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Crude Oil Transmission Study

An Assessment of the Social, Economic and Environmental Impacts Resulting from Oil Spillage and Disruption Caused by a Major Earthquake in the New Madrid Seismic Zone

by Ronald Eguchi

In 1989, NCEER launched a multi-year multi-disciplinary study of the seismic vulnerability of an important lifeline system. The production and delivery of crude oil is critical to every major industry and business sector in the United States. This nation's most crucial crude oil system traverses the midwest and is subject to seismic hazards ***posed*** *by the New Madrid seismic zone. To understandfully the significance of this system, particularly after major disasters such as earthquakes, it is necessary to quantify the level of seismic vulnerability of this system and the impact that may result should oil be released or disrupted. To address these questions, NCEER formed a multidisciplinary team representing researchers in seismic hazard assessment, component vulnerability analysis, system reliability analysis, and socioeconomic impact analysis. This team comprised Teoman Ariman, Tulsa University, Ricardo Dobry, Rensselaer Polytechnic Institute, Ronald Eguchi, EQE International, Mircea Grigoriu, Cornell University, Otto Helweg, University of Memphis, Howard Hwang, University of Memphis, Michael O'Rourke, Rensselaer Polytechnic Institute, Thomas O'Rourke, Cornell University, Masanobu Shinozuka, Princeton University, Kathleen Tierney, University of Delaware, and John Wiggins, EQE International. This article describes the social, economic and environmental consequences resulting from an oil spill in the New Madrid area. Questions and comments should be directed to Ron Eguchi, E&E International, at (714) 833-3303.*

This study had three major objectives. First, the seismic hazard potential in the midwest required quantification. Recent seismicity data suggest that the likelihood of a magnitude 7.6 earthquake in the New Madrid region is approximately 7% by the year 2000 (Johnston and Nava, 1985). Second, the seismic vulnerability of oil pipeline systems had to be evaluated. Vulnerability models were developed for underground pipelines and aboveground facilities to determine the likelihood of failure or damage during an earthquake. Finally, based on the seismic vulnerability of these systems, the indirect impacts caused by failure and disruption of this system were assessed. Indirect impacts included environmental damage caused by oil spillage and economic losses resulting from a disruption of oil delivery. To address these issues, multiple but coordinated research efforts were carried out by NCEER investigators.

The research plan called for investigations that focused on the following areas: quantification of seismic hazard potential, with emphasis on liquefaction hazards; seismic vulnerability modeling of underground pipelines; seismic vulnerability modeling of other oil pipeline system components, such as pump stations; system reliability analysis; environmental impact analysis; indirect economic loss analysis; and organizational and institutional response analysis to address the issues related to energy supply and distribution.

Results of the Research

The contributions from this study have been numerous. Perhaps, the most significant achievement is that a multidisciplinary research team was assembled to address a

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complex engineering and socioeconomic problem. Past efforts to address lifeline problems have only been marginally successful in quantifying the effects caused by lifeline failure. The reason for this limited success has been that expertise beyond that readily available within the engineering community must be applied. Also, to fully assess the nature of this problem, multi-year efforts are required. Only in a few cases are extended research efforts granted to investigate these multi-dimensional problems.

Some of the more important conclusions that have resulted from this study are listed below.

- It is difficult to generalize system reliabilities for linear pipeline systems, such as oil delivery pipelines, because damage or failure of one or several components can disrupt the entire serviceability of that system.
- Earthquake-induced pipeline failures will generate a range of direct and indirect social and economic effects in both the short and the longer term.
- The costs associated with the repair of a damaged oil pipeline system represent only a small percentage of the cost associated with its failure. Environmental damage, business interruption and regional economic losses caused by disruption of oil accounts for over 90 percent of the losses associated with these pipelines.
- The midwest lacks the resources necessary to manage major earthquake-induced oil spills.
- An examination of the infiltration, distribution and dissolution from hydrocarbon spills indicates that this process is slow, which would allow ample time for remediation should such a spill occur. However, the remediation effort must be complete to ensure that no health hazard exists.

The following sections discuss in more detail the research conducted by NCEER investigators that supports the major conclusions provided above.

System Reliabilities

O'Rourke and others (1992) demonstrate the complexity in assessing the seismic vulnerability of lifeline systems. While previous studies have addressed issues of seismic vulnerability or reliability, they generally have analyzed the problem solely on the basis of ground shaking, i.e., ground failure hazards, such as liquefaction, have been addressed only qualitatively. One of the main contributions of the current research is that it attempts to quantify the impact of ground failures (i.e., liquefaction and slope movement) on oil pipeline components by estimating the amount and direction of ground movement and their impact on component failure. Utilizing techniques developed by Youd and others (1989), the NCEER team quantified the amount of displacement expected from a large New Madrid earthquake and mapped this information onto critical oil pipelines in the midwest. Based on the orientation of the pipeline relative to these displacements, different probabilities of pipe failure were computed accounting for lateral and longitudinal spreading.

One interesting product that has resulted from this research has been a comparison of the Modified Mercalli intensity scale with the Liquefaction Severity Index (LSI) developed by Youd et al., (1989). Table 1 shows the estimated correlation between these two damage indices for the 1811-1812 New Madrid scenario. This table represents a significant improvement over past methods of characterizing the effects of liquefaction. By using a more quantitative scale for measuring the effects of liquefaction, more refined seismic vulnerability models can be applied.

Another major improvement resulting from this research was the application of geographical information system (GIS)

Table 1: Estimated Correlation Between MM/ and LSI for the 1811-1812 New Madrid Earthquakes (O'Rourke et al., 7992)

Modifed Mercalii intensity	Damage Description	Estimated LSI (inches)
Viii	Ejected sand and mud in small amounts	10to20 (250 to 500 mm)
IX	Cracked ground conspicuous; underground pipes sometimes broken	20 to 50 (500 to 1270 mm)
X	Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard run parallel to canal and stream banks...Landslides considerable from river banks and steep coasts,...bent railroads, rails siightiy....tore apart...crushed...pipeiines buried in earth.	>lOO (> 2540 mm)

methods to pipeline analysis. In this study, three key pipeline systems were analyzed for their seismic vulnerability during a large New Madrid earthquake. These pipelines are shown in figure 1. Based on data collected by the research team, GIS methods were used to quantify the number of miles crossed by each pipeline system in different MM1 and LSI zones. This information was used in combination with analytical seismic vulnerability models to estimate the number of pipeline breaks or leaks expected in the New Madrid event. Based on the number of these failures, failure probabilities were computed for each segment of pipeline.

The reliabilities that were computed for each pipeline are given in table 2. As seen in this table, the impact of shaking versus lateral spread effects varies significantly for each pipeline. Also, the reliabilities associated with particular pump stations and pipeline segments for each different pipeline system vary significantly. As a result of these sensitivities, it was concluded that for linear systems such as crude oil

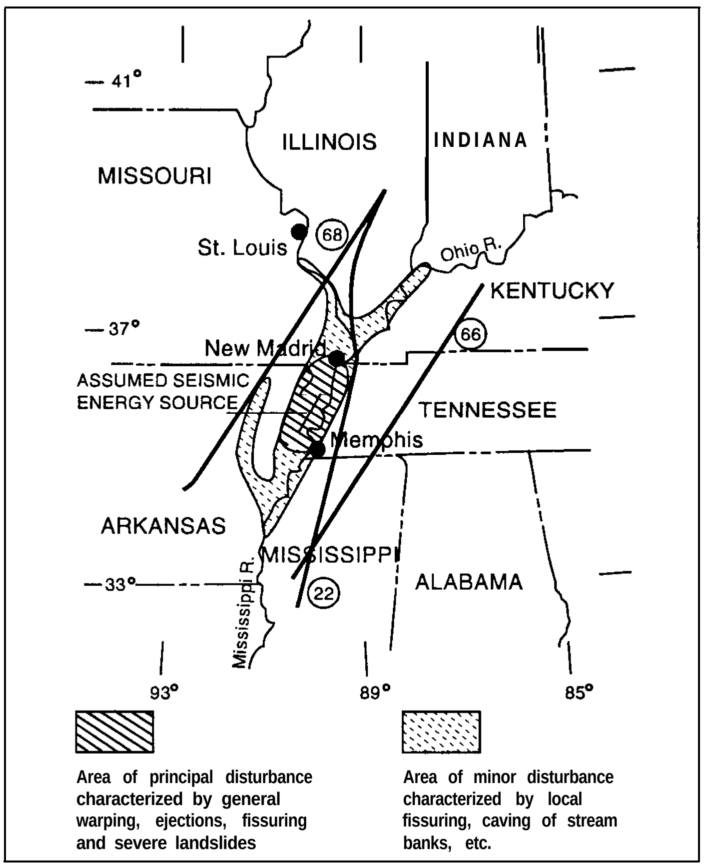

Figure 1: Assumed Surface Rupture of Energy Source for the 1811-12 New Madrid Earthquake and Areas of Disturbance Plotted by Fuller (1912), and Approximate Locations of Oil Transmission Pipelines 22, 66 and 68 (Modified After Turner and Youd, 1987)

Table 2: Reliability of Pipeline by Hazard for Recurrence of 1811-1812 Events (O'Rourke et al., 1992)

Pipeline No.	Pump Station		Pipeline	
	Shaking	Lateral Spread	Landslide	Lateral Spread
22	0.073	0.975	0.327	0.461
66	0.67	0.994	0.327	0.526
68	0.445	0.988	0.327	0.498

pipelines, it is difficult to generalize system performance, since failure of one or more components could lead to system shutdown. In more highly netted systems, such as water distribution or natural gas distribution, the failure of any single component will have less impact on the overall performance of the system. Redundancy plays a significant role in maximizing the reliability (i.e., probability of connectivity) in these more highly netted systems.

Social Impacts and Losses

In an initial effort to identify the potential consequences of earthquake-induced oil pipeline failures, the Disaster Research Center (Tiemey, 1992) undertook an extensive literature review. Among the topics examined were oil spill prevention and preparedness, the economic costs of oil spills, ecological and health effects, oil spill cleanup methods and their effectiveness, and governmental and industry policies and regulations related to oil spill management. Although the literature on earthquake-induced oil spills and their consequences was very sparse, and most of that work focused on areas other than the New Madrid region, many of the materials that were reviewed contained data and information that have implications for estimation of spill-related impacts in the central U.S.

The review concluded that the costs associated with pipeline failures and resulting oil spills are likely to depend on a number of factors, including: the extent of damage to the crude oil distribution system; the locations at which the damage occurs; the extent of damage to the disaster response

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Table 3: Impacts of Earthquake-Generated Crude Oil Pipeline Failure (Tierney, 1992)

Impacts	Phase of Emergency		
	Emergency Response	Short-Term Recovery	Long-Term Recovery
I. Oil Spill Effects			
Loss of Oil	X	X	
Surface Water Pollution	X	X	
Ground Water Pollution	X	X	X
Threats to Human Health	X	X	
Threats to Wildlife	X	X	X
Threats to Vegetation	X	X	X
Fire Hazards	X		
Threats to Water Supply	X		
Damage to Water Treatment Facilities	X	X	
Disruption of Crude Oil Supply	X	X	
Threats to Economic Activity	X	X	X
Threats to Aesthetic Values	X	X	X
II. Response-Related Demands (Oil Spill Only)			
Oil Containment and Cleanup	X		
Oil Waste Disposal	X	X	X
Repair of Pipeline and Other Components	X		
Restoration of Pipeline and Other Components	X	X	
Containment of Secondary Hazards (e.g., Fire)	X		
Protection of Health, Welfare of Residents	X	X	X
Protection of Wildlife	X	X	X
Protection of Vegetation	X	X	X
Enhanced Pipeline Maintenance		X	X
Restoration of Crude Oil SUPPlY	X	X	
Alternative Water Supply Acquisition	X	X	

system and its supporting infrastructure; local and regional capacity to contain damage and restore service; situational contingencies, such as the time of year the event occurs and the extent to which secondary hazards, such as fire, become a problem; and the duration of system disruption. The literature indicates that spills like those that could occur following a New Madrid event are likely to produce a variety of direct and indirect social and economic effects. These can be classified into two categories: effects related directly to oil spills, such as loss of oil and threats to the water supply; and containment and clean-up and the costs associated with repairing the system. While many of these effects will be felt in the short-term, others will continue over time. Table 3 summarizes the nature and duration of these impacts.

Indirect Economic Losses

The failure of lifeline systems in natural disasters can be devastating, hampering both response and recovery. Recent events, such as the 1989 Loma Prieta and 1994 Northridge earthquakes, have demonstrated that indirect impacts associated with the failure of lifeline systems may far outweigh the direct costs associated with system repair. As a result, the problem of quantifying possible indirect losses is currently receiving increased attention.

In order to address these indirect effects, EQE International developed methods of quantifying indirect or secondary losses associated with oil pipeline failure or disruption. In these studies, indirect loss included business interruption losses, environmental damage caused by oil spillage, and regional economic losses associated with a disruption of the oil supply.

One part of the EQE study focused on losses associated with the remediation of areas affected by oil spillage or leakage (Pelmulder and Eguchi, 1991). This methodology assumed that the same damage assessment techniques described in the previous sections could be used to identify the probable locations of these spills. Then, based on the amount of oil contained within the pipeline system, and other factors such as topography and pipeline size, EQE estimated the amount of oil released to the environment. Depending upon the soil and groundwater characteristics surrounding these spillage sites, different cost models were used to predict the extent of contamination and the remediation cost associated with its cleanup. Finally, these costs were compared to the repair costs for the pipeline.

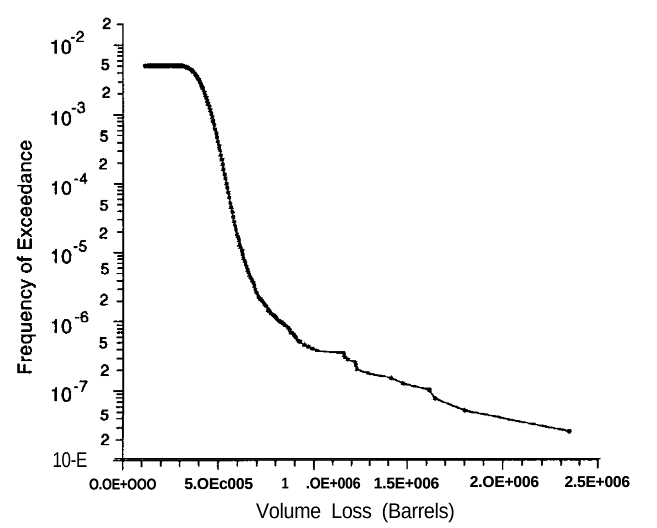

Figure 2: Frequency of Exceedance of Total Spill Volume in a Major Event in the New Madrid Seismic Zone (Pelmulder and Eguchi, 1991)

Figures 2 and 3 show frequency of exceedance curves for total spill volume and dollar loss, respectively. The range of spilled volumes during the New Madrid seismic zone simulation was 150,000 to 2,350,OOO barrels, with an average spill volume of 400,000 barrels. The 400,000 barrels represent the sum of spill volumes from all leaks during this hypothetical event. The average spill volume expected at a single site was calculated to be 4,700 barrels. Because this is an extreme earthquake event (M8+ New Madrid event), at least

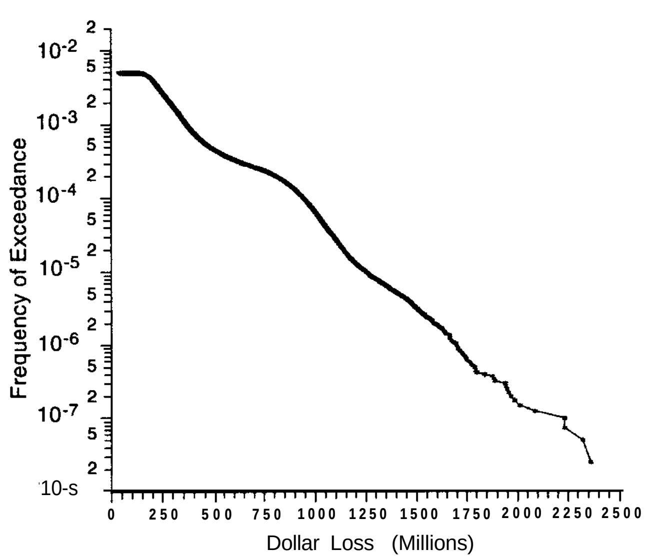

Figure** 3: **Frequency of Exceedance of Dollar Loss (Pelmulder and Eguchi, 1991)

one leak occurs in every simulation of the event. The maximum frequency (i.e., the frequency with which at least one leak occurs) is equal to the probability of this event occurring by the year 2000, i.e., 0.005%.

Possible dollar losses associated with this cleanup range from 30 million to 2.4 billion dollars. The large range of costs may be attributed, in part, to the significant difference between remediation costs for surface water and soil. When a large number of leaks occur in a simulation, many are in flood plains or on rivers, where there are high cleanup costs. Many more moderate cases are possible, however, and the average loss is expected to be $310 million. The expected loss at a single site is $3.6 million.

In addition to environmental losses, other higher-order economic losses are possible in a large New Madrid earthquake. Table 4 lists some of these higher-order losses and the parameters that influence their levels (Eguchi et al., 1993; Wiggins, 1994).

As part of the crude oil study, the EQE team assessed environmental, refinery/petroleum, and local and regional eco-

Table 4: Higher-Order Economic Losses

I. Direct Losses to Petroleum Industry
   A. Time-to-Restore
      1. Number of Pipeline Breaks
         a. Earthquake Magnitude
         b. Shaking Intensity
         c. Soil and Terrain Data
         d. Pipeline Material, Size and Type
         e. Vulnerability Model Assumptions
      2. Number of Available Crews
      3. Time to Repair Each Break
         a. Detection Capability
         b. Decision to Repair vs. Replace
         c. Material Availability
         d. Ease of Access to Break Site
   B. Oil Reserve Capacity
   C. Ability of Other Regions to Supply Oil
II. Indirect Losses to Economy
   A. Region of Impact
   B. Assumption of Input-Output (I-O) Economic Model
   C. Resources for Generation of I-O Model
III. Loss Type: Permanent or Time-Element

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Table 5: Comparison of Direct and Indirect Losses Caused by Damage to Oil Supply Pipelines in the New Madrid Seismic Zone (Eguchi et al., 1993)

Loss Type	Amount ($ million)	Percent of Total Loss	Ratio of Direct Loss
Repair Costs'	75	2.3	1.0
Environmental	310	9.6	4.1
Refinery/Petroleum Industry	720	22.1	9.6
Local/Regional Economy	2,147	66.0	28.6
Total	3,252	100.0	-

1 Note: Repair costs taken from ATC-25 (1991)

nomic losses from a M8+ earthquake in the New Madrid seismic zone. These losses are shown in table 5. The basic conclusion resulting from this study is that repair costs are but a fraction of the total loss associated with the failure and disruption of these oil pipeline systems. In table 5, repair costs account for approximately 2.3 percent of the losses contained in the table. The largest loss will probably be associated with local and regional economies that will suffer because of a disruption of oil. Contingency factors, such as alternative supplies however, have not been factored into the analysis. Nevertheless, disruption of oil supply will have a significant regional impact in the postulated New Madrid seismic zone event.

Emergency Response Capability

Responding to oil spills in a timely manner is an important factor in reducing the social disruption and losses that result from these events. Although legislation provides for national and regional level responses in major oil spills, local and state emergency response capability also plays a critical role in oil spill containment. Negative social and economic impacts will invariably be larger when agencies responsible for initial spill management are not able to respond effectively.

Research by NCEER investigators (Tiemey and Dahlhamer, 1993) indicates that the highest risk of an earthquake-generated spill is associated with the 40-inch Capline pipeline system, operated by Shell Corporation. Investigators singled out as particularly vulnerable several river-crossing areas in western Tennessee where earthquake-induced pipeline failures are likely due to the potential for soil liquefaction. Based on these research findings, field work was undertaken by the Disaster Research Center to determine the extent to which emergency management and response agencies in the vulnerable area were aware of the hazard and to assess their response capability. To address these issues, face-to-face interviews were conducted with local government and emergency officials in three high-risk counties in western Tennessee, as well as with representatives of four state emergency management, environmental protection, and regulatory agencies.

Analysis of the interview data and documentary materials that were collected during the field study indicate that (1) less than one-third of the local officials and emergency responders interviewed were even aware that a major crude oil pipeline passes through their communities; (2) few responders had considered the possibility that a New Madrid earthquake could cause a crude oil release; (3) local communities lacked resources for managing an oil spill, should one occur; (4) although general earthquake preparedness measures had been undertaken in the three-county area, largely as a result of the Iben Browning prediction of 1991, those efforts were quite modest; (5) virtually no linkages currently exist between the pipeline operator and either state and local officials that could be used as a basis for either emergency planning or response; (6) the resources that were available locally for managing disasters were insufficient, making it difficult to maintain an adequate level of basic earthquake preparedness and effectively ruling out planning for the control of secondary hazards such as oil spills; and (7) although earthquake preparedness was a high priority for the state emergency management agency, it had not planned for possible earthquake-induced pipeline failures, nor had it encouraged local officials to do so.

The study indicates that local and state officials did not recognize pipeline failures and crude oil spills as problems that could occur following a major earthquake. The first step in managing a hazard is to recognize it, and even this elementary recognition is lacking with respect to the oil spill problem. Further, there are few interorganizational linkages that could be activated should such an emergency occur, and the local communities that are most vulnerable lack resources to manage oil spills. As a consequence, it is highly unlikely that oil spills resulting from pipeline failures will be contained, or that early remedial actions will be undertaken. This information provides a context for developing and interpreting loss estimates for the New Madrid Seismic Zone.

Effects of Hydrocarbon Spills

This part of the study was undertaken by the Center for Earthquake Research and Information at the University of Memphis (Helweg and Hwang, 1993) to determine the effect of an oil spill, which might be caused by an earthquake rupturing a crude oil pipeline that crosses the recharge area of the Memphis Sands aquifer. To do this, two numerical models were used to simulate a potential rupture to the 40-inch crude oil pipeline located in Wolf River fluvial valley, which is susceptible to liquefaction-induced ground failure. The spilled oil would likely have detrimental effects on the ground water quality, especially impacting the Memphis Sands aquifer.

The simulation approach used two two-dimensional upstream weighted finite element models to predict the three-dimensional flow phenomenon of released crude in the unsaturated and saturated zones. ARMOS (Area1 Multiphase Organic Simulator) was used to simulate the crude oil migration horizontally and to evaluate the extent of the crude dispersion on the ground water table. MOFAT (Multiphase Organic Flow And Transport) was used to simulate crude oil saturation in the vertical flow domain, in order to evaluate the dissolution of particular monoaromatic hydrocarbon isomers such as benzene, toluene, ethylbenzene and xylene (BTEX) in the ground water system.

The simulated results aided in designing an appropriate strategy for site remediation. ARMOS predicted a plume covering an area of about 10,800 square meters after 10 days of migration. The plume covered a maximum area of about 18,800 square meters after 30 days of migration. MOFAT predicted the most soluble species, toluene, to dispense with the highest phase concentration of 0.20 kilogram per cubic meters at distances of 56,79, 102 and 130 meters away from the spill site over the periods of 30, 60,90 and 120 days of redistribution. The results show that although significant contamination of local aquifers is possible, the rate at which this contamination occurs may be slow. This should allow for ample time for remediation should a spill occur. However, the remediation effort must be complete to ensure that no health hazard exists.

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Seismic Vulnerability of Existing Bridge Abutments

by K.L. Fishman and R. Richards, Jr.

This article describes research conducted to date on the development of analytical procedures to assess the seismic performance of existing retaining structures and bridge abutments. It is part of a series of geotechnical studies being conducted under NCEERS Highway Project, Comments and questions should be directed to Professor Rowland Richards, University at Buffalo at (716) 645-2114 ext. 2417.

The objective of the research described in this article is to develop improved analytical procedures for assessing the seismic performance of existing retaining structures and bridge abutments. The current approach for analysis and design is based on the theoretical and experimental work of Richards and Elms (1979) and has been well documented in the AASHTO (1992) code provisions and commentary. The basis of this approach is a limit analysis using a sliding block mechanism for free standing walls or bridge abutments to estimate seismically induced permanent deformation. At present, only the possibility of a sliding mode of failure is considered in the code.

Earthquake damage reports and laboratory tests indicate that wall failure by rotation is fairly common. Bridge abutments may have restrained displacement at the deck level, so the possibility exists for a rotational and/or translational outward movement of the toe. Furthermore, the possibility exists for seismic loss of bearing capacity within the foundation soil in which case, beyond a threshold acceleration level, a mixed sliding and/or rotation mode of deformation can result. Therefore, the main focus of this research is to:

- Extend the current analytic method used to predict the seismic resistance of bridge abutments considering the possibility of seismic loss of bearing capacity
- Observe the seismic response of model bridge abutments in shake table tests
- Compare predictions of seismic resistance to observations, and
- Identify bridge abutments typical of those found in the eastern U.S. which may be considered free standing, and assess their seismic vulnerability

Research Approach

The seismic vulnerability of free standing bridge abutments on spread footings relates to their seismic resistance or that threshold acceleration level (k_h), beyond which permanent deformation will occur. A thorough seismic analysis must investigate the possibility of both a sliding mode of failure as well as seismic reduction of bearing capacity.

Theory

Figure 1 shows the forces acting on a gravity wall bridge abutment during seismic loading. Loads from the bridge deck are considered to act at the top of the abutment. Depending on the connection detail, horizontal loads from the inertia of the bridge deck may be transferred to the abutment. Body forces acting on the wall are present as well as lateral earth pressure behind the wall. The inertial loading applied to the foundation soil beneath the abutment footing is also considered.

Lateral earth pressures which develop behind rigid retaining walls which yield during earthquake loading may be evaluated using a rigid plastic model to describe soil behavior. This approach has been followed by Okabe (1926) and Mononobe and Matsuo (1929) who performed a modified Coulomb analysis in which the inertial load on the failed

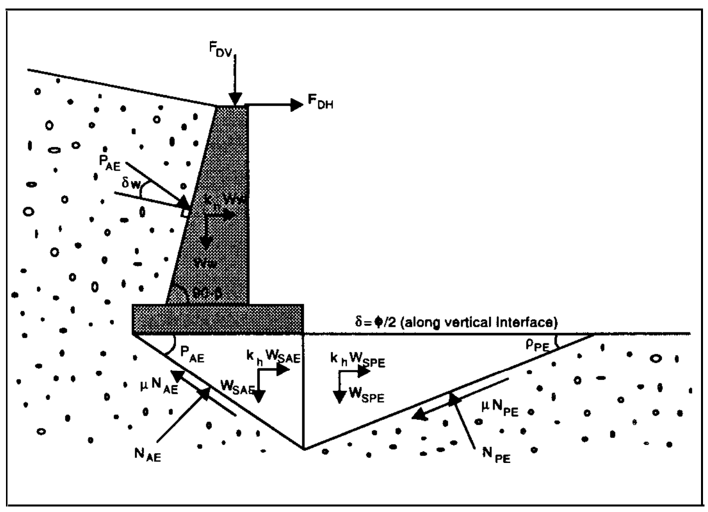

Figure 1: Forces Acting on a Gravity Wall Bridge Abutment

soil wedge was included in the analysis. The application of the Mononobe Okabe equation to seismic analysis of retaining walls is well established and details will not be repeated here. However, a relatively new approach to the problem of seismic reduction of bearing capacity is applied to the retaining wall problem and shall be described in what follows.

Seismic reduction in bearing capacity has been studied by Richards et al., (1990) and (1993), and Shi (1993). Seismic bearing capacity factors are developed considering shear tractions transferred to the soil surface as well as the effect of inertial loading on the soil in the failed region below the footing. For simplicity, a "Coulomb-type" of failure mechanism is considered within the foundation consisting of an active wedge directly beneath the abutment and a passive wedge which provides lateral restraint with the angle of friction between them of $\phi/2$. Bearing capacity is evaluated via a limit equilibrium analysis whereby the critical orientations of the failure planes are determined, which minimize the resistance. Shi (1993) compares the Coulomb mechanism with $\delta = \phi/2$ to results from the method of characteristics to verify its accuracy. Shear transfer between the footing and foundation soil is conveniently described by a friction factor:

$$f = \frac{S}{k_h F_v} \quad (1)$$

where S is the shear traction, k_h is the coefficient of horizontal acceleration, and F_v is the normal force applied to the foundation.

The analytic solution gives a bearing capacity formula in terms of seismic bearing capacity factors N_{qE}, N_{cE}, and $N_{\gamma E}$ as

$$p_{LE} = CN_{cE} + \gamma DN_{qE} + 1/2\gamma BN_{\gamma E} \quad (2)$$

similar to its counterpart for the static case. For a surface footing on sand only, $N_{\gamma E}$ provides bearing capacity. Figure 2 presents the ratio of $N_{\gamma E}/N_{\gamma s}$, where $N_{\gamma s}$ is the static case bearing capacity factor. The seismic bearing capacity factor is a function of the friction angle of the foundation soil, ϕ, seismic acceleration coefficient, k,, and f (Shi 1993).

Analysis

Since seismic bearing capacity factors are dependent on ground acceleration, determination of the threshold acceleration requires an iterative procedure easily programmed

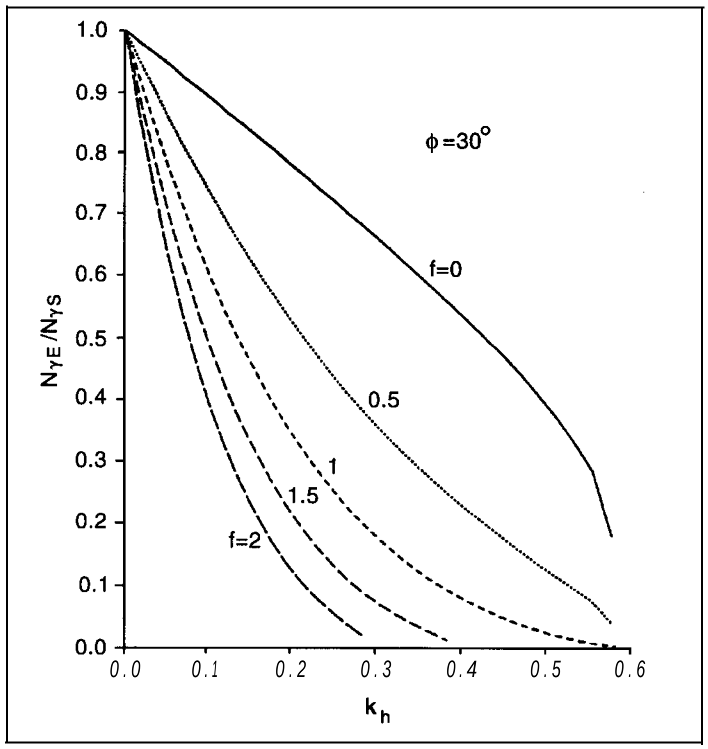

Figure 2: Seismic Bearing Capacity Factor

for digital computation (Fishman et al., 1995(a) and (b)). Referring to figure 1:

1. Assume a trial value for k_h and determine P_{AE} from the M-O equations.

2. Compute the vertical force result, F_v, as

$$F_v = F_{DV} + P_{AE} \sin(\delta w + \beta) + W_w \quad (3)$$

3. Compute the result of the shear traction to be transferred to the foundation soil as

$$S = F_{DH} + P_{AE} \cos(\delta w + \beta) + k_h W_w \quad (4)$$

4. Compute the factorfusing equation (1).

5. Sliding will occur when $S = F_v \tan \delta_f$ and therefore

$$FS_{slide} = \frac{\tan \delta_f}{k_h f} \quad (5)$$

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where δ_f is the interface friction angle between the abutment footing and the foundation soil.

6. Given the friction angle of the foundation soil, ϕ_f, andf from step 4, find the seismic bearing capacity factor from figure 2.

7. Compute the seismic bearing capacity p_{LE} using equation (2).

8. Compute the ratio of the limit load to the actual load as

$$FS_{B/C} = \frac{p_{LE} B_f}{F_v} \qquad (6)$$

9. If $FS_{B/C}$ determined in step 8 is nearly equal to one and FS_{slide} from step 5 is greater than one, stop the iteration procedure. The assumed value for k_h is the threshold acceleration for bearing capacity failure, k_h^b.

10. If FS_{slide} determined in step 5 is nearly equal to one, and $FS_{B/C}$ is greater than one, stop the iteration procedure. The assumed value for k_h is the threshold acceleration for sliding failure, k_h^s.

11. If neither of the conditions in step 9 or 10 is met, select a new trial value for k_h and return to step 1.

Description of Experiments

Small-scale bridge abutments were constructed in a seismic soil-structure interaction test chamber which was placed on the shaking table at the University at Buffalo. Complete details of the test chamber are provided by Fishman et al., (1995(a), (b) and (c)), and Divito (1994).

Ottawa sand (ASTM C-109) was used to study the response of dry soil in the test chamber. Engineering properties of this Ottawa sand are consistent and well established. Pluviation as described by Richards et al., (1990) was used to place the soil in the chamber. This placement method deposits a near homogeneous sand in a very dense state. In future testing, other densities may be obtained by varying the distance that sand is dropped from the hopper.

Model bridge abutments, shown schematically in figure 3, were constructed having a height of 46 cm and a footing width between 15 and 20 cm. The foundation soil beneath the wall footing was 46 cm deep so that development of a failure region, associated with a seismic loss of bearing capacity, was not inhibited. The top of the model provided support for two (W8xlO) girders representative of a bridge deck load. Although a prototype abutment may not be properly modeled in a lg test when elastic response is being considered, the limit state scaling laws apply; i.e., model dimensions are scaled in direct proportion to those of the prototype, whereas forces considered on the prototype are proportional to the dimensional scaling factor squared. Deformations are independent of scale.

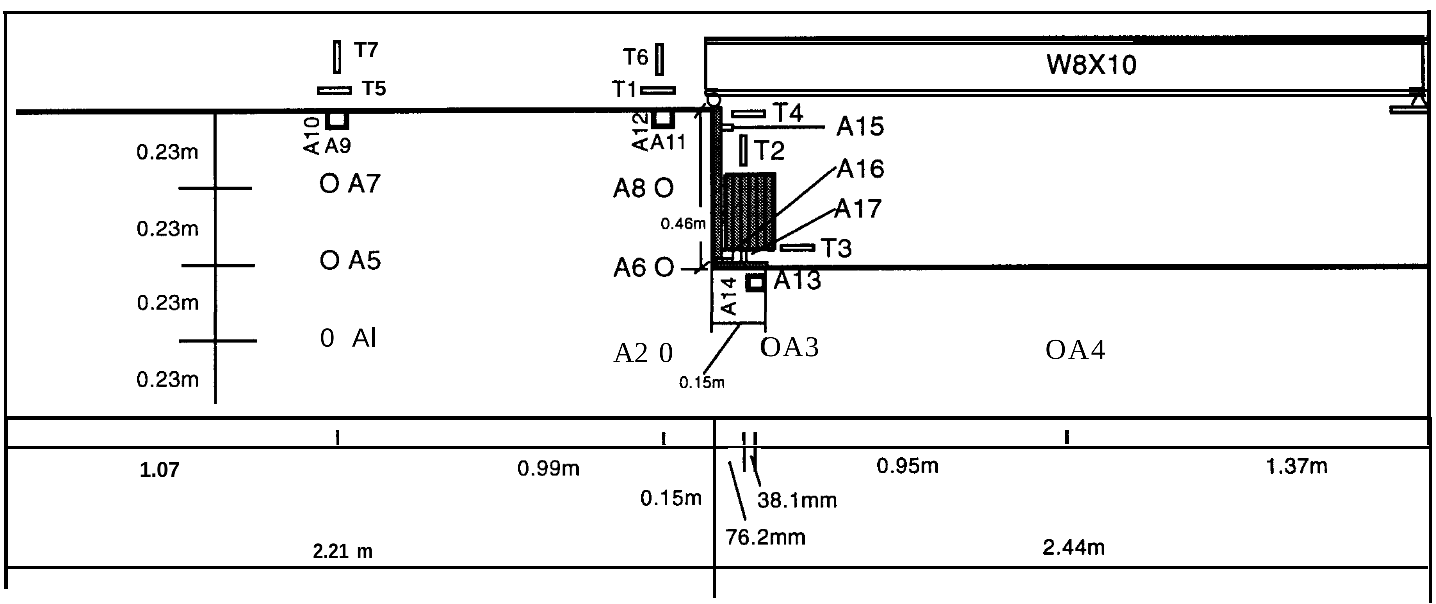

Figure 3: Model Bridge Abutments and Instrumentation ("A" = accelerometer, "T" = displacement transducer)

Table 1: Abutment Model Parameters

Model	W_w (N)	F_{deck} (N)	B_f (mm)	ϕ_w	δ_w	δ_f	ϕ_f	γ_w kN/m^3	γ_f kN/m^3
I	276	818	143	30	20	20	38	15.4	17.0
II	1172	356	152	36	22	30	38	16.7	17.0
III	1221	356	203	36	22	30	38	16.7	17.0

Three different models were tested. For Model I, the bridge deck rested on a roller support atop the bridge abutment such that no shear transfer was allowed between the deck and abutment. The abutment was designed such that a sliding mode of failure was expected. Model II used the same bridge deck/abutment connection detail, but failure from seismic loss in bearing capacity was anticipated. For Model III, a pinned connection between the bridge deck and abutment was used. Table 1 summarizes the parameters for each model including the wall weight, W_w, deck load, F_{deck}, length of footing, B_f, backfill/wall interface friction angle, δ_w, footing/foundation soil interface friction angle, δ_f, the foundation soil friction angle, ϕ_f, unit weight of the backfill soil, γ_w, and unit weight of the foundation soil, γ_f.

Interface friction angles for Model I and Models II and III are different. In Model I, the interface friction was developed between smooth steel and sand. Models II and III were designed to reduce the risk of sliding failure so interface shear strengths were increased by attaching coarse sand paper to the backside of the wall and the underside of the footing. Interface shear strengths were determined by pull tests with the model inside the test box.

Given the soil parameters and wall geometry for each model as presented in table 1, static loading from active earth pressure P_{As}, and static safety factors against sliding and bearing capacity failure were computed and are shown in table 2.

Table 2: Static Factors of Safety

Model	P_{AS} (N)	FS_{slide}	FS_{BC}
I[1]	347	1.4	1.4
II	374	2.77	3.7
III	374	2.86	3.54

[1] *In Series I, H = 406 mm initially. H is 457 mm for models II and III.*

Table 3 summarizes the threshold acceleration levels computed for each model. These were determined using the analytic method already described. The computed dynamic active earth pressure, necessary to develop sliding failure, P^s_{AE}, or bearing capacity failure, P^b_{AE}, is also shown in table 3. The smallest of these values governs the seismic response of the wall. The observed threshold acceleration of each test is also shown in table 3.

Table 3: Threshold Levels of Acceleration

Model	P^s_{AE}/P^b_{AE} (N)	k^s_h (sliding)	k^b_h (bearing)	k^{obs}_h (observed)
I[1]	365/?	0.2	0.5	0.25
II	743/587	0.30	0.22	0.20
III	1619/1023	0.60	0.43	0.46

[1] *In Series I, H = 356 mm when $k_h = 0.2g$. H is 457 mm for models II and III.*

Preliminary Results

Model Testing

Model bridge abutments were subjected to a series of sine ramped pulses of acceleration, sine train acceleration records, and time histories of acceleration from records of naturally occurring earthquakes. Colored lines were placed in a horizontal and vertical grid pattern beneath the footing and behind the bridge abutment in order to observe soil deformation. Figures 4 (a) and (b) are photographs of Model II before and after testing. Model II featured a free connection to the bridge deck at the top of the abutment. Figure 4(b) shows

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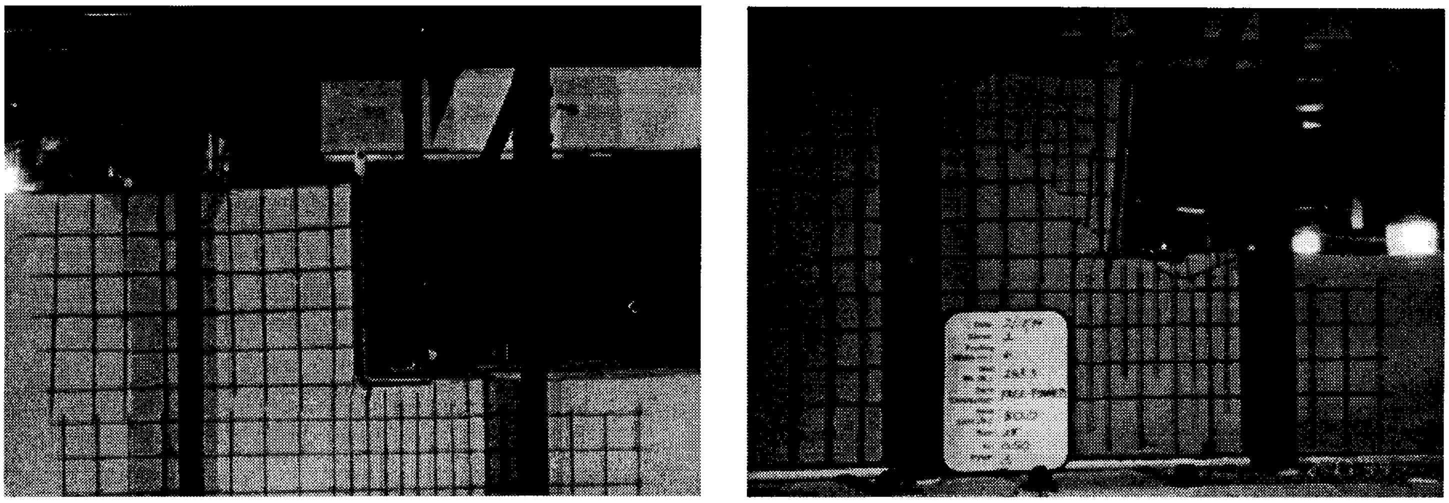


(a) ***Before Testing*** ***(b) After Testing***

Figure 4: Model II Bridge Abutment

the bridge abutment after being subjected to acceleration pulses with a maximum amplitude of 0.5g. Failure surfaces which developed within the backfill and foundation soil are vividly portrayed. Significant tilting of the bridge abutment is also observed corresponding to a loss of bearing capacity.

Figures 5(a) - (e) show the response of the Model II bridge abutment subjected to an input sine train acceleration record. Figures 5(a) and (b) display the time history of acceleration of the input (solid line) compared to the acceleration response observed at the bottom of the abutment (dashed line, 5(a)) and within the foundation soil (dashed line, 5(b)). Due to the sensitivity of accelerometer output to changes in alignment and the excessive rotations which occurred during deformation, the measured acceleration for the abutment and foundation soil did not return to zero at the end of the sine train. The error that rotation and corresponding misalignment of the accelerometers introduces on measured acceleration may explain the erroneous observation of increased seismic resistance with increasing cycles of input. Prior to excessive abutment tilting, a threshold acceleration level for the wall of 0.2 g is clearly evident. Furthermore, evidence of a threshold acceleration within the foundation soil is indicative of a seismic loss of bearing capacity.

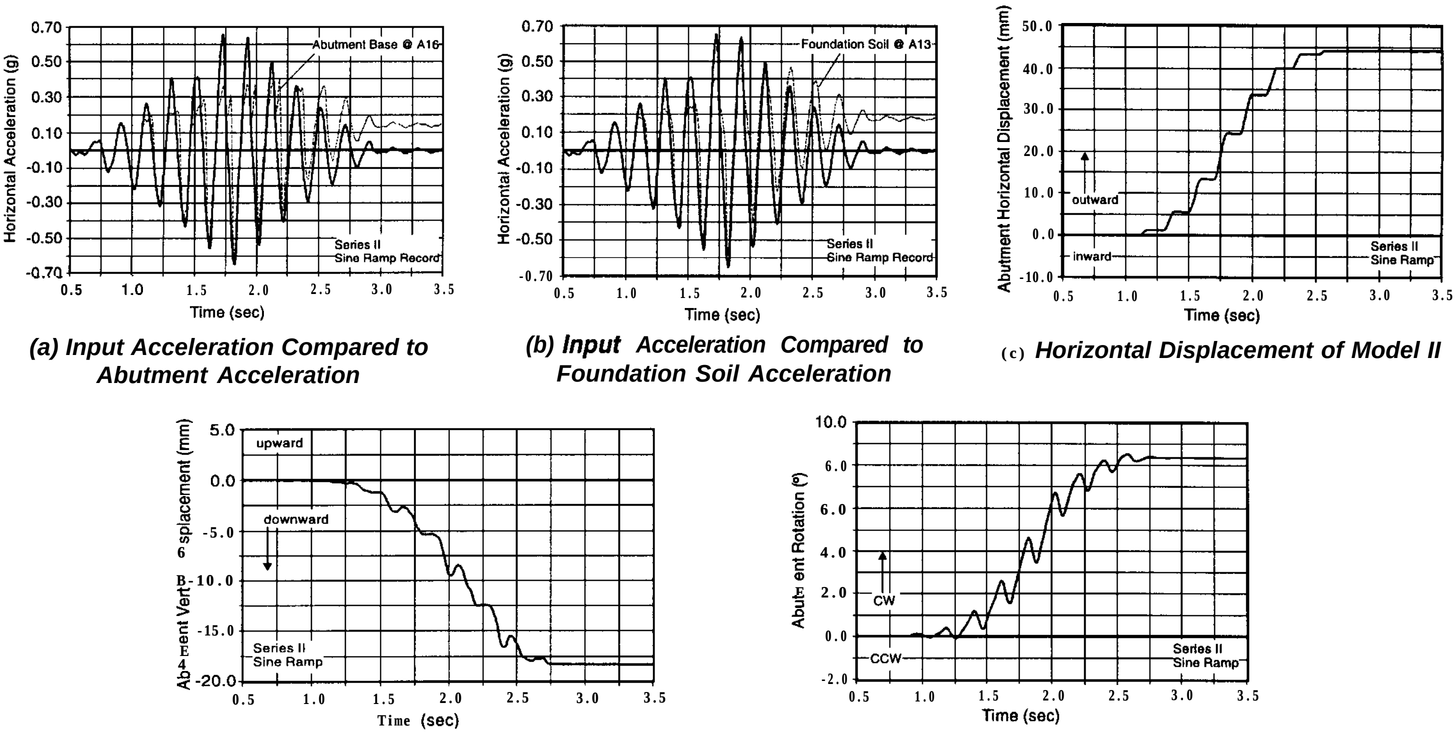
The observed permanent deformation presented in figures 5(c), (d) and (e) includes horizontal displacement, vertical displacement, and wall rotation. Note that permanent displacement only occurs when the input acceleration exceeds the seismic resistance of the bridge abutment (threshold acceleration). The occurrence of significant vertical displacements and eventual tilting of the bridge abutment confirms that the mode of failure is seismic loss of bearing capacity. Results presented in table 3 show that the predicted and observed response of the Model II bridge abutment are in good qualitative and quantitative agreement.

Summary of Results

Table 3 provides a summary of the observed threshold accelerations, k_h^{obs} for the three models, and provides a comparison with thresholds predicted for sliding and bearing capacity, k_h^s and k_h^b . In all cases, the observed threshold acceleration is close to the lowest, and therefore most critical, as predicted by the analysis of sliding and seismic reduction of bearing capacity modes. The comparison between predicted and observed threshold accelerations is considered good and implies a range of error between predicted and observed values off 0.05g. Further details of the shake table testing and results are presented by Fishman et al. (1995 (a) and (b)), and Divito (1994).

Survey of Existing Bridge Abutments

As part of its bridge inspection program, New York State maintains a comprehensive data base describing its existing bridge inventory (NYDOT, 1991). The data base may be obtained in a compressed format on diskettes and is accessible through a number of commercially available data base



(a) Input Acceleration Compared to Abutment Acceleration

(b) Input Acceleration Compared to Foundation Soil Acceleration

(c) Horizontal Displacement of Model II

(d) Vertical Displacement of Model II

(e) Rotation of Model II

Figure 5: Results of Sine Train Input on Model II

management programs. The data base contains over 170 fields of information for each bridge including the age of the structure, number of spans, type of bridge abutment, height of bridge abutment, foundation type, and details of the bearing between the bridge deck and the top of the bridge abutment. In the first part of the survey, this data base was queried to study the demographics of the bridge abutment population in the State and to identify those for which the methodology under investigation may apply.

Based on information obtained from the initial survey, fifty bridge abutments were identified for detailed analysis in part two of the survey. Construction drawings and subsurface soils data were obtained for the selected bridge abutments. Using this information, wall geometry, bridge deck loads and shear strength parameters of the wall backfill and foundation soils were determined. Each bridge abutment was analyzed to determine both static factors of safety as well as the seismic resistance. The following is a summary of results from the survey of New York State bridge abutments. A detailed discussion is presented by Younkins (1995).

Of the 39,346 bridge abutments listed in the New York State inventory, 15,716 are noted as being founded on spread footings placed on cut or fill material. Therefore, the analysis addressed by this research may be applicable to as much as 40% of all bridge abutments in New York State. Editor's *note: The state bridge inventory may not adequately reflect that many of these abutments could have piles under the footings. As a result, the conclusions regarding the number of abutments for which this analysis is applicable may have been overestimated.*

There is no clear distinction between the construction practices of the New York State Department of Transportation (NYSDOT) and those of other agencies within the state. NYDOT is the owner of 43% of the bridge abutments on spread footings. Historically, the practice of using spread footings has not changed when comparing those constructed prior to 1960 to those after 1960. However, since 1960, there is a clear trend favoring cantilever wall designs over gravity wall designs. Forty-five percent of all the bridge abutments on spread footings are the gravity type design, and 39% are the cantilever type. More than half (63%) of all the bridge abutments founded on spread footing are for single span bridges. Of particular interest is the fact that nearly half (44%) of the bridge abutments on spread footings are taller than 20 ft. The significance of this statement will become apparent from the results of the detailed analysis.

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Research Activities (Cont'd)

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The demographics of bridge abutments constructed in westem New York were compared to those of the state population and deviations were found to be minor. Therefore, the inventory of bridge abutments in western New York was considered representative of the state. Fifty bridge abutments located in western New York were selected for detailed analysis. As a point of reference, static safety factors relative to a sliding failure, overturning and bearing capacity were computed for all abutments considered. The computed safety factors for sliding and overturning were all above 1.5 and 2.0, respectively, but were much higher for shorter walls. This was due to the fact that deck loads are uncorrelated to wall height. For shorter walls, the deck load overpowers the weight of the wall itself; thus, it has a much larger impact on computed safety factors when compared to taller, heavier walls. Relatively speaking, for shorter walls, the seismic resistance is strongly affected by the connection detail between the top of the abutment and the bridge deck. If the bridge deck is fixed to the top of the abutment, an inertial reaction is transferred to the abutment/soil system which tends to drive the system to failure during a seismic event. If a free connection exists between the bridge deck and the top of the wall, this inertia is not transferred to the abutment and seismic resistance is higher.

Figure 6 presents the results of the seismic vulnerability study applied to western New York bridge abutments. All bridge abutments over 20 ft. high had a computed seismic resistance less than 0.2g with many less than 0.15g. These levels of acceleration are considered possible even with the moderate level of seismic hazard in parts of New York. Considering that there are 7,000 bridge abutments in New York over 20 ft. high and founded on spread footings, a significant portion of the bridge abutment inventory is vulnerable to seismically induced, permanent deformation.

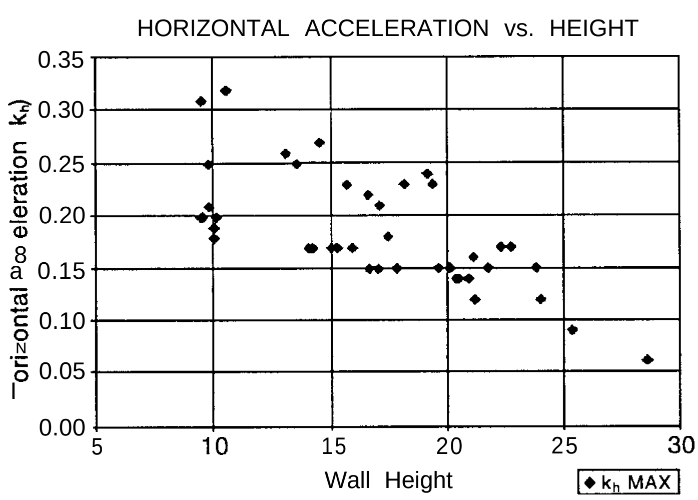

***Figure** 6: Seismic Resistance, k_h, of Typical New York State Bridge Abutments*

In addition, two of the cases studied, representing abutments over 25 ft. high, had computed seismic resistances of less than 0. lg with one as low as 0.06g. There are nearly 1,400 bridge abutments in New York State which could fit into this category. The likelihood of these structures suffering excessive permanent seismic induced deformation in the future is very high. A more thorough investigation of bridge abutments on spread footing having heights in excess of 25 feet is warranted, and strongly recommended.

Conclusions

The research presented in this article is part of a broader, six year research effort on Seismic Vulnerability of Existing Highway Construction sponsored by the Federal Highway Administration. The analysis described herein applies to bridge abutments which may be treated independent from the bridge superstructure and subject to a sliding and/or tilting mode of failure. The analytic method has been verified based on results from shaking table tests with small model bridge abutments. A survey of existing construction in New York State indicates that the analysis may be applicable to a significant portion of the inventory. The methodology will be useful from the standpoint of seismic risk assessment as applied to existing construction and levels of seismic hazard typical of the eastern United States.

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Post Earthquake Evaluation of Base Isolated Structures Using the 3D-BASIS Computer Program

by Satish Nagarajaiuh

This article presents research conducted on the further development and verification of the 3D-BASIS computer program, which is part of NCEER S program in Intelligent and Protective Systems. As ***part*** *of this research, correlation studies were conducted on the performance of base isolated buildings during the Northridge earthquake. Support for these studies was provided by the Caltfomia Strong Motion Instrumentation Program (CSMIP). For more information, contact Satish Nagarajaiah, University of Missouri-Columbia, at (314) 882-0071; or Andrei Reinhorn, University at Buffalo, at (716) 645-2114 ext. 2419.*

The objectives of the study presented in this article are to assess the analysis techniques used for base isolated structures – particularly 3D-BASIS; and to evaluate the effectiveness of seismic isolation. California Strong Motion Instrumentation Program (CSMIP) records (Shakal et al., 1994) of the response of the base isolated University of Southern California (USC) hospital during the Northridge earthquake provided a wealth of data for this study. The 3D-BASIS computer program was used for post earthquake evaluation of the USC hospital and the results are presented herein.

The 3D-BASIS computer program (Nagarajaiah et al., 1991a; 1991b) has been used for analysis and design of several base isolated buildings in California and other locations. Nonlinear analytical modeling using 3D-BASIS consists of (1) linear condensed superstructure model with three degrees of freedom per floor; and (2) the isolation system, which is modeled explicitly using nonlinear force-displacement relationships of individual isolators.

The USC hospital is an eight-story, steel braced frame, base isolated building, as shown in figure 1. The seismic isolation system consists of 68 lead-rubber isolators and 81 elastomeric isolators (see figure 1). The building has been extensively instrumented by CSMIP (Shakal et al., 1994); the sensor locations are also shown in figure 1. A detailed model

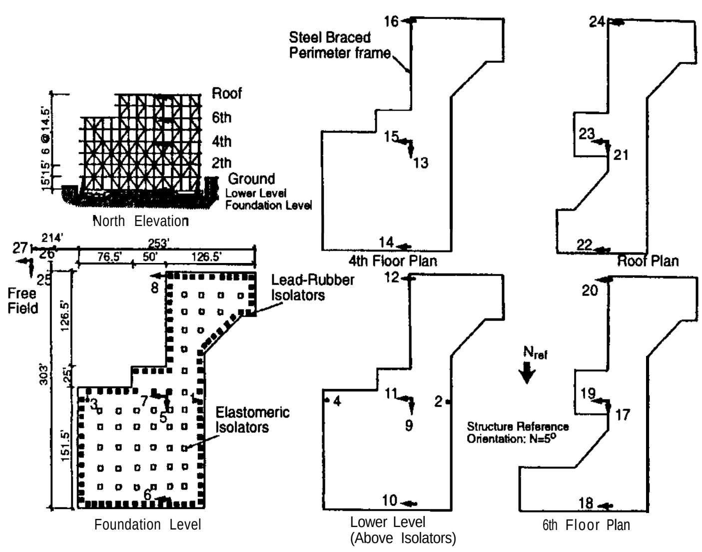

Figure 1: USC Hospital Superstructure, Isolation System Details and Sensor Locations (CSMIP Station No. 24605)

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of the superstructure was developed using ETABS (Wilson et al., 1975), with rigid floor slab assumption. ETABS uses six degrees of freedom (DOF) per node with three degrees of freedom per node slaved to the master node at the center of mass of the floor; hence, in the condensed model, only 24 DOF (8 floors x 3 DOF per floor) are retained for modeling the USC hospital. Eigenvalues and eigenvectors of the condensed model from ETABS were used in modeling the superstructure with 3D-BASIS. The dynamic characteristics from ETABS were further verified by comparison with system identification results (Nagarajaiah et al., 1995). Elastomeric isolators were modeled in 3D-BASIS using a nonlinear force-displacement relationship based on prototype bearing test results for the USC hospital.

The response of the USC hospital to the Northridge earthquake (foundation level acceleration CHN 5 and CHN 7, see figure 1) was computed using the nonlinear analytical model. Figure 2 shows a comparison between the recorded and computed response in the EW and NS directions; absolute accelerations and relative displacements at sensor locations shown in figure 1 were compared. The figure shows that the correlation between the computed and recorded response was good – both in phase and amplitude (except for the roof acceleration in the NS direction in one peak cycle of motion). Figure 3 shows the recorded and computed displacement and acceleration profiles at times of peak base displacement, peak acceleration, peak structure base shear (above base), and peak drift. The accuracy with which the analytical model captures the displacement response as shown in figure 3 is notable; there are, however, differences in acceleration response, which may be due to the complexity of the analytical model. Correlation of recorded and computed time histories and profiles demonstrate the accuracy of the analysis techniques and the nonlinear models used in 3D-BASIS. Identical results were obtained when 3D-BASIS-TABS (Nagarajaiah et al., 1993; Reinhorn et al., 1994) was also used.

The time history of the response shown in figure 2 indicates that the isolators yield (the yield displacement is 0.34 inch or 0.86 cm) and the isolation system responds in the inelastic range for a significant portion of the time history with a period of ~ 1.3 to 1.5 seconds. The peak ground acceleration

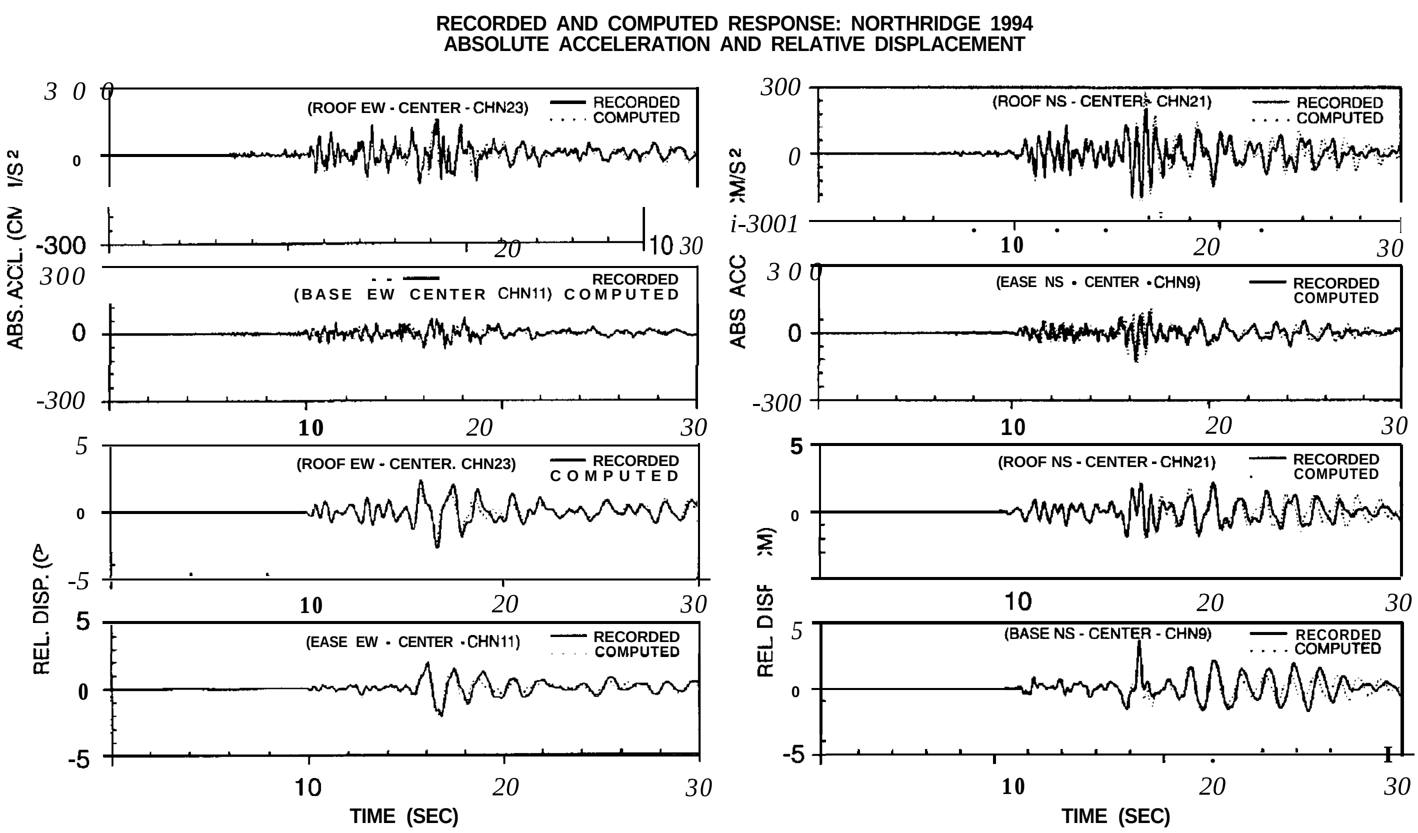

Figure 2: Recorded and Computed Response in the EW and NS Directions at Sensor Locations Shown in Figure 1

was 0.163 g in the EW direction and 0.37g in the NS direction. The peak acceleration at the base was 0.073g in the EW direction and 0.13g in the NS direction. The peak acceleration at the roof was 0.158g in the EW direction and 0.205g in the NS direction. The accelerations were deamplified because of base isolation. Figure 4 shows a comparison between the computed peak response envelopes of the base isolated USC hospital and probable response if the building was fixed-base. The benefits of seismic isolation become clear by examining the peak story shear and peak story drift envelopes, in both cases, in the EW and NS direction. The superstructure remains elastic in the base isolated case; however, the fixed-base structure will yield.

Furthermore, the higher mode effects were dominant in the fixed-base case; whereas, in the base isolated case, the higher mode effects were not as dominant. The changes in stiffness after the fifth floor, because of setbacks, were the cause for these higher mode effects; this is clear in the displacement and acceleration profiles in the NS direction, presented in figure 4. The profiles in figure 4 are at instants of occurrence of the peak acceleration, peak structure base shear (above base), and peak drift, in the base isolated and fixed-base case. In figure 4, examination of the displacement profile reveals that when the peak structure base shear occurs, in the base isolated building, the isolation mode is dominant. Further results of the evaluation of the effectiveness of the seismic isolation can be found in Nagarajaiah et al., 1995.

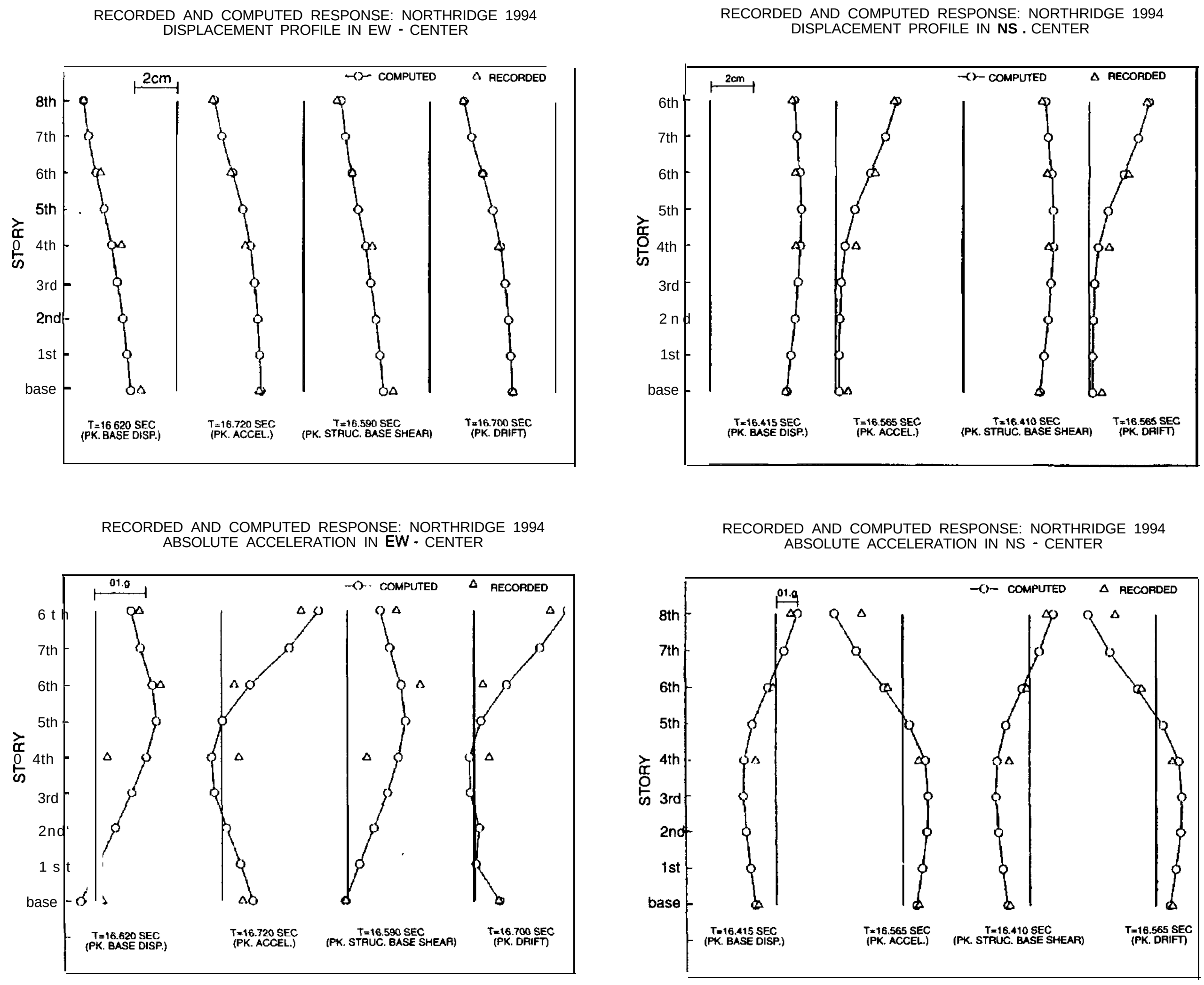

Figure 3: Recorded and Computed Displacement and Acceleration Profiles at Instants of Occurrence of the Peak Base Displacement, Peak Acceleration, Peak Structure Base Shear (above base), and Peak Drift - in the EW and NS Directions

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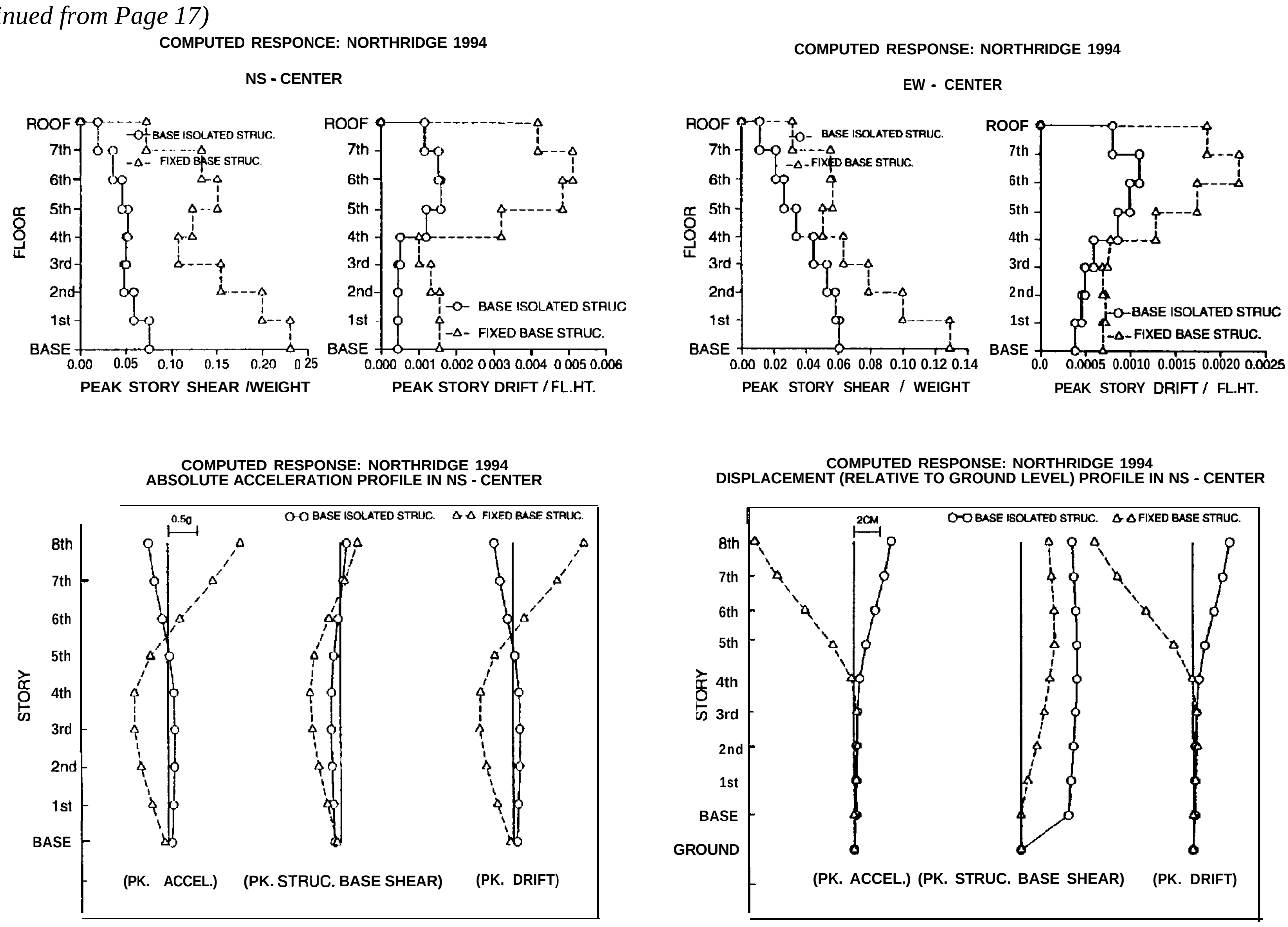

Figure 4: Comparison Between Base Isolated and Fixed-based Case: (1) Normalized Peak Story Shear and Drift Envelopes in NS and EW Directions; (2) Displacement and Acceleration Profiles at Instants of Occurrence of the Peak Acceleration, Peak Structure Base Shear (above base), and Peak Drift in the NS Direction

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Geotechnical and Seismological Aspects of New York Seismic Code Provisions

by K. Jacob

*This article describes geotechnical and seismological **factors** which were considered while developing seismic provisions for inclusion into building codes for both New York State and New York City. The draft seismic provisions for New York State have been presented at public hearings throughout the state and are now in a "receipt of comment" phase. The New York City seismic provisions have been signed into law (Local Law 17/95) and will take effect in February 1996 (see NCEER Bulletin, Volume 9, Number 2, pg. 17). Questions and comments should be directed to Klaus Jacob at (914) 365-8440.*

New York State is located in a region of moderate seismicity. For instance, since 1884, four earthquakes with magnitudes between about M=5 and M=5.5 have occurred in the state, and many smaller earthquakes are recorded every year. The greater New York City area alone can expect, on average, one magnitude M=5 earthquake about once every 100 years (the last such event occurred in 1884). The most seismically active regions in the state lie in the Adirondacks and near the Canadian border regions along the St. Lawrence River, followed by the New York City and Buffalo/Niagara/Attica regions. Based on geological considerations and comparison to geologically similar regions elsewhere, the possibility that magnitudes as high as M=7 may occur cannot be excluded for some regions of the state, including those offshore on the adjacent Atlantic coast shelf. This possibility for M>6 earthquakes exists despite the fact that in the short historic record (about 300 years), no larger earthquakes have occurred in the state. But larger events have historically occurred along the Atlantic coast both north and south of New York and in adjacent Canada.

The ground motions associated with earthquakes in the eastern U.S. differ distinctly from ground motions in the western U.S. in several important ways. Eastern earthquakes tend to release higher rock stresses compared to their western counterparts, thereby causing the ground motions to contain more high-frequency energy. The ground motion shaking is felt more intensely in the eastern U.S. over larger distances because the Earth's crust and its rocks transmit seismic waves more efficiently, especially at high frequencies. This stronger shaking, especially at shorter periods and over larger distances is caused by the fact that the crustal rocks in the eastern U.S. tend to be older, more competent, and less riddled with seismically active faults, when compared to generally younger California rocks along the tectonically active San Andreas fault system.

Other differences relate to the geological near-surface conditions: very competent, hard rocks have been exposed at the surface in many regions of the eastern U.S. ever since glaciers retreated from the area about 10,000 years ago. In or near lakes, river valleys and coastal estuaries, very soft sediments have been deposited since glacial times, sometimes almost directly onto the exposed, hard bedrock formations. The contrasts in stiffness between the soft soils and hard rocks often create extreme conditions for frequency-selective amplification of ground motions. On soft-soil sites, ground motions with periods shorter than 0.3 seconds tend to be attenuated (diminished in amplitude), and those with longer periods (>0.3 seconds) are often amplified, sometimes by factors up to 5 or 8. Finally, liquefaction of cohesionless soils, such as sands and silts, can be expected for smaller earthquakes and over larger distances in the eastern U.S. than in the western U.S.

The combined seismological-geotechnical information, some of it collected only in recent years, was carefully considered when reviewing whether the seismic provisions of the Uniform Building Code (UBC), which was used as the primary reference code, needed any modifications. The new seismic information from the eastern U.S. affects seismic load factors, seismic design-spectral shapes, spectral site coefficients for amplification of ground motions on soil sites, and liquefaction potential of soil sites. Accordingly, some of the seismic loads and soil parameters had to be modified from those quoted in the referenced UBC.

The main seismological-geotechnical features of the New York seismic code provisions are:

- The proposed design ground motions are intended, as a first order approximation, to represent ground motions expected to have a 90% probability of not being exceeded in 50 years, corresponding to an average recurrence period of about 500 years. This implies a 10% chance that the motions (and corresponding seismic loads) may be exceeded in 50 years. These values are only estimated

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targets that can vary slightly across the state, from soil to rock site conditions. With the occurrence of future seismic events, new information may come to light that may require that these estimates be updated periodically. Since the code represents only minimum requirements, some building owners may opt to seek greater protection by choosing design options capable of resisting ground motions and design forces higher than those outlined in the code.

- The seismic code provisions allow the design ground motions to be used either from code prescribed design spectra, or based on site-specific investigations.

- The entire state of New York is divided into four seismic zone catagories (A, B, C, and D) as shown in figure 1. The four catagories are associated with seismic zone factors Z, whose related peak ground acceleration values vary from 0.09, 0.12, 0.15 to 0.18 g, for zones A to D, respectively. For example, New York City is located in seismic zone C, with a seismic zone factor Z=O.15.

- Five rock and soil classes, SO to S4, apply. These can be determined using the standard soil classification schemes in conjunction with standard penetration test (SPT) blow counts and shear wave velocities for rock. The soil profiles need to be defined from geotechnical information generally to depths of 100 feet or less below grade.

- The five classes of rock and soil profiles are associated with five site coefficients that vary from S0=0.67 for hard rock, to S4=2.5 for the softest soils; thus the code allows for a maximum site amplification of S4/SO=3.75 between soft soils and hard rock. This is a higher ratio than used in most previous U.S. seismic codes that in the past have often failed to realistically quantify the observed differences in ground motions between soft soil and hard rock sites. The site factors thus reduce the code-prescribed seismic loads for structures founded on the hardest rocks, and introduce load penalties for structures founded on the softest soil sites, in accordance with site-dependent damage patterns observed globally during many past earthquakes.

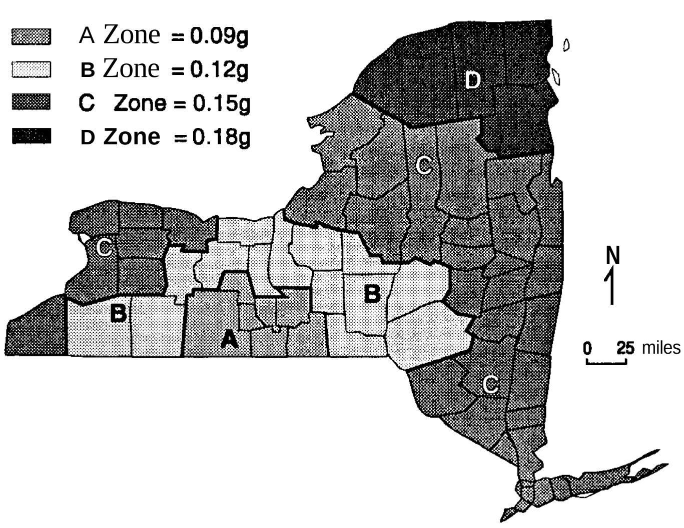


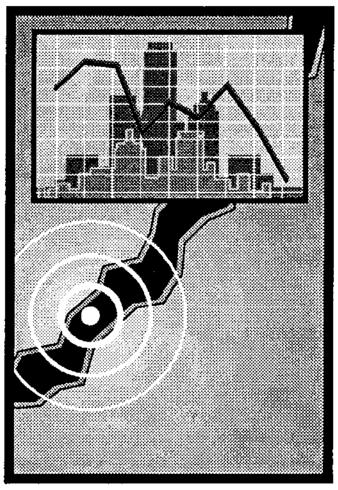
Figure ***1: Seismic Zoning Map for New York State Seismic Building Code***

- A liquefaction screening test has been included for sites containing water-saturated non-cohesive soils in the upper 50 feet. These soil profiles are identified based on geotechnical borings that measure SPT blow counts. Two separate criteria for liquefaction screening are used; one applies to buildings that belong to ordinary occupancy categories, and a more stringent one applies to more important buildings in special occupancy categories.

The geotechnical/seismic data and other types of information used to modify the code provisions and seismic loads are believed to reflect the current level of knowledge of seismic and geotechnical processes in the eastern U.S. Nevertheless, it must be kept in mind that the information used is based on a limited number of observations. Also, there is no guarantee that the limited past seismic experience can be used as an unequivocal guide to the future behavior of earthquakes in this region. The resulting design motions and seismic loads are believed to adequately represent the seismic and geotechnical conditions for New York, and for the targeted ground motion recurrence period of about 500 years. Therefore, the design motions should provide a nearly uniform and balanced level of protection between the different seismic zones and greatly differing soil and rock conditions that exist in New York.

But, as has already been stated, the provisions represent only minimum requirements. Owners and developers interested in added seismic protection for their structures are not prevented from using more severe ground motions than those specified as minimum conditions in the code. As a guide, it is estimated that doubling the code-specified minimum ground motions changes their average recurrence period by a factor of five, from about 500 to about 2,500 years, and the corresponding non-exceedance probability from about 90% in 50 years to about 90% in 250 years.

Conference on Economic Consequences of Earthquakes: Preparing for the Unexpected



Damage, losses, business disruption and the economic impact of earthquakes in United States urban centers will be the focus of a conference titled ***Economic Consequences of Earthquakes: Preparing for the Unexpected,*** to be held September 12-13, 1995 in New York City. Sponsored by NCEER, the conference will examine earthquake damage and disruption to critical public and private facilities and the potential impact on business, commerce, industry, insurance and the financial markets.

Aiming to attract economists, insurance executives, corporate finance officers, risk managers, owners, investors, public officials and those responsible for managing, operating and maintaining infrastructure, public and private facilities, the program will feature recognized leaders in the fields of economics, insurance, seismology, engineering and earthquake hazards mitigation. Speakers will examine exposure to earthquake risk and discuss measures to mitigate losses.

Conference speakers will review the economic aftermath of the January 17, 1995 Hanshin-Awaji (Kobe, Japan) earthquake, and consider consequences of a similar disaster striking the United States. The Kobe earthquake killed more than 5,000 people, destroyed tens of thousands of buildings, and rocked Japan's financial markets. Damage from the magnitude 6.9 earthquake crippled the country's shoe industry and has closed Kobe's port facilities for up to two years. Cost estimates for the damage caused by the earthquake have topped $110 billion

Speakers will explore the probability of damaging earthquakes in the central and eastern U.S., and the economic implications of damaged buildings, utilities/lifelines, transportation and port facilities resulting from such a disaster.

Case studies of the January 1994 Northridge, California earthquake and the 1993 Midwest floods will be used to illustrate the impact of recent U.S. disasters on business. Potential impact on the insurance industry and financial markets will also be discussed. A closing panel discussion will review precautionary measures that can be implemented to reduce exposure to risk.

Howard Kunreuther of the Risk and Decision Process Center of the University of Pennsylvania will deliver a keynote address on New *Strategies for Dealing with the Earthquake Hazard.* Other conference speakers include:

- S. Theodore Algermissen, U. S. Geological Survey
- Harold C. Cochrane, Department of Economics, Colorado State University
- Raymond De Voe, Legg, Mason, Wood, Walker
- Ronald T. Eguchi, EQE International
- Klaus Jacob, Lamont-Doherty Earth Observatory
- Eugene Lecomte, Insurance Institute for Property Loss Reduction
- Guy J. P Nordenson, Ove Arup & Partners
- Charles Scawthom, EQE International
- Kathleen Tiemey, Disaster Research Center, University of Delaware
- Stewart Werner, Dames and Moore
- Bojidar Yanev, New York City Bureau of Bridges

Professor Barclay Jones is the principal organizer of the conference program and can be reached at Cornell University, phone: (607) 255-0658 or (607) 255-6846; fax: (607) 255-197 1. To be added to the conference mailing list, contact Deborah O' Rourke at NCEER, phone: (7 16) 645-339 1, fax: (716) 645-3399, or email:nceer@ubvm.cc.bu.aalo.edu. General program inquiries should be directed to Andrea Dargush at NCEER.

Honors and A wards

NCEER Director Receives Awards for Meritorious Service

Dr. George Lee, NCEER Director, received the 1995 President's Medal from the University at Buffalo on May 14, 1995 by University President William Greiner. The President's Medal is awarded in recognition of extraordinary service to the university and is the highest tribute that can be accorded to a member of UB's community. Dr. Lee has served as Dean of the School of Engineering for 18 years, and during that time, has made many contributions to research, teaching and service. These include his role in the creation of both NCEER and the Calspan-University at Buffalo Research Center, and the development of programs to make engineering more accessible to minorities (Buffalo Engineering Awareness for Minorities, BEAM). He served as interim NCEER Director in 1989-1990 and as Director since September 1992.

Dr. Lee also received the Walter P Cooke Award from the University at Buffalo Alumni Association on May 9, 1995. This award is the most prestigious non-alumnus award, and was awarded to Dr. Lee for his notable and meritorious service to the university.

Dr. Lee retired as Dean of the School of Engineering and Applied Science and will serve as NCEER's Director on a full-time basis.

NCEER Information Service Recognized as Electronic Doorway

by Patricia A. Coty

The Information Service was recently recognized by the New York State Library for having met the requirements for Electronic Doorway Library status. A certificate was presented to NCEER during a recent reception. New York State Education Commissioner Thomas Sobol identified the Information Service as one of the first libraries in the state officially designated for its pioneering use of computers and telecommunications technology.

An electronic doorway library provides a two-way flow of requests and information, into and out of a library, by electronic means. Such a library uses computer and telecommunications technology, a full range of library resources and the services of skilled information professionals to meet the needs of its users. The official designation "electronic doorway library" recognizes that the NCEER Information Service uses advanced technology to revolutionize the delivery of library services, according to Joseph F. Shubert, New York State Librarian. The criteria for electronic doorway designation were developed by a statewide committee, and identifies libraries that reach beyond a library's walls to obtain information and resources and work to provide new ways of assembling, evaluating, and using information.

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NCEER Information Available Via the World Wide Web

NCEER information is now available via the World Wide Web (WWW) on the Internet. The NCEER WWW home page supplements the existing gopher and anonymous FTP site. All three sites offer a broad spectrum of information about NCEER and other earthquake hazard mitigation organizations. NCEER information includes the Quakeline® database, several back issues of the **NCEER Bulletin and the NCEER Information Service News, a comprehensive listing** of NCEER technical reports, and other miscellaneous information regarding the Center. The WWW address is *http://www.nceer.buffalo.edu. The* gopher address is *gopher nceer.eng.buffalo.edu* and the anonymous FTP site address is *ftp clark. eng. buffalo. edu* or *ftp 128.205.19.101*. The July 1994 and April 1994 issues of the **NCEER Bulletin contained articles describing** the NCEER gopher and anonymous FTP site, respectively.

Center Resources

NCEER Technical Reports

Two New Reporis 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 610025, Buffalo, New York 14261-0025, phone: (716) 645-3391; fax: (716) 645-3399; or email: *nceer@ubvm.cc.buffalo.edu.*

Pipeline Replacement Feasibility Study: A Methodology for Minimizing Seismic and Corrosion Risks to Underground Natural Gas Pipelines
R. T. *Eguchi, H.A. Seligson and D.G. Honegger, 3/2/95, NCEER-95-0005, 134 pp., $15.00*

This report presents a methodology which a utility can use to fold mitigation for seismic hazards into its ongoing repair and replacement program. The methodology was developed specifically for buried pipeline components within the Southern California Gas Company (SoCalGas) system. Both transmission and distribution pipeline systems are considered; however, suggested procedures differ, due in part to the importance and relative lack of redundancy (i.e., interconnectedness) for transmission pipe. In the past, the SoCalGas repair and replacement program focused on corrosion damage. The new methodology incorporates potential seismic damage as characterized by areas of potential ground failure. As part of this effort, a new procedure for estimating corrosion leakage rates in "data-poor" areas is proposed.

♦ ♦ ♦

Prioritization of Bridges for Seismic Retrofitting
N. *Basöz and A. S. Kiremidjian, 4/24/95, NCEER-95-0007,178 pp., $75.00*

This report presents a prioritization method developed for seismic retrofitting of bridges. The method is used to identify bridges that are in most need of retrofitting and to rank order these bridges based on vulnerability and importance criteria. Vulnerability assessment includes evaluation of the seismic hazard at the bridge site, classification of existing bridges into bridge classes and fragility analysis. Importance assessment considers the attributes that relate the consequences of failure of a bridge to the public safety and socio-economic well-being of a community. The importance of a bridge is considered to be closely related to its function within the transportation network system. A detailed review and critique of the existing prioritization methodologies is included. The developed methodology is illustrated by an example application conducted for the Palo Alto, California area.

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News from the Information Service

The Changing Face of Reference Provision at NCEER

by Dorothy S. Tao

Over the past year, the volume, character, and means of transmission of requests received by the Information Service have changed noticeably. Such changes seem to reflect the increasingly global and electronic environment in which we live. Following the occurrence of the devastating Hanshin-Awaji earthquake in Kobe, Japan on January 17, 1995, the volume of calls coming into the NCEER Information Service showed a marked increase. Total reference requests were up from 1,096 in the last quarter of 1994 to 1,950 in the first quarter of 1995, an increase of 854. While this increase was largely attributed to the Kobe earthquake, the signing in December 1994 of Executive Order No. 12941, which mandated the mitigation of seismic damage to Federal buildings, may also have been a contributing factor.

Who are our requestors and what kinds of information do they seek? A wide variety of information seekers, including engineers, journalists, academicians, students at every level, government administrators, insurance professionals, business people, and many concerned lay persons have contacted the Information Service. Their requests range from simple retrieval and photocopy of items, to complex research projects involving multiple searches and the acquisition of domestic and foreign materials. Both the origins of users and their interests are global in nature and show increased sophistication. For example, immediately after the Kobe event, a Japanese television network requested a satellite image of the Kobe area. Engineers, insurance practitioners, and business people have requested zoning/fault maps as well as seismic codes and histories for such diverse locations as Beijing, China and the Paraguanan Peninsula in Venezuela, or closer to home, San Diego, California and western New York. Engineers have also sought information on specifications for seismic design of particular types of structures like tilt-up buildings, silos, or nuclear plants. Lately, practicing engineers have needed digitized strong motion records and software for testing or instructions for online access to such data. Other users wish to borrow slides or videotapes for use in presentations and classes.

The comprehensive collection of research materials that the Information Service has acquired since 1987, which includes journals, books, technical reports, standards, maps, audiovisuals, and an extensive newspaper clipping collection, coupled with the sophisticated finding tools like the **Quakeline@** database, facilitate our capability to respond to the requests that are received. Reference service is further enhanced because the information professionals in the Information Service are immersed in the daily acquisition and provision of relevant literature, and can often map out possible answers before consulting standard reference sources.

Wide acceptance of the Internet has also been a factor in increased requests. Requests received via the Internet are up over 200% from a year ago. While intelligent Internet facilities, such as the NCEER anonymous FTP site, the NCEER gopher, and the new World Wide Web (WWW) Page (see page 22) are intended to improve direct user access to information, often even the most user-friendly computer screen does not replace a live information specialist. Having obtained a digital copy of the voluminous Catalog of Earthquakes East of New Madrid via the FIP, a user recently called to request next day delivery of a paper copy of the document for easier viewing. Many e-mail requests are for articles found in **Quakeline@** database searches that were performed via the Internet or accessed via the FTP. Frequently, users ask for transmission of both text and data files for strong motion records or computersearches via e-mail. The Information Service's ethernet connection facilitates instant transfer of such files.

The staff of the Information Service is gratified by the positive response that their efforts have generated. They will continue to assess their services and implement new technologies to better meet the many challenges that have occurred in the past year and which are certain to persist in the ever evolving global and electronic environment.

To contact the NCEER Information Service, phone: (716) 645-3377; fax: (716) 645-3379; or email: ***nemceer@ubvms.cc.buffalo.edu.***

Bulletin Board

Upcoming Events

73rd Annual ICBO Education and Code Development Conference

The International Conference of Building Officials will meet in Clark County, Nevada, September 10-15, 1995 for the *73rd Annual Education and Code Development Conference.* Over 1,000 building officials, building department personnel, architects, engineers and industry representatives from across the United States as well as representatives from several other countries are expected to attend. For more information, contact ICBO at 5360 Workman Mill Road, Whittier, CA 90601, or by fax, call the new ICBO Fax-on-Demand system at (310) 699-4253, code number 4226 for a complete copy of the registration materials and forms.

National Ground Motion Mapping Workshop

The Applied Technology Council (ATC), in conjunction with the U.S. Geological Survey (USGS) through the ATC-35 project, is sponsoring a *Workshop on National Ground Motion Mapping* on September 22-23, 1995 in Los Angeles at the Wyndham Hotel, Los Angeles International Airport. The objective of the workshop is to provide input to the USGS on several key broad issues that affect the preparation of the next generation of national ground motion maps. The workshop will also serve to initiate the ATC-35 Ground Motion Initiative, a longer-term effort to examine ground motion needs for a new generation of seismic design regulations and seismic design practice. For more information, contact the Applied Technology Council, 555 Twin Dolphin Drive, Suite 550, Redwood City, California 94065; phone: (415) 595-1542, fax: (415) 593-2320. The workshop registration fee is $125 ($100 for ATC subscribers) and includes workshop proceedings.

CUREe Symposium in Honor of George Housner

The California Universities for Research in Earthquake Engineering (CUREe) is sponsoring a symposium to honor the career of Professor George Housner during the weekend of October 27-28, 1995 in Pasadena, California. Co-sponsored by the California Institute of Technology, the symposium will bring together scientists and engineers from around the country and overseas who will discuss the progress made in various areas pioneered by Professor Housner including structural engineering, ground motion, public policy and education. As well as making connections with Dr. Housner's seminal work in these areas, the symposium presentations will include thoughts on future developments. Friday evening will feature a reception at Caltech's Athenaeum. For more information, contact CUREe, 1301 South 46th St., Richmond, CA 94804; phone: (510) 231-9557; or fax: (510) 231-5664.

First Biennial National Mitigation Conference *"Partnerships for Building Safer Communities"*

The Federal Emergency Management Agency's Mitigation Directorate and the Federal Insurance Administration will host the first *Biennial National Mitigation Conference* December 6-8, 1995 in Alexandria, Virginia. The conference theme is "Partnerships for Building Safer Communities." Topics to be discussed include: the National Mitigation Strategy, risk assessment, measuring mitigation success, building codes and enforcement, GIS/GPS, all-hazards insurance, public involvement in mitigation, legislative updates, retrofitting, and more. For more information, contact the Federal Emergency Management Agency, phone: (800) 769-3861.

National Seismic Conference on Bridges and Highways

The *National Seismic Conference on Bridges and Highways* will be held December 10-13, 1995 in San Diego, California. The conference is sponsored by the Federal Highway Administration (FHWA) and the California Department of Transportation (Caltrans). The objective of the conference is to provide a forum for the exchange of information on current practice and research for seismic design and retrofit of new and existing bridges. For further technical information, contact James Gates, Caltrans, phone: (916) 277-8773; fax: (916) 227-8174 or Roland Nimis, FHWA, phone: (415) 744-2653; fax: (415) 744-2620. For registration information, contact Barbara Murdock, phone: (202) 289-8 100; fax: (202) 289-8107.

7th U.S.-Japan Workshop on Improvement of Structural Design and Construction Practices - Lessons Learned from Kobe and Northridge

The Applied Technology Council and the Japan Structural Consultants Association are jointly sponsoring *theseventh U.S.-Japan Workshop on Improvement of Structural Design and Construction Practices — Lessons Learned from Kobe and Northridge,* which will be held January 18-20,1996, in Kobe, Japan. Abstracts on the following topics are currently being solicited: strong ground motion and earthquake damage, behavior of soils and foundations, performance of steel structures, performance of reinforced concrete structures, performance of wood structures, repair and strengthening of structures, seismic evaluation and rehabilitation of structures, and seismic design methodology. Six copies of a l- to 2 page extended abstract should be submitted to the Applied Technology Council, 555 Twin Dolphin Drive, Suite 550, Redwood City, California 94065; phone: (415) 595-1542; fax: (415) 593-2320. Abstracts are due August 31, 1995.

Upcoming Events

Pan Pacific Hazards '96

The *Pan Pacific Hazards '96: A Conference on Earthquakes, Volcanoes and Tsunamis* will be held July 29 - August 2, 1996 in Vancouver, British Columbia, Canada. Abstracts for papers or posters are currently being solicited. Abstracts should include a cover page with paper/poster title; type of paper/poster (research/technical, emergency management and/or practical application); conference topic; three to five key words; author(s) information (name, title and affiliation); and presenter's information (name, title, affiliation, mailing address, phone, fax and e-mail address). The abstract text must be in English and cannot exceed 200 words. Send either three printed copies of the abstract or a computer disk in ASCII or WordPerfect 5.1 format to: Program Committee, Pan Pacific Hazards '96 Conference, The University of British Columbia, Disaster Preparedness Resources Centre, 2206 East Mall, 4th Floor, Vancouver, BC, Canada V6T 123; phone: (604) 822-5518; fax: (604) 822-6164; email: *dprc@unixg.ubc.ca.* E-mail submissions are welcome. Abstracts are due by November 1, 1995.

Call for Participation

1996 International Young Scholars Summer Institute in Geographic Information

In the summer of 1996, the U.S. National Science Foundation and the European Science Foundation will jointly sponsor the second Summer Institute in Geographic Information in Berlin, Germany. The summer institute is organized by the National Center for Geographic Information and Analysis for the U.S. side and by the GISDATA program for the European side. Applications are invited from early career scientists who are currently working on, or have completed relevant doctoral research within the past few years at a U.S. institution. Applications must include a brief Curriculum Vitae and an extended paper abstract (1,500-2,000 words) on one of the following themes:

- User interfaces and visualization for GIS
- Progress in spatial decision making using GIS
- Multiple roles of GIS in global research
- Spatio-temporal data sets, data structures, and methods
- Information ethics, law, and policy for spatial databases
- Spatial information technologies and societal problems

Up to 15 fellowships will be awarded. The closing date for applications is September 30, 1995. Application forms are available from Sandi Glendinning, National Center for Geographic Information and Analysis, Department of Geography, University of California, Santa Barbara, CA 93106-4060; phone: (805) 893-8224; fax: (805) 893-8617; or email: *ncgia@ncgia.ucsb.edu.*

Book Reviews

The Northridge Earthquake of January 17, 1994: Report of Data Collection and Analysis Part A: Damage and Inventory Data

The Northridge earthquake was the most costly, as well as the best-documented earthquake in U.S. history. **The Northridge Earthquake of January 17, 1994: Report of Data Collection and Analysis - Part A: Damage and Inventory Data,** compiled by EQE International and the California Governor's Office of Emergency Service, contains a wealth of data and analyses covering the seismological, geotechnical, and engineering aspects of the earthquake. In addition to the most current narrative information on the Northridge event, the report offers tabular data, numerous illustrations and data overlays on color GIS maps. The detailed tabular data includes summaries for the regional building inventory (more than 2 million buildings) and the damaged structures (over 100,000 buildings). These tables were developed with researchers in mind, and include information on earthquake hazards (PGA and MMI) and structural characteristics (construction type, usage, age, and size). While the document was developed primarily to assist those conducting research on the earthquake, it is also a useful reference document for emergency planners, seismic safety policy makers, consultants, insurance executives, journalists and other professionals. Part B, expected later this year, will expand on the damage trends introduced in Part A. To order, send a check or money order for $60 (which covers the cost of printing) to EQE International, Attn: J. Taub, Lakeshore Towers, 18101 Von Karman Ave., Suite 400, Irvine, CA 92715; phone: (714) 833-3303; fax: (714) 833-3392.

Proceedings of the First World Conference on Structural Control

The **Proceedings of the First World Conference on Structural Control,** which was held in Los Angeles in August, 1994, have now been published in three hard bound volumes containing 235 papers. The papers deal with: active control, health monitoring, sensors and actuators, bridges, fuzzy control and neural networks, hybrid control, materials, passive control, adaptive control, system identification, robust control, and general control. The participants at the conference came from 15 countries with the largest representations coming from the United States and Japan. The proceedings present a good overview of the state-of-the-art in structural control with all the different phases of the subject being covered in 2,300 pages. The cost of the three volume proceedings is $75 plus $8 shipping by book rate. They can be purchased from the U.S. Panel on Structural Control Research, Department of Civil Engineering, University of Southern California, Los Angeles, California 90089-2531; phone: (213) 740-0581; fax: (213) 744-1426; or email: *uspanel @ vivian2. usc. edu.*

Abstract Journal in Earthquake Engineering

The 1994 volume (Volume 24) of the **Abstract Journal in Earthquake Engineering** provides comprehensive access to 1994 world literature in earthquake engineering and hazards mitigation. The volume contains 2,400 abstracts from technical journals, research reports, books, monographs and other publications of academic, professional and governmental organizations in 24 countries. To order, contact the National Information Service for Earthquake Engineering, Earthquake Engineering Research Center, University of California at Berkeley, 1301 South 46th Street, Richmond, CA 94804-4698;phone:(510)231-9554;fax:(510)231-9461;oremail: ***eerclib@eerc.berkeley.edu.***

Proceedings of the Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

The three volume **Proceedings of the Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics,** edited by Shamsher Prakash, have been published. The conference was held April 2-7, 1995 in St. Louis, Missouri and the proceedings can be ordered from University of Missouri-Rolla Continuing Education, 103 ME Annex, Rolla, MO 65401-0249; phone: (314) 341-4200; fax: (314) 341-4992. The cost is $400 for the three volume set.

Proceedings of the NSF Natural Hazards Mitigation Grantees Workshop

The **Proceedings from the National Science Foundation Natural Hazards Mitigation Grantees Workshop** have been published. The workshop was held April 27-281995 in Lake Tahoe, Nevada to facilitate the timely exchange of information among researchers whose projects are funded by the Natural Hazard Mitigation programs at the National Science Foundation (NSF). Five NSF programs, four within the Earthquake Hazard Mitigation (EHM) program, and the fifth on Natural and Technological Hazard Mitigation were represented at the workshop. The EHM programs were: Architectural and Mechanical Systems, Earthquake Systems Integration, Siting and Geotechnical Systems, and Structural Systems. Representative researchers from these programs were invited to give a brief presentation about their research. In addition, Dr. William Anderson, the Director of the Earthquake Systems Integration program, Dr. James Jirsa, a professor of civil engineering at the University of Texas, Austin, and Dr. George Lee, the Director of NCEER presented keynote speeches.

To obtain a copy of the proceedings, contact Dr. M. Saiidi, Civil Engineering Department/258, University of Nevada, Reno, NV 89557; phone: (702) 784-4839; fax: (702) 784-4466; or email: ***saiidi@scs.unl:edu.***

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Earthquake Hazards Reduction Fellowship Announced

Under a cooperative agreement with the Federal Emergency Management Agency, the Earthquake Engineering Research Institute is offering the 1996 Professional Fellowship to provide an opportunity for a practicing professional to gain greater skills and broader expertise in earthquake hazards reduction. The fellowship provides a stipend of $30,000, commencing in January, 1996, to cover tuition, fees, relocation and living expenses for a six-month period. All applications must be accompanied by a professional resume and letter of nomination from the faculty host(s) at the cooperating educational institution(s). Faculty members should also indicate the institution's ability to provide research facilities, including library, work space, telephone and computer access. Applicants must hold U.S. citizenship or permanent resident status.

Candidates may obtain an application form from the Earthquake Engineering Research Institute, 499 14th St., Suite 320, Oakland, California 94612-1934; phone: (510) 451-0905; fax: (510) 451-541 1. The application deadline is September 1, 1995.

Some of the material reported herein is based upon work supported in whole or in part by the National Science Foundation, the New York State Science and Technology Foundation, the U.S. Department of Transportation and other sponsors. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of NCEER or its sponsors.

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