the ground motion. For example, the likelihood of building collapse (and, consequently, the likelihood of related casualties, etc.) is dependent on the level of ground shaking. At a very low level of ground shaking, one can be almost certain that the building would not collapse. Conversely, at a very high level of ground shaking, one can be reasonably sure that the building would collapse. Between these extremes it is uncertain as to how severe the damage to a building would be. The absolute likelihood of collapse at any level of shaking depends on details of design, construction, and earth movement that are not known for a hypothetical earthquake. The function of the fragility curve is to assign, in this case, probabilities of collapse, having taken into account each source of uncertainty.

FRAGILITY CURVE DEVELOPMENT

A fragility curve can have any shape that increases in value from 0 to 1. In this work, it was assumed that the peak accelerations at which a structure fails have a lognormal distribution. The lognormal distribution is a smoothly varying function defined by two parameters; a median value and a standard deviation. The median peak ground acceleration establishes where the fragility curve is centrally located and corresponds to the acceleration level resulting in a 0.50 probability of failure. The standard deviation, on the other hand, establishes the spread or range of the fragility curve and accounts for the uncertainty in the estimate of structural damage.

Fragility curves are based on a combination of calculations, engineering judgment, and damage data from past earthquakes. In essence, two separate approaches, one based on calculations and one based on data, were used to determine the fragility parameters for each curve. The first approach relied upon calculations (and engineering judgments) to develop fragility parameters for specific geometries, materials, etc., which were deemed to best represent the characteristics of structures found in the Mississippi Valley region. The second approach relied upon the analysis of damage data from past earthquakes. The two approaches were conducted in parallel and composite fragility parameters were developed by a subjective weighting and combination of the individual results. In this manner, the fragility curves represent structures specific to the Mississippi Valley, while being calibrated by the general pattern of observed earthquake damage.

FRAGILITY CURVE ILLUSTRATION

Figures 1 and 2 illustrate fragility curves developed for this project. In this illustration Figure 1 is the "all"-structure fragility curves for wood frame buildings while Figure 2 is the "good," "average," and "bad"-structure fragility curves also for wood frame buildings. For each damage state in Figure 2, a shaded region between the upper- and lower-bounds is used to represent the range of possible fragility values for "good" to "bad" wood frame buildings.

The meaning of the fragility curves may be illustrated bv examining values extracted from the slight structural damage fragility curve shown in Figure 1.

For an earthquake intensity of MMI VI, it is almost certain that only nonstructural damage would occur to a typical wood frame building. Therefore, the probability of slight structural or greater damage at MMI V1 is 0.0. For an earthquake intensity of MMI XII, it is almost certain that structural damage to a wood frame building would be at least slight. Therefore, the probability of slight damage at MM1 X1I is 1.0. At intermediate earthquake intensities, the probability of slight damage is greater than 0.0 and less than 1.0. For example at MMI VIII, the probability of at least slight damage is 0.45. This means that if a wood frame building is subjected to an MMI VIII shock 100 times, it would be reasonable to expect at least slight structural damage on 45 of those occasions. From another viewpoint, if one had 100 wood frame buildings of unknown quality that were all subjected to an MMI VIII shock, then one might reasonably expect that 45 of the buildings would suffer at least slight structural damage.

At any given intensity there is a higher likelihood of moderate structural damage than of severe structural damage, a higher likelihood of slight than

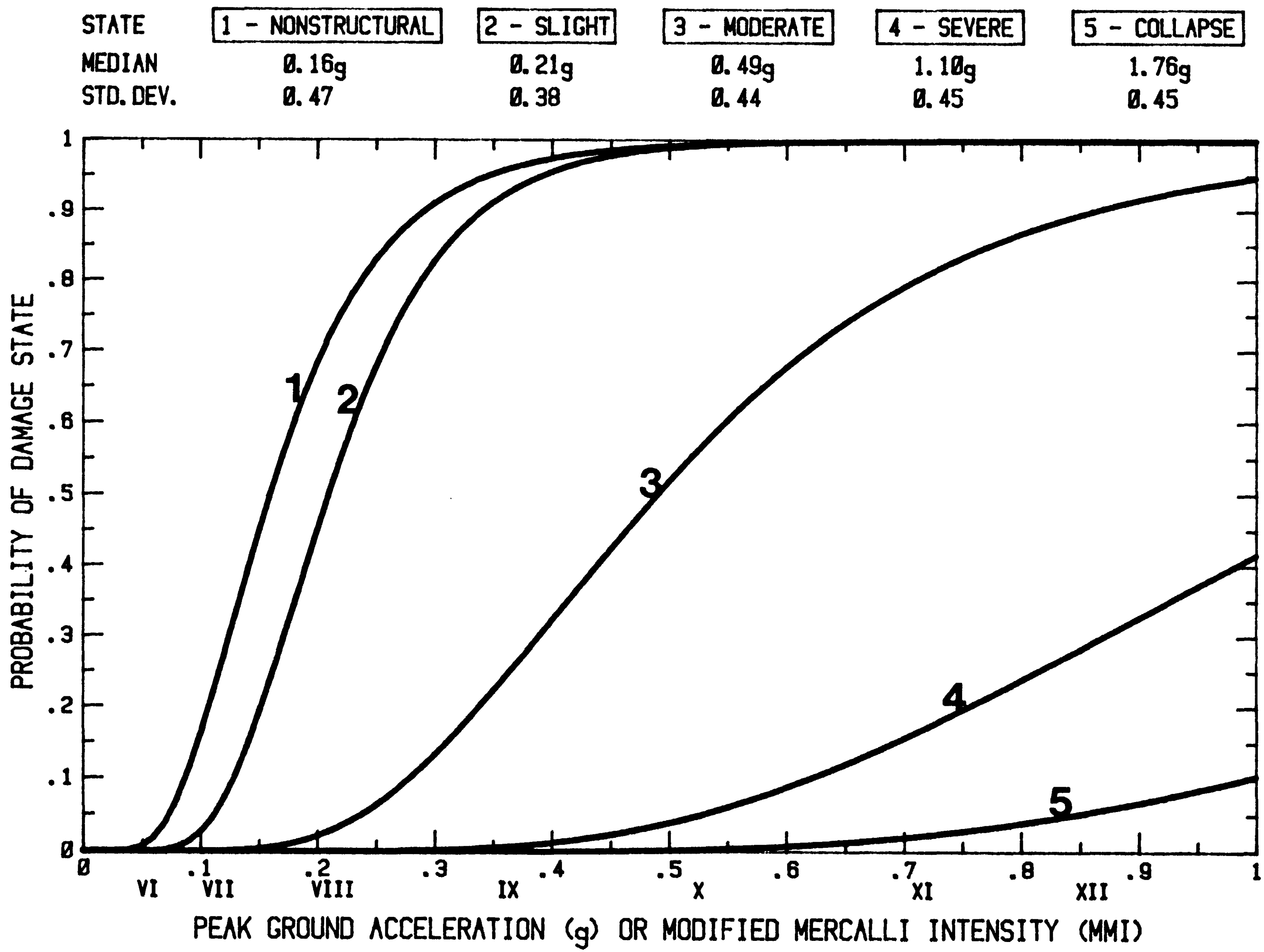

FIGURE 1: STRUCTURE TYPE : ALL WOOD FRAME BUILDINGS

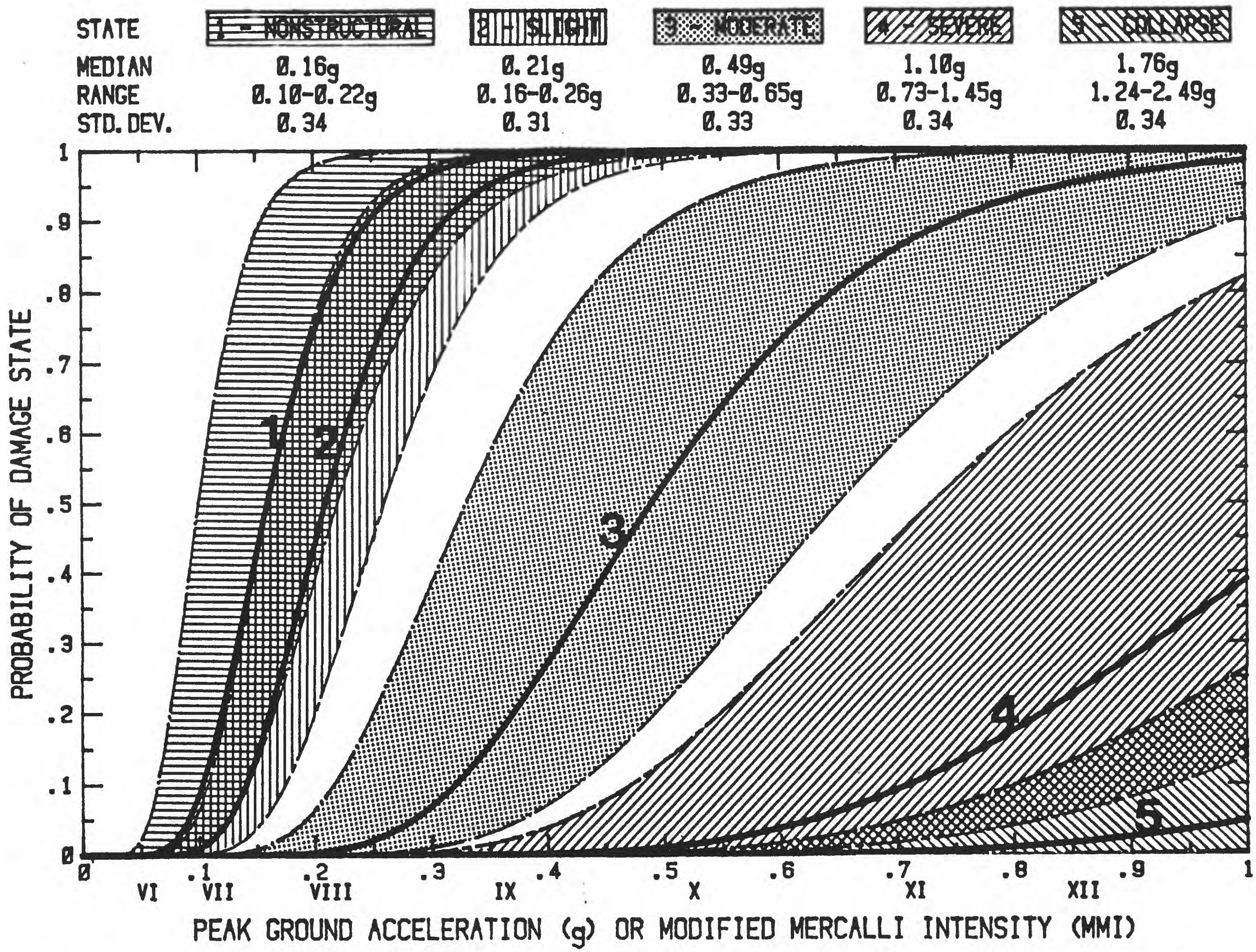

FIGURE 2: STRUCTURE TYPE : MEDIAN, UPPER AND LOWER BOUND WOOD FRAME BUILDINGS

moderate, etc. Thus, for a wood frame building of unknown quality (i.e., Figure 1) and earthquake intensity MMI IX, there is:

a 0.95 probability of at least nonstructural damage,
a 0.91 probability of at least slight structural damage,
a 0.23 probability of at least moderate structural damage,
a 0.01 probability of at least severe structural damage,
a 0.00 probability of collapse.

Hence, for a given earthquake intensity, the fragility curves provide a measure of the likelihood of reaching or exceeding each damage category.

The meaning of the information contained in the "good," "average," and "bad"-structure fragility curves is the same as the "all"-structure fragility curves, except a range of values is given for each damage state. For example, a wood frame building of known quality (i.e., Figure 2) and subjected to an earthquake intensity of MMI IX, has:

a 0.60 probability of at least moderate damage, if it's a "bad" wood frame building,
a 0.16 probability of at least moderate damage, if it's an "average" wood frame building,
a 0.03 probability of at least moderate damage, if it's a "good" wood frame building,

Each damage category has a range of values which represent the variability of the structure's quality.

For purposes of estimating long-term emergency management needs (e.g. disaster relief for restoration) it is equally important to estimate the expected financial losses. With appropriate information on the replacement value of each structure type, the fragility curves can be used to estimate the financial impact of a New Madrid earthquake. The expected financial loss associated with the damage to a structure can be computed at a given intensity level as the sum of the average dollar loss for each damage state (i.e., the average damage ratio for a damage state times the replacement value of the structure), weighted by the probability of the damage state. The total expected loss due to structural damage is a sum of the expected losses for all structures of a given type and all structure types.

COMPARISON OF FRAGILITY CURVES PROBABILITIES AND COALINGA DAMAGE DATA

On May 2, 1983, at 4:42 p.m. a moderate earthquake (ML = 6.5) struck near Coalinga, California. The reported duration of strong shaking was about 10-15 seconds. Preliminary estimates of the maximum intensity was MMI IX.

This event is of particular relevance to the CUSEPP study since many of the older masonry and wood frame buildings of Coalinga are similar in design to buildings found in the Mississippi Valley. That is, these structures were not designed for seismic forces. As a result of the Coalinga event, most older structures, which lacked adequate seismic design, were severely damaged or collapsed. In fact, damage to the older buildings in the center of the town was so severe that the entire area was eventually razed.

Immediately following the Coalinga earthquake the Earthquake Engineering Research Institute dispatched a reconnaissance team under the leadership of Professor Haresh Shah of Stanford University to survey the damage. The results of the team's preliminary survey of 139 buildings are given in Table 4, which is taken directly from their report on damage to Coalinga's commercial district (Reference 3). The pertinent damage ratios given in Table 4 for bearing wall (masonry) and wood frame structures were extracted from this table, expressed in a cumulative form and compared to the corresponding fragility curve probabilities. Table 5 and Table 6 show this comparison for bearing wall and wood frame buildings, respectively. The conclusions reached are discussed below.

In general, very good agreement is found between the fraction of bearing wall and wood frame buildings which were observed to have suffered a particular level of damage and the probability of reaching that state, as given by the appropriate fragility curve. For instance, identical values were found for the damage experienced by old or poorly constructed, unreinforced masonry buildings and the probabilities predicted by the "bad" bearing wall fragility curves at MMI 1X. This close agreement between observed damage and the predicted value is particularly significant, since this structure type (i.e., unreinforced masonry) is very common to the Mississippi Valley and figures dominantly in estimates of earthquake casualties.

SUMMARY

A methodology to estimate the damage associated with earthquake ground shaking based on the concept of seismic fragility was described. A seismic fragility curve provides an estimate of the likelihood that a structure will experience a particular level of damage as a function of peak ground acceleration. They are based on a combination of calculations, engineering judgment, and damage data from past earthquakes. Fragility curves have been developed for a total of 16 structure types for the CUSEPP.

The fragility curve format of estimating earthquake damage is advantageous in that it can provide an evaluation of the likelihood that a certain level of damage would be incurred, as well as offer an estimate of the expected financial losses. Each type of information is a necessary part of short- and long-term emergency management planning.

The estimation of damage utilizing the fragility curve concept is not uniquely applicable to seismic events. The general methodology as outlined is equally suited for making damage estimates associated with other natural hazards such as wind and flood.

REFERENCES

1. McCann, Jr., M. W., Sauter, F., and Shah, H. C., "A Technical Note on PGA-Intensity Relationships with Applications to Damage Estimation, BSSA, Vol. 70, No. 2, pp 631-637, 1980.

2. Basic Concepts of Building Codes, Vol I., International Association of Earthquake Engineering, Toyko, Japan, 1980.

3. Shah, H. C., et al.," A Preliminary Survey of Damage to the Commercial District, Coalinga Earthquake of May 2, 1983, prepared for EERI, May 5, 1983.

TABLE 4

NUMBER AND EXTENT OF BUILDINGS DAMAGED BY THE COALINGA EARTHQUAKE[1]

Damage Ratio	Old unreinforced masonry buildings	Newer brick masonry buildings	Concrete block buildings	Wood framed commercial buildings	Cast-in-place concrete (frames & walls)	Old wood frame residences on cripple walls
0-10%	0	5*	14*	24*	5	4
10-30%	3	7*	2*	3	1	12
30-60%	7	1**	0	1	0	1
60-100%	30	2**	0	1***	0	16[a]
Total Number of Buildings	40	15	16	29	6	33

1 Data taken from Reference 3.

* Reinforced brick or block masonry.

** These were new but unreinforced masonry.

*** This building collapsed because an adjacent unreinforced masonry building wall fell on it.

(a) Either the residence fell off the foundation or the cripple wall failed, resulting in buckled walls and roof.

TABLE 5

COMPARISON OF COALINGA DAMAGE FRACTIONS AND FRAGILITY CURVE PROBABILITIES FOR BEARING WALL BUILDINGS

Structure Description	Observed Damage[1] Damage State	Coalinga Damage Ratio Range (%)	Fraction Damaged	Fragility Curve[2] Probability MMI=IX	MMI=X
"Bad" Bearing Wall	Collapse	60-100	0.75	0.75	0.92
(40 old and poorly	Severe	30-100	0.93	0.93	0.98
constr., unreinforc-	Moderate	10-100	1.00	1.00	1.00
ed masonry buildings)	Slight	0-100	1.00	1.00	1.00
"Good" Bearing Wall	Collapse	60-100	0.06	0.02	0.06
(31 newer brick -	Severe	30-100	0.10	0.05	0.19
or reinforced	Moderate	10-100	0.39	0.55	0.84
masonry buildings)	Slight	0-100	1.00	0.82	0.95
"All" Bearing Wall	Collapse	60-100	0.45	0.28	0.45
(total population	Severe	30-100	0.56	0.41	0.59
of 71 buildings)	Moderate	10-100	0.73	0.85	0.95
	Slight	0-100	1.00	0.96	0.99

1 Data taken from Reference 3.

2 Probabilities are taken from Bearing Wall fragility curves.

TABLE 6

COMPARISON OF COALINGA DAMAGE FRACTIONS AND FRAGILITY CURVE PROBABILITIES FOR WOOD FRAME BUILDINGS

Structure Description	Observed Damage Coalinga[1]			Fragility Curve Probability[2]	
	Damage State	Damage Ratio Range (%)	Fraction Damaged	MMI=IX	MMI=X
"Bad" Wood Frame (33 older residence on cripple walls)	Collapse	60-100	0.00	0.00	0.00
	Severe	30-100	0.52[2]	0.02	0.13
	Moderate	10-100	0.88	0.60	0.90
	Slight	0-100	1.00	0.99	1.00
"Good" Wood Frame (28 newer, commercial buildings)	Collapse	60-100	0.00[4]	0.00	0.00
	Severe	30-100	0.04	0.00	0.00
	Moderate	10-100	0.14	0.03	0.22
	Slight	0-100	1.00	0.85	0.98
"All" Wood Frame (total population of 61 buildings)	Collapse	60-100	0.00[4]	0.00	0.00
	Severe	30-100	0.30[3]	0.01	0.04
	Moderate	10-100	0.54	0.23	0.52
	Slight	0-100	1.00	0.91	0.98

1 Data taken from Reference 3.

2 Probabilities are taken from Wood Frame Building fragility curves.

3 Although often a total loss (i.e., 60-100% damage), no wood fra tures collapsed. Therefore, these structures are considered t damaged.

4 The building which collapsed due to collapse of a neighboring building is excluded from the sample population.

REFERENCES

1. McCann, Jr., M. W., Sauter, F., and Shah, H. C., "A Technical Note on PGA-Intensity Relationships with Applications to Damage Estimation, BSSA, Vol. 70, No. 2, pp 631-637, 1980.

2. Basic Concepts of Building Codes, Vol I., International Association of Earthquake Engineering, Toyko, Japan, 1980.

3. Shah, H. C., et al.," A Preliminary Survey of Damage to the Commercial District, Coalinga Earthquake of May 2, 1983, prepared for EERI, May 5,

THE 1982-83 ENOLA EARTHQUAKE SWARM

by

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INTRODUCTION:

Swarm Description

The Arkansas (or Enola) earthquake swarm began quite suddenly in January, 1982, near the small town of Enola located 30 miles north of Little Rock and 15 miles northeast of Conway. The most intense activity was during the winter and spring of 1982 but it has remained active up until the time of this workshop. The Tennessee Earthquake Information Center (TEIC) has operated a network of portable seismic instruments in the region throughout the entire 20 months. Over 25,000 earthquakes have been recorded ranging in magnitude form the largest, M = 4.5, down to the thousands of "ultra-microquakes" of magnitudes about -3 to -4. At least 116 of the events have been felt, the two largest over approximately one-third to one-half of the State. However, only very minor damage was reported (maximum MMI=VI).

The Enola swarm is occurring in the Arkoma Basin geologic province (also called the Arkansas Valley), just north of the frontal transition zone of the Ouachita mountains. The geologic and tectonic context of this region is quite different from the reactivated rift structure of the New Madrid seismic zone located 165 km to the northeast. (Reference to Figure 1 will help clarify these geographic and geologic relationships.) It is more closely associated with the Ouachita Mountain belt, an ancient geologic feature consisting of a complex sequence of folded and faulted paleozoic sedimentary rocks. The belt represents the southeastern boundary of the North American craton, the oldest and most stable portion of the continental crust.

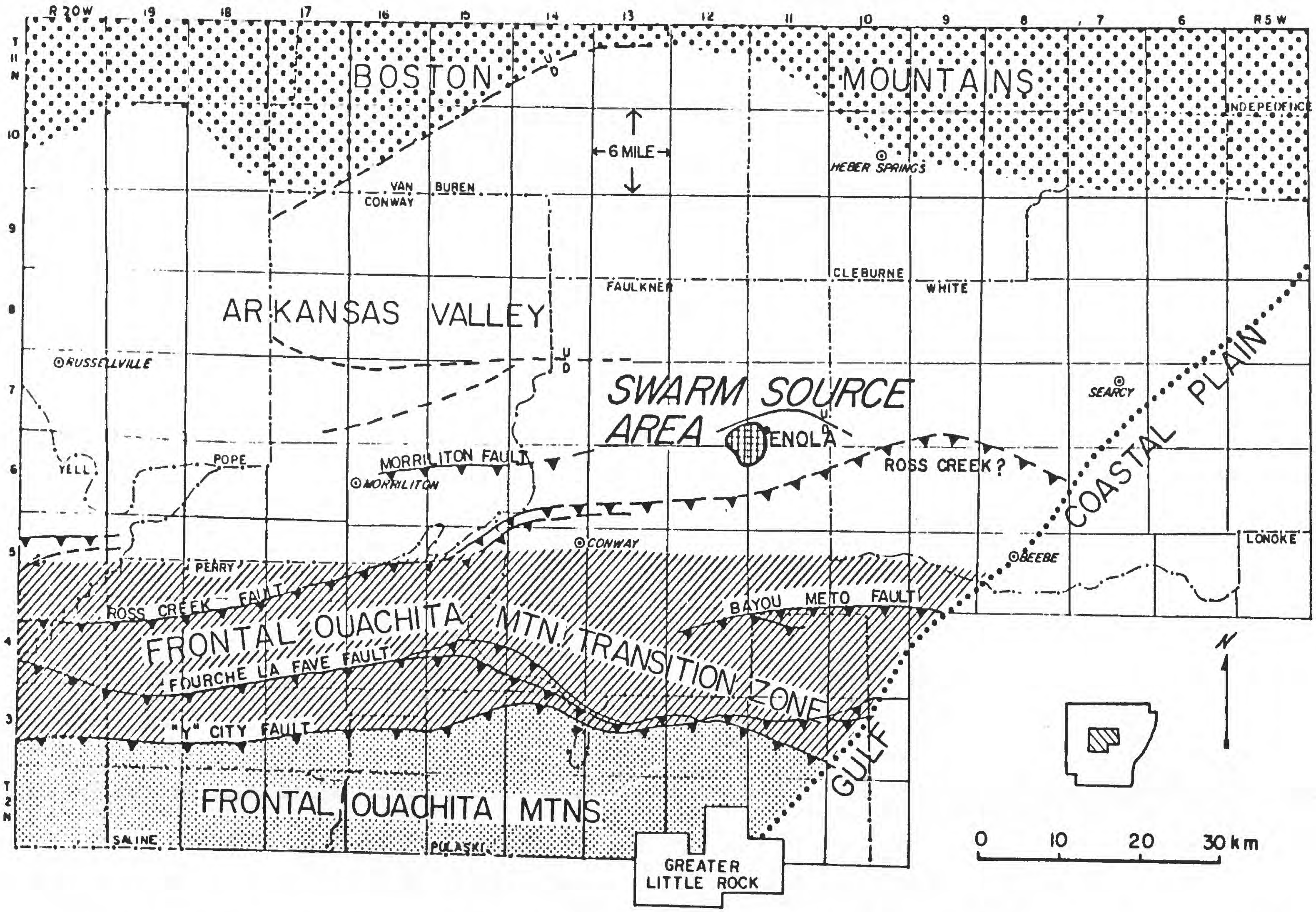

Figure 1. Tectonic/structural setting of the Arkansas swarm (modified from Stone, 1968) The normal fault just north of the swarm area is subsurface - taken from seismic reflection profiles. Faults of the Transition Zone are thrust faults with symbols on the hanging wall.

In the immediate area of the swarm the near-surface geology is dominated by a series of folds. South-dipping normal faults present in the region are thought to be growth faults. Intricate, steeply dipping thrust faults and folds overturned to the north characterize the frontal Ouachita transition zone that runs just south of the swarm location. Thus the earthquakes are occurring in an area (roughly 6 X 6 km) sandwiched between a zone of predominantly normal faults to the north and thrust faults to the south. Both sets of faults dip steeply southward, but the thrust faults are probably listric and approach horizontal above basement at a depth of 4-5 km. None of the mapped faults exhibit evidence of recent movement. Major late-paleozoic northward overthrusting did occur and the entire frontal transistion zone and southern Arkoma Basin are probably allocthonous.

Figure 2 depicts the time history of the first 18 months of the Enola swarm. The intense activity of early 1982 has gradually given way to an episodic seismic energy release in which bursts of several hundred events per day punctuate much longer quiet intervals lasting 1-3 months. As the swarm grows older, these quiet periods appear to be lengthening and contain an average of only several microquakes per day as opposed to the 10-30 events/day earlier.

Seismic wave analysis has firmly established that the type of faulting occurring is in response to a northeast/southwest maximum horizontal compressive stress, the same regional stress regime inferred for the New Madrid seismic zone. Still ambiguous, however, is whether slip is occurring on a predominantly north/south or east/west fault or set of faults. Earthquake depths concentrate between 4-6 km; thus both the underlying igneous basement and overlying sedimentary rock units appear to be undergoing strain energy release.

DISCUSSION

The Arkansas or Enola earthquake swarm is the largest, most intense occurrence of this type of seismic sequence to be instrumentally recorded in the Central or Eastern United States. Its seismic energy release exceeds that of the New Madrid seismic zone for the past 7 years. (This is, however, equivalent to only a magnitude 4.7-4.8 quake.) There are a host of seismological questions raised by this swarm, yet very few clear-cut answers are forthcoming. Here we

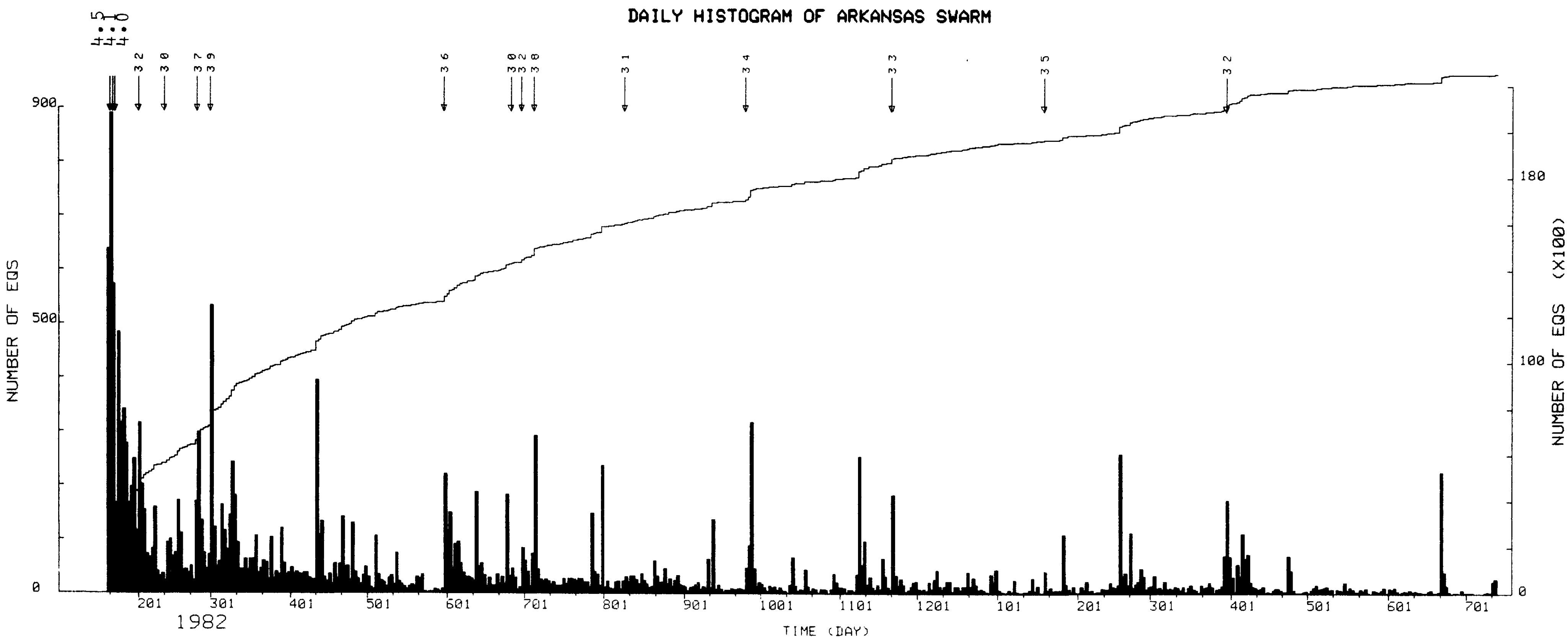

Figure 2. Daily histogram of the first eighteen months of Enola swarm activity. Dates of occurrence of larger events are shown at top. The right-hand scale is for the cumulative number of events graph.

will touch on only a few of the more interesting and relevent of these questions.

1) We don't know why the swarn is occurring at this time or at the Enola locale. Lifetime residents of the area have never experienced anything like it, and the region is blank on maps of historical seismicity. One of us (ACJ) previously pointed out the striking similarities between the Enola swarm and those that occur in volcanic areas such as Mono Lake, CA and Matsushiro, Japan (EOS. Trans. Am. Geophy. U., V.63, p.1209, 1982), but the most recent igneous activity from this area is Eocene (37-53 million years ago). lt's conceivable the swarm could be accompanying a small crustal intrusion of magma or some other fluid, but there is no other non-seismic evidence to support this. A detailed gravity survey to be undertaken by Southern Illinois University may shed some light on this question.

2) Why is the swarm a swarm? The usual mode of seismic strain release in the Central United States is a main shock accompanied by a small number of aftershocks, if any at all. The main event normally releases 96-99% of the total energy. For the Enola swarm the magnitude 4.5 quake represented only about 46% of the total energy, the rest being released over a prolonged period by thousands of smaller events both before and after the largest shock.

3) Is the Enola swarm dangerous? Is it perhaps a precursor to a future large-magnitude earthquake? Can the Enola region be expected to become a potentially hazardous seismic zone such as we have with the New Madrid zone? These questions cannot be answered with absolute certainty, but we believe the best answer to all of them is "no" for the following reasons.

   - Typical behavior for other swarms in other locales is to gradually diminish and die out. This is just what we are observing at Enola, though the prolonged period of significant activity has been surprising.

- We have observed no expansion or migration of the epicentral zone since the swarm began. The earthquakes constitute essentially a small, tight cluster of intense but low level activity. The dimensions of the cluster are too small to serve as a source zone for a destructive earthquake. Moreover, swarms are thought to originate in zones where rock is weak and highly fractured so that as stress increases, it is distributed among numerous faults and cracks and no single, large rupture can occur.

- The Enola swarm activity is too shallow. It is believed (but not proven) that larger magnitude events originate deeper in the crust where rock is stronger and can support stress build-up over significantly larger dimensions.

CONCLUSIONS

The Enola earthquake swarm represents quite a different phenomenon than the New Madrid earthquake activity further to the northeast. If a sports analogy is permitted, New Madrid is definitely major league while Enola is strictly minor league. The New Madrid zone is accorded this status in disaster planning because it comprises three essential elements:

1) A known capacity to generate great earthquakes:

2) On-going seismic activity sustained for a long time period at a moderate, yet significant level;

3) A defined geologic structure of dimensions sufficient to generate major earthquakes. Enola really exhibits none of these elements and thus at present should not be classified a significant seismogenic zone. Nonetheless it has caused significant rethinking of current ideas about midplate seismic activity, raised a number of fascinating seismological questions and presented earth scientists with a nonpareil natural laboratory to learn more about the earthquake process.

RECOVERY FOLLOWING AN EARTHQUAKE: A PROSPECTIVE ASSESSMENT FOR ARKANSAS FOLLOWING A CENTRAL UNITED STATES EARTHQUAKE

by

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INTRODUCTION

The rational preparation for and recovery from a future earthquake in the Central United States will depend upon developing a proper perspective on the nature and extent of its impacts. This paper explores a sequence of events that could happen following a great earthquake in the region. The purpose of this paper is to present a hypothetical future situation, not to represent that which is specifically expected to occur. While the author has attempted to be realistic in forming the estimate of future events, there is no representation that the events portrayed in this paper are expected.

The premise of this paper is that a massive earthquake has occurred with an epicenter near Blytheville, Arkansas. Shortly after the event the Governor of the State of Arkansas appointed an Earthquake Commission to advise him on how to manage the State's emergency policies and programs. The ten Commissioners represent the diverse interests within the State. The Workshop is presumed to take place in preparation for a Commission hearing. The participants were split up into three groups and asked to role-play as if they were members of a particular constituency: the Farm Bureau, the Business Roundtable, and the State Democratic Committee. The role-playing exercise proceeded through the following steps:

1. A background briefing on the event by Commission staff followed by questions from the participants;

2. Individual group meetings by the constituency groups to discuss the problems posed to them by the earthquake and the recovery process;

3. testimony before the Commission presenting the group's needs, views, and interests; and,

4. presentation by the Commission of its recommendations.

The Commissioners asked questions as did the audience. The highly interactive aspects of these presentations cannot be captured in a written paper.

ARKANSAS EARTHQUAKE COMMISSION

The Governor's original charge to the Commission was to:

1) Monitor State and Federal emergency programs;

2) Advise on areas where there are problems or inequities;

3) Recommend priority State actions to improve emergency response; and,

4) Act as the people's ombudsman.

Now that the immediate response problems are somewhat under control, the Governor has discovered that there has been little thinking on how to proceed with the recovery of the State. And, he has discovered that the political temperature is heating up as various interests sense their possibilities for gain and loss. He has directed the Commission to report to him on what the State should do to assure its rapid, economic, and equitable recovery. The Commission's preliminary report is to be ready within 2 weeks, and their final recommendations report within 10 weeks.

As the first part of its process, this Commission yesterday heard from a number of experts who have conducted research on the topic. Today they will hear from the organizations listed in Table 1.

The rules of the hearing were very simple. Each group's representative was given 10 minutes to express the group's position. Each speaker was accompanied by two others. The Commissioners asked a few questions on the positions discussed by the speakers as well as those positions taken by others. The presentations were succinct and to the point. Generally, the presentations covered the following items:

1) The special problems that their constituency groups face;

2) Specific policies or programs they advocate; and/or,

3) The criteria the Commission should use to evaluate its overall recommendations.

While written position papers were to be submitted, the oral presentations had the most influence on the Commission's formulation of the recommendations to the Governor.

Table 1 - Organizations testifying before the Arkansas Earthquake Commission on March 30

Citizens Coalition of Little Rock
State Emergency Response Director
Federal Coordinating Officer
Chairman, Memphis City Council
Little Rock Free Press
WXYX-TV News Director
The Southern Christian Leadership Conference
The Arkansas Farm Bureau
State AFL-CIO, Building Trades Council
Chairwoman, City Council of Ellenville
Ozark Tourist Development League
Association of County Executives
Business Roundtable of Arkansas
The Minority Caucus for Quality
Chairman, Arkansas Democratic Party
Chairman, Arkansas Republican Party
The Chairman, Peace and Freedom Party
The Chairwoman's Libertarian Party
Arkansas Poultry Development Council

BACKGROUND BRIEFING ON THE EVENT

On Tuesday, March 10, at 2:07 p.m., 20 days ago, a massive earthquake occurred in Arkansas. It is reported by the National Earthqiake Information Service in Golden, Colorado, to have a magnitude (M_s) of approximately 8.5. The earthquake was centered near Blytheville, Arkansas, just below the boot heel of Missouri. A preliminary analysis of the few strong ground motion recordings taken in the area, coupled with macroseismic observations, indicates that strong shaking lasted over 90 seconds, with a maximum effective acceleration of over 0.7 g.

A major aftershock, approximately 6.7 in magnitude (M_s), occurred on March 14. The event was centered just northeast of Little Rock, Arkansas. This latter event did substantial damage to already weakened structures. There have been numerous additional aftershocks that are continuing to this very moment. The event has caused substantial damage in nine States, with some damage reported in a total of 14 States. The press characterizes it as the most severe natural disaster to have occurred in the United States. There is considerable consternation in political circles because the great earthquake everyone expected in California happened here. Despite the efforts of some emergency response agencies the public was generally unaware of the risk. For all intents and purposes, the public was unprepared.

Earthquake damage in the region can be characterized by four major observations. First, damage to unreinforced brick structures, which have inherently little earthquake resistance, has been extensive; damage occurred as far as 400 miles from the epicenter. Second, there have been large soil failures on a scale not seen before in the United States. Third, the damage to lifelines is unprecedented. Lifelines are the electrical, water, sewer, communications and transportation systems that tie a community together and provide the services on which we all depend. Fourth, there has been extensive damage to flood control works, e.g. levees, locks, and flood control dams.

The Earthquake Engineering Research lnstitute (EERl) reconnaissance team has made an estimate for the Federal Emergency Management Agency (FEMA) of the extent of damage. Figure 1 shows a highly preliminary distribution of damage

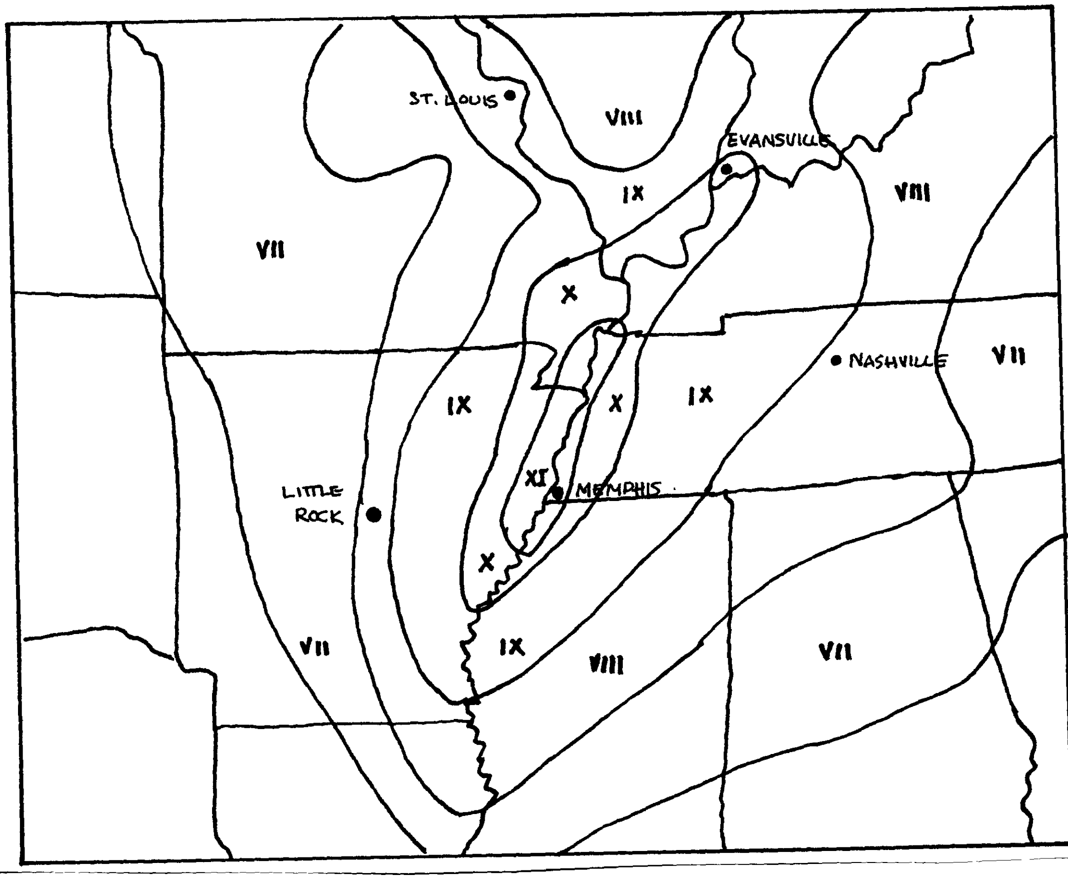

Figure 1.--Preliminary Isoseismals for the earthquake of March 10.

throughout the region for the March 10 event; Figure 2 shows the intensity distribution for the March 14 earthquake. Damage intensities are expressed in the Modified Mercalli Intensity (MMI) scale. Roughly speaking, the MMI can be characterized as given in Table 2. The distribution of damage from the latter event was more severe than might be otherwise expected because many structures damaged in the first event were "finished off" by the aftershock. Figure 3 presents a composite estimate of the damage distribution for the two events. It should be emphasized that more large, damaging aftershocks are expected in the region based upon historical precedents and comparable tectonic settings in other parts of the world.

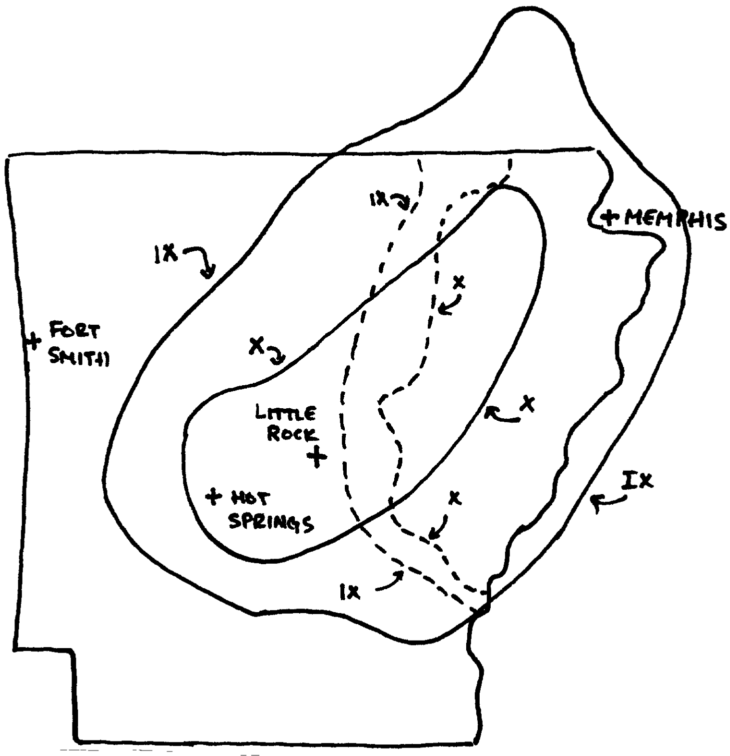

Figure 2.--Preliminary isoseismals for the earthquake of March 14 (solid lines) compared to those of the March 10 earthquake (dotted lines).

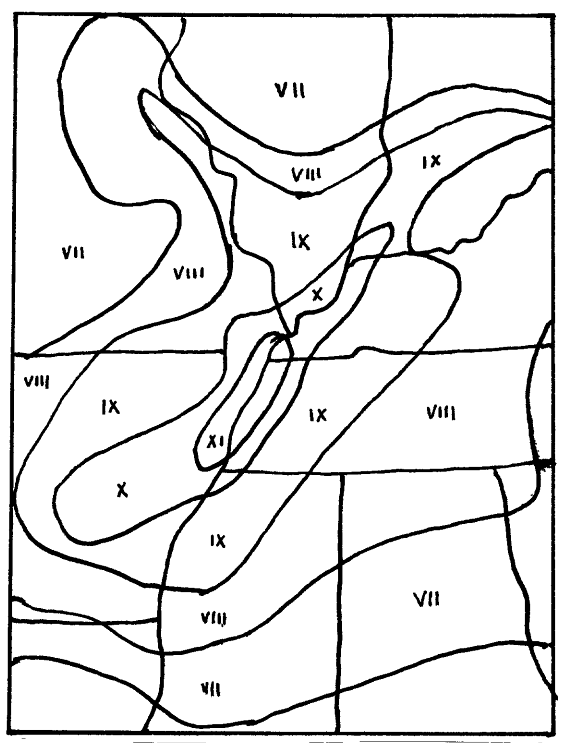

Figure 3.--Preliminary isoseismals for the combined March 10 and 14 earthquakes.

Table 2.--The Modified mercalli Intensity Scale (Abstracted)

MMI	Description
XII	Damage complete.
XI	Few if any masonry structures remain standing. Broad fissures in the ground.
X	Some well-built wooden structures damaged; most masonry and frame structures destroyed along with their foundations; ground badly cracked. Considerable landslides along river banks and steep slopes.
IX	Considerable damage in specially designed structures; well-designed frame structures thrown out of plumb. Buildings thrown off of theii foundations. Underground pipes broken.
VIII	Damage slight to specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fallen chimneys, factory stacks, columns, monuments anc walls. Heavy furniture overturned.
VII	Everyone runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable to poorly built or badly designed structures.
VI	Felt by all; many frightened and run outdoors. Damage slight.
V	Felt by nearly everyone; many awakened. Unstable objects fall over some plaster cracking.

Preliminary assessments of the extent of life loss, injury damage, and the extent of housing loss have been assembled from the hit areas. The loss of over 4,500 lives, over 18,000 injuries requiring hospitalization, direct damage in excess of $20 billion, and the loss of over 100,000 housing units are the largest each that peacetime emergency response organizations have had to cope with. Although these figures are huge, they are considerably less than the first reports of $100 billion in losses and 25,000 dead.

The specific impacts on Arkansas indicate over 800 dead, 3,000 injured and requiring hospitalization, approximately 20,000 dwelling units unusable, and about $4 billion in property damage, approximating that to the Nation from Hurricane Agnes.

The President has thus far declared disasters in Arkansas, Missouri, Illinois, Indiana, Kentucky, Tennessee, Mississippi, Louisiana, and Alabama. Several additional requests are still pending. All in all, this is the largest number of States for which declarations have been made for a single disaster. The resources of FEMA, State and local emergency response organizations, and supporting public relief organizations are being severely strained. Without the extensive use of National Guard personnel, it is doubtful that any organized response would have been possible.

Damage has been particularly heavy to commercial and governmental buildings, transportation and utility systems, and flood control works. Approximately two-thirds of the life loss and injury occurred within the MMI X area. Most of the housing loss is concentrated in the MMI IX and X regions. A preliminary assessment of impacts indicates:

1) Interstate highways are in limited service within MMI VIII areas; blockages and bridge collapses have reduce capacity to 33 percent of normal.

2) There has been damage to at least 50 earth dams in the epicentral area and over 500 miles of levees have been destroyed.

3) Over 1000 chemical spills have been reported. Most occurred at agricultural chemical storage facilities. The most serious have occurred at major chemical plants along the principal rivers of the region. The extent of water contamination and resulting health hazards are unclear.

4) No highway or railroad bridges that cross the Mississippi below St. Louis and above Vicksburg are usable.

5) River traffic on the Mississippi, Missouri, Ohio, and Arkansas rivers is limited. A large number of locks have been damaged and the lack of electrical power is preventing others from being used. Since these are linear systems, loss of one lock can shut down the entire river.

6) Airports within the region are closed to commercial traffic because of power outages, damage to control towers, and extensive damage to runways. The FAA has restricted flights within the MMI X area. Fuel and services availability are limited.

7) Rail access to the area is limited; many rail bridges have failed, and numerous embankment failures have closed lines.

8) Water systems in the region are heavily damaged. Public authorities have recommended against use of municipally supplied water within the MMI IX region due to extensive damage to water storage, treatment, and distribution systems. All users of surface water below St. Louis and Louisville on the Mississippi and Ohio rivers have been warned of potential contamination from massive chemical spills. Fishing has been adversely affected in the Mississippi delta.

9) Thirteen interstate natural gas and petroleum pipelines have been closed until they can be repaired and inspected. Natural gas pipelines within MMI XI areas are all closed pending inspection; numerous breaks have been discovered. Local natural gas distribution within MMI VIII areas has been curtailed.

10) Telephone service within the MMI IX region is approximately 20 percent of normal service; many areas are served only by short-wave radios. Amateur and CB radio operators have formed a fairly effective communications network.

11) Electricity production capacity in the region is now at 30 percent of the preearthquake level within the MMI VIII area. It is estimated that 50 percent capacity will be restored within the year; full restoration is at least 5 years away.

12) Electrical service is available to 70 percent of the residential areas within MMI VIII and to 50 percent of business areas. Traffic control and street lights are generally nonfunctioning.

13) Numerous schools suffered substantial damage with much associated life loss.

14) Approximately 50 percent of the preearthquake hospital beds within MMI IX, and 66 percent in MMI VIII are available.

15) The occurrence of large fires was moderated by the unusually heavy rainfall in the previous few days.

16) The impacts on the financial community has been unprecedented. Among the most important are:

a) The St. Louis Federal Reserve Bank computers have been down since the event, as have their branches at Little Rock, Louisville, and Memphis. While this load has been partially picked up by other reserve banks, the loss of data communications among member banks in the MMI V11 region has severly constrained the Federal Government's ability to perform its commercial and regulatory functions.

b) Standard and Poors Corporation has suspended the ratings of Missouri, Arkansas, and Tennessee municipal, special district, utility and selected business bonds, as well as those of numerous other communities in the nine State area. These bonds are widely held. Suspension has impaired their value, disrupted the market in tax-exempt bonds and thrown into question the viability of several retirement funds.

c) The financial condition of insurance companies within the region is uncertain. While there was little earthquake insurance written in the region, payments for medical costs, workman's compensation, business interruption, automobile damage, and professional liability are expected to be very large. The theory is already being advanced that earthquake damage should be covered by normal household insurance since the damage resulted from inadequate design and construction practices, not the earthquake itself. While this legal theory may sound farfetched, it has been successfully argued in California for landslides, and was the basis for large payments to householders after the 1983 Coalinga earthquake, even though their policies expressly excluded earthquake damage.

17) There are widespread shortages of construction materials, equipment and skilled personnel. Costs for some materials have been bid out of sight--particularly plywood. A large influx of potential construction workers from other areas is expected, although there is little use for them now except for debris removal and clean up.

18) The snowpack in the upper Mississippi, Missouri, and Ohio Rivers is unusually large. The spring thaw is now underway and the Corps of Engineers expects widespread flooding. They have yet to be able to take into account the impacts of the widespread damage to levees, dams, locks, or flood potential.

19) Cleanup and recovery is well underway at the individual and family level where they do not need externally supplied resources.

The citizens' response in the impacted area has been outstanding. Generally the cleanup and recovery processes at the individual family level are well underway. The outpouring of assistance has been overwhelming. There has been a large inflow of people from unaffected areas offering help. Disrupted roadways have impeded their entry to many areas. Social scientists refer to this as "convergence." Initially, public response organizations were overwhelmed with these offers of aid. The convergence of people at sites of extreme need far exceeded the capacity for utilization; they initially impeded efficient response. This is now under control, in part, due to the imposition of restricted access by the highway patrol in the most severely affected areas.

NATIONAL POLITICAL SITUATION

The political situation 20 days after the earthquake can be encapsulated in the following observations:

1) Approximately 40 Representatives and 16 Senators are demanding regular, personal briefings on the situation. Three Congressional committees have already scheduled hearings, and more are in the offing. There is a regular military shuttle being run to show Congressmen and high Administration officials the damaged area.

2) There are widespread reports that spilled toxic materials are just sitting there with no efforts underway to clean them up.

3) Over 40,000 people are still housed in temporary shelters, and there is no apparent plan on how or when these people will be placed in more permanent housing. The blockage of many roadways is preventing importation of trailers; they are being set up far from those who have need for them.

4) There is confusion on whether there should be an evacuation of the area near the local nuclear power station. There are reports that damage was done to the containment structure. Actions thus far by emergency response officials range from attempted evacuation to

assurances that everything is fine. The antinuclear groups are having a field day.

5) Priorities among Federal agencies are unclear; staff and resources are not consistently assigned. A perfunctory review indicated that even with the consolidation of emergency functions under FEMA several years ago, there are still many separate program responses underway.

6) A caucus of eight Senators and 35 Congressmen are publicly calling for the President to exert direct leadership for response and recovery.

Even though the earthquake occurred only 20 days ago, legislation providing additional funds to the depleted disaster response fund has been enacted and signed into law. In addition, the following bills have been introduced:

1) To remove the requirement of 25 percent cost sharing by the State as a condition for Federal assistance.

2) Reduce the SBA interest rate for reconstruction loans to 1 percent.

3) Increase the amount of individual family grants to $10,000.

4) Repeal the Davis-Bacon Act so that artificially high wages need not be paid for cleanup and reconstruction.

5) Eliminate minority contracting requirements for Federal procurement of goods and services.

6) Increase the minority contracting set aside to 45 percent, matching the percentage of minorities in the impacted area.

7) Waive payment of Medicare premiums for everyone in the impacted areas.

8) Provide Federal guarantees, after the fact, for State and local governmental bonds for those areas severely affected.

9) Provide Federal reinsurance for private firms, ex post facto.

10) Provide supplemental unemployment coverage, aid to dependent children, and welfare benefits.

This list is long and growing longer. There appears to be little constituency for restraint, and certainly none yet voiced at the national level.

COMMUNICATIONS PROBLEMS

There is a public information nightmare. The flow of information and misinformation to the public is staggering and continuous. The electronic media preempted their regularly scheduled programming and presented continuous, live broadcasts for the first days. Most of these reports have been pictures of the damage and interviews with either eye witnesses or "experts" from undamaged areas. These "experts" have included some with knowledge or experience directly related to this earthquake; some who have special interests they are trying to advance using this earthquake as a target of opportunity; and some with no knowledge of the area. "Factual" data from the damaged area is incomplete and often contradictory. The range of contradictory reports covers the need for medical transportation, the imminent collapse of dams, the contamination of water supplies, the extent of chemical spills, fire occurrence, public health threats, building safety, and the imminence of large aftershocks, to name but a few.

The disaster intelligence functions of the FEMA and other emergency response agencies have been overwhelmed with the problem of trying to verify rumors and respond to the immediate demands of the press. Among the key problems leading to this condition are:

1) Several key emergency response officials were killed or injured;

2) Many counties have no organized response capability;

3) Radio frequencies used by local fire, police, and emergency response organizations are different among themselves and among adjacent jurisdictions;

4) Unconfirmed reports are receiving widespread media coverage; and,

5) Reports are focused on individual observations.

As the social scientists are quick to point out, the conditions for rumoring are ideal:

1) there are conflicting official reports;

2) formal information channels are disrupted;

3) there are perceived harmful effects; and,

4) informal communications are heightened.

BUSINESS ROUNDTABLE

The Business Roundtable is made up of the chief executives of the 50 largest firms located within the State. They have assessed the situation within the State now that the emergency period is coming to an end and have reached several conclusions discussed below.

As the recovery process is now beginning, it is clear that there is no overall concept for recovery being fostered either by the Federal Government nor the State. What guidance there is seems to hold that the restoration of business and commerce is of the lowest priority, especially when compared to assistance to householders. While there was no objection to this during the lifesaving phase, now that recovery is underway the need is great to provide assistance that allows the economy to be restored. The business community does not want Government to assume a direct role of its activities, but it does want the Government to allocate some of its effort to the restoration of utilities, transportation, and the other intermediary functions that allow the business and commercial sectors to function.

Damage to the banking system has been great and is a matter of great importance and urgency. Most banks are highly dependent upon computer systems for every aspect of their operation. Data processing facilities were particularly hard hit. Such facilities are vulnerable to earthquake destruction and disruption. The Federal Reserve Systems interbank service is partially back in operation; however, there are major problems in restoring individual bank systems. The financial condition of many banks is in question and the ability of these banks to provide the financial resources and services necessary for the restoration of the commercial sector are severely lacking.

Electrical power, communications, transportation, and other utilities are the life blood of business. Currently, the first priority for allocation of these services is to households. Without a change, the business sector could be crippled. It is of the upmost importance that industry be given priority access to these important lifelines.

The distribution system for raw materials, intermediary products, and finished goods has been severely disrupted. Rail, river, and highway transportation is in poor condition and many routes are impassable. Without rapid restoration of a means to move products, the commercial and manufacturing sectors will be crippled.

Business Roundtable Recommendations

The viability of the State of Arkansas is intricately tied to the functioning capability of its industrial and business community. Between them, the manufacturers, processors, and retail distributors of the State have been a source of 80 percent of all the wages earned in Arkansas. Unless business can be back in operation within 6 months, competition from other areas will take over our markets and the entire economy of the state will collapse. With this in mind, the Business Roundtable asserts its need for representation on the Governor's Commission and makes the following recommendations to this body.

1) Banking -- Highest priority must be given to the recovery of the banking system. We recommend that the Governor request Federal assistance and relaxation of stringent interstate banking restrictions so that the cash and financing necessary for all aspects of recovery are available both to business and to the public. Allocation of emergency generators and available electricity to restore data processing facilities for banking is critical and of the highest priority.

2) Electrical Power -- The shortage of electrical power is a hardship for the entire State. For industry, however, it is a critical element--factories cannot function without it. We, therefore, recommend that electricity be brought in from outlying, less-effected areas, that private agencies be permitted to buy electricity from TVA at cost, as available, and that business and industry be given priority in allocation.

3) Communications -- Of the several State emergency communications networks now operating, we recommend that one be allocated to business and industry as they work to rebuild, repair facilities, reestablish supply relationships among manufacturers and distributors, and restore production.

4) Transportation -- The Governor take a leadership role in directing the restoration of transportation routes important to commerce. Only the Governor has the authority to organize the available equipment and personnel, both military and private, throughout the State so that repairs proceed in a logical and efficient manner. We recommend also that a portion of the helicopters and 4-wheel-drive vehicles, extant and under State control, be allocated to the business community for transportation of needed equipment, raw materials, finished products, and distribution of goods.

5) Labor-Management Cooperation -- Now is the time for labor and management to recognize that they are each vital components in the industrial equation. We urge that labor and management reopen, in

good faith, their existing contracts and work rules to assure that the joint objective that each share in continuation of businesses is achieved. In many cases this may require wage and work rule concessions. We urge that these be examined carefully and expeditiously outside the usual confrontation environment. We urge that business assure its employees that they will benefit from concessions in the future, if they are necessary, when the firm returns to a healthy, competitive state.

6) Funding for Reconstruction -- The capital needs of business far exceed that available from within the businesses community. Losses far exceed the amount of insurance coverage. Without access to additional capital, many businesses will be unable to reopen, severely crippling the economy of the State. The following measures are recommended:

    a) A national, State-guaranteed industrial bond issue to provide capital for business restoration;

    b) A moratorium under the State's Uniform Commercial Code on business debts for a period of 1 year;

    c) A moratorium on State taxes for businesses which have suffered greater than 25 percent loss or damage for a period of 5 years, or until recovery of the amount of uncompensated damage; and

    d) That the Governor recommend a 35 percent cut in Federal corporate taxes for impacted businesses until full recovery is achieved.

Through these immediate actions, the disastrous effects of the recent earthquake can be moderated. Rebuilding of the State's economy can proceed, taking advantage of improved machinery, processes, and techniques as well as restructuring to make better use of the natural and people resources of the great State of Arkansas.

A final note. It has been proposed that electrical rates be raised to four times their preearthquake level for power use in excess of 150 kwh per month. This will be devastating to industry. While the usage by households may be very elastic, the majority of industries have to use electrical power for production. Production of one unit of output requires a set amount of energy in most cases. We feel that the net effect of such an action will be to negate all the other positive steps recommended above to aid in the recovery of the economy of the State.

ARKANSAS FARM BUREAU

The Arkansas Farm Bureau represents the over 50,000 farms in the State. Agriculture is the largest business in the State. An analysis performed by a damage committee has concluded that the farming community has been severely affected. The public does not seem to be aware of this since the media have not focused on this problem because damage is not concentrated. The Commission's observations are given below, all focusing on the fact that planting is about to begin.

The high snowpack in the upper Mississippi, Ohio, and Missouri River watersheds portends the potential for large scale flooding. The earthquake damaged many levees and other flood control works principally through embankment failure. While there has been some action on the major levees protecting urban areas, there has been little action on those that protect farms. The ability of farmers to make repairs on their own is limited by their access to machinery and parts. Farm machinery was, in many cases, damaged by the earthquake and the availability of parts to repair or transportation to replace is limited. Unless the flood works are repaired immediately, a year's crop will be lost for about half the State. Compounding this problem is the short supply of fuel. Without fuel, there will be no planting season. Without transportation the seed and fertilizer will not be available.

Lastly, access to loans is disrupted by the problems banks are having. The farm industry is dependent upon loans to finance each year's activity. It is unclear what the full extent of continuing banking problems will be, but it seems clear that without an immediate break in the situation, many farmers will face foreclosure.

Farm Bureau Recommendations

Farming is the backbone of the economy in Arkansas. It is faced with a series of impediments that could seriously impact the ability to recovery. These problems and the Farm Bureau's recommendations for resolution are detailed below.

1) Flood Control -- The damage to levees in key agricultural areas represents a clear threat to farms, especially with the high probability of flooding in the near future. The extent of damage far exceeds the ability of landowners to repair both do to shortages of personnel and equipment. We recommend that the repair of levees and other flood control works be given highest priority for emergency reconstruction. Currently Federal personnel, principally military, are being used for a variety of tasks in cleanup and initial reconstruction that are of much lower priority. We recommend that the Governor direct that all available Federal personnel and equipment be directed at repair of flood control works. A personal appeal to Governor's of unaffected States for the use of their equipment and National Guard personnel in this emergency reconstruction effort should be made at the earliest possible time.

2) Loans -- Farmers depend on loans as the principal source of capital to purchase seed, fertilizer, and agricultural chemicals for the coming year's crop. The damage done to the banking system, and particularly the impaired financial condition of rural service banks, presents a special hardship to farmers. We recommend several direct actions:

   a) Low-cost loans to farmers for a 3-year period to help them recover. The Governor should make a special effort with the Department of Agriculture to assure that Arkansas gets special treatment under existing programs and that inappropriate regulations are suspended.

b) Low-cost loans for capital improvements be made available to farmers as they are to small businessmen under Federal and State programs.

3) Transportation -- While urban highways and main transportation routes are being reopened slowly, those of particular importance to transportation of agricultural materials and products seem to be of low relative priority. We recommend that the Arkansas National Guard be assigned responsibility as its principal activity to reopen transportation with first priority given to routes important to agriculture and industry.

4) Markets -- Farmers in other regions are already taking steps to limit the importation of agricultural products from Arkansas (arguing contamination and infestation risks) and to exploit the opportunity to sell they products here. We recommend that the Governor forcefully inform the Governor's of these States that we will not accept such blatantly discriminatory practices. If they persist, then the State should take whatever steps are necessary to protect the integrity of our basic agricultural industry by protecting future markets.

5) Fuel -- Current fuel allocation programs discriminate against agriculture. We recommend that the Governor give first priority to allocating fuel supplies under his control and authority first to lifesaving functions and second to agriculture. Without adequate fuel all the other actions recommended will have limited effects.

These actions are recommended as a package to assure that the State has the opportunity to prosper in the future and maintains the values that have made our State great.

STATE DEMOCRATIC COMMITTEE

The Democratic State Committee has met several times since the earthquake. During the emergency period, the public had a common goal of protecting life and property. Now that the emergency period is ending, the public is starting to observe their individual losses and sorting out who is gaining and who is losing. Politically, this is a time of ferment. The next statewide election will be held in 8 months. Tt has been observed that the last time there was a situatuation of this magnitude within the State's reconstruction following the War Between the States, the State stayed Democratic for a century. Scapegoating has started, and the Governor is under heavy criticism for the inadequacy of State and Federal response. While this may not be justified, it portends severe political problems as the various impacted groups start to press for advantage. Some have already suggested that the Governor be abandonod by the Party since there is a high likelihood that the public will blame him for everything that goes wrong, is not done, or is inequitable. Running against this situation is a lot easier than defending it.

The appointment of the Commission has deflected some of the political heat but it will not act as a shield for long. The Republican Party is rumored to be preparing an aggressive plan to seize political control of the State. Various minority groups are claiming that the poor and disadvantaged are not receiving equitable treatment and are unlikely to receive their fair share as benefits are channeled to the middle class and business. Regional tensions are starting to be observed as those sections of the State not particularly affected are seeing virtually every resource available to the State channeled to the impacted area.

Democratic Party Recommendations

This is no time for the traditional rivalries among different political interest groups to impede the strong, united effort of the people of this great State to recover from the devastating blow dealt by the recent earthquake. We reaffirm our commitment to the principal that government exists to serve the people. We call upon all interests to join in a truly humanitarian effort of public service that sets aside the petty differences of the past. We pledge that we will not as a party engage in any actions that takes partisan advantage of situations that are attributable to the earthquake and call on others to make the same public pledge.

The Democratic Party hereby makes available to the State and to the several public service associations now serving the State so admirably, the full assistance of its organization. As most will attest, we are well organized to the grass roots level and have the ability to muster great effort for and by the people.

We have three specific recommendations to the Governor for immediate action.

1) All recovery efforts be unified across party lines, and that no one should exploit the situation to advance any political cause or individual interest at the expense of the public. The Governor should appoint a bipartisan Council of citizens to monitor the actions of governmental officials to monitor their actions an recommend actions to assure that they are ethical, non-partisan and in the public interest. The Council should represent all the diverse interests of the State. The Council should have all the authorities and resources needed to assure its success.

2) The restoration of critical facilities should receive the highest priority for competing resources. Hospitals, emergency communications, hazardous materials containment, and emergency operations centers are at the center of our ability to respond to another earthquake, which the scientists tell us is likely.

3) The Governor requests a clear, concise, and realistic assessment of the total assistance likely to be available under Federal programs, both as a proportional share and absolute amount among the several impacted States. We specifically counsel that the Governor and our Congressional delegation push for aggregation of recovery support into block grants and loans for administration by the State. It is quickly becoming apparent that neither the public nor its elected leadership would allocate resources among competing interests in the way that Federal program officers are indicating they will. We must control our future, not relegate it to others who are not from our State or who will have to live with the results.

4) Considerable personal effort should be exercised by the Governor in consolidating and solidifying the efforts of all cabinet offices and departments of the State to assure consistent and appropriate action during recovery.

5) Now is the time for the public as individuals and families to recognize the extraordinary capacity it has demonstrated to help itself during this stressful time. The future will be a time of great testing of their resolve to prosper. We urge that the Governor give great emphasis to calling upon the people, individually, as family groups and through their churches and community organizations to foster self reliance and initiative. To recognize individual initiatives and efforts we recommend that the Governor establish a recognition program of awards for exemplary accomplishments. Gardens can be planted, community projects for repair and restoration of those less fortunate or unable to help themselves are but a few of the initiative that individuals can take. The creativity, energy, and capacity of the people is unbounded. Sustaining the public's extraordinary effort through the balance of the recovery can and will create a better Arkansas--one for which we can all take pride and credit.

COMMISSION'S INITIAL RECOMMENDATIONS

The Commission has met the Governor's requirement to report with high priority actions within 14 days. Their overwhelming view is the the people of Arkansas have the resolve, the adaptive capacity, and the will to recover and prosper following this massive event.

The first recommendation of the Commission, given 10 days ago, has already been acted upon. The Governor has met with the Governors of other impacted States--Missouri, Kentucky, Tennessee, and Illinois. They have jointly and unanimously agreed:

1) To jointly foster recovery of the impacted areas;

2) To avoid competition among their States for recovery assistance and industrial investment;

3) To cooperate to foster an economic resurgence of the region;

4) To enforce building codes, inspection procedures, and land use requirements that contain appropriate levels of earthquake protection to assure that various interests do not use lesser requirements as a means of attracting capital, jobs, and people to locate in one area versus another; and,

5) Not to sacrifice long-term preparedness for the expected aftershocks to achieve more rapid recovery.

They have agreed to meet regularly and have each assigned a senior advisor to communicate daily with their counterparts.

The Commission has recommended specific actions in four distinct areas--Resources, Finance, Lifelines, and Administration. They are enumerated below.

RESOURCES

1) Establish recovery information clearinghouses in several regions of the State to assure that information is available to everyone on the same basis. These clearinghouses should be vertically integrated with the central State office providing both information to the regional centers and aggregating needs for communications to the Governor.

2) Request that available Federal military personnel focus their assistance to the State on the restoration of flood control works, particularly levees. The expected flooding poses such a severe threat to the agricultural community and thus to the State as a whole, that this is one of the highest priorities. It is felt that focusing such Federal assistance in one area will improve performance substantially.

3) Undertake the sale of $500 million in State-guaranteed industrial Development Bonds to provide financial assistance to State business. The recommended interest rate is 9 percent with the first year's interest deferred. Equity participation is considered a condition for such loans, since the State should not incur the risk of loss without the potential for gain.

FINANCE

1) Declare a moratorium on financial obligations under the State's Commercial Code until June 10, at which time an extension may be considered. The legal status of many claims is in doubt, and the value of many assets questionable. The delay will afford the community the opportunity to better assess the condition of loans and forestall legal disputes that could be injurious to the financial future of the State.

2) Remove the State's restrictions on interstate banking. The condition of many banks is in question, and there have been several offers from eastern and western banks that if the interstate banking restrictions are lifted, they are prepared to move into the State in a big way. They are prepared to make the appropriate assurances that they will be good and productive additions to the State's economy.

LIFELINES

1) The National Guard should be assigned as its principal task the opening and restoration of transportation routes. Restoration is needed quickly to allow commerce and business to reestablish itself. The primary focus should be on commercial, business, and farm access roadways. Residential restoration is definitely a secondary priority and should only be undertaken where absolutely necessary for life safety.

2) Emergency approval by the State Utilities Commission of a raise in electrical rates to four times their preearthquake level for use in excess of 150 kwh per month. Current capacity and distribution networks are limited, and some mechanism must be found to allocate power among the competing users. The pricing mechanism is judged to be the most equitable one available. The 150 kwh level was selected as the amount needed to operate refrigerators and other essential household appliances. While it will pose some hardships on householders, these are deemed by the Commission to be within an acceptable level.

ADMINISTRATION

1) Call a Constitutional Convention to amend the State's Constitution to allow State debt. Currently the State may not run a deficit. This severely limits the State's ability to meet emergency lifesaving needs or to foster recovery. While there are other mechanisms to accomplish this purpose, they are all deemed too slow.

2) Add 10 people to the staff of State's Liaison Office in Washington, D.C. to assure that the State has access to what is happening in Washington, D.C. and to assure that the State's interests are adequately presented and defended before the Congress and the Administration.

3) Provide an emergency grant to the Arkansas Red Cross and cooperating relief agencies. They have rendered assistance of unquestioned value to the State's citizens. They have exhausted their meager resources and need aid if they are to continue. It is the Commission s conclusion that they are the lowest cost mechanism for the equitable provision of those in need.

4) Institute wage and price controls for 90 days. There are widespread reports that gouging for services and products is being practiced. Controls are felt by the majority to be the only effective means to put an end to such practices. A minority of the Commission feels that there are already adequate legal means to prosecute flagrant violators and that the price mechanism is the only equitable way to allocate scarce resources.

AFTERWORD

This discussion has been purely hypothetical. Its purpose was solely to stimulate the reader to think about the problems posed by a massive earthquake in terms other than the direct damage or the immediate emergency problems of lifesaving.

It would be impossible to convey in a paper the spontaneity of the discussions that was elicited from the role-playing at the Workshop. As the process proceeded, the participants became more involved and began to understand that the environment in which decisions will be made is one where parochial interests will be aired and political interests not only presented but served. After all, the political process is first and foremost the process wherein differing interests express themselves and work toward resolution of problems that are not well posed and have no optimal solutions. The purpose of the exercise was to illuminate the political nature of reconstruction policy and to initiate a process of accommodation.

Time and time again, we have learned that we cannot effectively respond to problems that have not been thought through prior to the need for immediate action. While emergency life- and property-saving functions are pressing and tax our resources, they are nonetheless straightforward. We know how to respond--only our lack of materials or management skills will prevent satisfactory action. The difficult problems are those where we cannot rely on our instincts or the goodwill of others and the public will not have a consistent view of satisfactory performance. These are problems that have no simple solutions--indeed, they probably have no best solution at all. But our ability to recognize, diagnose, and react to these complex socio-environmental issues is critical. This paper has attempted to start a process of examination that can bring these problems out into the open where they can be calmly and rationally discussed and functional relationships that lead to effective earthquake preparedness can be developed. It continues a process begun by the senior author in his paper "The Charleston Earthquake: A Prospective Assessment." Hopefully it will achieve this purpose.

ACKNOWLEDGEMENT

The senior author sincerely appreciates the contributions of those named for their assistance in conducting the exercise and to the participants in the Workshop for enlivening beyond his grandest expectations both his presentation and his notion of a role playing exercise.

REFERENCE

Thiel, C. C., 1983, "The Charleston Earthquake: A Prospective Assessment" in Conference Proceedings, The 1886 Charleston Earthquake and Its Implications for Today, edited by Walter Hays and Paula Gori, (in press).

LOCAL AND STATE RESOURCES IN DISASTERS

by

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Arkansas' Act 511 of 1973, established a State Office of Emergency Services to coordinate disaster planning and disaster response by State and local governments. This Act also directed the establishment of a county Office of Emergency Services to coordinate their disaster planning and response. Each county was directed to establish an organization and to prepare a county plan that is integrated with a State emergency operations plan. The State plan is functionally oriented and assigns responsibility for support of each major disaster response function to specific State or volunteer agencies. A basic assumption is made in disaster planning at all levels, that disaster response requirements must exceed local capabilities before State assistance is requested and State capabilities must be exceeded before they request Federal assistance.

In a large scale disaster, such as an earthquake, the State office would alert State agencies outside the disaster area immediately without waiting for assistance requests, but would delay committing State resources until preliminary damage reports made it possible to establish priorities for assistance. State resources at the disaster location would be committed by local supervisors immediately.

First priority will always be directed to alleviate threats to life and property, then to immediate needs to obtain access for emergency vehicles and restore communications. Following this will be provision of food, clothing and shelter to disaster victims, restoration of utilities and transportation access to the area. Finally, will come the restoration of public and private facilities to pre-disaster conditions.

In the event of a major earthquake in northeast Arkansas, destruction of roads, railroads, and airport runways would delay access to areas around the epicenter of the earthquake for a matter of hours or even days. Local governments would then be the only source of aid until avenues of transportation could be reopened. Heavy, all-terrain vehicles from the Arkansas Highway and Transportation Department, the Arkansas National Guard and from heavy construction companies would be utilized as well as helicopters from the Air National Guard to reach areas cut off from highway and rail access. The Arkansas Highway and Transportation Department would immediately commence restoration of key access routes to the affected areas, with assistance of commercial contractors under provision of "Plan Bulldozer" if required.

There are several packaged, air transportable, field hospitals in the State that could be moved into the disaster area to supplement medical facilities that survived the earthquake. Previously identified congregate care centers would be opened and used to house short term homeless disaster victims. Arrangements have been made to use Fort Chaffee, Arkansas, to house long-term homeless disaster victims, if the disaster is of sufficient magnitude to require such facilities.

Emergency communications would be via Office of Emergency Services radio net and the Arkansas State Police radio net. State Police Troop Headquarters in northeast Arkansas have backup emergency power and many of the emergency service radios also have backup power.

With no electrical power, refrigerated goods will rapidly spoil. Families stranded in areas cut off from outside aid will have to subsist on canned food and liquids and boil all water used for drinking or in preparation of food. Critical medication and food for infants may be delivered by air drop or helicopter.

The greatest problem will be to determine what was the extent of damage and to determine priorities for providing assistance. It is assumed that there would be a Presidential Disaster Declaration and that there would be assistance by Federal agencies; particularly in heavy equipment, temporary bridges, etc.

FEDERAL SUPPORT OF ARKANSAS EARTHQUAKE PREPAREDNESS: A REVIEW OF THE NEAR-TERM COMMITMENT

by

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INTRODUCTION

A major objective of this conference is to foster and develop a community of concerned individuals that can take effective short and long term actions to reduce earthquake losses in the Central United States. My comments will address the near term Federal effort in support of the above objective.

The following are the major aspects of the Federal effort as it relates to earthquake preparedness in the Central United States.

THE FEDERAL EMPHASIS ON THE CENTRAL UNITED STATES EARTHQUAKE PREPAREDNESS PROJECT (CUSEPP)

CUSEPP was formed in an effort to improve the preparedness and meet the objectives of the National Earthquake Hazards Reduction Program in the Central United States. CUSEPP is an amalgamation of Federal, State and local governments, and private and public sector participants. The CUSEPP planning area encompasses 21 States and 871 counties (including forty-seven in Arkansas) where moderate to severe damages could be expected from ground motion, measured in Modified Mercalli intensities of VII and above. However, the project's primary planning emphasis is directed toward those high impact areas, the 11 States and 394 counties within Zone VIII and above intensities.

Originally begun in 1980, the project was formally structured into the FEMA system under the direction of Louis O. Giuffrida, Director of FEMA, with the project leadership assigned to FEMA Region VII. A policy committee was, thereafter, established that included the Regional Directors from FEMA Regions IV, V and VI.

The purpose and goal of the CUSEPP is to improve the overall preparedness of the Central United States to a large and damaging earthquake and to reduce expectant damages and casualties. To achieve the above stated goal, three principal areas of focus have been identified by CUSEPP as the highest priority.

- CUSEPP seeks to foster the development, testing, and implementation of Federal, State, local and private sector response plans.

- CUSEPP seeks to foster the identification and implementation of Public Awareness Programs at the Federal, State, local and private sector levels.

- CUSEPP seeks to foster the identification and implementation of mitigative measures at all levels to reduce the impacts of a major earthquake.

In 1983, CUSEPP made significant progress in realizing its goals. Summarized below are the highlights of 1983's work:

- Creation and implementation of a Technical Advisory Panel.

  This independent advisory body provides technical review and comments on the Central United States Earthquake Preparedness Project reports, papers, policies and contract products. It is composed of a wide range of individuals with experience and interest in seismic safety. Panel membership includes emergency managers and planners, engineers and seismologists, and behavioral scientists from the State, local and private sector.

- Development of a comprehensive mapping program for the Central United States.

In FY-83, CUSEPP initiated a comprehensive seismic mapping program for the Project Area. Project area maps showing Modified Mercalli intensities for a 8.6, 7.5, and a 6.5 (Richter) earthquakes are currently being developed under this program. Detailed maps of major cities and SMSA's are also being considered. Large color wall maps for public education and large black and white work maps are also being prepared. Acceleration and spectral ground motion maps that could one day be useful in upgrading building codes are also being developed. The mapping program will augment future research and education activities for the overall preparedness effort.

- Development and Support of State Earthquake Safety Programs.

In a very significant step, CUSEPP developed and is initiating, beginning in FY-83, funding for the first year of a multi-year, comprehensive seismic safety program to be implemented at the State level. The State programs for seven central States has identified written goals, objectives, and benchmark dates for State and local response planning, public awareness and mitigation programs. The State programs will be consistent and complementary to the program goal sought by the National Earthquake Hazards Reduction program and the overall Federal effort.

- Development and Support of the State Seismic Advisory Panels

In FY-83, CUSEPP has made available funds for the development of State seismic advisory panels. We hope that these State panels will help foster the concern needed to support the State seismic safety program effort. CUSEPP hopes to see an emphasis on private sector involvement in these panels.

- Support leading to the development and implementation of a Central United States Earthquake organization.

In June of 1983, seven of the CUSEPP States took steps toward development of a formal Central United States Earthquake Consortium (CUSEC). Formed for the purpose of promoting earthquake response planning, mitigation, awareness, research, and seismic safety in the Central United States, CUSEC is expected to become operational this fall, and FEMA intends to support the effort of this consortium.

The formation of a consortium is considered a high priority by CUSEPP and important in fostering a close liaison between the Federal, State and local earthquake preparedness effort.

- Development of a Formal Report and Publication Series for CUSEPP.

  In order to serve as the coordinator and clearinghouse for information on the Central United States Earthquake problem, CUSEPP began a formal report series in FY-83. This series is dedicated to ensuring that major CUSEPP reports and publications, including video material, are included under the series. Also, the series is open for registration of any appropriate research or reports by any agency wishing its work formally recognized as documents pertinent to the Central United States.

- Development of an inventory and analysis methodology for critical facilities in the CUSEPP area.

  During FY-83, CUSEPP has developed and tested a methodology for inventory of key facilities that is consistent with the analysis methodology also developed in FY-83.

  These two components, when combined with the available intensity maps, will provide CUSEPP with the basis for generation of damage and casualty estimates that can be used for planning and public awareness throughout the project area.

- Development of Damage and Casualty Estimates for Six Cities in the CUSEPP areas.

A report that assesses the damages and casualties in six Central United States cities will be available soon. This report will serve as a prototype for future inventory and analysis efforts throughout the CUSEPP area. This is the first such vulnerability study accomplished for the Central United States. The cities selected for this prototype report are Little Rock, Arkansas; Carbondale, Illinois; Evansville, Indiana; Poplar Bluff, Missouri; Paducah, Kentucky; and Memphis, Tennessee.

- Federal Response Planning Initiatives in the Central United States.

  CUSEPP is working with the FEMA National Office on preparation of the "National Federal Plan for a Response to a Catastrophic Earthquake". Under this concept of operations, Federal Response Planning at the National and the Regional level is concerned with supplementing State and local government. CUSEPP will work with the States to ensure that the response plans are complementary.

  It is an objective of CUSEPP that in the next five years, the Federal, State, and local response plans will be developed, tested and implemented. CUSEPP plans call for a coordinated development and testing phase, with joint testing of plans to insure compatibility.

SPECIFIC AREAS OF FEDERAL SUPPORT TO EARTHQUAKE PREPAREDNESS IN ARKANSAS AND OTHER CENTRAL STATES.

Specific Federal support to Arkansas preparedness at the present is concentrated on the preincident phase. In this phase, CUSEPP is targeting program grants to support needed research, planning and program development. Specific programs aimed at enhancement of State preparedness include the following:

- Arkansas State Earthquake Safety Program

  This comprehensive multiyear program seeks in FY-84 to develop a State program for the three following areas: 1) State and local response planning, 2) Public Education and; 3) mitigation. This program is being developed by the Arkansas Department of Public Safety.

The State earthquake safety program will develop a written State seismic safety plan. This plan will contain a list of State goals and objectives and benchmark dates for their accomplishment. Three important areas are identified as a focus for the program, they are:

1. Development, exercising, and implementation of response plans for State and local governments identified by CUSEPP as having significant risk. Beginning first with those areas subject to ground shaking in Modified Mercalli intensity IX and above, and later Zone VIII.

2. Development of, and implementation of a public awareness program to complement the State's objectives.

3. Identification and initiation of mitigation opportunities, programs, and procedures for buildings, lifelines, structures, and hazardous materials under state and local jurisdiction.

- Arkansas State Earthquake Panel

Arkansas and the other CUSEPP States have received support for the establishment of State Advisory Panels. These panels are intended to serve as a forum for the State in formulating policy and programs for earthquake safety. These organized forums for communication for State agencies, local governments, academia, private firms and relief and volunteer organizations should help in achieving some of the goals identified in this conference.

- Hazard Vulnerability Analysis

CUSEPP is conducting hazard vulnerability studies in the planning area. Later this year, information (vulnerability information) on certain critical facilities in the Little Rock area will be available.

In FY-84, CUSEPP expects to begin an inventory of critical facilities in sixteen Arkansas counties, as part of an inventory in 149 counties in seven States in Zone IX and above. The collection and analysis of the information will take approximately 12 months. The results of the surveys will be production of damage and casualty estimates for those counties inventoried. The survey methodology calls for close coordination with the State of Arkansas, Office of Emergency Services, and local officials in the 16 Arkansas counties.

SUMMARY

The objective of fostering a community of concerned individuals that can take effective short and long term measures to reduce earthquake losses is closer to achievement because of the work of the Arkansas Office of Emergency Services, than ever before. Much effort is still required to bring the level of earthquake preparedness up to the threat. This is the challenge over the next five years. The implementation of a program to achieve the needed level of preparedness will mark the beginning of the largest comprehensive multi-State earthquake safety program in the history of the United States. Arkansas, through the efforts of its Office of Emergency Services, has taken a leading role in this overall effort.

FEDERAL EMERGENCY MANAGEMENT AGENCY'S EARTHQUAKE MITIGATION ACTIVITIES FOR THE CUSEPP AREA

by

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INTRODUCTION

I will outline for you mitigation-related activities that are being sponsored by the Federal Emergency Management Agency National Office and that can also be applied to the seismic threat in Arkansas. Because of their nature, they are activities that will come to fruition only in the long run.

SEISMIC CODES, STANDARDS AND PRACTICES

The most effective, single long-range action to mitigate both the human sufferings and the physical losses caused by earthquakes is to construct seismic-resistant structures. For this reason, one of FEMA'a responsibilities under the National Earthquake Hazards Reduction Program (NEHRP) is the development and encouragement of adoption of improved seismic codes, standards, and practices.

During the early 1970's, the National Science Foundation (NSF) sponsored a substantial program on earthquake engineering and soil-structure research. In the mid-1970's, the results of this research were synthesized and a set of up-to-date seismic building provisions were formulated. A large group of design practitioners, researchers, and building regulatory officials participated in this effort under the management of the Applied Technology Council (ATC), NSF, and Bureau of Standards funding.

Although the ATC document represented the consensus of a large number of disparate disciplines and groups, the provisions were not as widely adopted by building regulatory bodies as had been hoped for. The main reason was that they had not been subjected to an evaluative process to determine their workability, practicability, enforceability and cost impact. To fill this gap, FEMA in 1982 funded the Building Seismic Safety Council of the National Institute of Building Sciences to assess these provisions through a series of trial designs. About 50 buildings of different size, configuration, construction, and occupancy located in nine cities are being designed first according to existing local codes and then according to the ATC provisions. Memphis and St. Louis are two of the nine cities.

The specific objectives of this effort are to estimate the economic and social impact of the use of these provisions; evaluate their usability by designers, builders, and building regulatory officials; establish their technical validity; and produce objective information as to the transferability of the provisions to other locations. This phase of the project will be completed in about one year. Once the results are compiled, assessed, and adapted to local needs, a basis will exist for undertaking an evaluation of local construction codes, standards, and practices in each area. Local officials can then proceed to improve the seismic resistivity of new buildings.

FEMA is also funding a parallel effort aimed at the development of up-to-date and uniform seismic building standards to be applied to Federal and Federally funded or leased buildings. In this way it is hoped that the Federal government will set an example of earthquake mitigation here and throughout the nation and that the private sector will emulate it.

The recently completed Five-Year Program Plan of the NEHRP contains a substantially increased funding for seismic design. If approved, three major new thrusts will be added: development of technical guidelines for the strengthening of existing hazardous buildings; standards and practices for both new and existing lifeline facilities (e.g., roads, bridges, overpasses, water-treatment plants, power generation and transmission facilities, telecommunications); and development of a number of manuals of practices for design and building practitioners. The products of these additional efforts will also be available for the use of local officials in improving seismic resistance of structures in Arkansas in the long run.

HAZARD AWARENESS

In parallel with these activities related to structures, FEMA has an ongoing effort to increase hazard awareness and educate both the general public and specific audiences about the consequences of earthquakes. FEMA has a special obligation to provide the public with information on how individuals, families, and schools, and neighborhoods can reduce the life-threatening consequences of earthquakes. Participants in the workshop on "Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area" held in St. Louis in May 1982, suggested numerous ways to accomplish this objective. Their recommendations focused on utilizing existing community channels to provide earthquake safety information to various audiences.

Accordingly, FEMA has recently funded Earthquake Education Centers at the Baptist College in Charleston, South Carolina and at the Tennessee Earthquake Information Center in Memphis. These Centers will serve as repositories of basic earthquake-related documentation and foster general information transfer. They will provide a wide opportunity for public-and private-sector participation in the development of educational programs and will also serve as models for future FEMA-funded earthquake education centers in other high-risk areas.

The materials developed by these Centers and similar ones being prepared by the FEMA National Office should aid Arkansas officials in their task of stimulating awareness of and preparedness against earthquake hazards.

TECHNICAL ASSISTANCE

Technical assistance consists of available information and data, research results, other documents and reports, and expert personnel that the Federal government has available on a given topic--earthquakes in this case. (Please note that funding is not included). As leader of the NEHRP, FEMA can enlist the support of the participating agencies to provide you with technical assistance. Your best bet in this respect is to contact the FEMA Regional Office when a need of this kind arises.

DEPARTMENT OF HUMAN SERVICES OUTLINE FOR DELIVERY OF SERVICES DURING EARTHQUAKES IN ARKANSAS

by

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The following is an outline for delivery of human services during an earthquake in Arkansas.

<u>Social Services Division</u>

The Individual and Family Grant Program
Emergency Food Assistance

1. USDA Commodities for Shelter Feeding
2. Emergency Food Stamps

Professional Staff to operate Disaster Assistance Centers

<u>Mental Health Service Division</u>

Community Mental Health Centers

1. Crisis Counciling
2. Educational Workshop for Victims
3. Exit Interviewing - Disaster Assistance Centers

<u>Office on Aging</u>

Area Agencies on Aging

1. Transportation
2. Shelter - Senior Centers
3. Counciling and Outreach - Disaster Assistance Centers
4. Meals - Senior Centers

AIR FORCE ASSISTANCE AVAILABLE IF AN EARTHQUAKE OCCURS IN VICINITY OF LITTLE ROCK, ARKANSAS

by

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The amount of assistance rendered by Air Force personnel from Little Rock AFB will be dependent upon damage, if any, at Little Rock AFB, and the status of the international situation. Generally it will be limited to restoring and maintaining emergency transportation, communication systems, utilities and helping to prevent suffering and hardship. Law enforcement will be of Air Force concern only when needed for traffic control, prevention of looting and restraining of curiosity seekers. The following policies have been extracted from Air Force Regulation 355-1 for your information:

1. Commanders must act promptly during attacks and disasters to maintain the capability to execute the primary mission, save lives, reduce damage, and aid civil agencies in domestic emergencies following natural disasters or enemy attacks.

2. Each Air Force commander, when requested by proper civilian officials, msut act promptly to help save lives, prevent human suffering, and reduce great destruction or damage to property. The purpose of this aid is to help civilian officials, not to take charge of their functions.

3. Military resources may be used to assist local authorities in natural disaster relief when civil resources are not adequate to prevent loss of life, human suffering, or great property damage.

4. All resources of the Air Force within the United States are potentially available to assist civil authorities during a National Civil Defense Emergency. Air Force planning and proceedures to

support civil defense emergencies must be consistent with civil defense plans at the local, State, and National level.

Detailed lists of equipment that will be available are not possible to compile in advance; however, limited quantities of the following vehicles and equipment will be made available:

1. Staff cars, station wagons, auxiliary power units, pick-up trucks, heavy trucks, buses, five (5) and ten (10) ton tractors, fork lifts, and ambulances.

2. Cranes, bulldozers, mobil lighting units, mobile radio equipment, miscellaneous tools for rescue and debris removal.

3. Two (2) air transportable clinics.

4. Limited aircraft support, utilizing helicopters and cargo type aircraft.

5. Limited bedding equipment (sheets, blankets & pillows).

6. Fire Fighting equipment.

ROLE OF THE AMERICAN RED CROSS IN EARTHQUAKE PLANNING AND RESPONSE

by

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INTRODUCTION

The American Red Cross Disaster Services came of age after the San Francisco earthquake and fire of 1906. It was in the aftermath of that catastrophe that the President of the United States at the time recognized the relief activities that had been begun by Clara Barton in 1881, by asking the Red Cross to administer the funds that were being raised across the Nation for earthquake relief.

This historical note is offered as a preface to my remarks on how the American Red Cross would support individual and family assistance and interact with FEMA's response because it illustrates the continuing and important roles the Red Cross and other voluntary agencies have in relation to earthquake response planning, in the response itself, and in the public awareness efforts that can lead to the kind of citizen action that may reduce future earthquakes losses.

DISASTER PREPAREDNESS PLANNING

Red Cross Disaster Preparedness planning is linked closely to planning of Federal, State, and local emergency services agencies. The Red Cross in such planning assumes specific responsibilities related to its congressional charter as a voluntary disaster relief agency. Emergency services agencies in Arkansas, for example, must be reasonably familiar with our planning because in the past ten years, the Red Cross has been involved in close to 2,000 disaster responses in this State, many of them involving the resources of the National Red Cross organization.

How those 2,000 disaster responses would differ in nature from the response that would be called for in this and neighboring States when the New Madrid earthquake repeats is hard to anticipate because we still do not have the kinds of vulnerability analyses that are available for earthquake response planning in Southern California or the San Francisco Bay area. But anyone who has studied the reports coming from FEMA, St. Louis University, and the Earthquake Information Center at Memphis State University knows the potential damage and impact on human needs could well call for the largest Red Cross disaster response in the history of the Central United States.

It is obvious from the organization's history of disaster preparedness and response that there is a basic Red Cross disaster infrastructure within the Red Cross chapters throughout Arkansas, and, of course, in Tennessee, Kentucky, Missouri, and the other States that will be impacted by another New Madrid earthquake. But it is also obvious, from our experience in working with the Southern California Earthquake Preparedness Project, that this infrastructure will be just the beginning. The southern California plan, for example, calls for the Red Cross to operate 1,000 shelters for emergency evacuees, and for those shelters to be ready within 48 to 72 hours after the quake occurs.

Comparable planning is just beginning in the Central United States, and the Red Cross has been a part of this effort from its inception three years ago. To those of us who think in terms of all kinds of hazards, these three years have contained all kinds of localized--and in some cases widespread--dress rehearsals for the big one. There are times when it seems that the past year has been one continuous flood and tornado relief operation in Arkansas, Missouri, Illinois, and parts of other nearby States. When one remembers that the 1811-1812 earthquakes changed the course of the Mississippi River, you almost want to cry out--change it back, change it back, as the rains and the snows and the rains and the snows spread the Mississippi and its tributaries all over the map.

RESOURCES OF THE RED CROSS

In terms of what can be expected of the Red Cross as a resource to individuals and families affected by a major earthquake in this part of the United States, the Red Cross is planning to provide its basic disaster assistance program in coordination with appropriate Federal, State, and local agencies. This program consists first of mass care support for people made homeless by the earthquake--food, shelter, first-aid type medical care--until they can return home or find alternate places to live until their homes are restored. At the same time, we will be providing emergency assistance to individuals and families so they can begin to resume normal living...help with funds for food, clothing, transportation, essential furnishings, health needs including replacement of prescription drugs, eye glasses, dentures and the like, replacement of needed personal occupational supplies and equipment. In effect, we will be meeting basic needs on an emergency basis until Federally-funded individual assistance programs are in place. We will help families seek out such resources, then we may augument the government's help with additional assistance should such help be inadequate for a family's essential needs following an earthquake. Also, we will be providing blood and blood products for the seriously injured and will handle welfare inquiries from anxious relatives outside the earthquake area once communication lines are available.

In the Southern California planning, for instance, the Red Cross role in mass care, welfare inquiries and other areas is spelled out in both the State and Federal regional plans. At the National level the Red Cross is designated the lead agency by FEMA for planning in those functional areas.

However, delivery of the services I have just described after a repeat of the New Madrid earthquake will not be simple. For a period of time in some places, it may not even be possible. The planning process in which all of us here today are involved will be long, difficult, and at times bordering on the incredulous because the Central United States Earthquake Planning Project is dealing with what could well be the worst natural disaster in the history of our nation. Everyone's resources will be stretched to the limit, and then stretched some more, and some more, and some more.

The very magnitude of what we are planning for does, however, add important new dimensions to what might be called normal disaster planning. In California, for example, the Red Cross has joined forces with public officials and private industry to encourage plant by plant planning and awareness and to educate the public in self-protection. Much of this educational effort focusses on family or employee self-protection during the first two to three days while efforts to clear roads and restore at least some rudimentary utilities make possible the implementation of mass care services.

PUBLIC AWARENESS AND EDUCATION

The activities in California can be utilized as a basis for planning and public awareness education in the Mississippi Valley. However, there are problem factors that need to be considered--and these problems are certainly reflected in the planning reports developed by the Federal Emergency Management Agency's Region VII team. If the potential Mississippi Valley earthquake is as great as predicted, there may be such competition for resources that the smaller, more isolated communities in the epicentral area and elsewhere may have to be prepared to go it alone for a period of days, if not longer. This means stockpiling some kinds of supplies, intensified first aid training, plans for airdrops, etc. Also, general awareness and public education campaigns will need to be tailored to a large number of State and communities so that they have specific meaning for each population at risk. This is a lot of work, and it must involve voluntary agencies such as the Red Cross in every risk area. The voluntary sector can supply a lot of resources and manpower. The Red Cross family training program related to earthquake safety that began in Los Angeles, is being extended to other areas, and could be brought into the Central United States as part of the public awareness effort. We have had expressions of interest in Memphis and St. Louis, and will be working with FEMA and local groups on the development of localized training programs as the total CUSEPP plan progresses.

VULNERABILITY STUDIES

All of the planning and much of the public education must, of course, be based on reliable forecasts of what may happen. In California, everyone is working from seismic risk analyses done by the Federal Government. These analyses are quite specific in terms of what is likely to happen, or at least specific enough to know that 1000 shelters will be needed in the Los Angeles area and that over a quarter of a million people will be sheltered. However, in the Mississippi Valley there are still just a handful of prototype vulnerability studies. If the resources of the Red Cross, other voluntary agencies and government at various levels are to be effectively catalogued and put into a grand plan, all of us must find every effort to see that the prototype studies are completed for every community at risk. That's no small job considering the vast expense that is included in the risk areas we have been discussing. Although voluntary agencies are quite willing to work with government agencies in preparedness, awareness campaigns, and mitigation efforts, their efforts will be much more effective if they can relate to specific risk information for a given area. Perhaps, then, the first order of business is for all of us to find ways to support the mapping effort.

Participation in the mapping effort itself may give the participating groups a sense of urgency that is difficult to maintain in the face of social problems and economic priorities that seem more pressing than preparing for an earthquake that may be a century or two away. Anyone who is involved in translating the seismic risk map of Little Rock, for example, into plans for the possible collapse of specific buildings will, one believes, develop a sense of urgency that will be important to the earthquake planning effort.

SEISMICALLY SAFE FACILITIES

There is another important role that the Red Cross and other voluntary agencies can play. The voluntary groups, especially the religious ones, construct and operate a host of physical facilities--churches, schools, hospitals, recreation centers, etc. While such facilities would be primary locations for emergency relief centers and shelters, the chances are that in this part of the country they were built without regard for seismic safety. If the groups operating such buildings were to begin a program of retrofitting old buildings and designing new buildings for seismic resistance, and do so with attendant publicity, this could have a bellwether impact on the efforts of local, county and State governments to push for earthquake mitigation through improved construction standards. The very need for strengthening buildings so they could be used for emergency purpose could become a vital public awareness element in our total planning effort.

SUMMARY

While I am speaking primarily for the Red Cross, it is obvious that voluntary agencies have many roles to play in earthquake loss reduction. The foregoing represents the major roles as seen from the perspective of an agency that has been involved in disaster planning for many years and, more specifically, in the earthquake oriented planning activities of the last decade. I am sure as we work together, many more such roles will emerge.

THE UTILITY'S ROLE IN PREPARING FOR RECOVERY FOR A MAJOR EARTHQUAKE

by

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INTRODUCTION

Arkansas Electric Cooperative Corporation (AECC) is the power supply system for 17 of Arkansas' consumer-owned electric distribution cooperatives. Those systems, in turn, serve more than 260,000 homes, farms, businesses and industries. The electric distribution cooperatives of Arkansas serve 62% of the geographical area of the State, 26% of the State's population and 16% of the power requirement. Their service area is mostly rural and is heavily dependent upon electric service.

Arkansas Electric Cooperative Corporation is a member of the Southwest Power Pool (SPP), a regional electric reliability council consisting of 39 member systems located in all or part of 8 States. The primary function of the Southwest Power Pool is to promote reliability and adequacy of bulk power and energy. This function is accomplished by member systems' voluntary compliance with reliability planning criteria and operating policies.

THE UTILITY'S ROLE DURING AN EARTHQUAKE

While it is unlikely that any earthquake would cause physical damage to facilities of the entire region serviced by the Southwest Power Pool, it is not unlikely that an earthquake in or near Arkansas would affect some SPP members. Arkansas Electric Cooperative Corporation might be affected at the generation, transmission or distribution level of service or might be affected at all these levels. Power plants owned by AECC are shown in Figure 1.

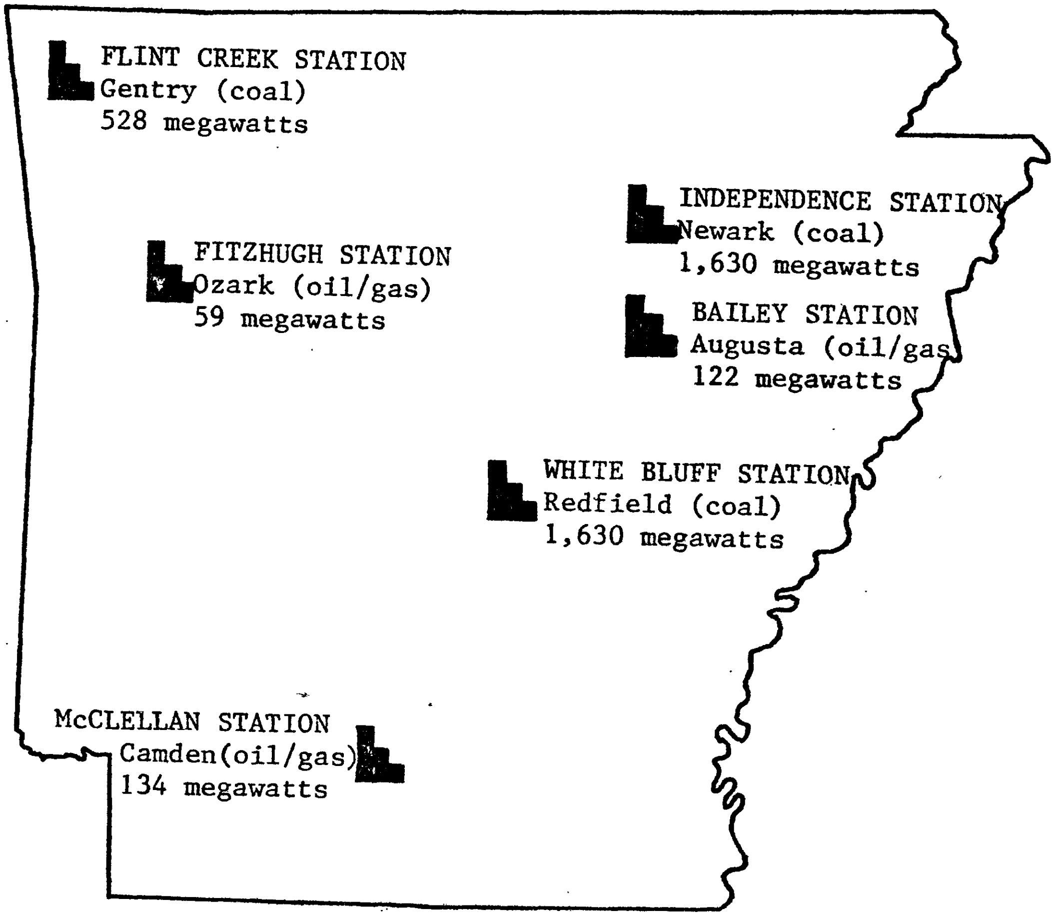

Figure 1.--AECC owns three oil/gas generating facilities - the Fitzhugh Station at Ozark, the Bailey Station at Augusta, and the McClellan Station at Cameden. The coal-fired Flint Creek Station at Gentry is co-owned by AECC and Southwestern Electric Power Company. AECC, Arkansas Power and Light Company and three cities are co-owners of the coal-fired White Bluff Station at Redfield. The Independence Station under construction at Newark is owned jointly by AECC, Arkansas Power and Light Company, Mississippi Power and Light Company and four cities. There are other power plants in the State that are owned by other utilities.

The power supply system at the generation level is designed to continue operating even with outage of some of the generating units for routine maintenance or outage due to unforeseen forces. A regional power supply problem could occur for simultaneous loss of several large generating units.

At the transmission level the power supply system is designed to continue operating even with the outage of a few of the high voltage and extra high voltage lines for maintenance or with outage due to unforeseen forces. A regional bulk power transfer problem could occur for simultaneous outage of a few large transmission lines.

The distribution level of power supply is generally not designed to continue operating with line outages. Since most electrical customers are supplied by the distribution level of service, thousands of miles of electrical distribution lines are required. Most distribution line maintenance is performed on energized lines; however, there are some outages for line repair and will be some outage due to unforeseen forces.

In the event of an earthquake, it would be normal for some power plants and some substations to trip out and become isolated for reasons of self-protection. It would also be normal for many homes, schools, churches, hospitals, farms, water districts, businesses, and industries, etc. to be without electric service from the utility prior to recovery. Consumer owned emergency power systems would be operating during this period of time while fuel was available. The following is considered to be the critical path to timely and orderly restoration of electric service:

- Verify or reestablish communications among power dispatch and control centers.

- Determine if power generation deficiency exists and if so, begin corrective action.

- Assess damage and extent of power failure.

- Mobilize work force and call for assistance from adjacent utilities if needed.

- Repair and place in service major transmission lines and switching stations.

- Repair and place in service substations and distribution lines with preference for critical loads such as hospitals, media stations, human service centers, water systems, emergency shelters, etc.

- Start up power plants and restore additional loads as the transmission and distribution systems are repaired. Mobile substations may be used if highways permit passage.

Utility system operator should coordinate load restoration as generating capability, voltage level and line loading allow. Any load should be restored only upon direct orders of the system operator. Extreme care must be exercised as to the rate at which load is restored to the system in order that limits of generation and transmission line loading are not exceeded. In so far as possible, remote control should be used to restore load; otherwise, manual restoration is preferable to insure positive control by the utility system operator.

Most, if not all, load control centers have a comprehensive and detailed restoration manual and implementation of the restoration plan would follow the occurrence of an earthquake for a safe and systematic recovery.

SUMMARY

The need for an adequate, dependable supply of electricity will increase, not lessen, in future years. AECC will help meet that need and will do it as efficiently and economically as possible.

EMERGENCY GAS-PIPELINE POLICY

by

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INTRODUCTION

Arkansas Louisiana Gas Company should be prepared in advance to implement an organized emergency plan to minimize hazards to the public and to protect public and company property in the event of a gas pipeline emergency.

POLICY

Each Arkla District shall have at its disposal a current Emergency Plan Book and have access to the accompanying emergency equipment specified in the district emergency plan. Each employee shall be familiar with the emergency plan and what his/her role would be should the plan be implemented at any time.

PROCEDURES

I. Receiving & Classifying Information

A. Emergencies on the Company's system shall be reported immediately to the Shreveport Dispatching Office and to his/her supervisor by a company employee who first discovers or is informed that an emergency condition exists;

B. Any situation that endangers lives, poses a threat to property, or drastically affects system operation, should be considered an emergency and the emergency procedure should be immediately implemented.

II. Communications

A. The Field Supervisor after evaluating the emergency shall notify the appropriate public safety agencies in the area, (fire, sheriff, police, etc.). Shreveport Dispatching Office will notify the appropriate State and Federal agencies as required.

B. The Shreveport Dispatching Office shall be in continuous communication by telephone or radio with personnel at the scene of the emergency. During an emergency when radio and telephone communications may not be possible, a messenger relay will be set up to relay information to Shreveport Dispatcher Office and any appropriate public safety agency.

C. In an emergency or a failure that results in personal injury or extensive property damage, the flow of information within the Company shall be as follows:

1. Field Supervisor to Dispatcher
2. Dispatcher to Manager of Dispatching, and
3. Manager of Dispatching to Vice President of Transmission and
4. Manager of Pipeline or Vice President of Distribution.

III. Emergency Response

A. Confirm the location of the emergency or disaster.

B. Take necessary steps to protect people first and to assist those that may already be injured. Cooperate with public safety agencies to minimize hazards to the public.

C. Classify the type emergency as one of the following and implement the procedures specified.

1. Gas detected inside or near a building:

a. Evacuate the area or building.
b. Ventilate the building.
c. Determine the source of the gas.
d. Shut the gas off for repairs.

2. Fire located near or directly involving a pipeline facility:

   a. Evacuate the area.
   b. Determine whether the pipeline facility is involved in the fire or if it is threatened by the fire.
   c. If yes, take steps necessary to interrupt gas flow to the area.
   d. Extinguish the fire if possible.

3. Explosion occuring near or directly involving a pipeline facility:

   a. Determine whether the pipeline facility has been damaged or jeopardized.
   b. If yes, take steps necessary to interrupt the gas flow to the area.

4. Natural disaster:

   a. Determine whether the pipeline facility has been damaged or jeopardized.
   b. If yes, take steps necessary to interrupt the gas flow to the area.

D. Always follow these general guidelines:

1. On advice of Shreveport Dispatchers, close or operate necessary valves to isolate the emergency.

2. Determine what materials and equipment are needed to repair the damage.

3. Send a repair crew to the emergency site.
4. Estimate the amount of time necessary to place the facility back in service and report same to the Shreveport Dispatchers.

5. Maintain communications with the Shreveport Dispatchers and advise them on the status of the repairs.

6. Coordinate with Dispatching and Distribution to restore service (lighting pilots, etc.).

IV. Coordination of Activities

Supervisors in the emergency area will coordinate the individual function of the available personnel and coordinate the movement of equipment and materials.

A. A current list of emergency services listing service, address, and telephone number shall be kept in the Emergency Plan Book at each district office. Accompanying that list should be an Arkla list of names, addresses, and phone numbers of anyone who might be subject to call during an emergency situation.

B. The following maintenance equipment shall be readily available and in good condition at all times. The Emergency Plan Book for each district should list the specific equipment available at that location.

Autos and trucks	Water pumps
Welding machines	Air compressors
Lighting plants	Radios
Acetylene and oxygen cylinders	Boats
Backhoes	Mowers
Heavy equipment	Auxiliary equipment
Extra batteries	First aid supplies
Spare parts for valves and regulators	Hand tools (including and brass or copper non-spart tools)

C. Spare pipe shall be kept on racks at selected sites throughout the Company's properties to be available during emergencies. This pipe shall be pre-tested and marked for test pressure, wall thickness, yield, and length. The pipe shall be inspected periodically and necessary maintenance performed to insure serviceability of the pipe. Each district shall maintain a list of pipes available in that geographic region. The list should be kept in the Emergency Plan Book.

D. Company keys have been issued to company personnel who regularly use locked enclosures.

E. Current Gate Maps showing Company facilities in the area shall be kept in each district's Emergency Plan Book. A large district map shall be posted in each district office to serve as an index for the individual gate maps.

V. Preparedness Planning

A. Preparedness offers the best insurance that emergency situations will be handled correctly. Emergency action discussions shall be placed on the agenda of Operational Meetings and other meetings during the year at all district locations and on the Management and Division levels. Each employee should be made aware of his role in the overall action scheme. They should have knowledge of all tools and equipment and know the location of Company facilities and be familiar with the movement of equipment and personnel.

B. Public agencies should be made aware of Arkla's Emergency Plan and receive a copy upon request. They should be included in Emergency Plan sessions whenever possible. Each District Foreman shall coordinate with the Distribution area to insure that public agencies are aware of the capabilities of the company in handling a pipeline emergency.

VI. Returning Facilities to Service

After the emergency, any facilities that have been removed from service shall be determined to be in a safe condition before gas pressure is restored.

A. All valves and protective devices should be determined to be in their proper settings.

B. Any air allowed in the system shall be purged in accordance with standard purging procedure.

C. Service shall be restored to customers and to Distribution facilities in accordance with standard procedures.

VII. Public Relations

Arkla Gas is publishing a notice in county newspapers informing the public of signs which mark the location of underground Arkla pipelines. The notice includes a telephone number for use in emergencies. The notice will be reprinted yearly.

VIII. Media Contact

A. The Company has an obligation to assist news media in getting quick, accurate coverage.

B. In line with the above principles, the following procedures shall be followed:

1. Reporters and news photographers should not be barred from the scene of emergency, except insofar as precautions for their personal safety dictate.

2. All facts, statements, and information shall be released, insofar as possible, from one central source. Unless otherwise designated by an Executive Officer of the Company at the time of the emergency, this source shall be the Company's Director of Public Relations.

THE ROLE OF ARCHITECTURAL PRACTICE IN EARTHQUAKE-RESISTANT DESIGN

by

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INTRODUCTION

The American Institute of Architects (AIA) indicates that "life safety is a primary responsibility of the architect but also a shared responsibility of all parties--the engineer, consultant, contractor, owner, user--involved in the design, delivery and occupancy of a building." A recent task force of the AIA reported that "life safety in buildings can not be achieved without the cooperation and contribution of all parties." The same philosophy exists in the planning and design of the earthquake resistant building systems.

For the architect, the design of complex building systems, and in particular the design of emergency services facilities, is a shared responsibility. Appropriate seismic design depends on technical information received from seismologists, geologists, geophysicists, engineers, planners, social scientists, public officials, the public and the client. In the definition of appropriate building standards, the building department, or department of public works, also has an important role to play in earthquake hazards reduction objectives. A large data base of technical information exists for the architect to use in the design of seismic resistant buildings, and it behooves the architect to use it.

Nineteen years ago research issues concerned with the seismic safety of buildings assumed a new perspective. Until then, principal efforts in earthquake hazards mitigation dealing with building science were directed primarily toward disciplines dealing with seismology, geophysics, and structural engineering. However, the Great Alaska Earthquake of 1964, and the San Fernando Earthquake of 1971, produced some changes in the manner in which several key issues were perceived. The earthquake in Alaska brought into sharp focus the fact that damage to an architectural building system and its nonstructural components could render a facility useless and subject to demolition even though it did not suffer structural damage or collapse. In an assessment of this earthquake it was realized that damage to architectural and nonstructural elements of a building could account for as much as 67% of the replacement cost of a facility as components independent of the performance of the structural system.

The San Fernando Earthquake of 1971, in addition, illustrated the need to have specific emergency services facilities and their important component parts remain functional and operational after an earthquake when four major medical facilities were damaged beyond repair in this event. Implications were very clear that certain emergency service buildings, such as hospitals and others, should not be subjected to nonstructural damage severe enough to cause functional loss or impair operations. At this point an additional emphasis was placed on the architectural, nonstructural components and elements of a building rather than solely on its structural system which in prior years had been one of the main focuses of building science research. Architects were called upon to assess current practice and to develop answers to assist in solving the problem.

THE ROLE OF THE ARCHITECT

In seeking effective damage control of buildings during a seismic event, the architect has a role to play in specific and critical areas:

1. Site planning and building location.
2. Architectural design and building layout (configuration).
3. Selection of materials of construction.
4. Detailing of connections and joints.
5. Interior design and furnishings.
6. Supervision of construction.

Failure of the architect to perform effectively in any of these categories can lead to disastrous results during an earthquake in which the building is required to absorb dynamic forces, lateral and vertical.

One of the most critical decisions regarding the ability of buildings to withstand earthquakes is the choice of basic plan shape and configuration. Given that earthquake forces at a site can come from any and all directions, and act upon all elements of the building virtually as well as simultaneously, the best choice is the design of a building with equal rigidity in all directions, plan and elevation, in order to be equally capable of withstanding forces imposed from any direction. An understanding of how variations in the rigidity and shape of a building can affect performance is most important. Significant torsion can also occur in buildings whenever the relative stiffness of one part of the building is different from another. Regular shaped buildings with balanced stiffness elements therefore avoid the secondary stressful effects of torsion and differential movement.

The architect must consider how a building is sited relative to other structures or annexes to the main building. Adequate separations must be provided to avoid "pounding" between building elements or adjacent buildings which can cause considerable damage. In several case studies recorded during earthquake reconnaissance field studies, a taller more flexible building experienced severe damage from pounding by an adjacent short, stiff building when inadequate separation between the two buildings existed. Site planning conditions also require that the architect be cognizant of soil-structure interaction effects. Prior to the development of site plans for the location of all major buildings, the architect must review geophysical reports on site conditions and be aware of all potential geological hazards in the area including the effect of earthquake induced landslides on site access and egress as well as on the building itself.

Since seismic forces affect all parts of a building, it is important to design and detail a building so that it will act as a unit to resist earthquake loadings. If the building is not tied together to respond as a unit, separate architectural elements or components will respond individually and even affect the response and performance of the total building system. Failure of several elements can cause a shift in load carrying or resisting ability of other elements which can lead to consequential failure due to unintended overloading. The nature and completeness of connections and joints will also determine the ability of the building system to perform. Typical connections conditions which can lead to abrupt failure include brittle rather than ductile connections, or the spacing of fasteners at inappropriate intervals. In addition, reinforcing bars may not be anchored, lapped or spliced adequately to develop the full strength of the connection. It is often said that the weakest part of a building is an inadequately detailed connection, and that the divergent motions produced by earthquake forces will immediately seek out and test such weak links in the design. By and large, inadequate joints and connections are the weakest spots in seismic design.

The dangers to which occupants are exposed during a severe earthquake, assuming that the basic structure does not collapse, include the toppling of free-standing furniture, equipment and storage systems such as filing cabinets and bookshelves. Suspended ceiling elements and lighting fixtures are particularly vulnerable unless properly fastened. Attention, which must be given to these elements of a building, increases as the population density of a building multiplies.

THE CONSTRUCTION PROCESS

Construction supervision, quality control, inspection and performance are of utmost importance. The architect is one of the important players in the construction process. Progress visits and supervision, or observation, of construction by architects are essential for effective quality control. Construction budgets must be set at the appropriate level to allow for this important function. In many cases, builders and construction team members may not be sufficiently aware of the importance of seismic requirements, so it relies on the architect to indicate why it is essential to follow the drawings. Careful review of all shop drawings by an architect, or reliable deputy, is equally important. Several notable failures have occurred because of inadequately supervised phases during the construction process, or insufficient review of details and shop drawings.

SUMMARY

The first step to take in developing programs in the life safety design of building systems located in an earthquake active region is to establish seismic provisions and to adopt them as part of local building code requirements. Without adequate seismic provisions in the current building code, the planning of design of buildings may not necessarily reflect appropriate seismic standards of the local and regional environments. Accordingly, before undertaking any other considerations, it is necessary to start with the promulgation of seismic standards in the building code. Such standards will allow design professionals to operate in an appropriate manner in meeting the demands of public safety.

SEISMICALLY SAFE STRUCTURES AND THEIR COST-EFFECTIVENESS

by

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INTRODUCTION

The total process by which seismic resistance is built into structures and made cost-effective involves a series of interconnected and highly complex professional activities occurring over many years. These activities embrace the contributions of geologists, seismologists, lawmakers, economic managers, planners, architects, engineers and builders.

The contributors have divergent primary professional goals expressed in highly unique languages, but each provides an element of knowledge that ultimately becomes fused into a chain of actions that provides our society an acceptable level of seismic safety.

This paper is designed to explore the role of the engineer as the goals of relative safety and cost-effectiveness are pursued. There is the hope that an improved understanding of this role by other professions will accrue to a safer seismic environment.

The engineer is responsible for the structural design of a building's foundation, columns, walls, girders, beams and floors--those elements of a building that give the building its seismic resistance. In discharging this responsibility, consideration must be given to building codes, cost, architectural design and available builders skills, as well as consideration of geology and seismology. In short, the engineer makes his decisions within a field of constraints that limit his options. It is not the purpose of this paper to comment on these in-place constraints but rather to explore how the engineer makes both seismically safe and cost-effective decisions within their limits.

BUILDING CODES AND BUDGETS

The two major constraints are building codes and budgets stated in a very explicit way: "The minimum acceptable seismic design is to be found in the governing building code and the maximum acceptable seismic design must be within the project budget."

As a practical matter the building code may be regarded by the engineer as unchangeable while the budget may have some flexibility. But it is very difficult to alter a budget and usually very little can be done unless very compelling evidence is discovered and effectively presented to justify spending additional money.

ARCHITECTURE AND PLANNING

The architecture and site planning are the second level of constraints but are nearly as rigid as the first since the design of a building is usually the product of lot shape, zoning ordinances and market demand for space. Thus, the size and height of a building are governed by factors which are to a great extent beyond the engineer's control. Within these constraints of law and budget, size, and height, the engineer can and does design buildings that are seismically resistive and cost-effective and socially acceptable. In the following sections of this paper the process by which this is done is described.

SEISMIC DESIGN

The engineering design of a building is a step by step process which is summarized simplicistically as "trial-test & cost". Each stage is conducted independently of the others and numerous cycles of trial-test & cost are needed before the best solution is found. The dominant variables that must be considered by the engineer involve: 1) materials, 2) column spacing, 3) beam and girder depths, 4) types of bracing, 5) types of connections, and 6) often foundations. Within these six major variables there are countless combinations. As a practical matter the engineer must choose the most effective candidate variables and based upon his professional judgement, create his basic designs.

CODE LEVEL OR PRELIMINARY DESIGN

Having chosen these variables the engineers will next develop preliminary or trial structural schemes that satisfy the building codes, architectural design and budget. It will be assumed for this paper that these schemes include consideration of both steel and concrete frames which are the leading structural materials in common use. Also it will be assumed that consideration is given to both braced and flexible frames. For you who are not engineers, a braced frame is one in which selected vertical elements or bays of a building are made very stiff through the use of "X" type bracing or reinforced concrete walls known as shear walls. On the other hand a flexible frame, as the name implies, is a system of columns, girders and beams that are connected in such a way as to provide adequate strength to resist both vertical loads of gravity and horizontal loads of earthquakes.

Next the engineer will test these schemes for the seismic loading that appears in the building code, which may vary from "no seismic requirement" to something very substantial. If the preliminary design is found lacking, the schemes are revised until solutions conforming to the code are found. These are the minimum acceptable structural solutions for the building frame.

Next the engineer must "cost" the structure. This is done by the engineer usually with the assistance of professional estimators and/or contractors who have a special costing expertise. The end product of this effort is a dollar price tag for each of the minimum schemes previously described.

With the information developed through the "trial-test & cost" process the engineer is now prepared to make a first-order decision among some four or more preliminary structural options. Knowing that each meets the requirement of the building code and the architectural design and knowing their relative costs, the schemes can now be ranked in their most cost-effective order and one of the more cost-effective and seismically resistive structures chosen for final design.

This process of code design by "trial-test and cost" is fairly simple and many successful structural designs have followed this process. For a very large number of structures, especially low risk structures, the code process is appropriate and adequate, but it should be borne in mind that the system has latent shortcomings that may reach serious proportions. These shortcomings arise from the absence of considerations regarding the relative safety of the different schemes when exposed to the full spectrum of seismic motion expected in the region and from the cost-effectiveness of designing for those ground motions in excess of the code minimum. For medium and high risk structures the value of this added information is vital to sound engineering, social and economical decision making. The answer lies in a more elaborate analysis process called "Seismic Spectrum Design".

SEISMICITY SPECTRUM DESIGN

Seismic Spectrum Design may be regarded as an extension of, rather than an alternative to, the previously described minimum design. It is based first on recognition of the fact that seismic events vary greatly from microtremors up to some maximum based on the crustal structure of the region. In addition it recognizes the attenuation of energy and alteration of the signal frequency content that are highly influenced by the magnitude of the earthquake, the region in which the earthquake occurs and the wave travel path to the structure. Some source areas are a great deal more active than others as can be readily seen by comparing the two States of Texas and California. These geoseismal variables are accounted for by seismologists and engineers through the establishment of magnitude recurrence or intensity-recurrence curves and attenuation-distance curves and frequency-distance curves unique to the region receiving the structure. These curves describe for the engineer the "best-estimated" range of seismic loads that a structure may possibly experience and they may be used to investigate a structure through rational loading structural analysis and probability procedures.

The engineering procedures by which a trial structure is "tested" against the seismicity spectrum utilizes either structural analysis procedures or the use of life-loss and damage parameters developed from building performances during actual earthquakes. A detailed discussion of these procedures and parameters is beyond the appropriate scope of this paper, but the products of the analysis and their application to balanced decisionmaking will be discussed.

The author has found it most satisfactory to begin a "Seismic Spectrum Design" using those structure schemes previously designed and described that meet the minimum requirements of the building code and project budget. Using these, a simulation is made of those seismic events that have been identified as credible by the regional intensity-recurrences curves.

The results of the simulations indicates both the dollar losses and the life losses to be expected from damages to each minimum scheme when it is exposed to each expected intensity of earthquake. The simulated losses may be evaluated in their absolute sense, i.e., how many dollars worth of damage and how many lives will be lost or they may be viewed in relative terms as is the custom of insurance companies in viewing other type losses.

In analyzing property damages, the author prefers to translate the property dollar damage into a ratio expressing the damages and the cost of the structure. This is done by simply dividing the value of damages by the cost of the structure and thus creating a dimensionless parameter L/C. For example, if a structure is expected to collapse during an intensity 9.0 earthquake it will be a total loss and the L/C ratio will be 1.0 for that structure following an intensity 9 and greater earthquake. The process is repeated for each trial structure and each credible earthquake; thus the process is referred to as the "seismic spectrum" process.

The results of such a process are amenable to graphic presentation and representative plots are given in Figure 1 which show property losses to a stiff, nonductile structure and a flexible structure (see Figure 1). Such an analysis gives the engineer the capability to look at the full range of credible seismic events and the performance of each trial structure. In this way the engineer maximizes the cost-effectiveness and the safety of his design.

Life losses may, like property losses, be analyzed using "seismic spectrum" methods. Each trial structure is exposed to each credible intensity earthquake and the life losses calculated. These losses may be looked at in

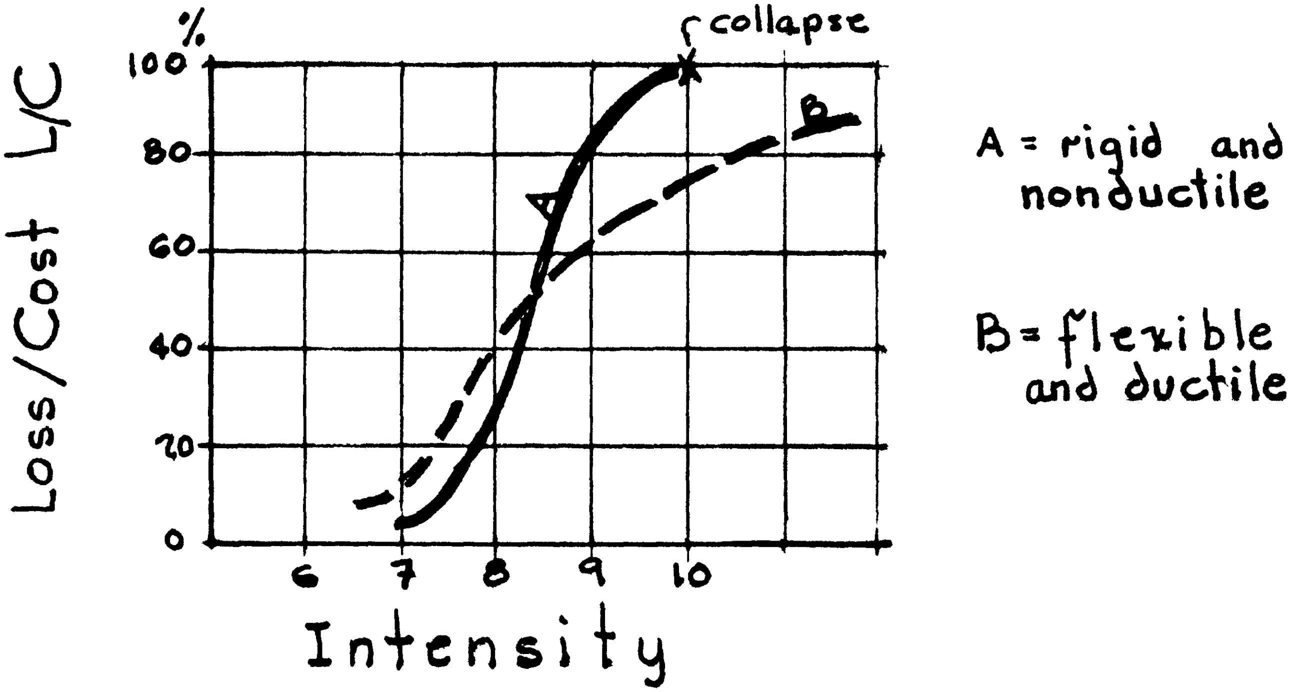

Figure 1--Property Loss Spectrum

absolute loss terms or expressed as a mortality ratio similar to insurance statistics or expressed as life loss to dollar-cost of the structure. Different engineers may prefer different terms but regardless of the specific dimensions of comparison there emerges from such an analysis an explicit profile of the seismic safety of each trial structure throughout the range of credible earthquake hazards. Typical results of an analysis of a brittle nonductile structure and a flexible ductile structure (See Figure 2) are shown in terms of the deaths to population ratio D/P of the structure. Here again, the engineer can extend the range of his understanding of the safety and cost-effectiveness of his design to embrace the full spectrum of risk to those who live in the buildings that he designs.

Since there is a unique relationship between expected intensity and time, the "Seismic Spectrum Design" process allows the engineer to extend his analysis to consider the probability of expected seismic events and their expected losses. In this way the cost-effectiveness of any realistic design option can be investigated probabilistically and related to the risks to which society is exposed such as fire, disease, and auto accidents.

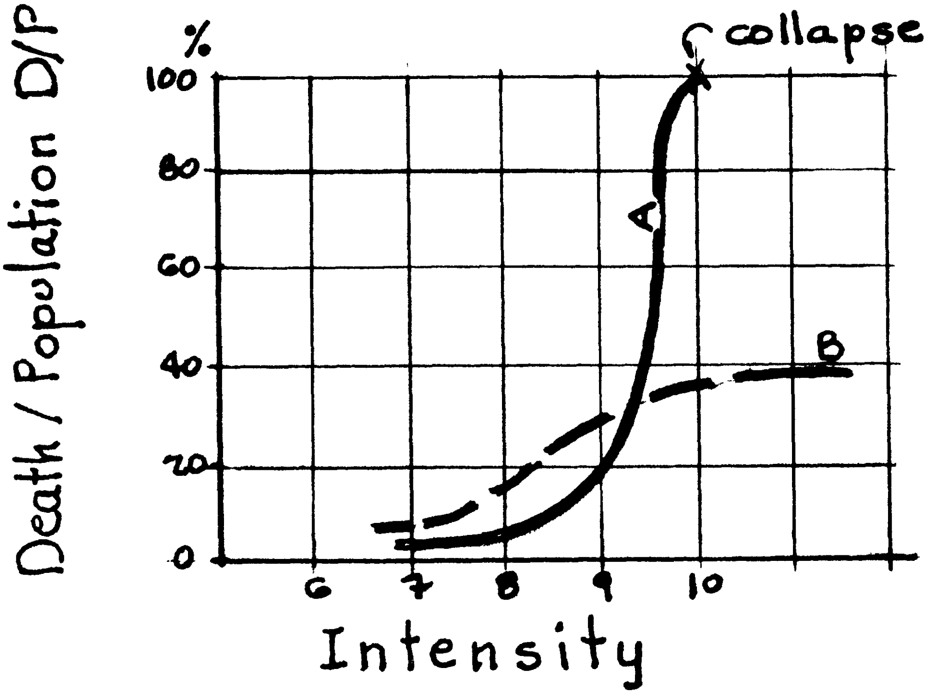

Figure 2--Life Loss Spectrum

CONCLUSIONS

The role of the engineer in the scenario of seismic safety is played in the company of many other equally dedicated players--seismologists, geologists, lawmakers, architects, planners and builders, all of which are important.

Because the safety and cost requirements of each building are unique, there are no structural solutions that fit all cases. For simple structures and low risk structures, the structural scheme may be selected and the design carried-out using the requirements found in building codes and manuals of practice. For complex structures and structures of high risk or importance to a community, the engineer has at his disposal the "Seismic Spectrum" approach that allows the engineer to minimize the potential losses of property and life and to maximize the cost-effectiveness of his contribution to his client and to the whole of society.

INTEGRATED EMERGENCY MANAGEMEMT SYSTEM AND THE EARTHQUAKE THREAT

by

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For a primitive tribe, earthquake planning was a matter of sacrificing an occasional goat to the gods, earthquake response was digging yourself and your neighbor out from under a fairly small pile of mud and thatch--earthquake recovery was finding a new supply of mud and thatch, and earthquake mitigation was hauling the mud and thatch over to the next valley, to rebuild where the gods were a little more friendly.

A Modified Mercalli intensity VIII in a modern metropolitan area today would not be a simple matter of goats, mud, and thatch. Nor would the planning, response, recovery, and mitigation required to deal with a major disaster be a simple series of acts. They each require very complex actions by specialists and generalists who are trained and knowledgeable in emergency management.

The idea of an individual manager at the working level of a disaster has been around for a long while. The senior fire captain on the scene has traditionally directed the firefighting efforts. The senior law enforcement officer has directed the police and so on. But the idea of someone to act as an overall manager to coordinate the broad range of activities demanded in responding to a major disaster is a fairly new concept, and one that requires a great deal of groundwork if it is to be successful.

First it requires advanced planning. Vulnerability analysis is the starting place within the jurisdication. Whether it be a town, county, State, or even a nation as a whole, the potential for disaster must be spelled out.

What is the natural disaster potential? Tornadoes? Flash Floods? Winterstorms? Drought? What about other potential disasters, such as, earthquakes, volcanoes, and earth subsidence? Has modern technology built manufacturing plants or refineries that involve dangerous or hazardous materials near populated areas? Are there transportation arteries, such as, interstate highways, rail lines, and riverways? Are pipelines located where they would endanger life and property? A study in "Murphy's Law," if you will, considering past history, the vulnerability of people and property, the potential for occurrence, and the effects of disaster in a worst case scenario.

Once these potential dangers and their possible effects are thoroughly reviewed, studied and evaluated, then you must try and rank them in some sort of priority of possible occurrence. If you've had a tornado every leap year since 1800 but only one drought then your priority for tornadoes would be pretty high. But you can't ignore a possible drought and its impact. After you've gotten your disasters in a line you must take a look at what needs to be done and who is qualified to do it!

That, unfortunately, is not so simple as it sounds when you consider the multilayered, overlapping areas of responsibility of assorted local, county, State, and Federal agencies. Complicate it further by the maze of political jurisdictional boundaries, the the potential for bureaucratic "turf" squabbles and the natural reluctance of most humans to think about unpleasant things like catastrophic disasters. The wonder is not that it takes so long, but that we're able to do it at all!

Perhaps the best example of the inertia involved in planning is the fact that we are here today, almost a decade since Dr. Otto Nuttli's research was completed and 140 years since the last major earthquake. We are basically still only in the talking stage! The overall, comprehensive earthquake plan for the New Madrid Seismic Zone is yet to come! I think that this is no reflection on us, only a concrete demonstration of the magnitude and complexity of the task before us, and the complexity involved in any major planning for disaster, be it natural, technological or even the ultimate disaster--nuclear war!

The second step is response. It is the basic test of your planning and the one true measure of success in emergency management. It is also the one we dread most because it means that despite all our work, all our planning, and all our mitigation efforts, disaster has come upon us!

Unfortunately, we here in Arkanas have had more than our share in the past 12 months. It has cost us two score dead, hundreds of injuries, and an estimated one billion dollars. Forty three of our 75 counties have been declared as Presidential Disaster areas.

As destructive as the past year has been, it pales in significance to the potential devastation of a major earthquake along the southern end of the New Madrid Seismic Zone. The result of that event would measure deaths in the thousands and destruction in the hundreds of billions of dollars. It would truly be, in Dr. Nuttli's words, "... a disaster second only to all out nuclear war."

The response force needed for a disaster of that magnitude boggle the mind when you consider it in individual terms of emergency medical services, search and rescue, debris removal, law enforcement, firefighting, and the human services burden of sheltering and feeding tens of thousands made homeless.

In this aspect, the response and recovery phases are linked during the initial post-disaster period, and their effectiveness is closely tied to how well we have planned for disaster.

The long term recovery effort is a joint local, State, and Federal operation that seeks to rebuild and restore society. It is tied to the fourth step of emergency management, mitigation which seeks to decrease the threat by insuring that society recognizes that certain phenomena and conditions do pose a threat to life and property, and certain actions can be taken to reduce that threat. Sounds easy, doesn't it? Everyone is going to leap at the chance to reduce the disaster threat--not so! Mitigation is the toughest part of the four steps, because it impacts tradition and most critical of all, the pocketbook!

For example, the consequences of these imaginary mitigation efforts. Establishing a flood plain ordinance to lower losses from flooding and find out how quick the property owners respond when told that the use of their land is now regulated by the government, and they must now abide by strict rules on land use. Tell a local government and local citizens that their town is contaminated with dioxin and on a flood plain and they, for their own safety, must be pulled up by the roots and be relocated, and watch the impact on City Hall, the State House, and even the White House. Look at the economic impact when a manufacturing facility, one that was the pride of the community and now is a potential disaster, is closed down or drastically reduced in operations to prevent a possible disaster. The economic impact of jobs lost, retail and wholesale business reduced to below the zero profit margin, tax base reduced with associated reduction in the basic governmental services needed to protect and maintain society, and see how well the citizens and their elected representatives accept mitigation.

That is one of the major things that we must all consider in the actions we propose here that relate to mitigation. If they are so complex, so expensive, so rigid, that they cripple the economy and bind the individual and local government in a stifling bureacracy, then we have created a situation where the operation was a success, but the patient died!

I will assure you from personal experience, that no matter how well meaning the regulations of mitigation are, they must not adversely impact the life and economy of the community. All the citizens must be convinced that the mitigation effort, however demanding it may be, is worth the cost. If either of those criteria are not met then mitigation will surely fail.

That, very briefly, is the idea of Integrated Emergency Management (IEM). It is nothing more than a systematic approach to look at ALL potential disasters in a given locality, to assess the people and resources available, and to formalize in a plan who does what, when, and where they can get additional help. IEM establishes a known and understood system of communications, coordination and cooperation between various agencies and their counterparts at various levels of government to bring in the volunteer groups who can supplement the existing response forces and insure that response is effective when disaster does occur. It further considers and organizes the recovery efforts, both immediate and long term, after disaster has occurred, and looks at the efforts to mitigate disaster by preventing situations that lead to disaster.

In the coming months you will hear much about "Integrated Emergency Management Systems" and "Comprehensive Emergency Management." They should be neither contradictory nor confusing to you. They simply mean "integrating" emergency planning--response, recovery, and mitigation into a single system to "comprehensively" manage any disaster large or small.

Our task is to insure that disaster planning for the New Madrid Seismic Zone, however large and complex it may be, is integrated into the existing emergency management systems of local governments of the seven States, and of the Federal sector. And that the response, recovery, and mitigation activities for dealing with earthquakes meet the comprehensive requirements of emergency management at all levels. If we succeed, then we will have met our goal to protect lives and property and preserve the fabric of our society, in so far as is humanly possible. I believe that is a worthy and challenging effort for us all.

PLANS OF U.S. GEOLOGICAL SURVEY FOR EVALUATION OF REGIONAL AND URBAN EARTHQUAKE HAZARDS

by

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INTRODUCTION

In Arkansas, as well as in every other State, the potential for an earthquake disaster depends upon three factors. They are:

1) The magnitude of the earthquake.
The larger the magnitude the greater the potential for generating severe levels of ground shaking and triggering other geologic hazards such as surface fault rupture and ground failure.

2) The location of the earthquake source relative to an urban area.
The closer the source of energy release to an urban area the greater the potential for damage and loss of life.

3) The degree of earthquake preparedness within the urban area.
The lower the level of preparedness the greater the potential for catastrophic losses and social and economic disruption following an earthquake.

The earthquake that devastated the city of Tangshan, China, on July 28, 1976, is one example of an extreme earthquake disaster that could have been mitigated. Tangshan, an industrialized city of approximately one million people, was located in a seismic zone which, according to the Chinese building Code, did not require earthquake-resistant design. Therefore, this city of unreinforced brick buildings was almost totally unprepared for the physical effects of ground shaking which the magnitude 7.8 earthquake generated. The earthquake's epicenter was within the city and the causative fault ruptured within and beyond the borders of the city. The result was a very great disaster. Eighty-five precent of the city's buildings collapsed or were severely damaged and several hundred thousand people lost their lives. Industries in Tangshan were out of operation for long periods and it took more than 6 years for one-half of the city to be rebuilt.

U.S. GEOLOGICAL SURVEY PROGRAM TO EVALUATE EARTHQUAKE HAZARDS

Beginning October 1, 1983, the U.S. Geological Survey (USGS) will initiate a new program entitled, "Evaluation of Regional and Urban Earthquake Hazards." This program, a part of the National Earthquake Hazards Reduction Program (NEHRP), was created after considerable debate and discussion. The goal is to acquire basic information and to establish the partnerships needed for evaluating earthquake hazards and risk in broad geographic regions containing important urban areas. This effort will provide a sound technical basis for loss-reduction measures that can be devised and implemented by local governments. The program is unique in that it combines comprehensive research goals and an effort to foster implementation of research results. The scientific emphasis is on developing a fundamental physical understanding of the cause, frequency of occurrence, and the physical effects of earthquake ground shaking, surface faulting, ground failure, and tectonic deformation in various geographic regions. The implementation emphasis is on evolving practical loss reduction measures. This program element requires a high degree of team work, utilizing a multidisclipinary Task Force to accomplish the program objectives. Users of the information produced by this program (for example: Federal, State, and local government agencies involved in emergency response, scientific research, building safety, and planning) cannot find such an integrated synthesis and assessment of earthquake hazards in the scientific literature. Also, loss estimates have not been updated in most urban areas for many years and the risk may be seriously underestimated due to the sharp increase in building wealth and construction.

The U.S. Nuclear Regulatory Commission and the Federal Emergency Management Agency have provided funding for selected research related to this element in the past and, as potential partners, may again fund research in FY 1984 or during the term of the program.

Although this program element is new, its general objectives were carried out in the past under the NEHRP. Past accomplishments of the NEHRP, such as the effort made in the past 3 years to synthesize and document the multi-disciplinary research studies on earthquake hazards conducted in the Los Angeles region, are transferrable. The urban areas that will receive priority attention include: 1) the Wasatch front, 2) Central Mississippi Valley, 3) Southern California, 4) Northern California, 5) Anchorage, Alaska, 6) Puget Sound, 7) Charleston, South Carolina, and 8) the Boston area. The objectives, strategies, and tasks of the program are described below:

Objective 1: Evaluation of Urban Hazards in the Wasatch front, Utah, Region

Strategy: In FY 1984, the top priority is to conduct research and topical studies in the Wasatch front, emphasizing implementation in the Salt Lake City-Ogden-Provo region. Other geographic regions of the Nation will receive lower priority. Research studies will proceed on both a regional and local scale and will be designed to delineate, evaluate, synthesize, and document earthquake hazards (ground shaking, ground failure, surface faulting, and tectonic deformation), and risk in the Salt Lake City-Ogden-Provo urban corridor. The objectives for FY 1984 will be accomplished by integrating independent research projects to achieve the program goals. A **Task Force** approach will be utilized. A multidisciplinary team, selected from throughout the USGS and through the USGS's external research program, will be formed to perform an integrated hazards assessment for the Wasatch front. The Task Force will have well defined short- and long-term goals. State resources and expertise will be involved in the planning process and the research program to the fullest extent possible, forging partnerships.

Task 1: Information System - Because each research project produces raw data and information, the goal is to develop a comprehensive data base, available to both internal and external users, that is as uniform in quality and as complete on a regional and urban scale as possible. The key is to develop a practical system for the development, management, and dissemination of new data needed in hazard evaluations. Creation of a directory showing where the basic data are located and their availability is a possible strategy in this task. Several categories of data can be identified, including: seismicity, gravity and magnetics, well logs, seismotectonic data, fault trenching data, stress measurements, seismic reflection profiles, ground failure data, soils data, ground motion data, inventory of structures, damage assessments, bibliographic references, publications, and maps.

Task 2: Synthesis of Geologic and Geophysical Data for Hazards Evaluations - The goal is to produce synthesis reports describing what is known about various earthquake hazards in the region and recommending future research to increase the state-of-knowledge required for the development and implementation of loss reduction measures. The research will provide a fundamental understanding of the nature and extent of the earthquake hazards of ground shaking, ground failure, surface faulting, and tectonic deformation. Development of models (hypotheses) and analysis of data are important aspects of this task.

Task 3: Ground Motion Modeling - The goal is to develop deterministic and probabilistic ground motion models and maps. Commentaries will be provided so that others can use the models for generating ground-shaking hazard maps and for evaluating the sensitivity of uncertainity in median values of important physical parameters.

Task 4: Loss Estimation Models - The goal is to develop economical methods for acquiring inventories of structures and to develop a standard model for loss estimation. Commentaries on the use of such a model and its limitations will be provided so that others can use it. Loss estimates will be produced.

Task 5: Implementation - The goal is to foster planning, in the Salt Lake City-Ogden-Provo area, to conduct workshops, and to publish open-file reports and a professional paper. All activities will build on the Governor's conference on geological and hydrological hazards convened in Salt Lake City, August 10-11, 1983. Meetings and workshops will be organized in cooperation with representatives of State survey personnel, other State agencies, academia, and private companies. An integrated workplan involving all concerned parties will be created. At least one workshop will be conducted every year to define the needs of the user community, to transfer the hazards information and research results, to make recommendations, and to foster an environment for implementation. Each workshop will be documented with an open-file report ("red book"). At the end of a three year period a professional paper will be compiled, building on results reported in prior workshops. The professional paper will describe the status of all research, specifying facts about what is known and the research that is required to reach the goal of implementation at the local level. Recommendations for future research needed to accelerate learning and to enhance implementation will be emphasized.

Objective 2: Evaluation of Urban Hazards in the Central Mississippi Valley Region

Strategy: Conduct research and topical studies in the Mississippi Valley, the location of three great earthquakes in 1811-1812. The goal is to delineate, evaluate, synthesize, and document earthquake hazards and risk in the central Mississippi Valley Region.

Task 1: Information System - Because each research project produces raw data and information, the goal is to develop a comprehensive data base, available to both internal and external users, that is as uniform in quality and as complete on a regional and urban scale as possible. The key is to develop a practical system for the development, management, and dissemination of new data needed in hazard evaluations.

Task 2: Synthesis of Geologic and Geophysical Data for Hazards Evaluations - The goal is to produce synthesis reports describing what is known about various earthquake hazards in the region and recommending future research to increase the state-of-knowledge required for the development and implementation of loss reduction measures. The research will provide a fundamental understanding of the nature and extent of the earthquake hazards of ground shaking, ground failure, surface faulting, and tectonic deformation. Development of models (hypotheses) and analysis of data are important aspects of this task.

Task 3: Ground Motion Modeling - The goal is to develop deterministic and probabilistic ground motion models and maps. Commentaries will be provided so that others can use the models for generating ground-shaking hazard maps and for evaluating the sensitivity of uncertainity in median values of important physical parameters.

Task 4: Loss Estimation Models - The goal is to develop economical methods for acquiring inventories of structures and to develop a standard model for loss estimation. Commentaries on the use of such a model and its limitations will be provided so that others can use it. Loss estimates will be produced.

Task 5: Implementation - The goal is to foster planning, in the central Mississippi Valley region, to conduct workshops, and to publish open-file reports. The activities will build on the comprehensive USGS's professional paper published in 1983. Meetings and workshops will be conducted in cooperation with representatives of State survey personnel, other State agencies, academia, and private companies to define the needs of the user community, to transfer the hazards information and research results, to recommend further studies, and to foster an environment for implementation. In April 1984, a workshop on earthquake hazards in the New Madrid Seismic Zone will be cosponsored with the Missouri Academy of Sciences; the proceedings will be documented with an open-file report ("red book").

Objective 3: Evaluation of Urban Hazards in Other Geographic Regions

Strategy: Conduct research and topical studies on earthquake hazards in other urban regions, such as: Northern California, Southern California, Puget Sound, Alaska, Southeastern United States, and the Northeastern United States. Although first priority will be given to establishing a "critical mass" of effort in the Salt Lake City-Ogden-Provo urban region, an effort will be made to continue to build expertise in other urban areas which, in time, will become the first priority of this program element.

Task 1: Information System - Because each research project produces raw data and information, the goal is to develop a comprehensive data base, available to both internal and external users, that is as uniform in quality and as complete on a regional and urban scale as possible. The key is to develop a practical system for the development, management, and dissemination of new data as well as existing data.

Task 2: Synthesis of Geologic and Geological Data for Hazards Evaluations - The goal is to produce synthesis reports describing what is known about various earthquake hazards in the region and recommending future research to increase the state-of-knowledge required for the development and implementation of loss reduction measures. The research will provide a fundamental understanding of the nature and extent of the earthquake hazards of ground shaking, ground failure, surface faulting, and tectonic deformation. Development of models (hypotheses) and analysis of data are important aspects of this task.

Task 3: Ground Motion Modeling - The goal is to develop deterministic and probabilistic ground motion models and maps. Commentaries will be provided so that others can use the models for generating ground-shaking hazard maps and for evaluating the sensitivity of uncertainity in median values of important physical parameters.

Task 4: Loss Estimation Models - The goal is to develop economical methods for acquiring inventories of structures and to develop a standard model for loss estimation. Commentaries on the use of such a model and its limitations will be provided so that others can use it. Loss estimates will be produced.

Task 5: Implementation - In FY 84, the goal is to foster planning, in Alaska, Puget Sound, northern and southern California, and South Carolina. Meetings and workshops will be conducted in cooperation with representatives of State survey personnel, other State agencies, academia, and private companies to define the needs of the user community, to transfer the hazards information and research results, to recommend further studies, and to foster an environment for implementation. Close cooperation with Association of Bay Area Governments (ABAG) and Southern California Earthquake Preparedness Project (SCEPP) will be continued in California. Each workshop will be documented with an open-file report ("red book"). Specialty seminars on all aspects of earthquake hazards and risk will be held in conjunction with the Eighth World Conference on Earthquake Engineering, scheduled for July 1984 in San Francisco. Planning for a National conference commemorating the 100th anniversity of the 1886 Charleston earthquake will be initiated in 1984.

CONCLUSIONS

This program will utilize both internal and external resources to build regional and local expertise in the evaluation of earthquake hazards and risk. An improved state-of-preparedness will result throughout the United States as a consequence of this program. With the next 10 years all parts of the Nation should benefit from this program.

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