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Seismic Vulnerability Assessment of Highway Systems

by *Stuart D. Werner, John B. Jernigan, Craig E. Taylor and Howard H. M. Hwang*

This article presents research conducted on the development of a seismic vulnerability assessment procedure for highway systems funded under NCEER's Highway Project. It represents work in progress and the data and models presented for the Memphis highway system are preliminary. They are for illustration purposes only and are subject to change. A more complete version of this paper will appear in the proceedings of the "National Seismic Conference on Bridges and Highways," sponsored by the Federal Highway Administration and Caltrans, to be held on December 10-13, 1995 in San Diego, California. Comments and questions should be directed to Stuart Werner, Dames and Moore, at (415) 896 5858.

Framework of Seismic Vulnerability Assessment Procedure

General Description

The general Seismic Vulnerability Assessment (SVA) procedure for a highway system is shown in figure 1. The procedure involves four main steps, which are: (1) initialization of the SVA; (2) development of system SVA results for each scenario earthquake and simulation specified under Step 1; (3) incrementation of the simulations and the scenario earthquakes and repeat of Step 2; and (4) aggregation of the SVA results for all earthquakes and simulations. Key to this process is a GIS data base, which comprises several modules that contain the data and models for implementing the various steps of the system SVA.

This SVA procedure has several desirable features. First, it would be carried out within a GIS framework, which will enhance data management, analysis efficiency, and display of analysis results. Second, the GIS data base would be modular, in order to facilitate the incorporation of improved data, procedures, and models, as they are developed from future research and development efforts. Third, the procedure would be able to consider the effects of uncertainties in the earthquake characterization, hazard models, and vulnerability models, and would have the capability of developing aggregate SVA results that could be either deterministic or probabilistic, depending on user needs. This range of results would facilitate the usefulness of the SVA for seismic retrofit planning, prioritizing, and criteria development for an existing highway system.

With this as background, the remainder of this section outlines the basic features of the GIS data base for the SVA procedure, together with each of the above four steps of the procedure that are listed above.

GIS Data Base

The GIS data base would contain the data, models, and methodologies for:

- Characterizing the system;
- Estimating the seismic and geologic hazards;

(Continued on Page 2)

- I N S I D E -

Research Activities.....**1

Center Activities.....12



Center Resources.....24

Bulletin Board.....26

Research Activities

(Continued from Page 1)

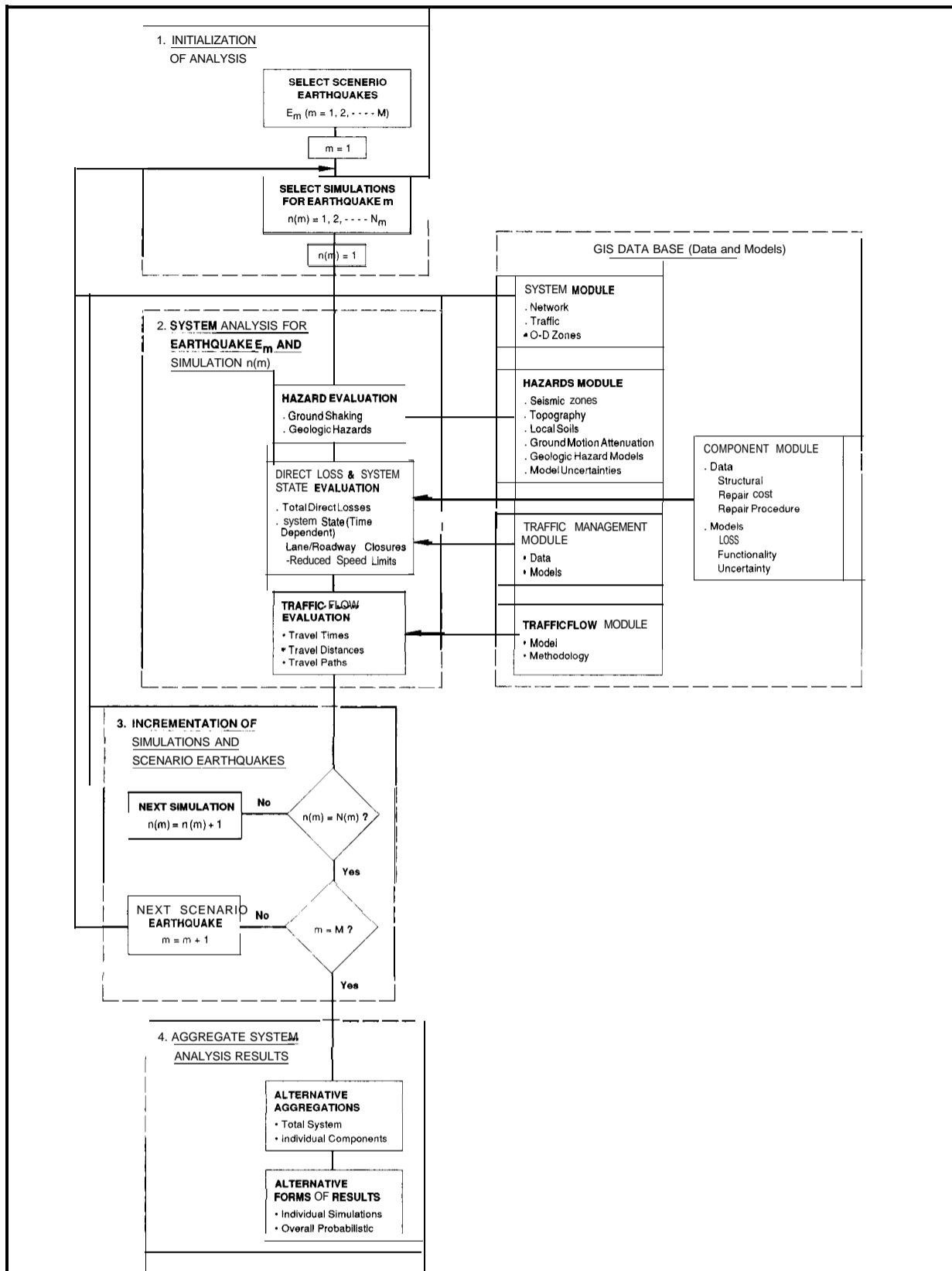


Figure 1: GIS-Based Seismic Vulnerability Assessment Procedure for Highway Transportation Systems

- Developing the component vulnerability models;
- Incorporating the effects of post-earthquake emergency traffic management procedures for alleviating traffic congestion; and
- Assessing the impacts of each scenario earthquake on traffic flows throughout the system.

The various modules that comprise the data base are summarized in the paragraphs that follow.

System Module. The system module would contain the basic data needed to define the system for the subsequent steps of the SVA. These data would describe: (a) system network configuration and linkages; (b) roadway widths (number of lanes each way); (c) traffic flows, capacities, and volumes for the roadways within the system; (d) component types and locations; (e) origin-destination zones; and (f) any special characteristics of the system, such as roadways designated as critical for national defense or for emergency response.

Hazards Module. The hazards module would contain the data and models needed to evaluate the seismic and geologic hazards throughout the system. The geologic data might include: (a) locations, earthquake activity rates, earthquake magnitude potentials, and tectonic displacement data for major faults and/or seismic zones in the region; (b) locations and topographic information for hills or valleys near the system that could be prone to landslide; and (c) data describing regional geology and local soil conditions throughout the system that would be needed to estimate ground shaking and potential ground movement due to liquefaction, landslide, etc. In addition, this module would include: (d) ground motion attenuation relationships; (e) models for estimating local soil effects on ground shaking; (f) landslide, liquefaction, and fault rupture models; and (g) models for characterizing uncertainties in ground shaking and ground movement.

Component Module. The component module would contain the data and models needed to estimate component vulnerabilities and their uncertainties. In this, component vulnerabilities would be characterized using loss models and functionality models. Loss models would estimate direct losses (repair and replacement costs) due to earthquake damage to the components. Functionality models, which are needed for post-earthquake traffic flow analysis, would represent the number of lanes open to carry traffic along each roadway link in the system at various times after an earthquake,

together with any reduced speed limits due to earthquake damage. Input data for developing these models would also be contained in this module. These data would include: (a) structural attribute data needed to evaluate the seismic performance of each component under various levels of ground shaking and ground movement; and (b) damage repair strategies, costs, and traffic impacts, including the number of traffic lanes to be closed during repair, the durations of these lane closures, and the reduced speed limits for traffic in the repair areas.

Traffic Management Module. The traffic management module would accommodate information on post-earthquake traffic management procedures for alleviating traffic congestion after an earthquake. For example, experience following the Northridge earthquake showed that emergency traffic management procedures implemented by transportation planners and engineers from the City and County of Los Angeles and from Caltrans were very effective in reducing traffic congestion from earthquake damage.

Traffic Flow Module. The transportation flow module would contain the traffic model and system analysis procedure to be used for estimating earthquake effects on traffic flows throughout the system, for a given post-earthquake system state. This would consist of a system traffic forecasting methodology that would estimate effects of each scenario earthquake and simulation on such quantities as travel times, travel distances, and travel paths. These quantities could be estimated on an overall system basis (which would serve as a rough indicator of overall system performance) and also between selected origin-destination zones in the system.

Step 1: Initialization of Analysis

With the development of the GIS data base for the system to be analyzed, the actual SVA itself could be initiated. This would incorporate two parts. The first part would involve the use of earthquake source models (including randomization models) contained in the hazards module of the GIS data base to define a suite of scenario earthquakes that could affect the highway system to be analyzed. Uncertainties modeled would include geographic location of the earthquake source. Other uncertainties that could in principle be incorporated at this stage could address: (a) magnitude range for each source; (b) magnitude vs. fault rupture relationship; (c) orientation of rupture source; (d) directivity of rupture propagation; and (e) earthquake model uncertainties (e.g., uncertainties in "a" and "b" values in the Gutenberg-Richter relationship). (Continued on Page 4)

Research Activities (Cont'd)

(Continued from Page 3)

tionship, or in characteristic earthquake models, time-dependent or time-independent models, etc.).

The second part of Step 1 would identify an adequate number of simulations for each scenario earthquake. In this, a "simulation" is defined as a complete set of hazards and component input parameters, in which the values of the parameters have been changed in accordance with the uncertainty characterizations contained in the hazards and component modules. For each simulation, a separate system SVA would be carried out under Step 2 (as described below). This process would be repeated until a sufficient number of simulations have been considered for each parameter to permit an evaluation under Step 3 of how the system SVA results are impacted by uncertainties in the parameter values. Effects of the uncertainties in each parameter can in principle be treated in this way. In what follows, each simulation for earthquake m ($m=1,2,\dots,M$) is designated as $n(m)$, (where $n(m) = 1(m), 2(m), \dots, N(m)$, and $N(m)$ is the total number of simulations for earthquake m).

Step 2: System Analysis for Earthquake m and Simulation $n(m)$

The next step in the SVA procedure would consist of a system analysis for each simulation associated with each scenario earthquake. For each simulation, the analysis would involve the following evaluations:

Hazard Evaluation. First, the data and models contained in the hazards module of the GIS data base would be used to estimate the earthquake ground motions and geologic hazards throughout the system.

Direct Loss and System State Evaluation. Once the hazards are estimated, the component module in the GIS data base would be used to evaluate the direct losses and the system state associated with the m^{th} earthquake and the $n(m)^{\text{th}}$ simulation for that earthquake. The direct losses would indicate the total cost for repair or replacement of damaged components within the system. The system state (defined at various times after the earthquake) would indicate the number of lanes that remain open to traffic along each roadway in the system, and any reduced speed limits within the system while the damage is being repaired.

Traffic Flow Evaluation. The system traffic flow models and traffic forecasting methodology contained in the traffic flow module would be applied for each system state, in order to assess how travel times, travel distances, and travel paths throughout the system and between its origin-destination zones would be impacted by the earthquake damage associated with the given system state. In principle, a local or regional socioeconomic model could be added at this stage, to evaluate broader social and economic impacts of the earthquake damage.

Step 3: Incrementation of Simulations and Scenario Earthquakes

This step simply represents the process wherein the system analysis from Step 2 is repeated for each simulation associated with each scenario earthquake.

Step 4: Aggregate System Analysis Results

This final step in the SVA process would be carried out after the system analyses for each simulation and each scenario earthquake have been completed. In this step, the results from all simulations would be aggregated and displayed. Depending on user needs, these aggregations could focus on the seismic risks associated with the total system or with individual components. Furthermore, the system or component results could be provided for individual simulations and/or for the broader (probabilistic) range of simulations. For research purposes, the impacts of incorporating variabilities into the SVA will be of considerable interest. For other purposes, such as the planning of seismic strengthening programs for existing highway systems, outputs can be adapted and/or simplified in accordance with the particular requirements of each user audience.

Demonstration Seismic Vulnerability Assessment

The above SVA procedure has been applied to a Memphis area highway system (fig. 2) in conjunction with currently available data and models, to demonstrate the application of the procedure and the type of results that can be obtained, and to also provide a basis for identifying and prioritizing research needs to be addressed in subsequent years of the NCEER Highway Project. It is noted that, because of the preliminary nature of much of the currently available data and models, the results of this demonstration SVA should

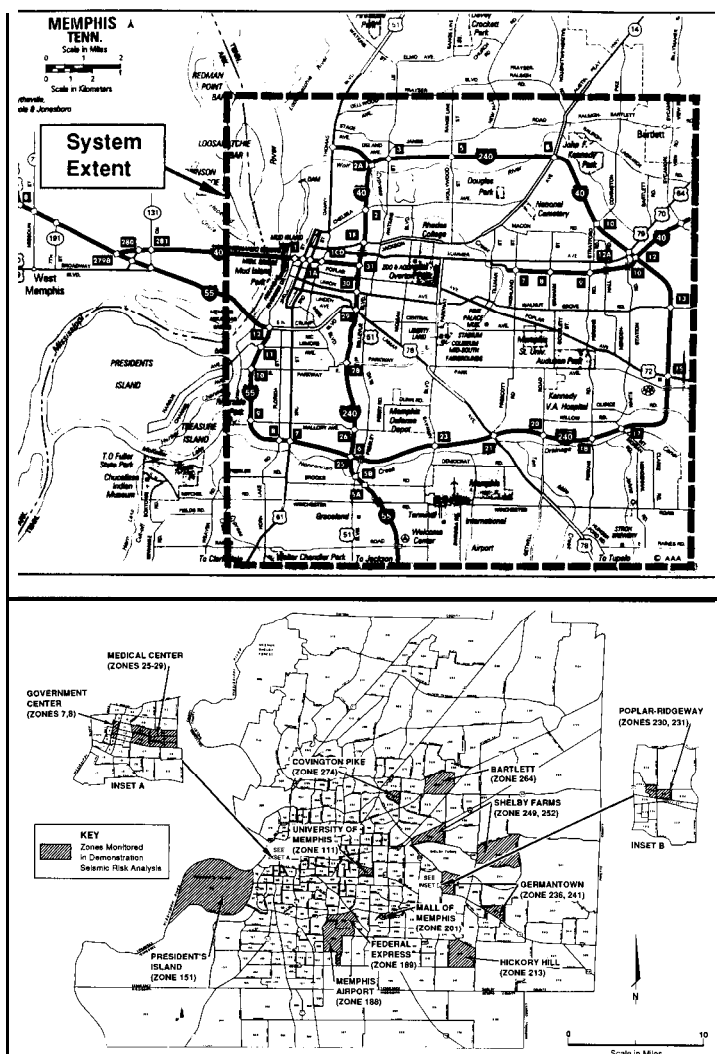


Figure 2: Memphis Area Highway System

not be interpreted as a prediction of the seismic performance of this Memphis area highway system at this time. As improvements to these data and models are developed under the Highway Project, the reliability of the system seismic performance estimates should increase substantially.

System

The city of Memphis is located in the southwestern corner of Tennessee, just east of the Mississippi River and just north of the Tennessee-Mississippi border. Because of its proximity to the New Madrid seismic zone, the potential seismic risks to the Memphis area are well recognized and have been studied extensively (e.g., A & H, 1982; Desmond, 1994). The Memphis area highway system evaluated under this demonstration SVA (fig. 2a) includes the beltway of inter-

state highways that surrounds the city, the two crossings of the Mississippi River (at Interstate Highways 40 and 55), major roadways within the beltway, and highways just outside of the beltway that extend to important transportation, residential and commercial centers to the south, east, and north. Locations of such centers within this system are shown in the Origin-Destination (O-D) zone map provided in figure 2b. The system contains a total of 286 bridges.

Assumptions

As noted earlier, this demonstration SVA is based on currently available data and models only. Because the data and models are very preliminary at this time, it has been necessary to incorporate certain simplifying assumptions into this SVA. These assumptions are summarized below.

Scenario Earthquakes. This demonstration SVA was carried out for four scenario earthquake events only. These four earthquakes represent a range of different moment magnitude levels and locations in the region surrounding Memphis (fig. 3a), and are as follows: (a) Earthquake A - which has a moment magnitude $M_w = 7.5$ (corresponding to a repeat of the largest earthquake in the 18 11-18 12 sequence) and is located at the southern end of the New Madrid seismic zone (Zone A in fig. 3a); (b) Earthquake B - which has a moment magnitude $M_w = 6.5$ and is located near the center of Zone A; (c) Earthquake C - which has a moment magnitude $M_w = 6.0$ and is located in Zone B to the west of Zone A; and (d) Earthquake D - which has a moment magnitude $M_w = 5.5$ event and is located in Zone B east of Zone A. The distances from the assumed epicenters of these various earthquakes to the closest and furthest points within the Memphis highway system range from about 35-50 km (for Earthquake D) to about 110-125 km (for Earthquake C). These earthquakes are described further in Werner and Taylor (1995). This article provides results for Earthquake D only.

System Module. The only system components that have been considered in this demonstration SVA are bridges and roadways. The system does not contain any tunnels, and other system components (e.g., retaining walls, etc.) have not been considered. The configuration and layout of the highways within the system were obtained as part of a GIS data base provided by the University of Memphis. An extensive data base of structural attributes relevant to seismic performance have been compiled for most of the bridges in the area, and (Continued on Page 6)

Research Activities (Cont'd)

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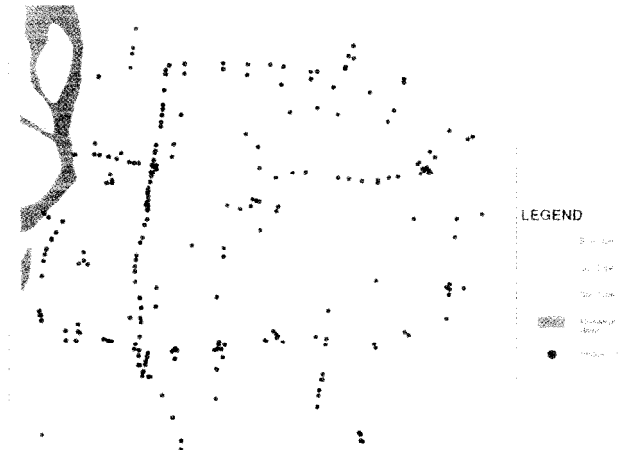
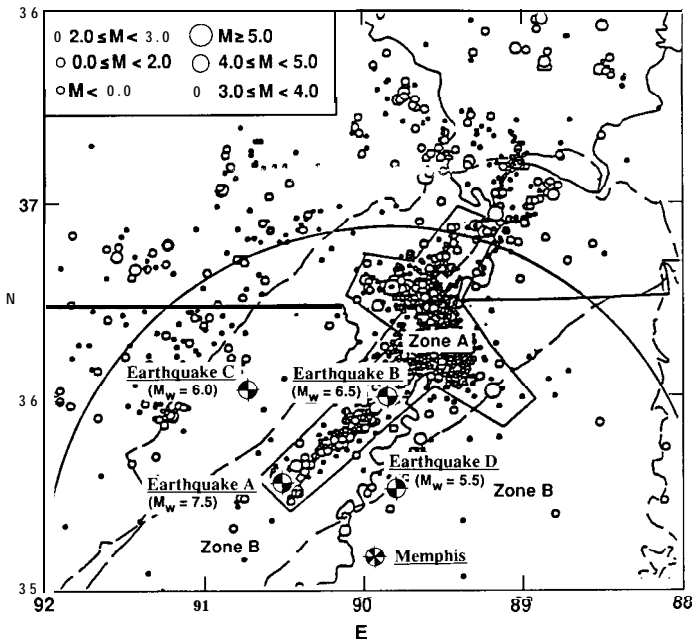


Figure 3: Scenario Earthquakes and Local Geology

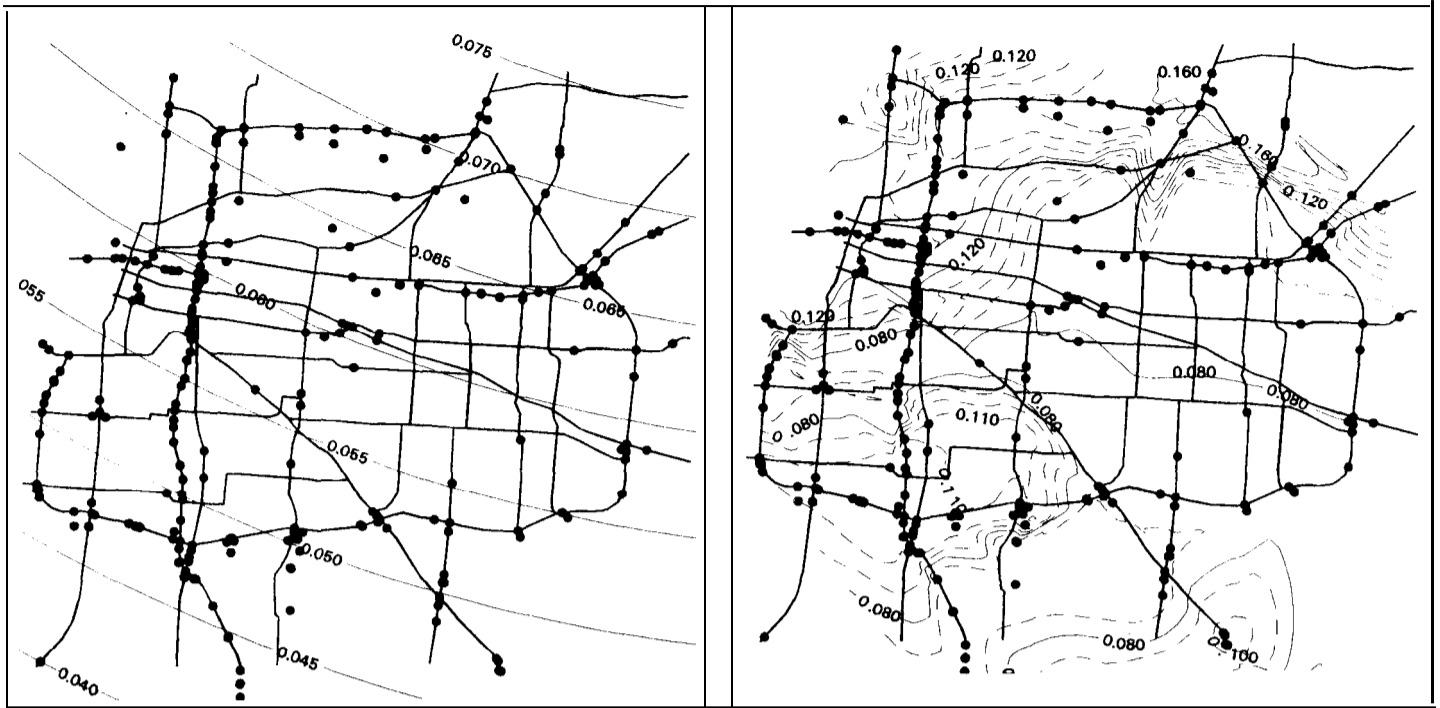
are provided in Werner and Taylor (1995). The traffic flow and volume data, roadway traffic capacities, and O-D zones within the system were provided by the Memphis and Shelby County Office of Planning and Development (OPD). The traffic flow data were from their 1988 traffic forecasting model.

Hazards Module. The only seismic and geologic hazard that has been considered in this SVA is ground shaking. Potential hazards from liquefaction, landslide, and associated

ground movement have not been included because of a lack of suitable data for carrying out such evaluations over a spatially dispersed region and for a range of scenario earthquake events. The ground shaking hazard was represented in terms of peak ground acceleration (PGA). It was estimated in two steps. First, bedrock accelerations at each bridge site due to each scenario earthquake were estimated using the attenuation equation developed by Hwang and Huo (1994). Then, effects of local soil conditions at each bridge site were represented by multiplying the bedrock accelerations by local geology factors developed by Martin and Dobry (1994) for various site categories and bedrock acceleration levels. This was based on the local geology mapping of the area carried out at the University of Memphis (fig. 3b), and is contained in the GIS data base for this demonstration SVA (Hwang and Lin, 1993; Tarr and Hwang, 1993). Figure 4 shows the resulting bedrock and ground surface peak accelerations for Earthquake D.

Component Module — Loss Model. In this demonstration SVA, loss models previously developed under the ATC-25 project for conventional highway bridges were used to estimate direct losses for each bridge in the system due to each earthquake (ATC, 1991). In these models, the direct losses depend only on whether the bridge has simple spans or is continuous/monolithic; i.e., other bridge structural attributes that could impact seismic performance have not been considered.

Component Module — Functionality Model. Because of a lack of available and suitably compiled data pertaining to post-earthquake traffic flows, repair procedures, and repair times for a given type and degree of bridge damage, only a very simple functionality model could be used for this demonstration SVA. Accordingly, the functionality model that was used represents the number of lanes open at discrete times after an earthquake, as a function of PGA and the original number of lanes along the bridge. Two different models were developed in accordance with the ATC-25 conventional highway bridge designations—one for bridges with simple spans and one for continuous/monolithic bridges. Reductions in traffic speeds were not considered at this time. In addition, to illustrate that system performance can vary with time after the earthquake, functionality models were developed for two discrete times. The first was intended to represent a time shortly after the earthquake, before any repairs



a.) *Bedrock*
Contour Interval = 0.005 g

b.) *Ground Surface*
Contour Interval = 0.01 g

Figure 4: Peak Accelerations (g) Due to Earthquake D

have been made but after undamaged bridges had been reopened and lane closures to accommodate immediate post-earthquake repair had been established. This time has been arbitrarily assumed to be three days after the earthquake (recognizing that this may be optimistic). The second time was assumed to represent a more extended time after the earthquake, when some bridge repair has been made and at least some lanes of the damaged bridges have been reopened to traffic. This time was arbitrarily assumed to be six months. These approximate functionality models do not represent all of the possible causes of bridge and roadway closure after an earthquake, nor do they consider alternative bridge repair strategies that may be employed (together with their associated costs, durations, and impacts on traffic flow). The functionality models that were used are discussed in detail in Werner and Taylor (1995).

Traffic Management Module. In view of the absence of information addressing emergency traffic management procedures that would be implemented in the Memphis area after a major earthquake, the traffic management module of

the GIS data base was not included in this demonstration SVA.

Traffic Flow Module. Our analysis of the impacts of each scenario earthquake on traffic flows within the Memphis area highway system was carried out using the MINUTP traffic forecasting software (Comsis, 1994). This software was selected because it is the procedure used at the Memphis-Shelby County Office of Planning and Development (OPD), and all traffic data for the region was available in the input format for this software. Although this procedure appeared to provide reasonable results for the various cases that were run (Werner and Taylor, 1995), it has the significant disadvantage of not being compatible with our GIS data base. Because this greatly increased the efforts required to develop suitable input data for the traffic flow analyses and to interpret the analysis results, the identification (or development, if necessary) of a suitable GIS-compatible traffic flow methodology is recommended as a high priority SVA research area.

(Continued on Page 8)

Research Activities (Cont'd)

(Continued from Page 7)

Results: Direct Loss Estimates, Scenario Earthquake D

In accordance with the ATC-25 model used in this demonstration SVA, direct losses due to damage to the system's bridges are represented as a damage ratio, DMG (%), which is defined as the ratio of the repair cost for each bridge to its total replacement cost.

The damage ratios for each of the 286 bridges in the Memphis area highway system due to each scenario earthquake are tabulated in Werner and Taylor (1995). To roughly compare the relative effects of each earthquake on the direct losses throughout the system, average damage ratios were computed (averaged over all of the 286 bridges) for each earthquake. This article provides results for Earthquake D only, for which this average damage ratio was 37.4%. From the results provided in Werner and Taylor (1995), this damage ratio turned out to be much larger than that computed for Earthquake C (whose effects on the system were relatively minor), and was slightly larger than the average damage ratio computed for Earthquake B. Only Earthquake A, which was by far the most severe of the four scenario earthquakes considered, resulted in damage ratios that were larger (by a substantial amount) than those due to Earthquake D.

Results: Traffic Flows, Scenario Earthquake D

Overview of Seismic Vulnerability Assessment Procedure. This seismic vulnerability assessment estimated how earthquake damage to the Memphis area highway system due to each scenario earthquake impacted traffic flows in the area. The analysis consisted of two parts. First, the PGAs esti-

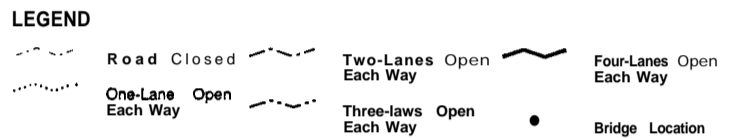
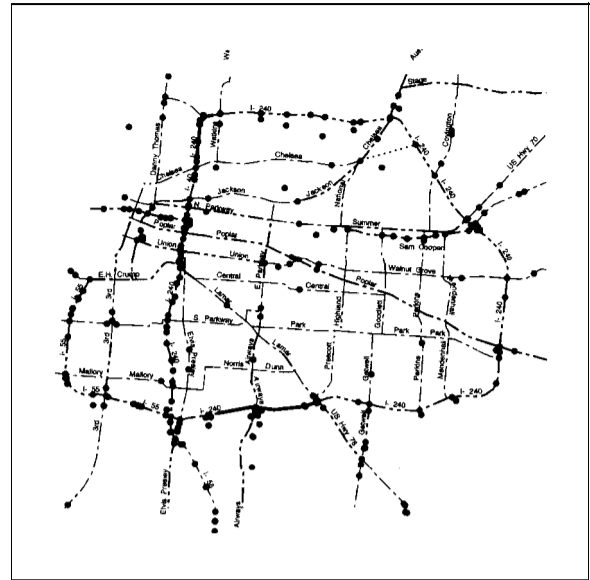


Figure 5: Pre-Earthquake System State

ated for each scenario earthquake were applied to the functionality models, in order to estimate the state of the system at times of three days and six months after each earthquake (in terms of the number of available lanes along each roadway in the system). Then, the effects of any reductions in the available lanes (due to earthquake damage) on traffic flows throughout the system were estimated by using the MINUTP transportation forecasting software, together with a regional traffic capacity and flow data base developed at the Memphis and Shelby County OPD. From this, travel

Table 1: Effects of Earthquake D on Total System Travel Times and Distances

| PARAMETER | PRE-EARTHQUAKE VALUE | T = 3 DAYS | | T = 6 MONTHS | |
|---------------------------------------------------------------------|----------------------|--------------------|------------------------------|--------------------|------------------------------|
| | | Value | Percent Increase over Pre-EQ | Value | Percent Increase over Pre-EQ |
| Total vehicle hours traveled over 24-hour period (incl. congestion) | 3.73×10^5 | 4.99×10^5 | 33.8 | 4.46×10^5 | 19.6 |
| Total travel distance (mi) over 24-hour period | 15.5×10^6 | 15.6×10^6 | small | 15.6×10^6 | small |

Note: T = Time after earthquake at which system-wide impacts are estimated.

times and distances throughout the system after each earthquake were compared to pre-earthquake travel times and distances (in which all travel times and distances are average values for a 24 hour period). Two sets of comparisons were made. One corresponded to an overall travel time and distance for the entire system, which are computed as the sum of the travel times and distances respectively between all origin-destination (O-D) zones in the system (fig. 2b). This set of comparisons provides an approximate measure of the impacts of each earthquake on overall system performance. The second set of comparisons involved a breakdown of these total travel times and distances for particular key O-D zones highlighted in figure 2b. These latter comparisons indicate the spatial distribution of the earthquake impacts throughout the system, and also show how travel to and from these important O-D zones are impacted by earthquake damage to the highway system.

System State Results. Based on the PGA estimates obtained throughout the system due to each scenario earthquake, to-

gether with the preliminary functionality models, the system state after each earthquake was estimated. This system state is defined as the number of lanes open along each link in the system. The pre-earthquake system state and example system state results for times of three days and six months after Earthquake D are shown in figures 5 and 6. These figures show that, although Earthquake D is the smallest of the four scenario earthquakes ($M = 5.5$), the gross models used for this SVA estimate that the proximity of this earthquake to the northern segment of the Memphis area highway system results in extensive roadway and lane closures in this segment, with lesser impacts on other sections of the system.

Overall System Travel Times. Table 1 shows that, as a result of the estimated bridge damage due to Earthquake D, overall system travel times three days after the earthquake are nearly 34 percent larger than the pre-earthquake values. Six months after the earthquake, the bridge repairs within that time have reduced the overall system travel time; however it is still nearly 20 percent larger than the pre-earthquake value.

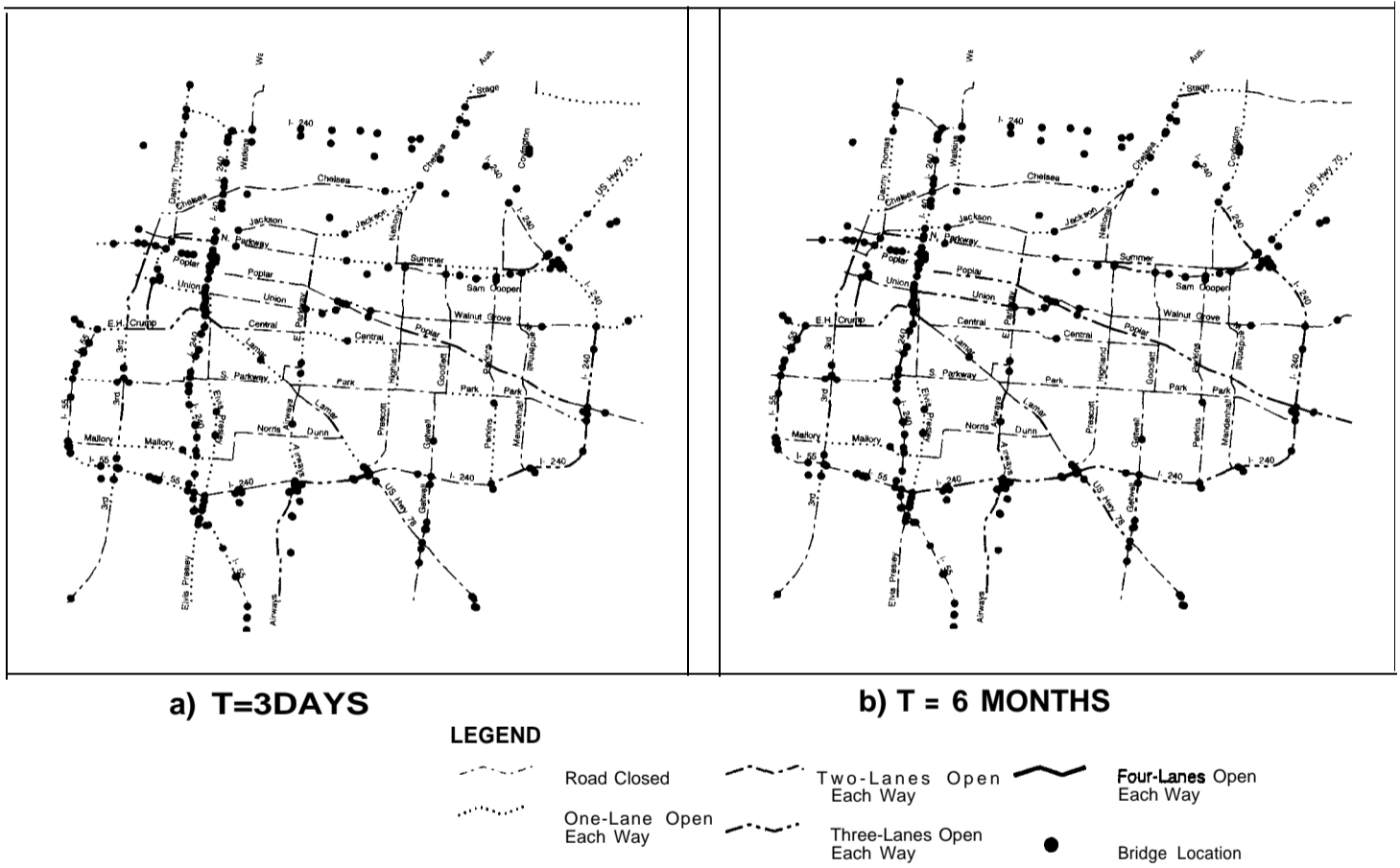


Figure 6: System State Results - Earthquake D

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Research Activities (Cont'd)

(Continued from Page 9)

Table 2: Effects of Earthquake D on Travel Time to or from Designated Origin-Destination Zones (Over 24 Hour Time Period)

| ORIGIN-DESTINATION ZONE | | PRE-EARTHQUAKE TRAVEL TIME (HOURS) | 3 DAYS AFTER EARTHQUAKE | | 6 MONTHS AFTER EARTHQUAKE | |
|--------------------------------------|-----|------------------------------------|-------------------------|-------------------------------------------|---------------------------|-------------------------------------------|
| Description | No. | | Travel Time (hrs) | Percent Increase over Pre-Earthquake Time | Travel Time (hrs) | Percent Increase over Pre-Earthquake Time |
| Government Center (downtown Memphis) | 7 | 128 | 143 | 11.7 | 133 | 3.9 |
| | 8 | 122 | 141 | 15.6 | 130 | 6.6 |
| Medical Center | 25 | 122 | 136 | 11.5 | 127 | 4.1 |
| | 26 | 114 | 129 | 13.2 | 121 | 6.1 |
| | 27 | 114 | 129 | 13.2 | 121 | 6.1 |
| | 28 | 115 | 129 | 12.2 | 121 | 6.2 |
| | 29 | 119 | 133 | 11.8 | 124 | 4.2 |
| University of Memphis | 111 | 119 | 131 | 10.1 | 122 | 2.5 |
| President's Island (Port) | 151 | 138 | 153 | 10.9 | 144 | 4.3 |
| Memphis Airport | 188 | 136 | 150 | 10.3 | 142 | 4.4 |
| Federal Express | 189 | 130 | 145 | 11.5 | 136 | 4.6 |
| Mall of Memphis | 201 | 127 | 145 | 14.2 | 133 | 4.7 |
| Hickory Hall | 213 | 171 | 185 | 8.2 | 177 | 3.5 |
| Poplar-Ridgeway | 230 | 130 | 148 | 13.0 | 136 | 4.6 |
| | 231 | 130 | 147 | 13.1 | 136 | 4.6 |
| Germantown | 236 | 141 | 157 | 11.3 | 147 | 4.3 |
| | 241 | 176 | 187 | 6.3 | 181 | 2.8 |
| Shelby Farms | 249 | 169 | 176 | 4.1 | 174 | 3.0 |
| | 252 | 127 | 211 | 66.1 | 152 | 19.7 |
| Bartlett | 264 | 148 | 199 | 34.5 | 155 | 4.7 |
| Covington Pike | 274 | 137 | 181 | 32.1 | 151 | 10.2 |
| TOTALS | | 2813 | 3255 | 15.7 | 2963 | 5.3 |

Overall System Travel Distances. Table 1 shows that overall system travel distances are not sensitive to the estimated bridge damage due to Earthquake D, despite the fact that the total number of trips estimated over a 24-hour period by MINUTP (solely on the basis of demographics) was nearly the same for the pre-earthquake system and for each scenario earthquake. This lack of change of travel distances, despite significant increases in travel times, is no doubt due to the types of more direct but less-time efficient routes that would need to be taken after an earthquake. For example, if faster but less direct routes along interstate highways and beltways that would ordinarily be used are closed because of bridge damage, slower but more direct routes along city streets with no damaged bridges would instead need to be used.

O-D Zone Travel Times. Table 2 shows that three days after Earthquake D, the travel times between the zones listed in the table are estimated to be, on the average, nearly 16 percent larger than those for the pre-earthquake system. The travel time increases due to damage from this earthquake are estimated to be largest for northernmost of the highlighted zones, which are at Shelby Farms (Zones 249 and 252), Bartlett (Zone 264), and the Covington Pike (Zone 274). Six months after Earthquake D, table 2 shows that the travel times to and from these zones have been reduced substantially, and are now only 5.3 percent larger than the pre-earthquake values.

O-D Zone Travel Distances. As for the overall system travel distances, the travel distances to and from the highlighted O-D zones are not sensitive to damage from Earthquake D (Werner and Taylor, 1995).

Acknowledgments

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drawings, and reports from their files. Finally, the authors are grateful to the following Dames & Moore personnel for their significant contributions to this research: C.B. Crouse (seismic hazard analysis), Ahmed Nisar (numerical analysis), and Jon Walton (GIS applications).

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Center Activities

In Memorial

Peter Gergely, Center Founder



NCEER co-founder and leader of the Building Project, Dr. Peter Gergely, died of cancer on August 25, 1995. Peter was one of the five principal investigators who established the Center and one of its primary leaders since its inception in 1986.

Throughout his long and illustrious career, Dr. Gergely made major contributions to a wide variety of structural engineering problems. His research has led to important advances in understanding the mechanics of reinforced and prestressed concrete, including shear phenomena, crack control, bond and anchorage, and splice behavior - with strong emphasis on using the research results to improve building codes. He has also made pioneering contributions in structural dynamics, earthquake engineering, and hazard mitigation, particularly for structures and facilities built in regions of moderate seismicity. His research has been reported in more than one hundred technical papers.

In recognition of his outstanding contributions to advancing the understanding of concrete structures under severe static and dynamic loadings, and for applying this understanding to design and to design codes, Dr. Gergely was honored with numerous national and international awards. He was a corecipient of the State of the Art of Civil Engineering Prize (ASCE, 1974) and the Raymond C. Reese Research Prize (ASCE, 1976); he was elected a fellow of ACI (1974); he received the Delmar Bloem Distinguished Service Award (ACI, 1981); and he was a corecipient of the Wason Award for Most Meritorious Paper (ACI, 1993) and the Structural Research Award (ACI, 1994). Of all his honors, the one that meant the most to him was the Honorary Doctorate he received in 1992 from his beloved alma mater, the Technical University of Budapest, given "for his outstanding international activities in advancing the development of his profession of mechanics and reinforced concrete."

Dr. Gergely was exceptionally generous in volunteering his time and talents to committees in professional societies and groups, including the American Concrete Institute, the American Society of Civil Engineers, the International Association for Bridge and Structural Engineering, the International Committee on Tall Buildings, the National Research Council, the Transportation Research Board, the Applied Technology Council, the Building Seismic Safety Commission, the National Committee on Property Insurance, and others. He has chaired many committees of these organizations and was elected to a term on the Board of Direction of ACI.

On the educational side, Dr. Gergely served as an inspirational teacher and adviser to many hundreds of undergraduates and graduate students at Cornell University since 1963. He was promoted to full professor in 1975 and held two prominent leadership positions at Cornell - chair of the Department of Structural Engineering (1983-88) and the director of the School of Civil and Environmental Engineering (1985-88). He was instrumental in developing a highly successful, design-oriented Master of Engineering program in Structural Engineering. He coauthored a three-volume undergraduate textbook series published by John Wiley in the 1970s. His numerous drafts of a book on structural dynamics and earthquake engineering have been used



Peter Gergely was able to attend most of the symposium held in his honor on August 7, 1995. He is shown shaking hands with Don Dosenberry, of Simpson, Gumpertz and Heger. His wife Kinga is behind him.



Many distinguished leaders in the structural engineering field today attended the Peter Gergely Symposium. Shown above, from left to right, are Jose Roesset, University of Texas; Bob Bruce, Tulane University; and Erhard Bruy, Stuttgart, Germany.

and circulated to others by many hundreds of students at Cornell and elsewhere. His expectations of students were uniformly high, and his students responded in an exceptional fashion to the examples of technical and professional excellence he set both inside and outside the classroom and laboratory. They also greatly appreciated his dry sense of humor and his constant support of their activities in ASCE and Chi Epsilon. Over the years, students have consistently ranked Dr. Gergely among the leading faculty members in the College of Engineering, and in 1995 he received a Dean's Prize for Excellence in Teaching.

Peter Gergely was born in Budapest, Hungary, on February 12, 1936. He grew up in Budapest and entered the Technical University of Budapest in 1954. He was a freedom fighter during the Hungarian Revolution of 1956, leaving Hungary at the very end of the Hungarian resistance to Soviet invasion to come to North America. He enrolled at McGill University in Montreal and received the BCE with Applied Mechanics honors in 1960. While in Montreal he also completed 21 months of structural engineering work with the Dominion Bridge Company and other firms. He entered graduate school at the University of Illinois in 1960 and received his M.S. degree in 1962 and his Ph.D. degree in 1963.

He is survived by his wife, Kinga, son, Zoltan, daughter Illa (David) Burbank, and grandson Istvan.

The Peter Gergely Seminar Series and Distinguished Lectureship in Structural Engineering

During his thirty-two-year tenure as a faculty member at Cornell University, Peter Gergely helped bring many leading engineers and researchers to Cornell University to present guest lectures to students and faculty in structural engineering. Subjects have included state-of-the-art reports on recent research, presentations of innovative designs, and discussions of professional, technical, legal, and historic topics in design and construction. These lectures have played a critical role in the education of both undergraduate and graduate students by introducing them to leaders in the engineering profession. In particular, these seminars have helped maintain the exceptionally high standards of the Master of Engineering professional degree program.

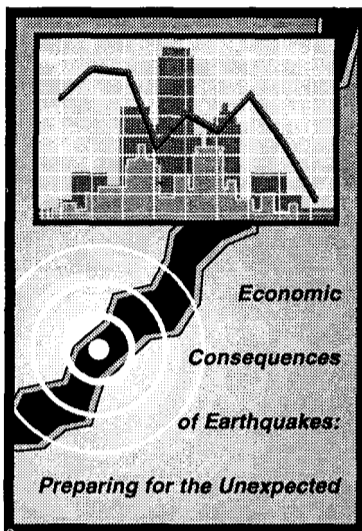
The **Peter Gergely Seminar Endowment** will further this mission by ensuring continued financial support for a program that will bring to campus world-class structural engineers and researchers who can provide an enriching series of lectures in the School of Civil and Environmental Engineering. It is the intention of the school to create an endowment fund whose income will provide travel support for at least one distinguished keynote lecturer each year, as well as travel assistance for speakers in a biweekly structural engineering seminar series. The lectureship and endowed seminar series will be a tribute to Professor Peter Gergely, who devoted his career to the advancement of the engineering profession through education and research.

The school welcomes the participation of alumni and friends in building this endowment fund. For information on making a gift, please contact Ms. Marsha Pickens, Director of Development and Alumni Affairs, College of Engineering, 248 Carpenter Hall, Cornell University, Ithaca, New York 14853.



Conference Review

Economic Consequences of Earthquakes: Preparing for the Unexpected



On September 12-13, 1995, NCEER, with conference cosponsor Federal Emergency Management Agency, hosted a conference to address the implications of damaging earthquakes on the financial and economic systems of urban regions. The program, *Economic Consequences of Earthquakes: Preparing for the Unexpected*, was developed by an organizing committee chaired by

Professor Howard Kunreuther of the Wharton School to bring together recognized leaders in the fields of economics, insurance, seismology, engineering and earthquake hazards mitigation to examine the potentially damaging effects of earthquakes on business, commerce, industry, insurance and the financial markets. Members of the organizing committee included William Anderson, National Science Foundation, George Lee and Ian Buckle of NCEER, Barclay Jones of Cornell University, Joanne Nigg and Kathleen Tiemey of the Disaster Research Center, University of Delaware, and Masanobu Shinozuka of the University of Southern California. Drawing on experiences from the Kobe and Northridge earthquakes, the program featured eight sessions including:

- Implications of the Great Hanshin (Kobe) Earthquake for Major U.S. Cities
- Potential Earthquakes in the Eastern and Central United States
- Economic Implications of Utility Lifelines and Port Facility Failures
- Economic Implications of Impact on Transportation Facilities and Buildings

- Business Disruption and Economic Consequences
- Potential Impact on Finance and Insurance
- Precautionary Preparation and Mitigation Plans to Reduce Impacts

In addition to members of the organizing committee, program participants were Ted Algermissen, Ron Eguchi and Charles Scawthorn of EQE; Jim Beavers, MS Technology, Inc.; Deborah Beck, Vice President of the Real Estate Board of New York; Hal Cochrane, Colorado State University; Raymond DeVoe, Legg, Mason, Wood, Walker; Klaus Jacob, Lamont-Doherty Earth Observatory; Eugene Lecomte, Insurance Institute of Property Loss Reduction; Guy Nordenson, Ove Amp & Partners; Franklin Nutter, Natural Disaster Coalition; Ralph Rose, Bear, Stearns and Company; Stu Werner, Dames & Moore; and Bojidar Yanev, New York City Department of Transportation. Dick Moore, FEMA Associate Director for Mitigation, addressed participants at a luncheon talk in which he reviewed current plans for a national disaster mitigation strategy. The evening's banquet speaker, Clement Dwyer, Executive Vice President of Guy Carpenter & Company, Inc., emphasized the potential catastrophic risk to the insurance industry due to earthquakes, and offered strategies to provide the insurance industry with the capital needed to mitigate the risk. Joel A. Miele, New York City Building Commissioner, luncheon speaker on the second day, explained the steps taken by New York City to insure the inclusion of seismic safety provisions in the City's code for new building construction.

Approximately 150 people attended the conference, which was held against the backdrop of New York's financial district at the Downtown Conference Center in the World Trade Center.

Selected abstracts of presentations from the conference by NCEER affiliates follow. The Proceedings from this conference are currently being prepared, and are anticipated to be available in 1996. The **NCEER Bulletin** will announce their availability, cost and order information. In addition, an Executive Summary report is being prepared in cooperation with FEMA to summarize key issues raised at the conference. The Executive Summary will be targeted at an audience of decision-makers, public officials, and others with a need to know about natural hazards and managing financial risk.

What Happened in Kobe and What if it Happened Here?

Charles Scawthorn, *EQE International*



The January 17, 1995 Mw 6.9 Kobe (Hanshin) earthquake occurred directly under a modern heavily industrialized urban area with a population of more than 4 million. Ground motions were in the range of 0.5-0.9g, and resulted in about 5,400 deaths, loss of 150,000 houses (12% of the residential building stock), and about 1,000 large steel and/or concrete engineered buildings collapsed or were severely damaged. Damage to infrastructure was also severe, with the water, gas, sewer, highway and rail networks made essentially unusable for several months. The Port of Kobe is one of the world's largest container ports, handling about 30% of Japan's traffic - more than 90% of the Port was destroyed or seriously damaged.

Kobe is perhaps the most significant earthquake to occur in the last half of the twentieth century - not from the geophysical perspective (there have been much larger events) or that of life loss (tragically, there have been a number of events with greater life loss), but rather in the social sense. In Kobe the entire range of low-rise wood, concrete mid-rise and modern steel and concrete tall buildings, old and new concrete and steel highway, rail bridges, major crossings and other infrastructure, and emergency systems and response measures, were all subjected to ground motions, liquefaction and permanent ground deformations of very large magnitude. This is the first example of this broad a range of structures and systems being so heavily affected. The performance of these structures was mixed, to the point that the urban function was severely impaired if not entirely disrupted. Maintenance of life-essential functions was very difficult, and normal economic activity was not possible. The direct damage and cost of repair for this event is estimated at well in excess of \$100 billion - the total impact on the Japanese and global economy has yet to be estimated.

Were a Kobe event to happen *here*, what would be the impact? The January 17, 1994 Mw 6.7 Northridge (Los Angeles) earthquake has many similarities and provides some insights - performance of engineered structures was about the same, while U.S. wood houses, being significantly different

from Japanese residential construction, in general did not collapse, but sustained substantial damage. While, relative to Kobe, few people were killed in the Northridge event, total damage was still substantial (about \$25 billion) and insurance losses were much higher (about \$12 billion, vs. about \$1 billion in Kobe). The lower total damage in Northridge is probably simply a reflection of the lower urban density there.

In order to better understand what would be the impacts if Kobe happened *here*, we have employed simulation modeling to examine the damage and economic impacts for large credible earthquakes in Los Angeles, San Francisco and other U.S. urban regions. The total damage is seen to be of Kobe-scale - losses unprecedented in modern U.S. history. Important issues arise from this level of damage - what are the consequences for heavily impacted business sectors, such as finance and insurance, or heavily concentrated industries, such as aerospace in the Pacific Northwest or the film industry in southern California and, lastly, what are the overall potential impacts for the regional and national economies?

Scenario Earthquakes for Urban Areas Along the Atlantic Seaboard of the U.S.

Klaus H. Jacob, *Lamont-Doherty Earth Observatory of Columbia University*



Based on the historic (x300-year) and instrumentally monitored (≈ 50 -year) seismic records, many portions of the Atlantic seaboard of the U.S. and adjacent Canada are prone to earthquakes at low to moderate rates of seismicity. The observed moderate rates do allow for large (magnitude $M=6$ and 7) earthquakes to occur, albeit at long recurrence intervals. Some of the larger historic events on record along the Atlantic margin of North America include the 1886 Charleston, South Carolina earthquake ($M_w=7.6\pm 0.3$) and the 1929 Grand Banks earthquake ($M_w=7.4\pm 0.2$). The largest historic event in the New York City area is the 1884 $M\approx 5+$ earthquake that occurred offshore; and the largest in the Boston area is the 1755 $M\approx 6+$ event near Cape Ann. Most of the larger earthquakes in the eastern U.S. have occurred prior to major population increases or, more recently, in less densely settled areas. These fortuitous circumstances have lulled the eastern U.S. popu-

(Continued on Page 16)

Center Activities (Cont'd)

(Continued from Page 15)

lation into the misleading perception that earthquakes do not pose a major threat.

The magnitudes to be considered for economic consequences range from relatively frequent earthquakes of magnitudes $M=4.5$ typically causing only minor losses of a few million dollars, to rare magnitude $M=7$ to 7.5 earthquakes potentially inflicting catastrophic losses in the tens to hundreds of billions of dollars, depending on distance from a major city and the value and vulnerability of the city's built assets. From the relationship between observed frequency of occurrence, and magnitude based on historic seismicity, magnitude distance pairs can be computed as a function of recurrence period for each city. For instance, a conservative estimate for New York City is that $M=5$, 6 and 7 earthquakes can be expected to recur about once every 500 years at median distances of about 20, 50 and 130 km, respectively; and during a 2,500-year period at the much shorter distances of 10, 25 and 60 km, respectively. These numbers are approximately equivalent to a 10% chance for such events to occur during exposure times of 50 and 250 years, respectively.

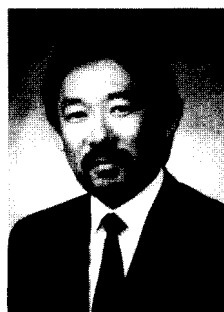
Two region-specific factors contribute to a potentially high seismic hazard in the eastern U.S., once a magnitude of an earthquake is given. First, seismic shaking, especially at high frequencies ($\geq 5\text{Hz}$) reaches to larger distances than in the western U.S.; and second, ground motions can vary more strongly between sites on very hard rock and very soft soils. Both shaking effects have to do with geologic conditions of the Earth's crust, its rocks and soils that can differ distinctly between the eastern and western U.S. The paper provides examples from various bridge studies recently carried out in the greater New York City area in which ground motions on different rock and soil conditions have been computed for the magnitude distance combinations quoted above. Some of these motions shake short-period (0.1 to 0.3 seconds) buildings (like typical New York Victorian walk-up "brownstones") if located on rock, and long-period (1-5 seconds) structures (like typical high-rise buildings and large bridges) if located on soil in such a way that damage is likely to occur. Damage patterns in urban environments largely depend on what type of structures are built on what type of soil or rock. These patterns have been observed over and over again in past earthquakes everywhere. Another contributing hazard is soil liquefaction, a condition whereby a sandy soil becomes a liquid, largely loses its shear and bearing

strength, and thus cannot support structures founded in or on liquefying soils. Liquefiable soils exist in eastern U.S. waterfront cities, and especially in those that were glaciated some 10,000 years ago, like Boston and New York.

The paper shows examples of past earthquake effects in the eastern U.S., adjacent Canada, and from geologically similar situations elsewhere. From these examples, scenario events are developed that are centered on magnitudes near $M=6$ since they fall somewhere between the "manageable" losses from $M=5$ events, and the virtually "unmanageable" catastrophic losses from the $M=7$ events, at least if they are centered on any major eastern city such as Boston, New York, Philadelphia or Atlanta.

Mitigating Risks to Lifelines Through Natural Hazard Reduction and Design

Ronald T. Eguchi, EQE International, Inc.



Recent disasters have underscored the need to assess the vulnerability of our nation's lifeline systems to natural hazard effects. Current estimates of lifeline damage as a result of the 1994 Northridge earthquake are in excess of \$2 billion. While this amount may appear low relative to other types of losses (e.g., damage to buildings) it only reflects those costs associated with the repair of damaged lifeline systems. Other costs which may more accurately reflect the impact of damaged or inoperable systems, such as business losses due to lifeline disruption, or tire damage resulting from loss of water supplies, may be several times higher than these repair costs. Also, it must be recognized that the Northridge earthquake was a moderate-sized event and that the Los Angeles area is capable of generating earthquakes of much larger magnitude. Therefore, the relatively good performance of lifelines in the Northridge earthquake should not promote complacency in acceptable design measures for lifeline systems.

This paper concentrates on five areas relevant to natural hazard reduction for lifeline systems. First, a brief history of lifeline earthquake engineering in the U.S. is presented in order to identify important milestones with regard to lifeline seismic design and construction. Second, a discussion of

lifeline interdependencies is given. This analysis is critical in understanding the complexity of system performance. As will be seen, many lifeline systems are dependent on other lifeline systems for operation. Without an analysis of these dependencies, the reliability of these lifeline systems in post-disaster periods may be greatly overstated. Third, a discussion of indirect versus direct economic losses associated with the failure and disruption of lifeline systems in earthquakes is presented. As stated earlier, the larger impacts associated with damaged lifeline facilities may depend on how long these critical lifeline systems are out of service. Fourth, we offer several case histories which demonstrate how mitigation has been effective in reducing earthquake losses. An important program in this respect is the Caltrans bridge retrofit program. The cost-effectiveness of this program is reviewed against the experience of two major earthquakes in California: the 1989 Loma Prieta earthquake in the San Francisco Bay area and the 1994 Northridge earthquake in Los Angeles. Finally, several opportunities for impacting lifeline earthquake engineering design practices are discussed. The paper shows where these opportunities might build on federal initiatives. One important initiative focuses on the adoption of seismic design standards for private and public lifeline systems in the U.S.

Impacts of Recent U.S. Disasters on Businesses: The 1993 Midwest Floods and the 1994 Northridge Earthquake

*Kathleen J. Tierney, Disaster Research Center,
University of Delaware*



This paper summarizes findings from two Disaster Research Center surveys that document how disasters affect businesses and how business owners cope with disaster-related disruption. Both studies used randomly-selected, representative samples that included both large and small firms and a range of business types. The first survey, conducted in 1994, focused on a sample of 1,069 businesses in Des Moines/Polk County Iowa, a community that sustained extensive damage and disruption as a result of the 1993 Midwest floods. The second survey, which was conducted in 1995 using an almost identical methodological approach, assessed the impacts of the 1994 Northridge earthquake on 1,060 businesses in Los Angeles and Santa Monica, California.

The two disasters differed in their physical effects. Direct damage due to flooding was not widespread in Des Moines; just under 15% of the businesses surveyed were actually flooded. In contrast, approximately 56% of the businesses in the Los Angeles/Santa Monica sample experienced some type of direct physical damage due to the Northridge earthquake. The major impact the Midwest floods had on Des Moines was the disruption of lifeline services; around 80% of all Des Moines businesses were without water as a result of the flooding, 40% lost sewer and wastewater treatment services, and one-third lost either phone or electrical services. In Los Angeles, loss of electricity and phones were the most common lifeline impacts, reported by 61% and 54% of businesses, respectively. While some utilities were disrupted for weeks as a result of the 1993 floods, lifeline services were restored relatively quickly after the earthquake.

Both the floods and the earthquake forced large numbers of businesses to shut down. In Des Moines, 42% of the businesses surveyed reported they had to close for at least some period of time. The most frequently-cited reasons for closing in Des Moines were loss of water, electricity, sewer services, and customers. In the Northridge sample, approximately 56% of the businesses surveyed indicated they were forced to close. In that event, the most common reasons given for business interruption were the need to clean up damage at the business, loss of electricity, the inability of employees to come to work, and loss of telephone service. The median length of time businesses in Des Moines were closed due to flood-related damage and disruption was four days, while the median closure period following the earthquake was about two days.

Both surveys asked detailed questions on the sources of recovery assistance businesses used, including insurance and government assistance, such as the Small Business Administration disaster loan program. Just under 8% of the businesses surveyed in Des Moines had flood insurance at the time of the floods; 20% of Los Angeles businesses reported having earthquake insurance. Rates of business interruption insurance coverage were comparable for the two samples - 18% for Des Moines and just under 21% for Los Angeles. In both disasters, few businesses actually used or attempted to use their insurance coverage; similarly, businesses tended to avoid using other outside sources of assistance, such as SBA and bank loans. In both disaster situations, a significant proportion of disaster-related losses appear to have been absorbed by business owners.

(Continued on Page 18)

Center Activities (Cont'd)

(Continued from Page 17)

At the time the Des Moines survey was conducted, 70% of business owners indicated their business activity had returned to a level comparable to what it had been just before the floods; about 18% reported being better off, and 12% considered themselves worse off. In Los Angeles, 52% of the businesses surveyed rated their well-being as just about the same as it had been prior to the earthquake. The remaining businesses were roughly evenly split between those that were worse off and those that were better off than before the earthquake.

The findings discussed above refer to general patterns; however, the survey data also revealed that both disasters frequently had differential impacts, depending on business size and type. In Los Angeles, for example, small businesses were more likely to experience interruption than larger ones, and small service-sector businesses tended to stay closed longer. At the time of the survey, small businesses, particularly trade-related and service firms, were more likely than other businesses to report that they weren't doing as well as they had been before. In contrast, manufacturing and construction firms were better off.

Forecasting the Indirect Impacts of a Midwestern Earthquake

Hal Cochrane, Colorado State University



Regional economic disruption, the so called ripple effects stemming from damage to housing, plant, equipment and public infrastructure, has puzzled analysts for the better part of 20 years. Theoretically, dislocations due to post event supply shortages, insufficient demand, indebtedness, and bankruptcy could amplify losses. Yet, recent events (hurricanes Andrew and Hugo;

the Northridge, Loma Prieta and Kobe earthquakes; and the 1993 Mississippi floods) produced only minor dislocations. This paper explains the discrepancy between projections based on theoretical conditions and what has been observed. Based on an analysis of the forementioned events, I have concluded that, given appropriate circumstances, these so called ripple effects are potentially very large. The paper

outlines what those circumstances are and the degree to which they were present in Northridge, San Francisco and Kobe. In particular, the paper investigates several important sources of potential economic instability: the adverse response of financial markets; losses sustained by banks and thrifts; inflationary pressures; a depressed real estate market; diminished availability of insurance due to lost surplus; and the economic dislocations due to supply restrictions (such as the collapse of several interstate highways in and around Los Angeles as a result of the Northridge earthquake or the loss of port facilities in Kobe). The discussion then turns to the New Madrid region, exploring Shelby county's resilience to an 8 plus magnitude earthquake. The paper indicates the circumstances which would lead to a serious economic dislocation and suggests several policy options for dampening ensuing economic ripple effects.

Upcoming Conference

International Conference on Retrofitting of Structures

The *International Conference on Retrofitting of Structures* will be held on March 11-13, 1996 at Columbia University, New York City, New York. The conference is sponsored by the Department of Civil Engineering and Engineering Mechanics of Columbia University, the National Science Foundation and NCEER.

The three day conference will consist of oral presentations and technical discussion sessions in the broad category of retrofitting, including the retrofit of bridges and buildings, innovative retrofit methods and modern, nondestructive evaluation techniques. Sixteen invited speakers from the U.S., Japan and Europe, including practicing engineers, university researchers, and government representatives, will present their work.

The registration fee to the conference is \$350. For further information, contact Professor Raimondo Betti, Department of Civil Engineering and Engineering Mechanics, Columbia University, 610 S.W. Mudd Building, New York, NY 10027; phone: (212) 854-3143; fax: (212) 854-6267; or email: betti@cucers1.civil.columbia.edu.

Seismic Sleuths, A Teacher's Package for Grades 7-12

by Katharyn Nottis



What do a roll of adding-machine tape, a pile of Styrofoam blocks, a pie plate full of sand, a line of people being pushed at one end, and a candy bar all have in common? All were used at a workshop for secondary school teachers to make earthquake generating mechanisms and the effects of earthquakes clearer. *Seismic Sleuths*, a two day workshop for secondary level teachers, was held July 25-26, 1995 in Buffalo, New York.

This workshop, jointly sponsored by NCEER and the Federal Emergency Management Agency, focused on *Seismic Sleuths*, a package of materials for grades 7-12. These materials were developed by FEMA and the American Geophysical Union (AGU). However, additional information and activities were provided by workshop instructors that focused on earthquakes in the northeast, effectively using different teaching methods (e.g., analogies) to convey difficult-to-understand concepts, and the place of hazard education in the new National Science Standards. This hands-on workshop also gave teachers the opportunity to delve deeper into par-

titular aspects of plate tectonics. For example, Steven Boyar, an earth science teacher at Scarsdale High School in New York State, led a break-out session on using paleomagnetic data to demonstrate plate motion while Gary Nottis, from the New York State Geologic Survey, led a session on locating earthquakes in the northeast, critically examining velocity models. Len Sharp, an earth science teacher at Liverpool High School in New York State, led a break-out segment on using logarithmic magnitude and energy scales to compare earthquakes and John Gallagher, an earth science teacher from Port Angeles High School in Washington State, provided a session on designing and building structures to carry vertical and horizontal loads.

A highlight of the workshop was a hands-on demonstration of P and S waves. Based on an activity developed by Dr. John E. Mylroie, participants formed a chorus line, linking their arms about one another's shoulders. They were told that this represented a solid material and that P-waves would first be generated. The leader then walked to the end of the line and gave the last person a push on the shoulder in the direction of the lined-up individuals. The P-wave could be seen to progress slowly down the line, moving in the same direction as the students. S-wave transmission was then demonstrated by moving the end person in the front or back (back and forth motion), an impulse applied at right angles to the direction of propagation. The demonstration was completed by having participants drop their arms but stay touching, shoulder to shoulder, to demonstrate both waves through a liquid.

Activities such as the P and S wave chorus line enhance textbook information while giving a visual demonstration of P and S wave motions. Information presented in a number of modalities (visually, auditorally, tactilely) is more likely to be remembered, and connected to other related information.

The workshop was planned by Katharyn Nottis, now at Bucknell University and former NCEER Education Specialist, and Marilyn MacCabe, Federal Emergency Management Agency.

Center Activities (Cont'd)

Honors and Awards

NCEER Director Appointed Senior University Advisor for Technology



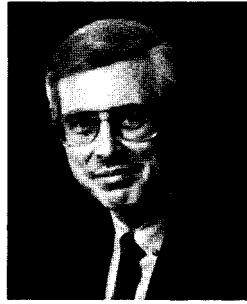
NCEER Director George Lee has been appointed to the post of Senior University Advisor for Technology at the University at Buffalo. Dr. Lee will serve as the presidential and provostal advisor regarding opportunities for the University at Buffalo to expand its presence in technological development and technology transfer and to form new technology-related partnerships.

Professor Lee's extensive familiarity with national and international technology issues and of the global environment for technological innovation has been – and continues to be – an exceptional resource for UB. His leadership in establishing NCEER and formulating the current infrastructure initiative has led to enormous advances for the University at Buffalo, as have his international initiatives and his commitment to community partnerships in research and service. By building on this base, as Senior University Advisor for Technology, he will provide the University with key support as new partnerships continue to be developed in the Niagara Region and around the world.

NCEER Affiliates Receive ASCE Awards



Professor Jose Roesset, Chairman of NCEER's Scientific Advisory Committee from the University of Texas at Austin, received ASCE's 1995 Nathan M. Newmark Medal. The Medal is awarded jointly by ASCE's Engineering Mechanics and Structural Division, and was awarded to Dr. Roesset for his contributions strengthening the scientific base of structural engineering.



Professor Thomas O'Rourke, an NCEER investigator from Cornell University, received ASCE's 1995 C. Martin Duke Award. This award is made annually "to an individual who has made a definite contribution to the advancement of lifeline earthquake engineering." As the recipient of this award, Dr. O'Rourke presented a keynote lecture entitled "Lessons Learned from Lifelines and Liquefaction in San Francisco" at ASCE's *Fourth U.S. Conference on Lifeline Earthquake Engineering* in San Francisco, August 10-12, 1995.



Professor Maria Q. Feng, an NCEER investigator from the Department of Civil and Environmental Engineering, University of California, Irvine, received the 1995 Alfred Noble Prize which is a joint award by the following five societies: ASCE (American Society of Civil Engineers), ASME (American Society of Mechanical Engineers), IEEE (Institute of Electrical and Electronics Engineers), AIME (American Institute of Mining, Metallurgical, and Petroleum Engineers), and WSE (Western Society of Engineers). The prize was awarded for the recognition of exceptional technical merit of her paper entitled "Application of Hybrid Sliding Isolation System to Buildings" which presented the result of her research supported by a joint NCEER-Taisei Corp. research project and was published in ASCE's **Engineering Mechanics Journal**, October 1993 edition. Professor Feng was also awarded the 1995 Collingwood Prize from ASCE for technical excellence and immediate adaptability of the idea developed in the same paper to professional practice. Professor Feng accepted these prizes on October 25, 1995 at the ASCE 1995 Annual Convention in San Diego, California.

At the same time, Professor Feng is a recipient of the 1995 National Science Foundation Career Award. Through this award, she will be supported by NSF's Natural and Technological Hazard Mitigation Program, with Dr. E. Sabadell as Program Director, for a period of four years to enhance her education and research activities.

Highway Seismic Research Council

by Ian M. Friedland

The Annual Meeting of NCEER Highway Project participants was held on October 5-7, 1995 in Buffalo, New York. The Annual Meeting provides an opportunity for the members of the Highway Seismic Research Council (HSRC), the project advisory committee, to review research progress and results, provide recommendations on future work, and assist in coordinating Highway Project studies and deliverables with other earthquake research programs and end-user implementation organizations. The meeting was well attended by both HSRC members and project researchers.

The meeting convened with a welcome by NCEER Director George Lee and a review of the preceding year's progress and accomplishments by NCEER Deputy Director Ian Buckle. Presentations were then made on several important Highway Project studies. These included the following:

- Demonstration Seismic Vulnerability Assessment of the Highway System in Memphis Tennessee, by Stuart Werner-The core of a methodology to conduct seismic vulnerability assessment of a highway system or region has been developed and a demonstration of its use was prepared. (See related article on page 1 of this issue.)
- Review of Seismic Design Criteria and Philosophies, by Christopher Rojahn -A comprehensive review was conducted of U.S. and international seismic design practice and criteria, ongoing research in criteria development, and the philosophies behind the seismic resistant design of highways, bridges, tunnels, slopes, and retaining structures. The result of this review will be used as the basis for the development of the next generation of seismic design codes for highway systems and structural components.

- National Ground Motion Mapping Workshop, by Maurice Power – To ensure that the needs of the highway engineering community are adequately addressed in the next generation of seismic ground motion maps, the Highway Project sponsored the participation of 10 bridge and geotechnical/ geosciences engineers in the ATC-35 Workshop.
- Liquefaction Hazard Screening Guide, by T.L. Youd – A draft screening guide for the identification of liquefaction hazards at bridge sites has been developed. The guide is currently undergoing a review by a number of project participants and is being tested by the Utah Department of Transportation.

Following these presentations, a series of overview presentations were made on the progress within each major project technical area. This was then followed by working group meetings in each area which provided for in-depth discussion on each research task, including the research approach and expected end-products. Presentations and working group sessions were coordinated by members of the Highway Project Research Committee as follows: Maurice Power –



Klaus Jacob, a Highway Project researcher from Lamont-Doherty Earth Observatory and Bojidar Yanev, a member of the Highway Seismic Research Council from the City of New York Department of Transportation informally discuss aspects of the Highway Project research program.

(Continued on Page 22)

Center Activities (Cont'd)

(Continued from Page 21)

Seismic Hazard and Ground Motion; John Mander – Design Issues and Details; Ian Buckle – Performance and Design Criteria, and Analysis and Protective Systems; Masanobu Shinozuka – Fragility and Risk; and Geoffrey Martin – Foundations and Soils.

At the conclusion of the meeting, the HSRC provided a report noting its comments and recommendations with respect to Highway Project direction along with individual research tasks. Researchers were congratulated for their efforts and progress made to date, and suggestions regarding the need for improved coordination in several technical areas were provided.

Meeting Announcement

Center Investigators Annual Meeting

NCEER's Year 10 Research and Implementation Program is currently being submitted to the National Science Foundation for review and final approval. While knowledge and technology transfer have long been prominent elements of the NCEER program, a significant aspect of the Year 10 program is the strong emphasis which is being placed on the culmination of longstanding research projects with parallel development of deliverables which might be usefully implemented.

To promote this objective, NCEER Director George Lee has recommended that the annual meeting, which is typically held the last weekend in October and involves all National Science Foundation-supported researchers in extensive task-oriented and interdisciplinary discussions, be rescheduled. It is instead to be replaced by a number of smaller focus group meetings to allow more intensive coordination of project/program area activities and goals. Research Committee project/program coordinators will be organizing the focus group meetings throughout Year 10. A date for a future meeting of all investigators will be determined based on the activities of the focus groups.

Cooperative Research

People's Republic of China Delegation Visits NCEER

On August 14-15, 1995 NCEER hosted a delegation of nine people from the People's Republic of China as part of the US/PRC Protocol for Scientific and Technical Cooperative Research in Earthquake Studies. The delegation was headed by Liu Zhigang, Director of the Earthquake Resistance Office of the Ministry of Construction, and was hosted during its U.S. stay by Leon Wang, Professor Emeritus, Old Dominion University. Delegation members represented the Ministry of Construction's Earthquake Resistance Office, Department of International Relations, and the Harbin University of Architecture.

NCEER Director George Lee provided an overview of NCEER, its mission, and its research and implementation program. The group discussed avenues for cooperative research. The NCEER visit was one of a five-part visit to the U.S. by the delegation during August. Other areas visited included: Los Angeles, San Francisco, Washington D.C., and Norfolk, Virginia. The US/PRC Protocol was initiated by the National Science Foundation and the Ministry of Construction.



NCEER hosted a delegation from the People's Republic of China as part of the US/PRC Protocol for Scientific and Technical Cooperative Research in Earthquake Studies.

Center Resources

News from the Information Service

Three Earthquake-Related Databases on One Updated CD-ROM

by Patricia Coty

The eagerly anticipated first update of the CD-ROM **Earthquakes and the Built Environment Index** has been published. This comprehensive index includes three of the world's leading bibliographic databases on earthquakes, earthquake engineering, and related topics together on one CD-ROM. These databases are the **Quakeline®** database, produced by NCEER; **Earthquake Engineering Abstracts**, produced by the Earthquake Engineering Research Center (EERC) at the University of California at Berkeley; and the **Newcastle Earthquake Database**, produced by the Newcastle Earthquake Project in Newcastle, Australia. The library holdings records of the NCEER and EERC groups are also included on the CD-ROM. The various databases can be searched concurrently, individually, or in any combination.

Earthquakes and the Built Environment Index provides close to 90,000 citations. Source materials include periodical articles, conference proceedings, technical reports, books, publications of worldwide academic, professional, and governmental organizations, archival records, building reports, codes, surveys, newspaper articles, slide sets, theses, videotapes, and software. The citations in **Earthquakes and the Built Environment Index** can be searched by keyword, author, title, year of publication, and virtually any other term or numeric string, using software that is built into the CD-ROM.

The new update is enhanced by the addition of a multilingual user interface: users can now search the CD-ROM in either English or Spanish. Citations can then be reviewed and output to print or electronic file in a user-customized format. A choice of three levels of searching sophistication - novice, advanced, and expert - allows for quick exploration by users with various levels of experience in bibliographic searching. Numerous "Help" screens simplify the searching experience. "Help" screens are available in English and Spanish.

Earthquakes and the Built Environment Index is published by National Information Services Corporation (NISC), 3 100 St. Paul Street, Baltimore, MD 2 1218; phone: (410) 243-0797; fax: (4 10) 243-0982. NISC's software, which is included on the CD-ROM, is specially designed to work with bibliographic databases. The software offers intuitive navigation by beginners, as well as experienced users and professionals requiring sophisticated search tools. Full Boolean and proximity retrieval, field-specific indexes, and easy record display, sorting and output are some of the features of this software. The occasional inconvenience of duplicate records is resolved by the CD-ROM software, which creates special *composite records* that contain the information shared by two or more source records, plus any data that is unique to a record. A multilingual user interface and search software allows for English or Spanish interaction; French and German capabilities will be added in the future.

Earthquakes and the Built Environment Index can be used with any DOS-capable PC (IBM-compatible), single station or network; any CD-ROM drive; monochrome or color monitor; and either 5 12 KB RAM, or 165 KB of free conventional memory if the computer has at least 1.5 MB of extended memory available.

An annual subscription to **Earthquakes and the Built Environment Index**, which will include at least one update, costs \$295 US from the publisher. NCEER and EERC offer special conference rates of \$195 at various professional meetings throughout the year - discount coupons are available at NCEER and EERC exhibits. For additional information, contact Patricia Coty at the NCEER Information Service, 304 Capen Hall, University at Buffalo, Buffalo, NY 14260-2200; phone: (716) 645-3377; fax: (716) 645-3379; or email: nercoty@ubvms.cc.buffalo.edu; or Katie Frohberg at NISEE, University of California, Berkeley, 1301 South 46th Street, Richmond, CA 94804-4698; phone: (510) 231-9401; fax: (501) 231-9461; or email: katie@eerc.berkeley.edu.

NCEER Technical Reports

Three New Reports Reviewed

NCEER technical reports are published to communicate specific research data and project results. Reports are written by NCEER-funded researchers, and provide information on a variety of fields of interest in earthquake engineering. The proceedings from conferences and workshops sponsored by NCEER are also published in this series. To order a report reviewed in this issue, fill out the order form and return to NCEER. To request a complete list of titles and prices, contact NCEER Publications, University at Buffalo, Red Jacket Quadrangle, Box 6 10025, Buffalo, New York 14261-0025, phone: (716) 645-3391; fax: (716) 645-3399; or email: nceer@ubvm.cc.buffalo.edu.

Experimental and Analytical Investigation of Seismic Retrofit of Structures with Supplemental Damping: Part 1 - Fluid Viscous Damping Devices

A.M. Reinhorn, C. Li and M. C. Constantinou, 1/3/95, NCEER-95-0001, 208 pp., \$20.00

This report, the first in a series, presents the evaluation of fluid viscous dampers used as additional braces in reinforced concrete frame structures. This is part of a larger experimental investigation of different damping devices being carried out at the University at Buffalo. A series of shaking table tests of a 1:3 scale reinforced concrete frame incorporating a variety of damping devices were performed after the frame was damaged by prior severe (simulated) earthquakes. An analytical platform for evaluation of structures integrating such devices was developed and incorporated in IDARC Version 3.2. The experimental and analytical study shows that the dampers can reduce inelastic deformation demands and, moreover, reduce the damage, quantified by an index monitoring permanent deformations.

Method for Developing Motion Damage Relationships for Reinforced Concrete Frames

A. Singhal and A. S. Kiremidjian, 5/1/95, NCEER-95-0008, 132 pp., \$15.00

This report presents formulations for developing fragility curves and damage probability matrices for reinforced concrete (RC) frame structures. Three different classes of RC frames, based on the story heights, are considered. The comparison of the damage probability matrices (DPM) for the three classes of RC frames, developed in this study, with those in ATC- 13 (1985) shows that the ATC- 13 DPM's potentially underestimate the damage, particularly at high intensity levels. Because existing definitions of damage to RC structures are found to be inadequate, a new technique for identifying different damage states is presented that considers crack widths and interstory drift ratios.

Experimental Performance and Analytical Study of a Non-Ductile Reinforced Concrete Frame Structure Retrofitted with Elastomeric Spring Dampers

G. Pekcan, J.B. Mander and S. S. Chen, 7/14/95, NCEER-95-0070, 756 pp., \$15.00

This experimental study describes the use of elastomeric spring dampers, which have a distinct re-centering capability. The dampers were used to retrofit a non-ductile, previously damaged 1/3 scale model reinforced concrete building frame. The structure was then subjected to a variety of ground motions in shaking table tests. A velocity dependent analytical model was developed and verified for the elastomeric spring dampers. This model was implemented in the nonlinear dynamic time history analysis computer program DRAIN-2DX to produce response predictions which were in good agreement with experimental observations. The elastomeric spring damper devices significantly attenuate the seismic response of the structure and provide a considerable amount of energy dissipation while the main non-ductile reinforced concrete structural load carrying elements remain elastic. The effect of varying the damper configuration on the structural response was also investigated.

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Bulletin Board

Call for Papers

Analysis and Design of Retaining Structures During Earthquakes

Papers are invited for a session on *Analysis and Design of Retaining Structures During Earthquakes* to be held during the ASCE Annual Convention on November 10-14, 1996, Washington, D.C. One-page abstracts should be submitted by December 15, 1995 to Professor Shamsheer Prakash, 308 Civil Engineering Department, University of Missouri-Rolla, Rolla, MO 65401; phone: (3 14) 341-4489; fax: (3 14) 34 1-4729; email: prakash@novell.civil.UMR.edu.

Sixth International Symposium on Natural and Man-Made Hazards

The *Sixth International Symposium on Natural and Man-Made Hazards, Hazards-96* will take place July 21-26, 1996 in Toronto, Canada. The theme of the symposium is "Major Natural Disasters in the 90's - What can we learn from them?" Papers related to the scientific, social and economic aspects of this theme with particular emphasis on case studies from recent major disasters are invited. Abstracts up to 500 words should be submitted by February 29, 1996 to Dr. S. Venkatesh, Chair, Scientific Committee HAZARDS-96, Environment Canada, 4905 Dufferin St., Downsview, Ontario M3H 5T4, Canada; phone: (416) 739-4911; fax: (416) 739-4221; email: svenkatesh@cid.aes.doe.ca.

Book Reviews

Lifeline Earthquake Engineering

Lifeline Earthquake Engineering, edited by Michael J. O'Rourke, contains the proceedings of the *Fourth U.S. Conference*, sponsored by the Technical Council on Lifeline Earthquake Engineering of the American Society of Civil Engineers. The conference was held August 10-12, 1995 in San Francisco, California. Papers at the conference were presented in sessions on: bridge analysis and rehabilitation, bridge earthquake damage assessment, bridge hazard assessment and prioritization methods, case studies, electric power and communications, gas and liquid fuels, infrastructure rehabilitation, lifeline interaction, Northridge earthquake, post earthquake investigations, seismic hazards, socio-economic effects, water and sewage. To order this 813-page report, contact the American Society of Civil Engineers, Publications, 345 47th Street, New York, New York 10017-2398; phone: (800) 548-ASCE. The cost is \$72.00.

Book Reviews

Seismic Safety Commission Publishes Report on the Northridge Earthquake

The Seismic Safety Commission has published a report to the Governor of California regarding the January 17, 1994 Northridge earthquake. The 169-page report, **Northridge: Turning Loss To Gain**, contains recommendations which fall into six areas: effects of the Northridge earthquake; geologic and geotechnical aspects; achieving seismic safety in buildings; achieving seismic safety in lifelines; achieving seismic safety through land use planning; and reducing earthquake risk in California. The report contains findings and recommendations for policy changes in land use planning and the overall process of design and construction of structures and lifelines. The report can be purchased for \$30.00 from the Seismic Safety Commission, 1900 "K" St., Suite 100, Sacramento, CA 95814. For orders outside of the U.S., call the Commission for exact price quotes at (916) 322-4917. A **Compendium of Background Reports on the Northridge Earthquake** was also prepared as part of an effort to help respond to Governor Wilson's Executive Order. These technical background reports identify particular issues, summarize findings from the Northridge earthquake and present a full array of potential alternative actions for the Commission's consideration. The **Compendium** is available for \$35.

Vibration Problems in Structures - Practical Guidelines

Vibration Problems in Structures - Practical Guidelines by H. Bachmann, W.J. Ammann, F. Deischl, J. Eisenmann, I. Floegl, G. Hirsh, G. Klein, G. Lande, O. Mahrenholtz, H. Natke, H. Nussbaumer, A. Pretlove, J. Rainer, E-U. Saemann and L. Steinbeisser provides structural and civil engineers working in construction and environmental engineering with practical guidelines for counteracting vibration problems. The book presents tools that aid in decision-making and in deriving simple solutions to cases of frequently occurring "normal" vibration problems. Complex problems and more advanced solutions are also considered. In all cases, these guidelines should enable the engineer to decide on appropriate solutions expeditiously. This 256-page hardcover book is available in the U.S. through Springer Verlag for \$49.00 plus shipping. To order, call (800) 777-4643 and request ISBN 0-8176-5148-9. Outside the U.S. contact Birkhauser Verlag, PO Box 133, 4010 Basel, Switzerland; fax +41 (61) 271-7666; email: 100010.23@Ompuserve.com.

Upcoming Events

**Disaster Mitigation in Health Care Facilities:
Formulation of Guidelines for Latin America
and the Caribbean**

The *International Conference on Disaster Mitigation in Health Care Facilities: Formulation of Guidelines for Latin America and the Caribbean* will take place February 26-29, 1996 in Mexico City. The purpose of the conference is to develop recommendations on: guidelines for developing cost-effective interventions and comprehensive national programs; guidelines for developing national plans of action; and policy on disaster mitigation for health facilities in the region. For more information, contact: Conference Coordinator, Emergency Preparedness Program, PAHO/WHO, 525 23rd St., N.W., Washington, DC 20037; phone: (202) 861-6681; fax: (202) 775-4578; email: *disaster@paho.org*.

**International Conference and Exposition on
Natural Disaster Reduction**

ASCE is hosting the *International Conference and Exposition on Natural Disaster Reduction* on March 5-8, 1996 in Washington, D.C. The conference will address topics such as hazard identification, vulnerability assessment, risk management, mitigation, education, institutional issues, response and recovery, and more. For more information, contact NDR '96, Conferences and Conventions Dept., ASCE, 345 East 47th St., New York, NY 100 17; phone: (800) 548-2723; fax: (212) 705-7975.

Announcements

**CERF Announces Innovation
Awards Program**

The Civil Engineering Research Foundation (CERF) invites organizations that can illustrate the application of innovative research ideas into construction industry practice to enter the CERF 1996 Innovation Awards program. Entries can be made in two award categories: innovative applications and innovative concepts. Awards will be presented February 5, 1996 at CERF's International Research Symposium, *Engineering and Construction for Sustainable Development in the 21st Century* in Washington, D.C. For more information, contact Suzanne Weiblen; phone: (202) 842-0555. Deadline for entry is December 1, 1995.

EERI Forms New Madrid Chapter

The Earthquake Engineering Research Institute (EERI) has announced the formation of the New Madrid Chapter that will encompass Alabama, Arkansas, Kentucky, Mississippi, Missouri, Tennessee, and the southern parts of Indiana and Illinois. The new chapter will promote the objectives of the EERI in the Midwest, which are the advancement of the science and practice of earthquake engineering and the solution of earthquake engineering problems to protect people and property from the effects of earthquakes. The chapter will focus on earthquake awareness and preparedness, emergency planning, technical issues related to structures, seismology, lifelines, and societal impacts. For more information about EERI, contact Pat Peck, phone: (5 10) 45 1-0905.



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email: nceer@ubvm.cc.buffalo.edu

Editor: Jane Stoyke
Illustration and Photography: Hector Velasco
Production and Mailing List: Laurie McGinn

Contributors:

H. Cochrane, Colorado State University
P. Coty, NCEER Information Service
A. Dargush, NCEER
R. Eguchi, EQE, Inc.
I.M. Friedland, NCEER
H.H.M. Hwang, University of Memphis
K. Jacob, Lamont-Doherty Earth Observatory
J.B. Jernigan, Ellers, Oakley, Cheters and Rike
K. Ross-Nottis, Bucknell University
C. Scawthorn, EQE, Inc.
C.E. Taylor, J.H. Wiggins Company
K. Tierney, Disaster Research Center, University of Delaware
S. Werner, Dames and Moore

Permanent Soil Deformations After Earthquakes - Implications for Design

The British Society for Earthquake and Civil Engineering Dynamics (SECED) and the French Association for Earthquake Engineering (APFS) are sponsoring a joint seminar entitled *Permanent Soil Deformations After Earthquakes - Implications for Design*, to be held December 18, 1995 in London. Following the highly successful joint AFPYSECED colloquium in Paris in 1993, a second one day meeting in the general field of seismic soil structure interaction will be held. Six recognized experts in the field will make presentations, with a final session devoted to general discussion and short contributions from the floor. The aim is to exchange and discuss the state-of-the-art in the two countries in this important and rapidly developing field. For more information contact Edmund Booth, Ove Arup and Partners, phone: +44 (171) 465-2232; fax: +44 (171) 465-2150 or Denis Aubry, Ecole Centrale Paris, phone: +33 (1) 4113-1321; fax: +33 (1) 4113-1442.

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