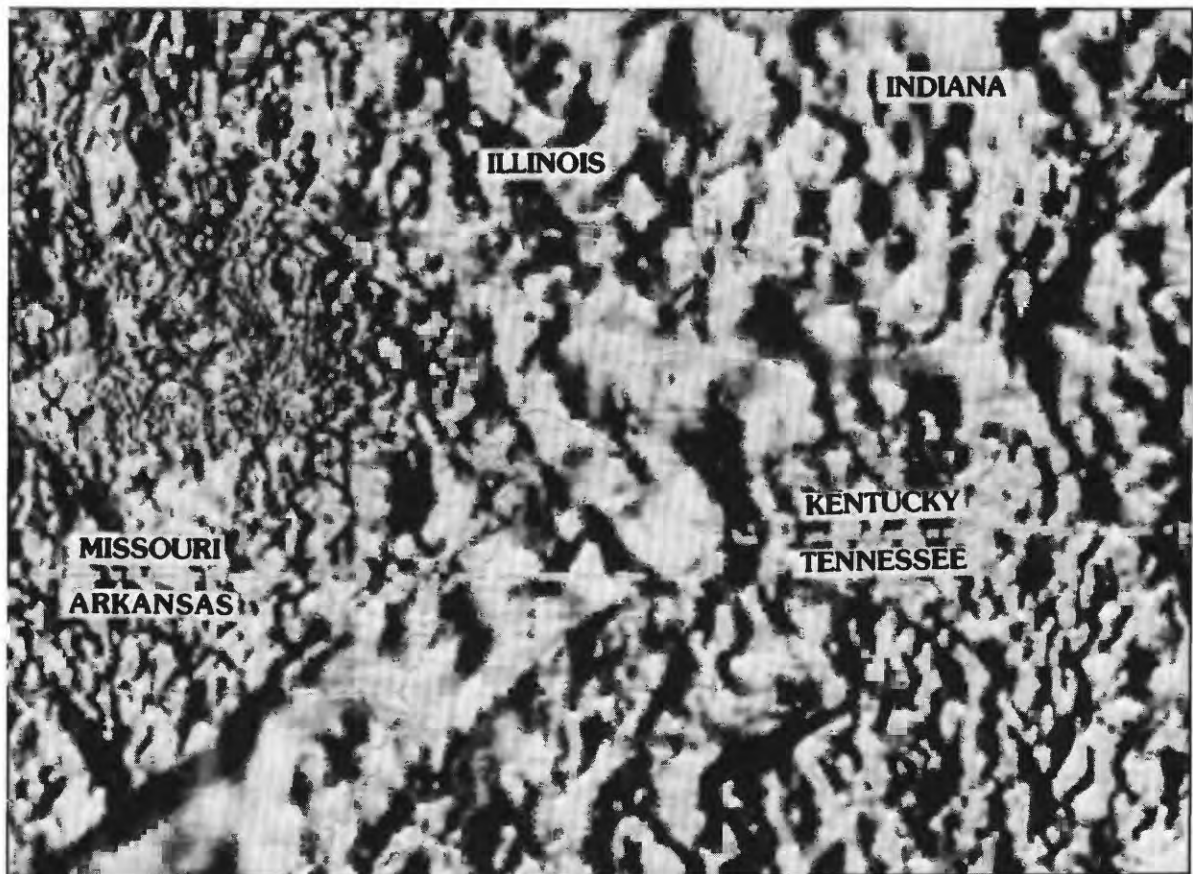


Geodetically Derived Strain Across the Northern New Madrid Seismic Zone

Seismic Hazard Mitigation in the Central United States: The Role of the States

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1538-F-G



Cover. Part of a gray, shaded-relief, reduced-to-pole magnetic anomaly map. Map area includes parts of Missouri, Illinois, Indiana, Kentucky, Tennessee, and Arkansas. Illumination is from the west. Figure is from *Geophysical setting of the Reelfoot rift and relations between rift structures and the New Madrid seismic zone*, by Thomas G. Hildenbrand and John D. Hendricks (chapter E in this series).

Investigations of the New Madrid Seismic Zone

Edited by Kaye M. Shedlock and Arch C. Johnston

F. Geodetically Derived Strain Across the Northern New Madrid Seismic Zone

By Richard A. Snay, James F. Ni, and Helen C. Neugebauer

G. Seismic Hazard Mitigation in the Central United States: The Role of the States

By Robert B. Olshansky

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1538-F-G

*Chapters F and G are issued as a single volume
and are not available separately*



UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For Sale by U.S. Geological Survey, Map Distribution
Box 25286, MS 306, Federal Center
Denver, CO 80225

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Library of Congress Cataloging-in-Publication Data

Geodetically derived strain across the northern New Madrid seismic zone / by Richard A. Snay ... [et al.]. Seismic hazard mitigation in the Central United States: the role of the States / by Robert B. Olshansky.

p. cm.—Investigations of the New Madrid seismic zone : F–G U.S. Geological Survey professional paper ; 1538)

Includes bibliographical references.

Supt. of Docs. no.: I 19. 16: 1538–F–G

1. Seismology—Missouri—New Madrid region. I. Title: Geodetically derived strain across the northern New Madrid seismic zone. II. Title: Seismic hazard mitigation in the Central United States: the role of the States. III. Series. IV. U.S. Geological Survey professional paper ; 1538.

QE535.2.U6159 1994 vol. F–G

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Geodetically Derived Strain Across the Northern New Madrid Seismic Zone

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U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1538-F



UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

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GEODETICALLY DERIVED STRAIN ACROSS THE NORTHERN NEW MADRID SEISMIC ZONE

By Richard A. Snay,¹ James F. Ni,² and Helen C. Neugebauer¹

ABSTRACT

Data from a 1991 Global Positioning System (GPS) survey are combined with preexisting GPS and triangulation-trilateration data to estimate the rate of horizontal deformation across the northern New Madrid seismic zone (NMSZ) for the 1929–91 interval. We estimate that the maximum horizontal shear-strain rate, $\dot{\gamma}$, equals 0.030 ± 0.019 $\mu\text{rad/yr}$ and the direction of maximum horizontal contraction, θ , equals $116^\circ \pm 19^\circ$. (Throughout this report, a dot over a symbol denotes the time derivative of the quantity represented by the symbol.) We also estimate $\dot{\gamma}$ and θ for four subregions of the northern NMSZ to test if spatial variability in the strain field might explain why our estimate for $\dot{\gamma}$ for the entire northern NMSZ does not differ from zero at the 95 percent confidence level. Two of these subregions define a north-south partition of the northern NMSZ; the other two define an east-west partition. Estimates for $\dot{\gamma}$ and θ do not differ from one subregion to another at the 95 percent confidence level, nor do any of the four $\dot{\gamma}$ estimates differ from zero at the 95 percent confidence level. Our estimate of $\dot{\gamma}$ for the northern NMSZ is consistent with (linear) strain rates derived from seismic and geologic evidence. Our estimate of $\dot{\gamma}$, however, differs significantly from a geodetic estimate of $\dot{\gamma}$ that is in excess of 0.1 $\mu\text{rad/yr}$ —this geodetic estimate has been derived for the southern NMSZ.

INTRODUCTION

Three major earthquakes, each with body magnitude greater than 7, occurred in the New Madrid area during the winter of 1811–12. Moreover, a high level of microseismicity has been observed in this area since the installation

of a seismic network in 1974. Epicenters of more than 2,000 small events ($m_b \leq 5.0$) recorded since 1974 delineate three linear trends (fig. 1). Focal mechanisms for events on the southern and northern trends indicate right-lateral slip on near-vertical faults in the 4- to 14-km depth range (Himes and others, 1988). Events on the central trend distribute on northwesterly trending planes that dip to the southwest in this same depth range (Chiu and others, in press). This central trend represents a left-restraining step connecting the two right-lateral fault segments.

Strain rates for the New Madrid seismic zone have been inferred from seismic and geologic evidence. The inferred rates range from 0.007 $\mu\text{strain/yr}$ (Anderson, 1986) to 0.150 $\mu\text{strain/yr}$ (Johnston and Nava, 1985) with several values in between. To measure strain rates directly, a GPS survey was conducted in the early spring of 1991 (fig. 1). The survey measured relative positions among 46 previously established geodetic stations. Forty of these 46 stations had been positioned originally by triangulation surveys performed between 1929 and 1955. Moreover, some of these stations had been occupied during two or more geodetic surveys prior to the 1991 GPS survey.

Two independent research groups have analyzed different combinations of the new GPS data with preexisting geodetic data. One group (Liu and others, 1992) has studied a combined geodetic data set for the region located south of lat 36.4°N ., here called the southern NMSZ. We report here on our study of geodetic data for the region located north of this latitude, the northern NMSZ.

DATA

The GPS survey commenced on 12 March 1991 and concluded on 24 April 1991. The survey involved 30 individual observing sessions. Sessions averaged 5.5 hours in duration and were scheduled during that part of the day when the geometry of the satellite constellation was optimal for measuring relative positions among the stations. Five Trimble 4000SST dual-frequency receivers were deployed simultaneously for most sessions. Some sessions,

¹ National Geodetic Survey, Coast and Geodetic Survey, National Ocean Service, NOAA, Rockville, MD 20852.

² Department of Physics, New Mexico State University, Las Cruces, NM 88003.

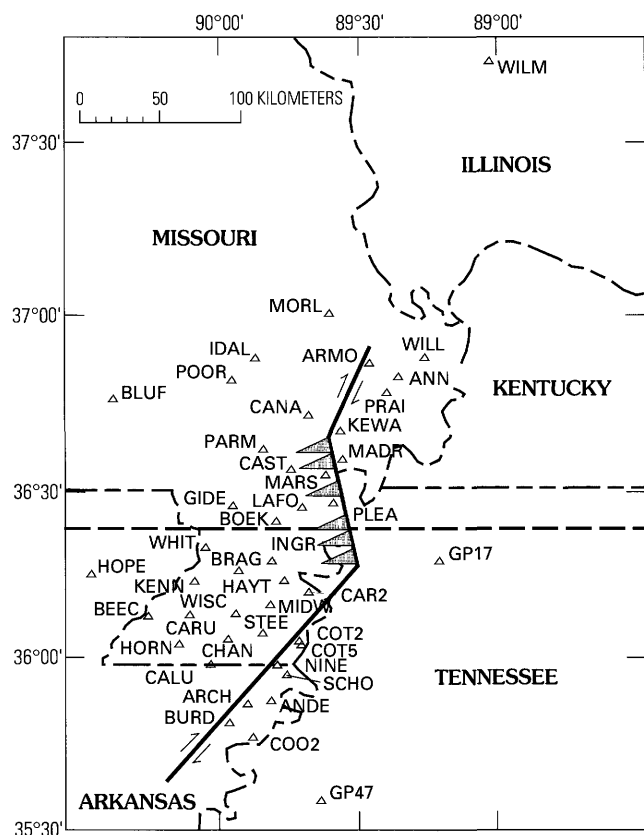


Figure 1. Geodetic stations occupied during the 1991 GPS survey of the NMSZ. Fault lines are inferred from recent seismicity. Triangles on central fault segment indicate events that occur on northwesterly trending planes that dip to the southwest. The dashed line denotes the boundary between the northern NMSZ and the southern NMSZ.

however, involved as many as seven receivers, others as few as three. Each station was occupied for at least two sessions.

We processed the GPS phase data using the OMNI software package (Mader and others, 1991) to derive three-dimensional intersite vectors together with appropriate covariance information among these vectors. Each intersite vector ($\Delta X, \Delta Y, \Delta Z$) represents the difference between the positional coordinates of two geodetic stations in an adopted Cartesian reference system. We processed the data using "precise" orbital information for the GPS satellites as provided by the Defense Mapping Agency. The term precise is used to distinguish these orbits, which have been postfit to satellite-tracking data, from those orbits that are broadcast in real time as part of the GPS signal.

The 30 observing sessions, in combination, produced 120 intersite vectors that we subsequently employed to estimate three-dimensional positional coordinates for the 46 GPS stations in the context of a least squares network adjustment. The ADJUST software of Milbert and Kass (1987) was used for this estimation process. Data residuals

from this network adjustment provide an indication of the internal precision for the GPS vectors. The north-south components of the 120 residual vectors have a precision, p , of 7.0 mm:

$$p = \left(\sum_i v_i^2 / f \right)^{0.5} \quad (1)$$

where

v_i denotes the north-south component of the i th residual vector, and

f denotes the degrees of freedom for the north-south components of these vectors.

In particular,

$$f = 120 \text{ vectors} - 46 \text{ stations} + 1 \text{ constraint} = 75$$

The constraint was imposed because intersite GPS vectors provide no information about absolute position. Hence, the latitude of one station was specified and held fixed for the estimation process. Similarly, the longitude and the elevation of this station were also specified and held fixed. Correspondingly, the east-west components have a precision of 11.6 mm, and the vertical components have a precision of 42.8 mm.

Figure 2 shows the distribution of residuals in each component as a function of intersite distance. Given that each station was occupied for at least two observing sessions, derived horizontal coordinates should have a precision of at least 10 mm in each component relative to the adopted coordinates for the "fixed" station, "Bluffport" (BLUF in fig. 1). In contrast, coordinates derivable from existing triangulation-trilateration data have a precision that is more than an order of magnitude larger.

From the geodetic database maintained by the National Geodetic Survey (NGS), we extracted preexisting geodetic observations involving stations located within or near the rectangular region bounded by lat 36.25°N. and 37.25°N. and by long 89°W. and 90°W. This region encloses the northern NMSZ, plus it slightly overlaps the southern NMSZ. These data, some measured as early as 1929, include observed directions, azimuths, and distances for lines that connect monumented geodetic stations. The data also include some 78 intersite GPS vectors that had been observed prior to the 1991 survey.

Whereas an azimuth refers to the orientation of a line relative to geographic north, a direction refers to a line's orientation relative to an arbitrary azimuth—the azimuth of the zero mark on the measuring instrument. Directions for several lines emanating from a station are measured as a group; whereby, angles among these lines may be obtained by differencing directions in the group. The standard error for a typical direction observation is about 0.7 seconds of arc (Gergen, 1989); for a typical azimuth observation, the standard error is about 1.4 seconds of arc (Strange, 1989);

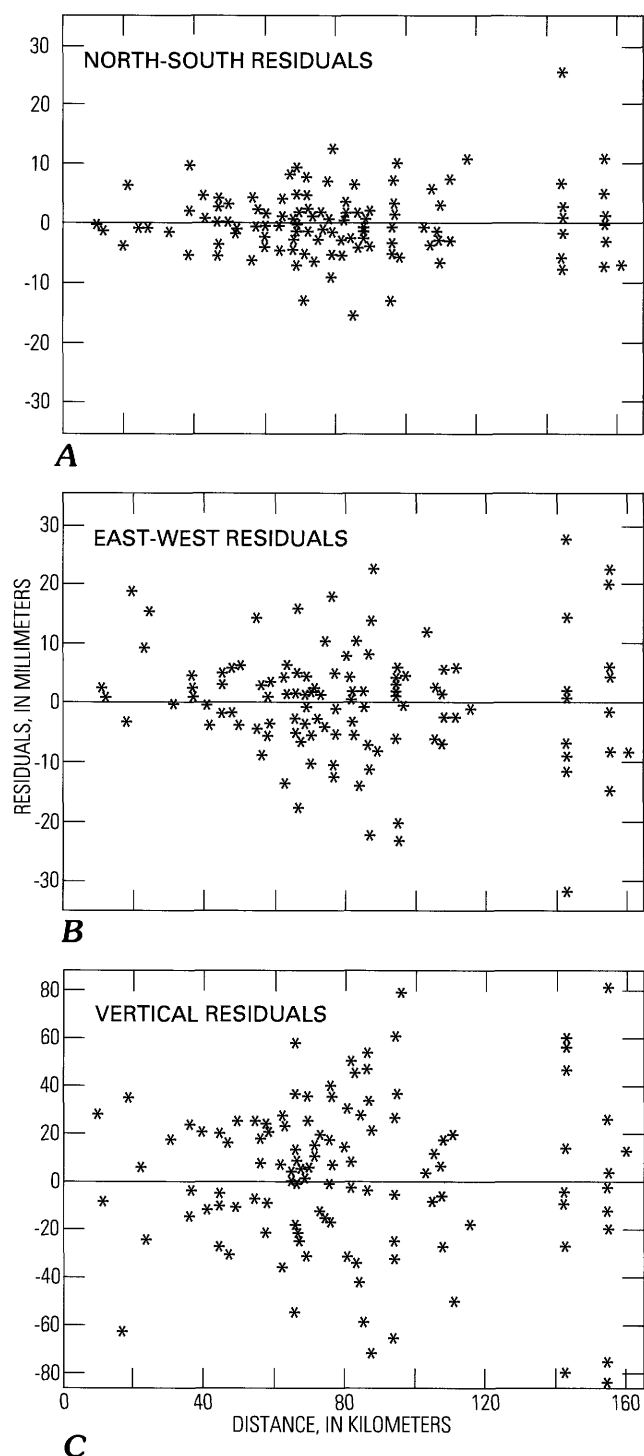


Figure 2. Residuals for intersite GPS vectors from a minimally constrained adjustment of the data. Residuals are plotted as a function of intersite distance. *A*, North-south residuals; *B*, East-west residuals; *C*, Vertical residuals.

standard error is about 1.4 seconds of arc (Strange, 1989); and for a typical distance observation, the standard error is between 1 and 2 parts per million (Gergen, 1989).

ESTIMATING HORIZONTAL DEFORMATION

We combined the 1991 GPS vectors with the pre-existing geodetic data for the northern NMSZ. Table 1 summarizes the temporal distribution of this combined data set, and figure 3 summarizes the spatial distribution. Note that the combined data set contains 288 geodetic stations, whereas figure 3 shows only those 44 stations that were occupied for at least two different surveys with at least 15 years separating the first and last occupations. These statistics reveal that the data for most of the geodetic stations contribute only indirectly towards the resolution of crustal deformation by providing network ties among the repeatedly observed geodetic stations.

We processed the combined data set through the software package entitled DYNAP (Drew and Snay, 1989). This software accepts various geodetic data types to generate least-squares estimates for the positional coordinates of the stations and, simultaneously, for parameters that characterize crustal deformation rates. For our application, we assumed that the deformation rate is spatially uniform throughout the area spanned by these data and that deformation occurred at a constant rate during the 1929–91 interval.

Certain constraints were introduced to eliminate existing datum defects and configuration defects in the data. For example, because the data provide height information at the GPS stations only, the heights at all the non-GPS stations were constrained to adopted values, and the tilt-rate parameters in DYNAP were constrained to zero. In all cases, we selected constraints so as to avoid biasing the geodetic data.

Preliminary results with DYNAP revealed several inconsistencies among the data involving station "Pleasant" (PLEA in fig. 1). We subsequently treated "Pleasant" as two separate stations—one for the GPS data and one for the triangulation-trilateration data—and these inconsistencies disappeared. Estimated horizontal positions for these

Table 1. Distribution, by decade and type, of geodetic data used for estimating deformation within the northern NMSZ.

Interval	Directions	Distances	Azimuths	GPS vectors
1920–29	111	1	2	0
1930–39	215	2	2	0
1940–49	20	8	0	0
1950–59	665	8	0	0
1960–69	78	16	0	0
1970–79	217	231	7	0
1980–89	0	0	0	8
1990–91	0	2	0	190
Total	1,306	268	11	198

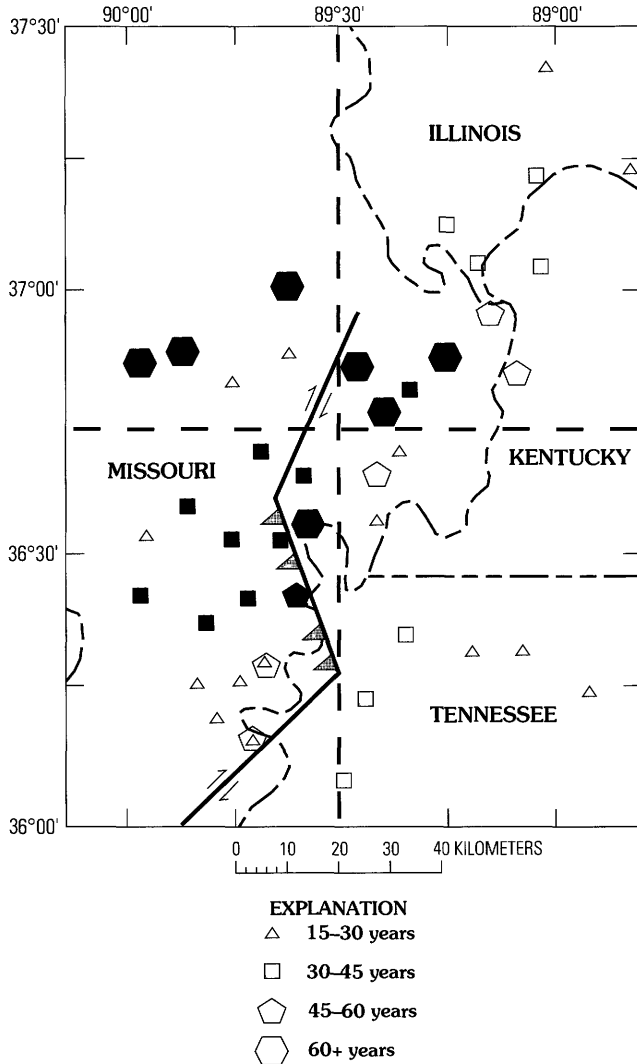


Figure 3. Selected geodetic stations in the northern NMSZ. Symbol shape indicates the time interval between the earliest and latest observations at the corresponding station. Solid symbols identify stations that were occupied for the 1991 GPS survey. The horizontal dashed line denotes the boundary between the upper and lower subregions of the northern NMSZ. The vertical dashed line denotes the boundary between the eastern and western subregions. Triangles on central fault segment indicate events that occur on northwesterly trending planes that dip to the southwest.

two stations (as derived with DYNAP) differ by more than 2 m. Because this difference exceeds any tectonic motion that may reasonably be expected, we suspect that “Pleasant” may have been disturbed by human activity.

As described by Drew and Snay (1989), the deformation parameters estimated with DYNAP may be mathematically converted into more familiar parameters. Of these parameters, only those that characterize horizontal shear-strain rates are resolved with a reasonable degree of accuracy. These parameters are conventionally represented by the symbols $\dot{\gamma}_1$ and $\dot{\gamma}_2$, where $\dot{\gamma}_1$ denotes the rate of change of a right angle whose initial side is oriented 135°,

and $\dot{\gamma}_2$ denotes the rate of change of a right angle whose initial side is oriented 90°. Here the right angles exist in a plane approximating the Earth’s surface, and angles are reckoned positive in the clockwise direction. By virtue of the fact that deformation rates are here assumed to be spatially uniform, the deformation rate, $\dot{\alpha}$, of any angle in the horizontal plane may be expressed by the equation:

$$\dot{\alpha} = (\sin 2\beta_2 - \sin 2\beta_1)\dot{\gamma}_1 + (\cos 2\beta_2 - \cos 2\beta_1)\dot{\gamma}_2 \quad (2)$$

where

β_1 and β_2 denote the azimuths of the initial and terminal sides of the angle, respectively.

The parameters $\dot{\gamma}_1$ and $\dot{\gamma}_2$ may be further transformed into the parameters $\dot{\gamma}$ and θ by the equations:

$$\dot{\gamma} = \left(\dot{\gamma}_1^2 + \dot{\gamma}_2^2 \right)^{0.5} \quad (3)$$

$$\theta = 0.5 \arctan (-\dot{\gamma}_2 / \dot{\gamma}_1) \quad (4)$$

where

$\dot{\gamma}$ denotes the maximum horizontal shear-strain rate (that is, the magnitude for the rate of angular change that is greatest among all right angles in the horizontal plane), and

θ denotes the direction of maximum contraction (or, equivalently, minimum extension) as measured clockwise from north.

Using the combined geodetic data set for the northern NMSZ, we estimate that $\dot{\gamma}$ equals 0.030 ± 0.019 $\mu\text{rad/yr}$ and that θ equals $116^\circ \pm 19^\circ$. Corresponding estimates for $\dot{\gamma}_1$ and $\dot{\gamma}_2$ are given in table 2. This estimate of $\dot{\gamma}$ does not differ from zero at the 95 percent confidence level. A possible explanation for the lack of detectable deformation is that the strain field is not spatially uniform across the region as was assumed. Significant strain in one subregion could cancel equally significant strain of opposite orientation in another subregion.

To test for spatial variability, we estimated the shear-strain rates for four subregions of the northern NMSZ (fig. 3). Two of these subregions define a north-south partition of the northern NMSZ. They are separated by lat 36.75°N . (We call these subregions “upper” and “lower” to distinguish them from the regions that we have designated as the northern NMSZ and the southern NMSZ.) The other two subregions define an east-west partition of the northern NMSZ. They are separated by long 89.5°W . Shear-strain rates derived from the geodetic data for these four subregions (table 2) do not differ from one another at the 95 percent confidence level. Also, none of the corresponding $\dot{\gamma}$ estimates differ from zero at the 95 percent confidence level. Figure 4 demonstrates these results graphically.

Table 2. Estimated shear-strain rates with standard errors for the northern NMSZ and four of its subregions.

[Northern NMSZ region is shown in fig. 1; subregions within the northern NMSZ are shown in figure 3. $\dot{\gamma}_1$, $\dot{\gamma}_2$, $\dot{\gamma}$, and θ are described in the text]

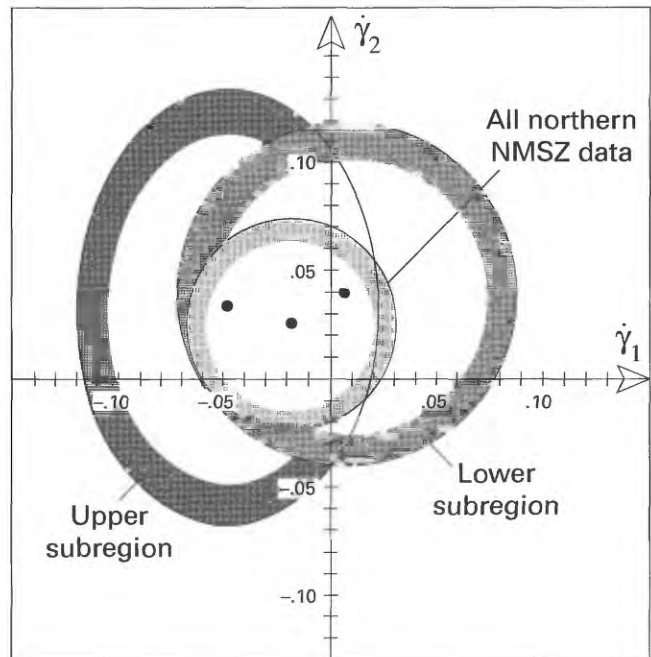
Region or subregion	$\dot{\gamma}_1$ ($\mu\text{rad/yr}$)	$\dot{\gamma}_2$ ($\mu\text{rad/yr}$)	$\dot{\gamma}$ ($\mu\text{rad/yr}$)	θ (degrees)
N. NMSZ region	-0.018 ± 0.018	+0.024 ± 0.020	0.030 ± 0.019	116 ± 19
Upper subregion	-0.048 ± 0.029	+0.032 ± 0.040	0.058 ± 0.030	107 ± 20
Lower subregion	+0.006 ± 0.031	+0.039 ± 0.032	0.040 ± 0.033	140 ± 23
Eastern subregion	-0.036 ± 0.036	+0.010 ± 0.045	0.037 ± 0.033	97 ± 36
Western subregion	+0.001 ± 0.032	+0.057 ± 0.035	0.058 ± 0.035	136 ± 16

Although it is possible to partition the northern NMSZ in various ways, we venture to conclude that the level of spatial variability in the shear-strain rate lies within the uncertainty level of the geodetic data. In particular, the data do not allow us to distinguish between the shear-strain rate of the upper subregion and that of the lower subregion even though these two subregions span distinctly different segments of the linear features delineated by recent seismicity (solid lines in fig. 3). That is, the upper subregion spans only the most northern of these seismic trends, which is thought to correspond to a near-vertical, right-lateral fault (Himes and others, 1988). The lower subregion, on the other hand, spans the central seismic trend as well as part of the other two seismic trends. Chiu and others (in press) suggest that this central trend corresponds to an active fault having a component of reverse slip.

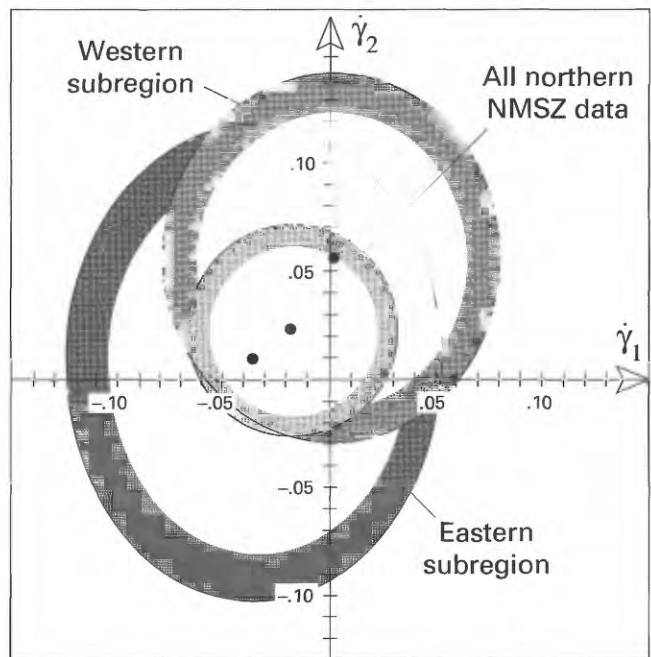
EPILOG

Geodetic data indicate that $\dot{\gamma}$ equals 0.030 ± 0.019 $\mu\text{rad/yr}$ for the northern NMSZ over the 1929–91 interval. This result is consistent with both seismic and geologic evidence. Anderson (1986, table 8) presents estimates for the linear strain rate, $\dot{\epsilon}$, in the range from 0.007 to 0.045 $\mu\text{strain/yr}$, based on seismic evidence, and in the range from 0.023 to 0.070 $\mu\text{strain/yr}$, based on geologic evidence. Furthermore, Johnston and Nava (1985) estimate that $\dot{\epsilon}$ ranges from 0.10 to 0.15 $\mu\text{strain/yr}$, based on geologic evidence. Here

$$\dot{\epsilon} = \max(|\dot{\epsilon}_1|, |\dot{\epsilon}_2|) \quad (5)$$



A



B

Figure 4. Estimated shear-strain rates with 95 percent confidence ellipses for the northern NMSZ and for four of its subregions. Axes are labeled in units of $\mu\text{rad/yr}$. Diagrams show data for: A, all of the northern NMSZ, the upper subregion, and the lower subregion; B, all of the northern NMSZ, the western subregion, and the eastern subregion. Subregions of the northern NMSZ are shown on figure 3.

where

$\dot{\epsilon}_1$ denotes the linear strain rate in the direction of maximum extension, and

$\dot{\epsilon}_2$ denotes the linear strain rate in the direction of maximum contraction (extension is reckoned as positive).

Even though $\dot{\gamma}$ and $\dot{\epsilon}$ are not directly comparable, they are related. In particular, because

$$\dot{\gamma} = \dot{\epsilon}_1 - \dot{\epsilon}_2 \quad (6)$$

it follows that

$$\dot{\gamma} \leq 2\dot{\epsilon} \quad (7)$$

for shear-strain rates expressed in units of $\mu\text{rad/yr}$ and linear strain rates expressed in units of $\mu\text{strain/yr}$.

Our estimate for the shear-strain rate across the northern NMSZ does not differ statistically from zero; however, Liu and others (1992) find that shear strain is accumulating across the southern NMSZ at a rate in excess of 0.1 $\mu\text{rad/yr}$. Their estimate is derived from a combination of the 1991 GPS data with preexisting geodetic data spanning the southern NMSZ.

ACKNOWLEDGMENTS

The 1991 GPS survey was performed by a National Geodetic Survey (NGS) field crew with assistance from David Tralli and Paul Lundgren of the Jet Propulsion Lab and from John Weber and Lisa Leffler of Northwestern University. The U.S. Geological Survey funded the greater part of this GPS survey. Edward Carlson, Cindra Craig, John Love, and Richard Yorczyk (all at NGS) and Shawn Larsen (Lawrence Livermore Lab) helped us plan the GPS survey and organize the combined geodetic data set. We thank Stephen Hilla (NGS) and Edward Timmerman (NGS) for comments that improved the presentation of this

paper. One of us (J.F.N.) was supported under U.S. Geological Survey grant no. 14-08-0001-G1933.

REFERENCES CITED

- Anderson, J.G., 1986, Seismic strain rates in the Central and Eastern United States: *Seismological Society of America Bulletin*, v. 76, p. 273–290.
- Chiu, J.M., Johnston, A.C., and Yang, Y.T., in press, Imaging the active faults of the central New Madrid seismic zone using PANDA array data: *Seismological Research Letters*.
- Drew, A.R., and Snay, R.A., 1989, DYNAP: Software for estimating crustal deformation from geodetic data: *Tectonophysics*, v. 162, p. 331–343.
- Gergen, J.G., 1989, Terrestrial data, in Schwarz, C.R., ed., *North American Datum of 1983*: Rockville, Maryland, National Geodetic Information Center, National Oceanic and Atmospheric Administration, NOAA Professional Paper NOS 2, p. 27–35.
- Himes, L., Stauder, W., and Herrmann, R.B., 1988, Indication of active faults in the New Madrid seismic zone from precise location of hypocenters: *Seismological Research Letters*, v. 59, p. 123–131.
- Johnston, A.C., and Nava, S.J., 1985, Recurrence rates and probability estimates for the New Madrid seismic zone: *Journal of Geophysical Research*, v. 90, p. 6737–6753.
- Liu, L., Zoback, M.D., and Segall, P., 1992, Rapid intraplate strain accumulation in the New Madrid seismic zone: *Science*, v. 257, p. 1666–1669.
- Mader, G.L., Schenewerk, M.S., and Chin, M.M., 1991, OMNI 2.00 User's Guide: Rockville, Maryland, National Geodetic Survey, National Oceanic and Atmospheric Administration.
- Milbert, D.G., and Kass, W.G., 1987, ADJUST: The horizontal observation adjustment program: Rockville, Maryland, National Geodetic Information Center, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NOS NGS-47, 53 p.
- Strange, W.E., 1989, Extraterrestrial data, in Schwarz, C.R., ed., *North American Datum of 1983*: Rockville, Maryland, National Geodetic Information Center, National Oceanic and Atmospheric Administration, NOAA Professional Paper NOS 2, p. 39–47.

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

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SEISMIC HAZARD MITIGATION IN THE CENTRAL UNITED STATES: THE ROLE OF THE STATES

By Robert B. Olshansky¹

INTRODUCTION

The purpose of this research is to examine potential for State-level seismic hazard mitigation policies in the seven member States of the Central United States Earthquake Consortium (CUSEC). The seven States are: Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee. The work aims at identifying:

1. Existing State-level seismic mitigation programs in the seven States,
2. General trends in the seven States regarding potential for new seismic hazard mitigation programs, and
3. Potentially effective and feasible policy directions for implementing seismic hazard mitigation.

This research assumes the plausibility that large earthquakes will occur in the New Madrid region within our lifetimes and within the lifetimes of presently existing structures. Although precise estimates of this risk vary, this general statement appears well supported by current scientific consensus (Johnston and Nava, 1985; Nishenko and Bollinger, 1990).

BACKGROUND—EVOLUTION OF EARTHQUAKE POLICY IN THE CENTRAL UNITED STATES

Scientists and policy makers over the past two decades have steadily increased their interest in the hazards of the New Madrid seismic zone. The initiation of this interest is largely attributable to the work of the late Otto Nuttli (1973). He struggled for years, virtually alone, to remind scientists and the public of previous studies (Fuller, 1912) and to recast previous work into a present-day context (Nuttli, 1987). Dr. Nuttli's work coincided with a period of gradually increasing concern with earthquake hazards throughout the United States.

FEDERAL ACTIVITIES

CONGRESSIONAL INTEREST IN EARTHQUAKE HAZARDS

Federal interest in earthquakes steadily increased following the 1964 Alaska earthquake and the 1971 San Fernando earthquake. Five years of congressional efforts culminated in the enactment of the Earthquake Hazards Reduction Act of 1977, which created the National Earthquake Hazard Reduction Program (NEHRP) (see VSP Associates, 1989). The 1977 Act was aimed largely at research and provided funding to the U.S. Geological Survey (USGS) and National Science Foundation. Congressional amendments in 1980 made the NEHRP into a more action-oriented program and added funding for the National Bureau of Standards and the newly formed Federal Emergency Management Agency (FEMA), which was designated as the lead agency.

USGS EFFORTS

In the years preceding enactment of the Earthquake Hazards Reduction Act, the USGS began to increase its presence in the Central United States. In 1973, the USGS began to study the deeply buried geologic structure in the New Madrid region (noted by McKeown, 1982, p. 7), and Saint Louis University, with USGS support, established a regional seismic network in 1974 (Stauder, 1982). These projects and related work performed by or in association with the USGS in the mid to late 1970's are reported by McKeown and Pakiser (1982).

Following the Earthquake Hazards Reduction Act, USGS research efforts in the region increased to about \$1 million per year. Beginning in 1977, the USGS began to hold a series of regional workshops and conferences that were designed to gather knowledgeable participants, exchange ideas, and strengthen earthquake hazard reduction activities in the region. By 1987, the USGS had held 38 such

¹ Department of Urban and Regional Planning, University of Illinois at Urbana-Champaign, 907 1/2 West Nevada Street, Urbana, IL 61801.

workshops (VSP Associates, 1989), with at least five of them in the Central United States: September 1981 in Knoxville, Tenn.; May 1982 in St. Louis, Mo.; September 1983 in North Little Rock, Ark.; November 1984 in Cape Girardeau, Mo.; and March 1986 in Nashville, Tenn. (Hays and Gori, 1986). Most of these workshops were cosponsored by FEMA and local agencies.

USGS research efforts in the New Madrid area increased following the Loma Prieta earthquake of October 1989. The USGS convened a workshop in Memphis in November 1989 to prepare recommendations for intensified research in the New Madrid seismic zone (Hamilton and Johnston, 1990). Congress appropriated additional funds to the USGS in fiscal year 1990 for earthquake research, including \$3 million that was allocated for New Madrid studies. A level of increased funding has continued since that time.

FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA)

FEMA was created by Executive Order in April 1979. It consisted of a reorganization of several existing Federal departments, scattered throughout Washington, D.C. (VSP Associates, 1989). In 1980, Congress designated FEMA as the lead agency in NEHRP. VSP Associates (1989) observed that, because of the youth of the agency and the ambiguous charge given by Congress, the early 1980's were characterized by periodic reorganizations and lack of direction. According to the NEHRP Five-Year Plan for 1985-89 (Federal Emergency Management Agency and others, 1984), NEHRP objectives assigned to FEMA included: post-disaster mitigation studies, earthquake hazard mitigation strategies, federal response planning, State and local preparedness planning, multihazard planning, and earthquake education and information transfer.

A major role of FEMA under NEHRP has always been to provide financial and technical assistance to the States, such as its financial support of CUSEC, cosponsorship of regional workshops, and publication and free distribution of the popularly termed "yellow book" series of technical reports. In 1989, FEMA formally began a cost-sharing program with eligible States under the Earthquake Hazards Reduction Assistance Program (44 CFR 361). Under this program, FEMA has given annual grants to the seven CUSEC States, ranging from about \$25,000 to \$75,000 per year, matched by equal amounts of State funds. Prior to this program, beginning in the early 1980's, FEMA had provided grants to the States on an individual-project basis. Most of the grants were aimed at increasing earthquake awareness and improving emergency preparedness and response capabilities.

REGIONAL ACTIVITIES

CENTER FOR EARTHQUAKE RESEARCH AND INFORMATION (CERI)

In 1977, the same year as the passage of the Earthquake Hazards Reduction Act, the Tennessee State Legislature established the Tennessee Earthquake Information Center, now called the Center for Earthquake Research and Information (CERI), at Memphis State University. The establishment of this center was prompted by a 1976 earthquake near Marked Tree, Ark. This earthquake, coupled with the increasing level of earthquake interest nationally and regionally, focused the attention of State legislators on earthquake risk, particularly in the Memphis area. CERI's primary function has been as a scientific research institution, but it also has been a leader in earthquake awareness activities in the Central United States. CERI has benefited from substantial State funding to support its academic and basic functions, particularly since Tennessee designated it as a Center of Excellence in 1984, but CERI also has received considerable Federal funds via NEHRP programs to support its research. In 1983, CERI received FEMA funding to be one of three, 3-year, pilot Earthquake Education Centers (Federal Emergency Management Agency, 1987). One purpose of the program was to introduce earthquake information into an area with little previous knowledge or interest in the subject. CERI now has a seismic resource center, with a full-time manager responsible for public information.

CENTRAL UNITED STATES EARTHQUAKE PREPAREDNESS PROJECT (CUSEPP) AND CENTRAL UNITED STATES EARTHQUAKE CONSORTIUM (CUSEC)

In 1981, FEMA initiated the Central United States Earthquake Preparedness Project (CUSEPP) to assist State governments in their earthquake-planning efforts. This organization, based in Kansas City, was directly responsible to FEMA, and for this reason, according to VSP Associates (1989), it was not effective in engaging local and regional activities.

As a response to CUSEPP, the emergency management directors of the seven potentially affected States founded their own organization, the Central United States Earthquake Consortium (CUSEC) in 1983. In 1984, they opened an office in Marion, Ill., and contracted with FEMA to support the project. CUSEC's initial charge was to promote and support earthquake preparedness in the Central United States, improve the administration of earthquake preparedness through the agencies of the member States, and address the needs of the Earthquake Hazard Reduction Act—planning, public education, and mitigation (Jones, 1988). Following the death of its first executive director, CUSEC moved in

January 1989 to its current office in Memphis, Tenn. In 1991, CUSEC added four associate members: Alabama, Ohio, North Carolina, and Louisiana. Currently, CUSEC has four outreach goals: public awareness and education, mitigation, multi-State planning for response and recovery, and research. Most of CUSEC's annual budget consists of base funding from FEMA, but this has been increasingly supplemented by project-specific grants and numerous corporate sponsors.

AWARENESS OF LOCAL OFFICIALS

Drabek and others (1983), in a 1981 study of local government officials and building professionals in Missouri, found a surprisingly high level of concern for earthquake hazards, much higher than the previous work of Rossi and others (1982) had implied. For example, 92 percent of respondents were either very concerned or somewhat concerned about the occurrence of a damaging earthquake. However, the level of activities at that time were relatively low: only 18 percent of key actors could recall meetings during the previous 5 years at which the topic was seismic safety, and only 21 percent indicated that their agencies were in the process of developing or had developed earthquake mitigation plans. In sum, despite a relatively high level of awareness and concern among the key actors, "Earthquake mitigation policies and activities in Missouri were found to be minimal and/or short-lived" (Drabek and others, 1983, p. 74). The only mitigation activities identified were U.S. Army Corps of Engineers seismic requirements for public dams and some cases of local adoption of seismic-load requirements in building codes.

Mushkatel and Nigg (1987a, 1987b) performed an earthquake-risk-opinion survey of residents and local government officials in the New Madrid seismic area between November 1983 and April 1984. They surveyed residents of areas identified as having high and moderate risk from an earthquake on the New Madrid fault zone. They found that a substantial proportion of citizens and government officials were at least somewhat worried about the possibility of a damaging earthquake before the year 2000. They also found high levels of support for mitigation measures in both groups, although, surprisingly, the support was much stronger among community residents than government officials. Among government officials only, they found significant differences in attitudes toward mitigation policies between the high- and moderate-risk zones (Mushkatel and Nigg, 1987b). For example, 53 percent of government officials from the high-risk area felt that building codes were justified for their community, whereas only 21 percent of the respondents from the moderate-risk areas agreed. Retrofitting codes and land-use restrictions received less support, both measures being supported by 41 percent of government officials in high-risk areas, compared to 11 percent and 10 percent in moderate-risk areas. Administrative officials were

significantly more favorable than elected officials toward these mitigation actions.

The surveys by Mushkatel and Nigg (1987a, 1987b) are significant in several ways. First, they document a higher level of concern among public officials than was suggested by previous studies (e.g., Wyner and Mann, 1986). Second, this was the first study to compare opinions of community residents to those of government officials, and it found a higher level of concern among the residents than the officials. Previous studies (e.g., Drabek and others, 1983; Wyner and Mann, 1986) had found that government officials perceive that they have a higher level of seismic awareness and concern than does the citizenry, and this study shows that perception to be incorrect. Third, the study demonstrates that government officials are sensitive to objective risk: the scientific information is reaching them, and their policy decisions are sensitive to the level of risk determined for their community.

SUMMARY: HISTORICAL TRENDS

This historical account documents several trends. First, Federal interest in earthquake hazard reduction throughout the United States has increased steadily over the past 20 years. Second, Federal funding for earthquake research and hazard mitigation in the Central United States began in 1974 and has steadily accelerated since then. Third, local officials are aware and concerned about earthquakes but have taken relatively little action. Fourth, as of the mid-1980's, the seven New-Madrid-area States had taken relatively little initiative other than establishment of the Center for Earthquake Research and Information and the initiation of CUSEC. Fifth, Federal policy initiatives and Federal funding have driven most of the earthquake preparedness and mitigation activities that exist in the Central United States. Even CUSEC and CERI owe much of their success to Federal financial support. A sixth trend, discussed below, is that Federal earthquake policy has increasingly emphasized mitigation.

PROBLEM STATEMENT

NEED FOR HAZARD MITIGATION

Mitigation is an important aspect of disaster management. Increasingly, Federal disaster policy has emphasized reducing hazards rather than responding to disasters. Mitigation of earthquake hazards, by improving design and construction practices, is one of the major stated purposes of the National Earthquake Hazard Reduction Program. FEMA explicitly requires that at least 15 percent of its financial assistance to States under the National Earthquake Hazard Reduction Program be spent on mitigation, and this proportion will increase over the next few years (CFR 361.3(g)).

Hazard mitigation also is required as a condition of receipt of post-disaster Federal assistance under the Stafford Disaster Relief and Emergency Assistance Act (PL 100-707, Section 409), which applies to all types of disasters. As a result of this act, most States have begun to prepare hazard mitigation plans (e.g., Tennessee Emergency Management Agency, 1991).

Potential seismic hazard mitigation activities have been listed by Berke and others (1989) and Bolton and others (1986). Gori and Millen (1991) classify earthquake hazard mitigation actions into two groups: (1) those that reduce expected losses, such as land-use regulations, building codes, building practices, structure siting, retrofitting buildings, and securing objects within buildings; and (2) those that support mitigation actions, such as assessing and mapping hazards, estimating vulnerability and loss, improving seismic construction practices, and training design professionals and public officials. This classification provides a useful framework for reviewing mitigation actions in the Central United States

LIMITED EXISTING STATE PROGRAMS FOR SEISMIC HAZARD MITIGATION

Despite the Federal programs cited above, few States outside of California have implemented seismic hazard mitigation programs (see May and Williams, 1986, p. 98-101). California's programs include land-use planning requirements, construction standards, and mitigation of hazards in existing unreinforced masonry buildings (see California Seismic Safety Commission, 1988). The USGS also has been working in Utah to implement mitigation measures based on the hazard information developed by its studies of the Wasatch Front (e.g., Christenson, 1989). Drabek and others (1983) documented early initiatives to develop earthquake mitigation policy in the States of Missouri and Washington and analyzed the limited implementation of the policies in those States. Earthquake preparedness efforts in the Central United States began in the mid-1980's with the advent of CUSEC, but mitigation efforts have lagged.

NEED FOR STATE ACTION

States are the governmental entities that will most directly affect emergency management activities. Federal agencies have provided basic tools to aid emergency preparedness and response. FEMA provides funding and guidance to the States, and the USGS performs basic research to better understand the risks. But it is the States that can produce tangible results in earthquake hazard mitigation, both by their own administrative programs and by their direct support of local activities (May, 1991; Berke and Beatley, 1992). State mandates are an important initial condition to

local government actions (Wyner and Mann, 1986, p. 69). Policies and funding priorities set by the States translate into direct action in reducing earthquake hazards.

NEED TO STUDY THE ROLE OF THE STATES

Most earthquake mitigation studies have focused on the role of local communities in implementing seismic safety policies. Most of this work has studied communities in seismically active regions wholly within a single State or two neighboring States, such as California, Washington, Oregon, or Utah (e.g., Wyner and Mann, 1986; May, 1989). Studies in the Central United States have continued in this vein, examining awareness and implementation at the community level (Mushkatel and Nigg, 1987a, 1987b; Berke and others, 1989). Only Drabek and others (1983) looked at activities at the State level, examining the early policy initiatives in Washington and Missouri.

Much of this previous work implicitly assumes a California model, in which local governments implement State policy. In California, the State has initiated seismic policy through major legislation such as: the Field Act (1933), a requirement for seismic-safety elements in local plans (1971), Alquist-Priolo Special Studies Zones Act (1972), the establishment of the Seismic Safety Commission (1974), Unreinforced Masonry Act (1986), and Seismic Hazards Mapping Act (1990). It has fallen on local governments to implement these mandates, and the success of these local efforts has been of great interest to researchers and policy makers alike. Thus began a tradition of studying local awareness and implementation of seismic policy.

In contrast, in the Central United States, several factors point to the States as the key actors in promoting seismic safety. First, the hazard in the Central United States encompasses several States, and adequate preparedness demands cooperation among the States. Second, the hazard is diffuse, and variations in hazard are not distinguishable at the scale of local jurisdictions. Third, most of the initiative in policy setting has come from the Federal Government. Thus, in the Central United States, it is the States that play a key role as both the implementors of Federal earthquake policy and the initiators of their own policy to catalyze local action.

FACTORS AFFECTING IMPLEMENTATION OF SEISMIC MITIGATION POLICY

As pointed out by May (1991), all of the previous earthquake-awareness studies show relatively high levels of awareness and concern by local officials but little action by local governments. Various reasons have been suggested: earthquakes themselves are not well understood; there is no public constituency; costs are immediate and benefits uncertain; benefits do not occur during current elected officials'

tenure; public safety is not visible; and other public issues are more immediate (Wyner and Mann, 1986; May, 1991; Berke and Beatley, 1992; Atkisson and Petak, 1982). The point is that, even with improved awareness, political and institutional roadblocks exist.

Various authors have drawn lessons from case studies of local implementation of earthquake policies. Several of these can apply to State-level implementation as well. Alesch and Petak (1986, p. 223–234) offer insightful observations on factors influencing the adoption of earthquake mitigation policies, the most conclusive of which I summarize as follows: (1) recognition of the problem by the policy community; (2) an available, practical policy option; (3) persistent and credible “inside” policy advocates; (4) windows of opportunity; (5) political solutions to complement technical ones; and (6) attendance by local officials at professional meetings and conferences. Berke and Beatley (1992) found that factors internal to local governments were key in facilitating local mitigation actions: (1) presence of credible advocates, (2) coordination and communication among key participants, (3) availability of resources, and (4) linkage to other issues.

Drabek and others (1983, p. 213–214), in a study of State-level policy, found only very limited policy successes in Missouri and Washington. Based on these two cases, they provided some guidance as to what circumstances appeared to encourage implementation: (1) a key person or group becomes concerned and has authority to act, (2) Federal agency actions cause earthquake mitigation to become a State or local policy issue, and (3) the earthquake issue links to another policy issue.

Lambright (1984), in a study of southern California, North Carolina, and Japan, examined a range of seismic policy environments, from emergent to mature. He outlined the course of earthquake policy innovation as follows: (1) awareness of a problem by a few “entrepreneur” individuals, (2) a trigger that converts awareness into policy action, (3) search for an appropriate response, (4) adoption of a policy option by government, thereby giving legitimacy to the policy, (5) implementation of policy into program action, and (6) institutionalization of programs. Most programs in the Central United States are still in the early stages of this process.

Some common themes emerge from these studies. Earthquakes are not high on the political agenda because they occur infrequently and are overshadowed by more immediate, visible issues. Seismic safety never elected a governor or mayor. On the other hand, seismic safety policies do get adopted by local governments, usually due to the following factors: (1) awareness of the problem, (2) persistent and credible advocates, (3) opening of a window of opportunity, (4) existence of a politically acceptable and feasible solution, (5) linkage to other issues, and (6) repeated communication among key participants. In addition, implicit in most of these studies is some sort of policy mandate from

a higher level of government. These observations appear to be as applicable to State governments as they are to local governments. Indeed, we found all, except linkage to other issues, to apply to successful State-level programs in the Central United States. Because many of these factors have occurred in the Central United States over the past decade, earthquake mitigation activities have increased above the levels reported by Drabek and others (1983) a decade ago. Still, mitigation activities are not yet as widespread in this part of the country as in the Western United States.

RESEARCH METHOD

This research represents an initial step in examining current and potential policy activities at the State level. Because the number of cases is small (seven States), a case-study approach is the most appropriate method. The research has been exploratory, attempting to document and measure all relevant activities. This could serve as the basis for a later more systematic study, perhaps one that would include other States that have seismic concerns.

RESEARCH QUESTIONS

The research focused on the following questions: (1) What is the current role of each State in seismic hazard mitigation? (2) What are the unique aspects of seismic hazard in each State, requiring customized policy approaches, such as liquefaction zones, port facilities at risk, or historic resources? (3) What agencies are best equipped to implement seismic hazard policy, and what is their potential role? (4) What new legislative or policy efforts might be most effective in each State?

RESEARCH TASKS

Research tasks included review of existing legislation, interviews with key officials, and acquisition and review of relevant government documents. For each State, the following documents were collected: emergency preparedness acts, planning enabling acts, building code legislation, seismic mitigation work plans, public information documents relating to earthquakes, agency program statements, proposed legislation, internal memoranda, and a variety of technical and policy reports.

For each State, we identified individuals in the following categories: Earthquake Program Manager (Emergency or Disaster Agency), State Geologist or designee, Building Code Administrator, architect/engineer in charge of design of State buildings, engineer in charge of dam-safety program, engineer in charge of highway bridge and embankment design, other individuals identified as being active advocates of seismic mitigation (such as university professors in engineering or earth sciences).

We also sought to interview two to three knowledgeable local planners in each State. In the absence of any State-level agencies that coordinate local land-use planning, we interviewed officers of each State's chapter of the American Planning Association.

Fifty-nine comprehensive interviews have been conducted, 37 of them in person. These encompass 30 different State agencies in the seven States, as well as six universities, several local agencies, and professional associations. Thirteen key planning professionals in the seven States also have been interviewed. These in-depth interviews (averaging two to three hours each) have identified additional issues, which are still being investigated via telephone interviews.

OBSERVATIONS—RECENT STATE ACTIVITIES

The Central United States is different from the seismically active Western United States, where earthquake hazard mitigation programs have been most active. These differences reflect: the geophysically different nature of the hazard (widespread, diffuse, level topography), differences in earthquake experience and awareness, and differences in political culture. Some of the more notable findings of this research are those that highlight the unique characteristics of the practice of seismic hazard mitigation in the Central United States and show how State policies must necessarily be different from those in the Western United States.

Following is a summary of recent State-level activities related to seismic hazard mitigation. They are organized under topical headings, progressing from awareness activities to direct hazard reduction.

STATE AGENCY ROLE IN MITIGATION ACTIVITIES

Most Central U.S. States are concerned about mitigating seismic hazards and are making slow but steady progress. Interagency communications regarding this issue have increased dramatically over the past decade, and this administrative activity has resulted in a number of creative new programs. However, virtually all the States are constrained by very tight State budgets (including hiring freezes). Furthermore, mitigation is not an exciting political issue—indeed, some mitigation actions, such as seismic building codes, are unpopular (see Drabek and others 1983, p. 90). Still, many States have used creative and cost-effective techniques to initiate programs to mitigate future earthquake damages. These successes are generally due to the presence of effective advocates inside the government.

AWARENESS

Awareness of the seismic hazard in the Midwest has increased dramatically since 1980 (as documented at that time by Drabek and others, 1983). This is due primarily to: educational efforts by Otto Nuttli and colleagues at Saint Louis University, the 1977 formation of the Tennessee Earthquake Information Center (now the Center for Earthquake Research and Information) at Memphis State University, the 1983 formation of CUSEC, ongoing efforts by FEMA and the USGS under the National Earthquake Hazard Reduction Program, the 1989 Loma Prieta earthquake, and the December 3, 1990, earthquake prediction by Iben Browning.

The latter two events were particularly significant in accelerating awareness and preparedness activities since late 1989. In many ways, the hysteria of late 1990 was a mixed blessing. All seven States reported being overwhelmed by requests for earthquake information during the latter half of 1990. For example, Illinois and Missouri each distributed 250,000 copies of their earthquake preparedness brochures. On the positive side, most State officials reported a tremendous increase in public awareness, although opinions were mixed regarding whether this corresponded to improved preparedness. In some States, most of the resources of the emergency management agency were dedicated to providing earthquake information. The positive benefits of public education may have been outweighed by the inability of so many public officials and researchers to do any other work. In addition, several officials expressed concern that citizens now doubt the credibility of all earth scientists, mistakenly equating Browning's credentials with those of the various geological surveys. The most positive long-term result was the acceleration of preparedness and mitigation activities within State agencies and by public utilities.

WINDOWS OF OPPORTUNITY

The most prominent window of opportunity was the year following the Loma Prieta earthquake and the subsequent New Madrid earthquake prediction by Iben Browning. Legislation, new programs, and executive orders in the States of Missouri, Arkansas, Indiana, and Illinois can all be directly attributed to the heightened awareness during this time period. In both Arkansas and Missouri, drafts of legislation existed prior to October 1989, and their proponents explicitly used the window of opportunity to advance their goals.

Heightened interest and knowledge in the New Madrid region has allowed major earthquakes that have occurred elsewhere in the world to provide windows of opportunity. Respondents in Missouri and Tennessee reported increases in earthquake interest following the 1988 Armenia and 1985 Mexico City earthquakes. Following any major event, the

press is quick to point out similarities to local conditions. In general, some of the newspapers in the region have been effective in maintaining a level of interest, which provides an environment for seizing opportunities as they arise. For example, the St. Louis Post-Dispatch ran a series on earthquake hazards during September 1989. Following the Loma Prieta earthquake the next month, some of the information presented in these articles caught the attention of State legislators and triggered the enactment of comprehensive seismic-safety legislation in 1990.

SEISMIC ADVISORY COUNCILS

Earthquake advisory councils are an extremely effective way of promoting earthquake awareness in State agencies and of providing leadership in mitigating the effects of future earthquakes. They serve to involve stakeholders, use knowledge of local experts, and promote interagency communication (see Berke and Beatley, 1992). FEMA has encouraged the formation of seismic advisory councils in States receiving Federal earthquake funds. The most successful model of such a body is the California Seismic Safety Commission, formed as an independent agency in 1974 (see Olson, 1982). The advisory councils in the Central United States are more modest in scale and are not independent organizations, but they are very effective at collecting available expertise and promoting interagency coordination.

The council in Kentucky was the first to form in the Central United States (1983) and is an excellent model. Its regular meetings foster steady progress in helping several agencies meet mitigation goals. The panel currently has 23 members representing the public sector, the technical community, State legislature, and major utilities. Kentucky has been very successful at using small amounts of funding to leverage extraordinary amounts of work from its members.

Arkansas' advisory council, formed in 1984, was the key to the drafting and successful legislative enactment in 1991 of a State seismic building code. The council developed the idea several years earlier, drafted the bill, argued for seismic codes whenever members gave public presentations, and shepherded it through the legislature. The council currently has 37 members, all of whom volunteer considerable time to the council's work.

Interagency communication fostered by Indiana's advisory board is at least partly responsible for an innovative agreement in 1990 between the State's building code office and the State geological survey. This agreement may have occurred anyway, but the advisory board provided a mechanism for frequent contact between these key agencies. Indiana's board has 23 members.

Mitigation efforts appear to be much less coordinated in States without active advisory councils. Both Tennessee and Missouri briefly formed advisory councils in the early 1980's, but neither one has been active since that time. The

Governor of Illinois formed an Earthquake Preparedness Task Force in October 1989, but it disbanded following submittal of its report in April 1990.

ASSESSING AND MAPPING HAZARDS

Seismic hazard maps are an important step in any earthquake hazard reduction program. Although the earthquake hazard in the Central United States does not vary at a fine enough scale to be useful for local land-use planning, such basic information is vital for estimating risk and planning for emergency response. Estimates of magnitude and spatial variation of damages, such as the so-called "Six Cities Study" by the Central U.S. Earthquake Preparedness Project (1985), are invaluable for State and local governments in preparing earthquake plans and policies.

Seismic zonation or risk mapping has been very limited in the Central United States. The most substantial effort in the region has been by the State of Indiana. The Indiana Geological Survey, under contract to the State Department of Fire and Building Services since June 1990, has been collecting basic geotechnical and geophysical data in southern Indiana, with the ultimate aim of producing a seismic zonation map for the State building code. A unique aspect of this project is the funding sources: State building permit application fees, supplemented by a grant from the city of Evansville. Missouri enacted legislation in 1990 authorizing its geological survey to map geologic and seismic hazards, but the program has not yet been funded. The Center for Earthquake Research and Information at Memphis State University has prepared a liquefaction potential map of the Memphis area (Chang and others, 1991). The University of Kentucky in 1992 completed a seismic microzonation study of Paducah, identifying three zones of relative amplification of seismic shaking. The Kentucky and Illinois Geological Surveys have been actively seeking funding for seismic zonation activities. Illinois and Arkansas received grants from the U.S. Geological Survey in 1990 for investigations of earthquake-induced landsliding. All seven States have discussed performing a prototype study to establish a consistent methodology for seismic zonation, but this project has not yet been funded.

LAND-USE REGULATION

The diffuse nature of the seismic hazard in the Midwest and the relatively level topography imply limited effectiveness of land-use regulations, except perhaps along river bluffs and liquefiable alluvial bottomlands. Until the USGS or the States produce specific ground-failure and liquefaction-hazard maps, land-use regulation would not be a very effective means of seismic hazard mitigation (see Bolton and others, 1986, part D). Mushkatel and Nigg (1987b) found

that most local officials, even in high-hazard zones, do not believe land-use restrictions would be justified for reducing seismic hazards in their communities.

The role of land-use planning in addressing seismic hazard is limited, not only by the geographic characteristics of the hazard, but also by typical functions of local planning in these States. Local planning agencies appear to be best suited for indirect activities to support earthquake preparedness, such as collecting, coordinating, and distributing information that could aid emergency response planning. Local planning agencies also could prepare plans to support mitigation activities of local building officials and public works agencies. Local comprehensive plans could address priorities for seismic retrofitting of critical structures and could also establish policies for post-earthquake rebuilding (see Spangle and others, 1987). These activities are potentially significant but are less direct than those typically proposed in the Western United States. Awareness by local planners of earthquake hazards and of the role they can play in hazard mitigation currently is quite low in the Central United States according to our interviews of planners.

REDUCING HAZARDS IN NEW CONSTRUCTION

Building codes in general, and seismic codes in particular, are not very popular in the Midwest but are slowly gaining acceptance. Concurring with this perception, Mushkatel and Nigg (1987b) found that slightly over half (53 percent) of local government officials surveyed in the high-risk zone believed that building codes were justified for their community. New seismic codes were enacted in Missouri in 1990 and Arkansas in 1991. Missouri's new law requires all local governments to adopt ordinances requiring that all new public and educational buildings meet the seismic requirements of the Building Officials and Code Administrators (BOCA) Code or Uniform Building Code (UBC). Arkansas' law requires all new public structures to meet the seismic-design provisions of the latest edition of the Standard Building Code (SBC).

Three of the States have had codes for several years. Indiana has had a State building code since 1923 and, since 1973, has adopted the Uniform Building Code, including its extensive seismic-design requirements. Kentucky, since 1979, has used the BOCA Code, which has been updating its seismic requirements over the past few years (the 1992 version is based on the latest Federal NEHRP standards). Tennessee also has a State-wide code, based on the Standard Building Code, and adopted the 1988 SBC seismic provisions in 1990. Memphis attained some notoriety in the trade press in 1989 and 1990 when it decided against adding seismic protection to its new downtown arena ("the great American pyramid"), and it adopted the 1988 SBC with reduced seismic requirements. Under State law,

however, Memphis will need to fully comply with the 1988 SBC by 1996.

Only Mississippi and Illinois have no State-wide code requirements, although many individual municipalities in these States do have building codes. Over 300 communities in Illinois use the BOCA Code, although many of these are in the northern part of the State where earthquake hazard is relatively low. Most of the major municipalities in the highest risk area of Mississippi have adopted the Standard Building Code.

Having a code and enforcing it are two very different matters. Enforcement depends on level of commitment, political support, level of expertise, and funding for adequate plan review and inspection. These factors vary among States and among localities within each State. Quality of local enforcement is difficult to document and was beyond the scope of this study. CERI, in 1992, is beginning a study of local implementation of seismic codes, and the results should shed considerable light on this issue. Typically, larger towns have their own building departments that provide plan review and inspections. In Indiana, Kentucky, and Tennessee, the State reviews plans for significant buildings not otherwise covered by a local agency. In Arkansas, the new code puts much of the responsibility on professional engineers, who must sign the plans. Missouri's new code emphasizes enforcement by local government. Generally speaking, in all seven States, code enforcement focuses on larger buildings and urbanized areas.

Seismic-design expertise of architects and engineers is generally quite low throughout the CUSEC States. This is beginning to change, however, and some seismic-design training courses have recently been initiated in Illinois and Kentucky. Since 1991, Illinois requires a seismic problem on the structural engineer licensing exam, and this has created a demand for more training courses. Indiana also runs courses on the Uniform Building Code.

In contrast to regulation of private construction, States can easily require seismic standards in construction of publicly funded buildings and highways. The Federal Government has set an example in this area, in the President's Executive Order 12699 (January 5, 1990), "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction." Illinois has an active program promoting and implementing seismic design of new State-owned structures, supported by an Executive Order of the Governor. Missouri, in 1990, passed legislation directed at improving seismic safety and preparedness in schools.

Most States have requirements for seismic design of new dams and highway bridges, although almost all these requirements have been introduced in only the last 10 years, generally in response to federal requirements. The States generally follow Corps of Engineers guidelines for dam construction and American Association of State Highway and Transportation Officials (AASHTO) design guidelines for highway bridges.

Non-structural hazards in new buildings are not being addressed very effectively. In contrast to the increased attention to structural design, most architects and mechanical engineers are not very aware of methods of designing for earthquake hazards, according to several interviewees.

REDUCING HAZARDS IN EXISTING CONSTRUCTION

The greatest hazard in the Midwest is the large number of existing unreinforced masonry buildings (URM's), according to most observers (see also Central U.S. Earthquake Preparedness Project, 1985, p. 3-31-3-37). Most of these were built many years ago with no seismic-design considerations. Many observers have noted similarities between towns in the Central United States and Coalinga, Calif., which sustained significant damage from Modified Mercalli Intensity VIII shaking in May 1983 (Hopper and others, 1983). Most of the severe damage occurred to pre-1930 brick buildings in the downtown area (Scholl, 1986), and 75 percent of these buildings were total losses (Hopper and others, 1983). Although there is virtually no data on seismic susceptibility of building stock in the Central United States, the damage data from Coalinga is indicative of the magnitude of risk in this region.

Existing buildings represent a very sensitive issue because the hazard is substantial and extensive in its magnitude and the costs of adequately mitigating the hazard are enormous. Our research found that numerous officials were reluctant even to discuss hazards to existing buildings. Older areas, central business districts, low-income areas, and historic districts are particularly vulnerable. Retrofit requirements, such as the Unreinforced Masonry Law (SB 547, 1986, codified as Government Code Section 8875 et seq.) in California, would be politically unacceptable to State governments, infeasible, and not very cost effective. For example, Drabek and others (1983) describe the political controversy that erupted in St. Louis in 1976 when the Department of Housing and Urban Development (HUD) tried to impose seismic standards for building rehabilitation. Local officials were concerned that it would stifle development in the central city. Many URM's exist in the Midwest, and, unlike California, the economy does not have enough new development money to help cover the needed repairs. Of course, it would be misleading to imply that the URM law in California has been without controversy. Indeed, Alesch and Petak (1986) describe the contentious 8-year battle to enact an existing building ordinance in the City of Los Angeles. The ordinance was finally enacted in 1981. A similar result appears unlikely anywhere in the Central United States.

Some States tentatively have begun to identify hazardous structures. The State of Kentucky, in 1992, will be providing some of its FEMA funds to the University of

Louisville to screen existing buildings in downtown Paducah. This is an outgrowth of a project begun voluntarily by a member of the State's seismic advisory council. In a USGS-funded project, CUSEC is testing the feasibility of using local government personnel in evaluating hazardous buildings, conducting building surveys in Evansville, Ind., and Cape Girardeau, Mo., using the method of ATC-21 (Applied Technology Council, 1988). States and local governments have shown a willingness to cooperate in such evaluations, but very few have taken the initiative. If the CUSEC study shows them to be cost effective, such evaluations may become more widespread.

Kentucky and Illinois have initiated major long-term programs to identify, assign priorities, and correct seismic deficiencies in existing highway bridges on designated priority routes. The Illinois Department of Transportation, following the report of the Governor's Task Force in 1990, internally reallocated over \$1 million to evaluate and assign repair priorities to bridges. Kentucky, in 1990, completed a 4-year study, funded by the Federal Highway Administration, to inventory priority routes. Detailed analyses were made of 283 bridges, and 111 bridges were found to be in need of retrofitting. Kentucky retrofitted 11 of the bridges in 1991. Missouri and Arkansas also have identified bridges likely to fail on priority routes but have not systematically evaluated or ranked them. Tennessee has no organized seismic retrofit program, but the State repairs approximately 60 bridges per year under the Federal bridge inspection program, and each repair routinely includes upgrading to seismic standards.

Existing non-structural hazards also are a significant problem in the Central United States. Many of these hazards can be secured easily and inexpensively, but earthquake awareness is not a part of people's daily lives in the Central United States. One of the easiest ways to help reduce seismic hazards is to include information on non-structural hazards in earthquake awareness programs. Many States are doing this and, in particular, are focusing on critical institutions, such as schools and hospitals. However, only Illinois and Kentucky currently have programs that directly support non-structural mitigation actions. Illinois actively promotes and implements non-structural mitigation activities in local schools. The State performs walk-through hazard surveys of approximately 10 schools per year and also provides grants to purchase materials for local non-structural projects. Kentucky, in 1991, began a matching-fund grant program to support local hazard mitigation efforts, including non-structural hazard mitigation projects.

RELATION TO OTHER PLANNING ISSUES

It is known that hazard mitigation efforts are more likely to be successful if they can also address other issues, such as environmental protection or economic development

(e.g., Drabek and others, 1983, p. 214; Berke and others, 1989). For example, floodplain protection serves the purposes of hazard reduction, environmental protection, and urban recreation (e.g., Task Force on Federal Flood Control Policy, 1966).

Unfortunately, there appears to be no other existing issue that could help carry seismic regulations in the Midwest. In fact, the converse may be true for rehabilitation of existing structures: existing planning policies serve to discourage URM seismic rehabilitation. This is because the most hazardous URM's tend to be concentrated in decaying central business districts, which often are the focus of planning efforts for physical preservation and economic revitalization. Such revitalization efforts usually are not well funded, and requirements for seismic rehabilitation would severely strain their budgets (see Drabek and others, 1983, chapter V). In many ways, requirements to rehabilitate or demolish URM's would run counter to these deeply rooted, existing policies for revitalizing traditional community centers. Nelson (1990) documented some of the problems encountered in Santa Cruz, Calif., when concerns for historic preservation conflicted with public-safety decisions. Public officials need to recognize this dilemma and seek solutions before disaster occurs.

RECOMMENDATIONS—A STRATEGY FOR STATE ACTION

A useful way to summarize the conclusions of this research is to organize them by type of policy action. The following list is divided into major legislative efforts, other legislative efforts, and administrative programs.

The most effective State actions for seismic mitigation would require explicit mandates by legislatures and governors. Such actions, all of which appear to be feasible in most of the seven CUSEC States, include:

1. Seismic building codes for new construction, although implementation may be limited by enforcement problems.
2. Seismic advisory councils (made up of representatives of State agencies, major industries, and universities) with regular meetings (approximately two per year).
3. Tax incentives for seismic rehabilitation.

Even in States where enactment or enforcement of building codes would be difficult, States could take the following minimum legislative actions:

4. Seismic codes and enforcement procedures for new schools, hospitals, fire and police stations, and utilities (power, water, sewage treatment).
5. Requirements for long-term identification and mitigation of existing hazards in schools, hospitals, fire and police stations, and utilities.
6. Seismic standards for State-owned structures:

- a. Seismic design of all new structures.
- b. Identification and retrofit of all vulnerable State-owned structures, such as highway bridges and dams.

The following actions could be initiated by individual agencies, without explicit authorization by the legislature or governor. However, all these actions would be facilitated by legislative mandates, particularly if accompanied by funding appropriations.

7. Geologic mapping to identify potential ground-failure hazard areas in order to assist emergency management agencies as well as inform the public.
8. Programs to encourage non-structural mitigation, including handbooks, training programs, and distribution of mitigation kits.
9. Cooperation with historic preservation agencies to prepare guidelines for rehabilitation that is sensitive to both cultural resources and seismic safety.
10. Seismic mitigation handbooks and model plans for local officials addressing: building inventory methods, establishing retrofitting priorities, identifying funding opportunities for seismic retrofitting, and guidelines for post-earthquake demolition and reconstruction.
11. Education programs (workshops, handbooks, newsletters) for design professionals in order to elevate the accepted standard of practice (this has legal implications that encourage compliance).

CONCLUSIONS

All seven States have greatly increased their seismic awareness and preparedness activities since 1985, and activities accelerated following the 1989 Loma Prieta earthquake and subsequent Browning earthquake prediction. Currently active mitigation programs are summarized in table 1. The most tangible activities have been the adoption and implementation of State-wide requirements for seismic design and construction. Building codes had also previously been identified by others as being the most prevalent and popular action for seismic hazard reduction at the local level (Mushkatel and Nigg, 1987b; Berke and others, 1989). This is likely to continue to be an area of activity in the future, although, in some States, it may be necessary to initially emphasize only critical facilities. On the other hand, all the States suffer from inadequate awareness in the building-and-design-professional community, and only a few educational programs have begun to address this. A major success has been the seismic advisory councils, most of which formed in the 1980's. These groups are extremely effective relative to their minimal cost and are thus easily supported by elected officials.

Strengthening of existing hazardous buildings needs public attention. We cannot eliminate these hazards, but we can reduce them. Any actions that can cost-effectively

Table 1. Existing State-level programs for seismic hazard mitigation in the Central United States.

[X, major program or State-wide requirement; x, limited program; --, minimal program or no program. For some programs, year of initiation, if known, is indicated in parentheses above mark in column. If a program type is not listed (such as structural retrofitting), it is because no such programs exist in any of the seven CUSEC States]

Seismic hazard mitigation program	State						
	Ark.	Ill.	Ind.	Ky.	Miss.	Mo.	Tenn.
Earthquake program in State disaster agency, fully staffed.....	(1983) X	(1982) X	x	(1983) X	(1991) X	(1985) X	X
Seismic advisory council	(1984) X	--	(1986) X	(1983) X	--	(1979) x	(1980) x
Seismic building codes.....	(1991) X	--	(1973) X	(1979) X	--	(1990) X	(1990) X
Seismic-design criteria for new State buildings	X	X	X	X	x	X	X
Identifying and evaluating existing structural hazards	--	--	X	X	--	--	--
Nonstructural hazard reduction.....	--	X	--	X	--	--	--
Seismic zonation mapping.....	x	x	X	--	--	x	--
Highway bridges—hazard identification	--	X	--	X	x	x	x
Highway bridges—retrofit.....	--	--	--	X	--	--	X
Training of design professionals	--	X	X	--	--	--	--

reduce property damage and save lives are warranted. The most effective and feasible approaches at this time are to identify existing hazards (such as by the method of Applied Technology Council, 1988) and prepare long-term plans to identify possible mitigation opportunities in the future. In particular, these efforts should focus on critical facilities (schools, hospitals, fire and police stations, utilities, and transportation). In addition, States should explore ways to encourage private rehabilitation efforts, such as by providing tax incentives. Experiences in Santa Cruz and Charleston in 1989 (Nelson, 1990) have shown that, with some foresight and interagency cooperation, historic resources can be saved from natural disasters.

Several States have initiated seismic-risk mapping efforts for use by emergency-management and building-code agencies. These efforts are funded incrementally, through grants from the USGS, private contributors, and other State agencies, and this is likely to continue to be the case. A new trend, such as in Indiana, is for potential users to fund data collection and map production. Another example of this trend elsewhere in the United States is California's Seismic Hazards Mapping Act (A.B. 3897, 1990, codified as Public Resources Code Section 2690, et seq.), under which earthquake insurance funds are to be used to prepare seismic hazard maps (see Holden and Real, 1990).

Non-structural hazards, in both existing and new structures, are not being effectively addressed in most States. Because of the variety of non-structural hazards (Lagorio, 1990, p. 107–137), they typically are not addressed by building codes but need instead to be addressed by architects, mechanical engineers, and building users. The most effective State-level programs would need to be directed at these parties and could include manuals, training programs,

demonstration projects, or direct distribution of materials (such as velcro, bolts, etc.) for stabilizing non-structural elements.

How does this research compare to previous work on local implementation of seismic safety policies? Our observations are generally consistent with the six factors of successful implementation, summarized earlier in this paper. First, awareness of the problem clearly has been effective as a first step, and the heightened awareness of 1989 and 1990 produced tangible results. Second, persistent and credible advocates, from Otto Nuttli to the current members of the seismic advisory councils, have played a key role in keeping seismic safety on the public agenda. Third, almost every legislative act for seismic safety in the Central United States occurred during a window of opportunity following an earthquake. Fourth, actions have necessarily been limited to those that are politically acceptable; programs have been pragmatic and incremental. Fifth, there is virtually no positive linkage of seismic safety to other issues in the Central United States. The absence of this factor probably is the most significant reason why seismic policy in this region presents such a difficult implementation problem. And, sixth, communication among key participants, largely through the seismic advisory councils, clearly has played a significant role in identifying, designing, and implementing programs to reduce seismic hazards in the seven CUSEC States.

One of our interviewees stated that the ultimate goal of improving earthquake preparedness is to integrate seismic awareness into all of our activities. This is a simple and profound observation. Seismic hazard mitigation programs will have succeeded when they no longer need to be separate programs. To effectively mitigate earthquake hazards, awareness must be smoothly integrated into building codes,

building design, facility maintenance, State and local emergency preparedness, local planning, and historic preservation programs. States, through legislative and administrative policy decisions, can contribute significantly to the realization of this goal. This paper has documented some of the creative ways in which Central U.S. States are already addressing the problem, and this research has identified some of the most feasible and potentially effective strategies to pursue in the coming years.

ACKNOWLEDGMENTS

The contents of this paper were developed under a grant from the Department of the Interior, U.S. Geological Survey under award number 14-08-0001-G1938. However, the contents of this paper do not necessarily represent the policy of the USGS, and one should not assume endorsement by the Federal Government.

REFERENCES CITED

- Alesch, D. J., and Petak, W.J., 1986, The politics and economics of earthquake hazard mitigation: Boulder, Colorado, The University of Colorado Institute of Behavioral Science, Program on Environment and Behavior Monograph No. 43, 273 p.
- Applied Technology Council, 1988, Rapid visual screening of buildings for potential seismic hazards: A handbook (ATC-21): Washington, D.C., Federal Emergency Management Agency, Earthquake Hazards Reduction Series 41, FEMA-154, 185 p.
- Atkisson, A.A., and Petak, W.J., 1982, The politics of community seismic safety, *in* Preparing For and Responding To a Damaging Earthquake in the Eastern United States, Proceedings of Conference XV: U.S. Geological Survey Open-File Report 82-220, p. 92.
- Berke, P.R., and Beatley, T., 1992, A national assessment of local earthquake mitigation: Implications for planning and public policy: *Earthquake Spectra*, v. 8, no. 1, p. 1-15.
- Berke, P.R., Beatley, T., and Wilhite, S., 1989, Influences on local adoption of planning measures for earthquake hazard mitigation: *International Journal of Mass Emergencies and Disasters*, v. 7, p. 33-56.
- Bolton, P.A., Heikkala, S.G., Greene, M.M., and May, P.J., 1986, Land use planning for earthquake hazard mitigation: A handbook for planners: Boulder, Colorado, University of Colorado, Natural Hazards Research and Applications Information Center, Special Publication 14, 121 p.
- California Seismic Safety Commission, 1988, California at risk: Steps to earthquake safety for local government: Sacramento, California, Report No. SSC 88-01, 55 p.
- Central United States Earthquake Preparedness Project (CUSEPP), 1985, An assessment of damage and casualties for six cities in the Central United States resulting from earthquakes in the New Madrid seismic zone: Washington, D.C., Federal Emergency Management Agency, 13 sections.
- Chang, T.S., Tang, P.S., Lee, C.S., and Hwang, H., 1991, Liquefaction potential in the Memphis area, *in* Proceedings, Fourth International Conference on Seismic Zonation: Oakland, California, Earthquake Engineering Research Institute, p. II-459.
- Christenson, G.E., 1989, Utah's Wasatch Front county hazards geologist program: *Natural Hazards Observer*, v. 14, no. 1, p. 1-2.
- Drabek, T. E., Mushkatel, A.H., and Kilijanek, T.S., 1983, Earthquake mitigation policy: The experience of two States: Boulder, Colorado, University of Colorado, Institute of Behavioral Science, Program on Environment and Behavior Monograph No. 37, 238 p.
- Federal Emergency Management Agency, 1987, Final report on the evaluation of three earthquake education projects: Washington, D.C., Office of Natural and Technological Hazards Programs.
- Federal Emergency Management Agency, U.S. Geological Survey, National Science Foundation, and National Bureau of Standards, 1984, National Earthquake Hazards Reduction Program five year plan, fiscal years 1985-89: Washington, D.C., Federal Emergency Management Agency, five sections.
- Fuller, M.L., 1912, The New Madrid earthquake: U.S. Geological Survey Bulletin 494, 119 p.
- Gori, P.L., and Millen, J.H., 1991, Opportunities to expand earthquake hazards mitigation efforts by the Federal Emergency Management Agency through State and local programs: Chicago, Illinois, Federal Emergency Management Agency, Region V, July 1991, unpublished, 15 p.
- Hamilton, R.M., and Johnston, A.C., 1990, Tecumseh's prophecy: Preparing for the next New Madrid earthquake: U.S. Geological Survey Circular 1066, 30 p.
- Hays, W.W., and Gori, P.L., eds., 1986, Proceedings of Conference XXXV: A workshop on earth science considerations for earthquake hazards reduction in the Central United States: U.S. Geological Survey Open-File Report 86-425, 172 p.
- Holden, R., and Real, C.R., 1990, Seismic hazard information needs of the insurance industry, local government, and property owners in California: Sacramento, California, California Department of Conservation, Division of Mines and Geology, Special Publication 108, 83 p.
- Hopper, M.G., Thenhaus, P.C., Barnhard, L.M., and Algermissen, S.T., 1983, Damage survey in Coalinga, California, for the earthquake of May 2, 1983, *in* Bennett, J.H., and Sherburne, R.W., eds., The 1983 Coalinga, California Earthquakes: Sacramento, California, California Division of Mines and Geology, Special Publication 66, p. 5.
- Johnston, A. C., and Nava, S.J., 1985, Recurrence rates and probability estimates for the New Madrid seismic zone: *Journal of Geophysical Research*, v. 90, no. B8, p. 6737-6753.
- Jones, E.E., 1988, Central United States Earthquake Consortium, *in* Hays, W.W., ed., Proceedings of Conference XLI: A review of earthquake research applications in the National Earthquake Hazards Reduction Program: 1977-1987: U.S. Geological Survey Open-File Report 88-13-A, p. 272.
- Lagorio, H.J., 1990, Earthquakes: An architect's guide to non-structural seismic hazards: New York, John Wiley & Sons, Inc., 312 p.
- Lambright, W.H., 1984, Role of States in earthquake and natural hazard innovation at the local level, a decision-making study: Syracuse, New York, Syracuse Research Corporation,

- [prepared for National Science Foundation, distributed by U.S. Dept. of Commerce, NTIS], eight sections.
- May, P.J., 1989, Anticipating earthquakes: Risk reduction policies and practices in the Puget Sound and Portland areas: Seattle, Washington, University of Washington, Institute for Public Policy and Management, unpublished, 31 p.
- 1991, Addressing public risks: Federal earthquake policy design: *Journal of Policy Analysis and Management*, v. 10, p. 263–285.
- May, P.J., and Williams, W., 1986, Disaster Policy Implementation: Managing Programs Under Shared Governance: New York and London, Plenum Press, 198 p.
- McKeown, F.A., 1982, Overview and discussion, *in* McKeown, F.A., and Pakiser, L.C., eds., Investigations of the New Madrid, Missouri, Earthquake Region: U.S. Geological Survey Professional Paper 1236-A, p. 1–14.
- McKeown, F.A., and Pakiser, L.C., eds., 1982, Investigations of the New Madrid, Missouri, Earthquake Region: U.S. Geological Survey Professional Paper 1236, 201 p.
- Mushkatel, A.H., and Nigg, J.M., 1987a, Opinion congruence and the formulation of seismic safety policies: *Policy Studies Review*, v. 6, p. 645–656.
- 1987b, Effect of objective risk on key actor support for seismic mitigation policy: *Environmental Management*, v. 11, p. 77–86.
- Nelson, C.L., 1990, Protecting the past from natural disasters: Washington, D.C., The Preservation Press, National Trust for Historic Preservation, 192 p.
- Nishenko, S.P., and Bollinger, G.A., 1990, Forecasting damaging earthquakes in the Central and Eastern United States: *Science*, v. 249, p. 1412–1416.
- Nuttli, O.W., 1973, The Mississippi valley earthquakes of 1811 and 1812—Intensities, ground motion and magnitudes: *Bulletin of the Seismological Society of America*, v. 63, p. 227–248.
- Nuttli, O.W., 1987, The effects of earthquakes in the Central United States: Marion, Illinois, Central United States Earthquake Consortium, 33 p.
- Olson, R.A., 1982, The California Seismic Safety Commission, 1975–80: Public policy and a practitioner's observations, *in* Jones, B.G., and Tomazevic, M., eds., Social and Economic Aspects of Earthquakes: Institute for Testing and Research in Materials and Structures, Ljubljana, Slovenia, and Program in Urban and Regional Studies, Cornell University, Ithaca, New York, p. 275–285.
- Rossi, P.H., Wright, J.D., and Weber-Burdin, E., 1982, Natural Hazards and Public Choice: New York, Academic Press, 337 p.
- Scholl, R.E., 1986, Reducing earthquake hazards: Lessons learned from earthquakes: El Cerrito, California, Earthquake Engineering Research Institute, Publication 86-02, 208 p.
- Spangle, W.E., Meehan, R.L., Degenkolb, H.J., and Blair, M.L., 1987, Pre-earthquake planning for post-earthquake rebuilding: Pasadena, California, Southern California Earthquake Preparedness Project, 96 p.
- Stauder, W., 1982, Present-day seismicity and identification of active faults in the New Madrid seismic zone, *in* McKeown, F.A., and Pakiser, L.C., eds., Investigations of the New Madrid, Missouri, Earthquake Region: U.S. Geological Survey Professional Paper 1236-C, p. 21–30.
- Task Force on Federal Flood Control Policy, 1966, A unified national program for managing flood losses: Washington, D.C., U.S. Government Printing Office, Communication from the President of the United States, August 10, 1966, House Document No. 465, 47 p.
- Tennessee Emergency Management Agency, 1991, State of Tennessee Hazard Mitigation Plan: Nashville, Tennessee, June 1991, 83 p.
- VSP Associates, Inc., 1989, To save lives and protect property: A policy assessment of Federal earthquake activities, 1964–1987: Washington, D.C., Federal Emergency Management Agency, FEMA-181, 246 p.
- Wyner, A.J., and Mann, D.E., 1986, Preparing for California's earthquakes: Local government and seismic safety: Berkeley, University of California, Institute of Governmental Studies, 109 p.

APPENDIX—PROGRAMS FOR SEISMIC HAZARD MITIGATION IN THE CENTRAL UNITED STATES, LISTED BY STATE

Following is a list, by State, of the most significant programs for earthquake hazard mitigation in the Central United States. This list does not include any programs for awareness, public information, preparedness, or post-earthquake response. For purposes of this list, "mitigation" follows the Gori and Millen (1991) definition and includes actions that reduce expected losses as well as those that support mitigation actions.

ARKANSAS

Building Code.—The Standard Building Code applies to all buildings in Arkansas and is administered by the State Fire Marshal. The latest edition of this code has seismic-design requirements.

Seismic Design of Public Buildings.—Act 1100 (1991) requires that all public structures (buildings open to the public) be designed to resist seismic forces in accordance with the 1988 Standard Building Code or latest edition. Structural plans must be signed and sealed by a qualified, registered professional engineer. The act specifies seismic zones by county. This act is somewhat redundant with the State's existing building code requirements, but it is more authoritative in that it legislatively requires seismic design.

Code Enforcement.—The State reviews plans for certain types of public buildings. State Building Services reviews plans for State buildings. The Education Department reviews plans for school buildings to enforce the requirements of Act 1100. The State Health Department reviews plans for hospitals and health clinics.

Building Alterations.—Act 1100 applies to alterations and repairs that increase the market value of a building by at least 100 percent.

Dams.—Since 1990, the design of dams that meet the criteria for "high" or "significant" hazard must address stability against seismic forces.

Professional Training.—The State Office of Emergency Services, with the University of Arkansas at Little Rock, offered earthquake hazard mitigation courses in 1991. The University of Arkansas at Little Rock also has an Earthquake Engineering Technology Transfer Center to provide technical seminars to engineers, architects, and contractors.

Earthquake Advisory Council.—Arkansas has a 40-member Earthquake Advisory Council, which has existed since 1984. It is very active, meets at least twice a year, and has three active subcommittees.

Geologic Hazard Assessment.—The Arkansas Geological Commission, with USGS funding, has performed a seismic-induced landslide study in northeast Arkansas.

ILLINOIS

Seismic Design of State-Owned Buildings.—Illinois has no State-wide building-code requirement, nor does it have a seismic-design requirement. However, the Capital Development Board has required seismic design of State buildings since 1977. This policy was reinforced by an Executive Order of the Governor in 1990, applying to all State-owned, leased, or regulated buildings.

Existing State-Owned Buildings.—When State-owned buildings are renovated, the work must comply with the seismic provisions of the most recent applicable code.

Highway Bridges.—New highway bridges have been designed to seismic standards for several years. In 1990, the Illinois Department of Transportation funded (approximately \$1 million) a study of 6,000 existing bridges. More detailed analysis has begun for the 160 bridges found to have the highest priority. No repairs have begun.

Dams.—Illinois follows U.S. Army Corps of Engineers guidelines for design of new dams. The State also has inspected existing dams and requires correction of defects by their owners.

Non-Structural Hazards.—The Illinois Emergency Management Agency distributes to public schools an earthquake hazard survey, which is not only a guide to non-structural hazards in schools, but also includes diagrams of low-cost solutions and a list of local sources of supplies. The agency also conducts a walk-through hazard survey of approximately 10 schools per year, attended by officials from neighboring schools. Illinois also provides grants to local organizations for hazard mitigation projects.

Professional Licensing.—Illinois has separate licensing for structural engineers as an engineering specialty. As of 1991, the licensing exam includes a mandatory seismic question. The Structural Engineers Association of Illinois now includes material on seismic design in its annual exam-review course.

Geologic Hazard Assessment.—The Illinois State Geological Survey, with USGS funding, has performed a seismic-induced landslide study along the Ohio River.

INDIANA

Building Code.—Indiana has had a State building code since 1923. Since 1946, the Indiana Building Code has generally followed the Uniform Building Code and therefore has included seismic requirements for many years. Plans for all buildings open to the public are reviewed by the State Department of Fire and Building Services. Local

governments are supposed to issue the permits and perform inspections, although numerous small towns and rural counties still have not adopted the required ordinances.

Hazard Assessment.—CUSEC, with USGS funding, performed a rapid visual assessment pilot study in Evansville, partly because of Evansville's many past efforts at seismic hazard reduction.

Highway Bridges.—Indiana has followed seismic-design criteria for new bridges since 1984.

Professional Training.—The Department of Fire and Building Services holds classes on the Uniform Building Code seismic requirements, which people from outside of Indiana have also attended.

Geologic Hazard Assessment.—The Indiana Geological Survey, with funding from Evansville and the Department of Fire and Building Services, conducted a 2-year study to assess seismic response of geologic materials in the southern part of the State. The Indiana Geological Survey also has cooperated with the USGS in research on liquefaction features in the Wabash Valley. Earthquake studies now represent approximately five percent of the State Geological Survey's annual budget.

Seismic Advisory Board.—Indiana has a 23-member Seismic Advisory Board, begun in about 1986. It meets periodically, and the members of its six committees maintain informal contact by telephone.

KENTUCKY

Building Code.—Kentucky has had a State building code since 1991, based on the BOCA Code. The code is updated every 3 years and therefore includes recent BOCA seismic standards. The State Department of Housing, Buildings, and Construction reviews plans, issues permits, and provides inspection for all major buildings. Six of the larger cities and counties administer the code themselves. Plans must be signed by a structural engineer.

Hazard Assessment.—The department of Disaster and Emergency Services and the University of Louisville, assisted by a FEMA grant, are systematically evaluating existing buildings in downtown Paducah. This project should be completed in 1992.

Highway Bridges.—Since the mid-1980's, new bridges must be built to AASHTO seismic standards. In 1990, the Kentucky Transportation Center, University of Kentucky, completed a 4-year study of potential hazards along more than 1,000 miles of priority routes in western Kentucky. It identified 111 bridges in critical need of retrofitting. Eleven of them have been repaired at a cost of \$237,000.

Dams.—All designs for dams rated as having high or moderate hazard must include seismic-stability analysis before receiving a permit.

Non-Structural Hazard Mitigation.—Kentucky has provided several grants to support local non-structural hazard mitigation projects, with a local cost match of 25 percent. One county, for example, is using \$5,000 for a demonstration project in a public school.

Professional Training.—The department of Disaster and Emergency Services has twice conducted a course in earthquake hazard mitigation for utility lifelines. In 1991, several agencies cosponsored a seismic-design workshop for structural engineers. The Kentucky Transportation Cabinet, in 1990, sponsored the Federal Highway Administration's short course on seismic design of highway bridges.

Geologic Hazard Assessment.—The University of Kentucky maintains a seismic network in the State. A doctoral student at the University of Kentucky completed a microzonation study of Paducah in 1992. Three zones of ground amplification were mapped.

Infrastructure.—The Center for Hazards Research and Policy Development at the University of Louisville has several projects related to risk management for utilities, with seismic risk as a significant component. One project is looking at risk management for water companies and includes an assessment of liquefaction potential in Louisville. The director of the center is the chair of the Governor's Earthquake Hazards and Safety Technical Advisory Panel's (GEHSTAP) mitigation committee.

Earthquake Hazards Advisory Panel.—Kentucky's Governor's Earthquake Hazards and Safety Technical Advisory Panel (GEHSTAP) has existed since 1983. It now has 23 members, four committees, and several subcommittees. It meets four times per year and has been actively involved in developing all of Kentucky's earthquake hazard programs.

MISSISSIPPI

Seismic Design of State-Owned Buildings.—Mississippi has no State-wide code requirement. The Department of Finance and Administration, General Services Division, Bureau of Building is responsible for monitoring contracts for new State buildings. The Bureau administratively requires compliance with the Standard Building Code and is now using the latest edition that includes seismic requirements.

Highway Bridges.—New bridges are designed according to the latest AASHTO standards. The State Highway Department hosted the Federal Highway Administration's earthquake-design workshop in 1991. The department has evaluated existing bridges in the highest risk portion of the State but has no plans for retrofitting.

Dams.—Since 1990, Mississippi has considered seismic factors before granting permits for designated high-hazard dams.

MISSOURI

Seismic Building Codes.—Missouri has no State-wide building code requirement, although most larger communities do have building codes. Missouri's Geologic Hazard Preparedness Act, enacted in 1990, requires the 47 highest risk counties to adopt an ordinance, stating that all new buildings larger than 10,000 ft², as well as all public and educational buildings, must comply with the seismic-design standards of either the Uniform Building Code or the BOCA Code. All jurisdictions have now adopted such an ordinance. The act does not address administration or enforcement.

Seismic Design of State-Owned Buildings.—As a result of the Geologic Hazard Preparedness Act, the State's Division of Design and Construction is now beginning to review all State-funded buildings for seismic design.

Renovation of Existing Buildings.—The Geologic Hazard Preparedness Act requires seismic design for major renovations of buildings, as defined by BOCA and UBC. The State delayed enforcement of this provision until late 1991 because of a legislative attempt to delete it (the attempt failed).

Highway Bridges.—Since 1989, new bridges have been designed according to the latest AASHTO standards. The Highway and Transportation Department sponsored a National Highway Institute 4-day course on seismic design in early 1990. A task force, organized by the Highway and Transportation Department, has identified 630 critical bridges requiring retrofitting. Priorities for repair have not yet been established.

Dams.—The Missouri Dam and Reservoir Safety Act, enacted in 1979, regulates the construction and operation of all new non-Federal dams exceeding 35 ft in height. The Dam and Reservoir Safety Council enacted seismic regulations in 1985, and 21 new dams have been constructed to this standard.

Non-Structural Hazards.—The Geological Hazard Preparedness Act requires all schools to include "protective measures" as part of their earthquake preparedness planning. This may mean that more schools will be engaged in non-structural hazard reduction projects in the future. The Emergency Management Agency has taught some courses on non-structural hazard mitigation.

Geologic Hazard Assessment.—The Geologic Hazard Preparedness Act provides for geologic hazard assessments throughout the State, but these activities have not yet been funded. The Division of Geology and Land Survey has completed two pilot studies to identify potential inundation areas if dams were to fail in an earthquake. Saint Louis University maintains a regional seismic network.

TENNESSEE

Seismic Building Code.—Tennessee has had a mandatory State building code since 1982. The State administratively has chosen to adopt the Standard Building Code. The State, in 1990, adopted the 1988 SBC, the first one containing seismic requirements. Twenty-five local governments administer their own code, and the State Department of Commerce and Insurance, Division of Fire Prevention, provides plan-review and inspection services for the rest of the State. The Division of Fire Prevention maintains jurisdiction over all State-owned and educational buildings.

Highway Bridges.—All new bridges are designed according to the most recent AASHTO standards. Since 1987, Tennessee has evaluated, ranked, and repaired existing bridges under the federal bridge inspection program. Approximately 60 bridges per year are repaired. Seismic risk is not a factor in determining repair priority, but when repair work is done, it is done according to current seismic standards.

Dams.—The Safe Dams Act of 1973 provides for permitting of new non-Federal dams and for periodic inspection of existing dams. The program has had seismic-design requirements since at least 1987.

Professional Training.—The Division of Fire Prevention has provided a course on seismic design.

Geologic Hazard Assessment.—The Center for Earthquake Research and Information, Memphis State University, maintains a regional seismic network. Researchers at CERI, in 1991, published a liquefaction potential map of the Memphis area.

Hazard Mitigation Council.—Tennessee does not have a seismic advisory council, but it does have an interagency Hazard Mitigation Council, with 14 members. This group completed a State hazard mitigation plan in 1991. One of its recommendations was to improve local enforcement of seismic codes.