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Buffalo, Berkeley and Illinois Receive NSF Earthquake Engineering Center Grants

Researchers from the National Center for Earthquake Engineering Research (NCEER) are among those from three engineering research centers that were awarded $10 million grants from the National Science Foundation (NSF), to conduct and coordinate earthquake engineering research for the nation.

The five-year NSF grant, the third received by NCEER investigators in 11 years, will support a Center for Advanced Technologies in Earthquake Loss Reduction, to study the application of advanced and emerging technologies to minimize earthquake damage and losses nationwide. NCEER was originally established by NSF in 1986 following a national competition.

This latest award is part of a $30 million NSF commitment to expand earthquake research by funding three engineering research centers. The others, newly established, are the Pacific Earthquake Engineering Research (PEER) Center, headquartered at the University of California at Berkeley, and the Mid-America Earthquake Center, based at the University of Illinois, Urbana-Champaign.

With its 1997 grants, NSF seeks the most comprehensive knowledge attainable about earthquake hazards mitigation.

“These new centers are needed to extend our understanding of the impacts of seismic events on buildings, roads, bridges energy sources and other components of our built environment and societal institutions,” said William A. Anderson, director of the NSF’s Earthquake Mitigation Program. “The knowledge gained...and shared with engineers, architects and planners will help reduce hazards and save lives.”

The awards call for NSF to invest $2 million a year for five years in each of the three centers. The centers are expected to match federal funds dollar-for-dollar with funds from non-federal sources, and develop significant cooperation with industry and government organizations that are key stakeholders in reducing earthquake hazards.

According to NSF, each center will form a consortium of public and private institutions committed to integrated research and education activities, and will use a team approach to draw on experts in a range of fields including engineering, geology, geophysics and the social sciences.

In learning of the awards, NCEER director Dr. George C. Lee said, “NSF is sending a strong signal that the concept of center-funded earthquake engineering research has proven effective in developing methods to mitigate damage wrought by earthquakes. We are very appreciative and proud to be a part of NSF’s new program of earthquake engineering research centers.”

Dr. Lee added that NCEER’s emphasis on networking across institutions and disciplines has been integral to its success — and he gratefully acknowledged support from New York State and the institutional members of the Center's consortium.

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The advanced technology center seeks to explore and adapt new and emerging technologies to: develop better methods to quantify losses from future earthquakes; improve performance of critical buildings and lifelines; and increase the effectiveness of emergency response and crisis management.

Technologies to be examined include those in the categories of: high-performance computing environments, site remediation, structural control and simulation, high-performance materials, condition assessment, robotics, and decision support systems.

The Center's research plan will be implemented around three case studies or demonstration projects that will enable researchers to study the promise of advanced technologies and impediments to their use, in real-world situations.

The planned demonstration projects involve the water supply and electrical power systems of the Los Angeles Department of Water and Power (LADWP), and a New York City hospital complex — and depict western and eastern U.S. scenarios which offer different sets of engineering and socioeconomic circumstances that impact implementation of loss-reduction measures.

Research tasks are organized under three cross-disciplinary programs:

- ***Performance Assessment of the Built Environment*** — to quantify expected losses;
- ***Rehabilitation of Critical Facilities*** — to develop cost-effective rehabilitation technologies; and
- ***Intelligent Response and Optimal Recovery*** — to improve post-event response and recovery through intelligent crisis management and strategic planning.

Institutions taking part in the research program include the University at Buffalo, Cornell University, Rensselaer Polytechnic Institute, the Disaster Research Center at the University of Delaware, EQE Center for Advanced Planning and Research, University of Nevada at Reno, University of Southern California, Virginia Polytechnic Institute and State University, and the Wharton Risk and Decision Process Center at the University of Pennsylvania.

Dr. Lee serves as principal investigator (PI) on the advanced technology center project. Co-PIs are: Dr. Masanobu Shinozuka, University of Southern California; Dr. Tsu T. (Larry) Soong, University at Buffalo; Dr. Kathleen Tierney, Disaster Research Center, University of Delaware; and Dr. Richard White, Cornell University.

Dr. Lee praised his co-PIs and other researchers for their contributions to the successful proposal. He also acknowledged Center researchers for their ability to work together on focused projects, joining those with expertise in earthquake engineering with those who study seismology and the social and economic impacts of earthquakes. "Their combined knowledge produces a research team that is well-prepared for the challenge of developing sound engineering and disaster-management solutions that are economically feasible and socially acceptable," he said.

He added that the Buffalo-based center looks to strengthen its network of institutions, cooperating with the centers at Berkeley and Illinois to establish a nationwide system of centers for earthquake engineering research. A council of center directors will work to assure coordination and continuity among them.

The Pacific Earthquake Engineering Research (PEER) Center, led by Dr. Jack P. Moehle, of the University of California at Berkeley, will develop technologies to reduce urban earthquake losses. Its consortium comprises nine core universities: UC Berkeley, UC Los Angeles, UC Davis, UC Irvine, UC San Diego, Stanford University, California Institute of Technology, University of Southern California, and the University of Washington in Seattle. Affiliated institutions in seven western states will augment efforts.

The Mid-America Earthquake Center, directed by Dr. Daniel P. Abrams, at the University of Illinois, Urbana-Champaign, will emphasize reducing potential earthquake losses in the central and eastern U.S. by concentrating on problems associated with low-frequency seismic events. Its consortium includes seven universities: University of Illinois, Georgia Institute of Technology, Texas A&M University, University of Memphis, Washington University, St. Louis University, and Massachusetts Institute of Technology.

Research Activities

An Evaluation of Progressive Damage in Reinforced Concrete Circular Bridge Columns

by Sashi K. Kunnath and Ashraf El-Bahy

This article presents research resulting from NCEER's Highway Project, task 106-E-5.3. It summarizes research reported in an upcoming NCEER technical report entitled ***Cumulative Seismic Damage of Reinforced Concrete Bridge Piers****, NCEER-97-0006 (see report review on page 17). The work was conducted by researchers at the University of Central Florida and the National Institute of Standards and Technology (NIST). Comments and questions should be directed to Sashi Kunnath, NIST, at (301) 975-6078; email: kunnath@pegasus.cc.ucf.edu.*

A comprehensive experimental study was undertaken to investigate the mechanics of damage accumulation in reinforced concrete circular bridge piers subjected to a series of simulated earthquake excitations. Twelve identical quarter-scale bridge columns were designed and fabricated in accordance with current AASHTO specifications. A unique setup to expedite the testing process was designed and built in the structural test facility at the National Institute of Standards and Technology (NIST).

The testing was divided into two phases. Phase I testing consisted of benchmark tests to establish the monotonic force-deformation envelope, the energy capacity under standard cyclic loads, and constant amplitude tests to determine the low-cycle fatigue characteristics of the bridge column. Phase II testing was composed of a series of analytically predicted displacement amplitudes representing the bridge response to typical earthquakes. The results of Phase I testing provided information on the fatigue behavior of reinforced concrete and Phase II provided data on the effects of load path on cumulative damage.

A major departure from past practice of laboratory testing that was pursued in this investigation was the development and use of random displacement histories rather than "standard" displacement cycles with increasing amplitudes. Given the complexity of the cumulative damage process and the innumerable parameters affecting the response, every effort was made to keep system variables to a minimum. Consequently, the imposed displacement history was the only variable introduced in the experimental testing.

Test observations indicate two potential failure modes: low cycle fatigue of the longitudinal reinforcing bars; and confinement failure due to rupture of the confining spirals. The former failure mode is associated with relatively large displacement amplitudes in excess of 4% lateral drift while the latter is associated with a larger number of smaller amplitude cycles. Analytical studies indicate that most earthquakes induce few large amplitude cycles pointing to the need for proper confinement to prevent catastrophic failure.

Figure 1 shows a typical displacement history and the resulting shear force versus drift response of the bridge column.

The results of the testing were also used in an analytical study of cumulative damage. A simple fatigue-based model, derived from existing theories in the literature, was used to predict cumulative damage in flexural bridge piers. Critical damage measures, such as stiffness degradation, dissipated hysteretic energy, ductility, and fatigue were evaluated against observed behavior. It was found that none of these damage measures consistently predict observed damage limit states though fatigue-based models demonstrated better reliability.

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Research Activities (Cont'd)

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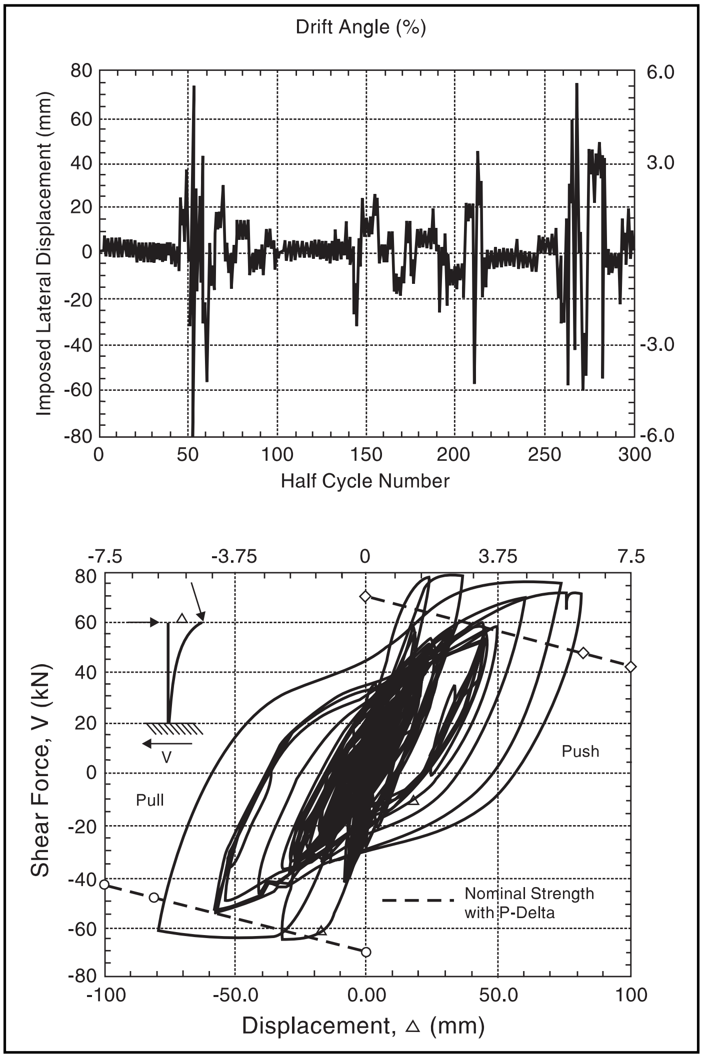

Figure 1: Typical Series of Imposed Displacements and Resulting Column Response

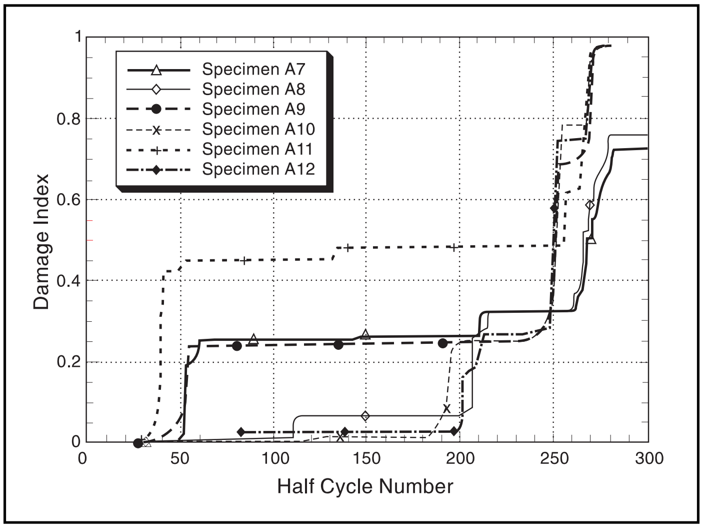

Figure 2: Progressive Damage Predicted by Fatigue-Based Damage Model

Fatigue-life expressions, using a Coffin-Manson rule in combination with Miner's hypothesis, account only for low-cycle fatigue damage of steel. It appears that a model which combines low-cycle fatigue failure in combination with confinement deterioration will yield excellent results. A simple fatigue life relationship was proposed, derived from the original work of Mander and Cheng (1995), based on the experimental data generated from constant-amplitude testing of specimens in Phase I, and was shown to produce improved damage prediction characteristics. The following expression was obtained to define the number of half-cycles to failure:

$$N_{fi} = 2.0^{*} \left\{\frac{Drift}{10.6}\right\}^{3.51} \qquad (1)$$

and the resulting damage, expressed in terms of a damage index D.I., is computed from the following expression:

$$D.\,I. = \Sigma \frac{n_{di}}{N_{fi}} \qquad (2)$$

where n_{di} is the number of half cycles at a particular drift "*di*" obtained from the analysis indicated in step (a), and N_{fi} is the number of half cycles to failure at the same drift "*di*" obtained from Equation (1). Figure 2 shows the predicted damage to all columns tested in Phase II using a damage index based on the above formulation.

It was further observed that the energy-dissipation capacity of members is path-dependent, hence, models of seismic damage that rely only on measures of energy dissipation cannot predict failure if it is not related to ductility. Findings from this study will provide additional input into the development of performance-based design specifications wherein design is linked to damage limit states.

National Representation of Seismic Ground Motion for Highway Facilities

by Ian Friedland and Maurice Power

This article summarizes discussions from a recent FHWA/NCEER workshop conducted through NCEER's Highway Project, task 106-F-5.4.1. More detailed information is available in ***Proceedings of the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highways****, NCEER-97-0010. Comments and questions should be directed to Ian Friedland, NCEER, at (716) 645-3391; email: imf@acsu.buffalo.edu.*

A significant amount of research has been conducted within the FHWA / NCEER Highway Project between 1993 and 1997 on how to adequately portray the national seismic hazard in highway design specifications and guidelines. This work included a review of existing national, state, and regional seismic hazard maps, an evaluation of alternative strategies for the future portrayal of the national seismic hazard, and the development of alternative recommendations for presentation to AASHTO and other highway design and specification authorities. During this time, the USGS published new national seismic ground motion maps in 1996 which appear significantly different than those currently in AASHTO specifications.

In order to ensure that the key issues related to the development of national seismic hazard portrayals were adequately addressed, NCEER organized and conducted the *FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities* on May 29 and 30, 1997, in San Francisco, California. The workshop provided a forum under which more than 50 earth scientists, geotechnical engineers, and structural engineers were brought together to discuss a number of these key issues and develop consensus recommendations with respect to their implementation in new highway facility design specifications (see review of the workshop in the July 1997 issue of the *NCEER Bulletin*, Vol. 11, No. 3).

The ground motion issues that have emerged in recent years as potentially important to highway facilities design and that were considered at the workshop were:

- Issue A: Should new (1996) USGS maps provide a basis for the national seismic hazard portrayal of highway facilities? If so, how should they be implemented in terms of design values?
- Issue B: Should energy or duration be used in a design procedure?
- Issue C: How should site effects be characterized for design?
- Issue D: Should vertical ground motions be specified for design?
- Issue E: Should near-source ground motions be specified for design?
- Issue F: Should spatial variations of ground motions be specified for design?

These issues were considered sequentially at the workshop. For each issue, selected workshop participants prepared papers and made presentations illuminating the issues and proposing a course of action in terms of design criteria and procedures and / or further development. Papers covering the presentations by each speaker are contained in the workshop proceedings (report number NCEER-97-0010, which will be available from NCEER in late fall).

Following the presentations on each issue, the workshop participants as a whole discussed the issues and developed conclusions and consensus recommendations. A final set of recommendations will be presented to AASHTO in the spring of 1998. The following summarizes the key elements in the discussion of each issue and the conclusions and consensus recommendations resulting from the workshop.

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Research Activities (Cont'd)

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Using the New USGS Maps

In 1996, the U.S. Geological Survey (USGS) developed new seismic ground shaking maps for the contiguous United States (maps for Alaska and Hawaii are under development). These maps depict contours of peak ground acceleration (PGA) and spectral accelerations (SA) at 0.2, 0.3, and 1.0 second (for 5% damping) of ground motions on rock for probabilities of exceedance (PE) of 10%, 5%, and 2% in 50 years, corresponding to return periods of approximately 500, 1000, and 2500 years, respectively. These maps for the contiguous United States and separately for California and Nevada are available from and can be viewed or downloaded from the USGS World Wide Web site at

http://geohazards.cr.usgs.gov.

The workshop considered whether the new USGS maps should replace or update the maps currently incorporated in AASHTO specifications, which were developed by the USGS in 1990. The key issue regarding whether the new USGS maps should provide a basis for the national seismic hazard portrayal for highway facilities is the degree to which they provide a scientifically improved representation of seismic ground motion in the United States. Based on an analysis of the process of developing the maps, the inputs to the mapping, and the resulting map values, the workshop concluded that these new maps represent a major step forward in the characterization of national seismic ground motion. The maps are in substantially better agreement with current scientific understanding of seismic sources and ground motion attenuation throughout the United States than are the current AASHTO maps. The workshop therefore concluded that the new USGS maps should provide the basis for a new national seismic hazard portrayal for highway facilities.

The workshop also examined the issue of an appropriate probability level or return period for design ground motions based on the new USGS maps. Analyses were presented showing the effect of probability level or return period on ground motions and comparisons of ground motions from the new USGS maps and the current AASHTO maps. The workshop recommended that for design of highway facilities to prevent collapse, consideration should be given to adopting probability levels for design ground motions that are lower than the 10% probability of exceedance in 50 years that is currently in AASHTO (i.e., ground motion return periods longer than 500 years should be considered). This recommended direction is consistent with proposed revisions to the 1997 NEHRP Provisions for buildings, in which the new USGS maps for a probability of exceedance of 2% in 50 years (an approximate 2500 year return period) have been adopted as a collapse-prevention design basis. (The NEHRP proposal for buildings was described at the workshop and is summarized in the Proceedings.) Figure 1 provides an example of how Maximum Considered Earthquake (MCE) ground motion maps were developed for use in design (see paper by Hamburger and Hunt in Friedland et al., editors, 1997).

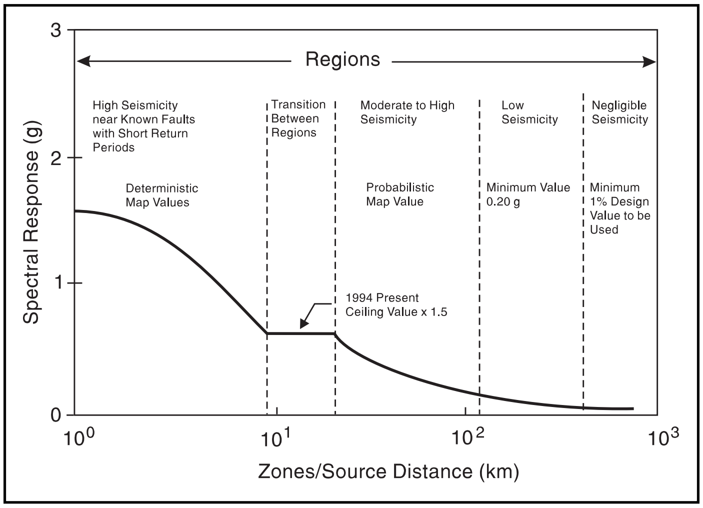

Figure 1: Development of the Maximum Considered Earthquake ground motion map for spectral acceleration of T =1.0, Site Class B

Using Energy or Duration in Design Procedures

At the present time, the energy or duration of ground motions is not explicitly recognized in the design process for bridges or buildings, yet many engineers are of the opinion that the performance of a structure may be importantly affected by these parameters, in addition to the response spectral characteristics of the ground motion. Based on the presentations and discussions at the workshop, the participants concluded that some measure of the energy of ground motions is important to the response of a bridge, but, at present, we do not have an accepted design procedure to account for energy. Research in this area should be continued to develop energy-based design methods that can supplement current elastic response-spectrum-based design methods. The workshop also concluded that energy, rather than duration, is the fundamental parameter affecting structural behavior.

Characterizing Site Effects

At the *Workshop on Site Response During Earthquakes and Seismic Code Provisions*, held in 1992 at the University of Southern California (USC), a revised quantification of site effects on response spectra and revised definitions of site categories was proposed. Subsequently, these revised site factors and site categories were adopted into the 1994 NEHRP Provisions and the 1997 Uniform Building Code (UBC). Since the development of these revised site factors, two significant earthquakes occurred, Northridge in 1994 and Kobe in 1995, which provided substantial additional data for evaluating site effects on ground motions, and research using these data has been conducted.

The site factors and site categories in the current AASHTO specifications are those that were superseded by the USC workshop recommendations for the NEHRP Provisions and the UBC (see Table 1, taken from Dobry et al. in Friedland et al., editors, 1997). The questions for consideration at this workshop were whether the USC workshop recommendations should be utilized in characterizing ground motions for highway facilities design and whether they should be modified to reflect new data and new knowledge since the 1992 workshop. The most significant differences in the USC workshop recommendations and the previous site factors (those currently in AASHTO) are: (1) the revised site factors include separate sets of factors for the short-period and long-period parts of the response spectrum, whereas the previous site factors were only for the long-period part; (2) the revised site factors are dependent on, rather than independent of, intensity of ground shaking, reflecting soil nonlinear response; and (3) the revised site factors are larger (i.e., show a greater soil response amplification) than the previous factors at low levels of shaking, which is important for the lower-seismicity regions in the United States.

The workshop found that the post-Northridge and post-Kobe earthquake research conducted to date generally was supportive of the site factors derived during the 1992 USC workshop, although revisions to these factors might be considered as further research on site effects is completed. The workshop therefore recommended that the factors developed at the USC workshop and adopted by the NEHRP Provisions and the UBC be proposed as part of a new national representation of seismic ground motion for highway facilities design.

Table 1: Site Categories in New Building Codes (NEHRP 1994, UBC 1997)

Soil Profile Type	Description	$\bar{V}_s$ top 100 ft (fps)
S1 A	Hard rock	> 5000
B	Rock	2500 - 5000
S1 and S2 C	Very dense soil/soft rock	1200 - 2500
D	Stiff soil	600 - 1200
S3 and S4 E	Soft soil	< 600
F	Special soils requiring site-specific evaluation	

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Additionally, current AASHTO specifications incorporate a conservatively slow decay of long-period response spectra with increasing period (response spectral accelerations proportional to $1/T^{2/3}$, where T = period, rather than 1/T as is typically seen in ground motions). The workshop recommended that the new higher site factors not be coupled with the conservative long-period response spectral decay currently in AASHTO. Rather, long-period ground motions should be permitted to decay in a more natural fashion, i.e., approximately proportional to 1/T rather than $1/T^{2/3}$.

Specifying Vertical Ground Motions

At present, the AASHTO specifications do not contain explicit requirements to design for vertical accelerations. Ground motion data from many earthquakes in the past 20 years have shown that, in the near-source region, very high short-period vertical spectral accelerations can occur. For near-source moderate- to large-magnitude earthquakes, the rule-of-thumb ratio of two-thirds between vertical and horizontal spectra is a poor descriptor of vertical ground motions. At short periods, the vertical-to-horizontal spectral ratios can substantially exceed unity, whereas at long periods, a ratio of two-thirds may be conservative (see Figure 2 in paper by Foutch in Friedland et al., editors, 1997). The workshop demonstrated that our current understanding and ability to characterize near-source vertical ground motions is good, especially in the western United States where the near-source region is relatively well defined (i.e., near mapped active faults).

The workshop also demonstrated that high vertical accelerations as may be experienced in the near-source region can significantly impact bridge response and design requirements in some cases. On the basis of these findings, it was concluded that vertical ground motions should be considered in bridge design in higher seismic zones for certain types of bridge construction. It was recommended that specific design criteria and procedures be developed for identified bridge types.

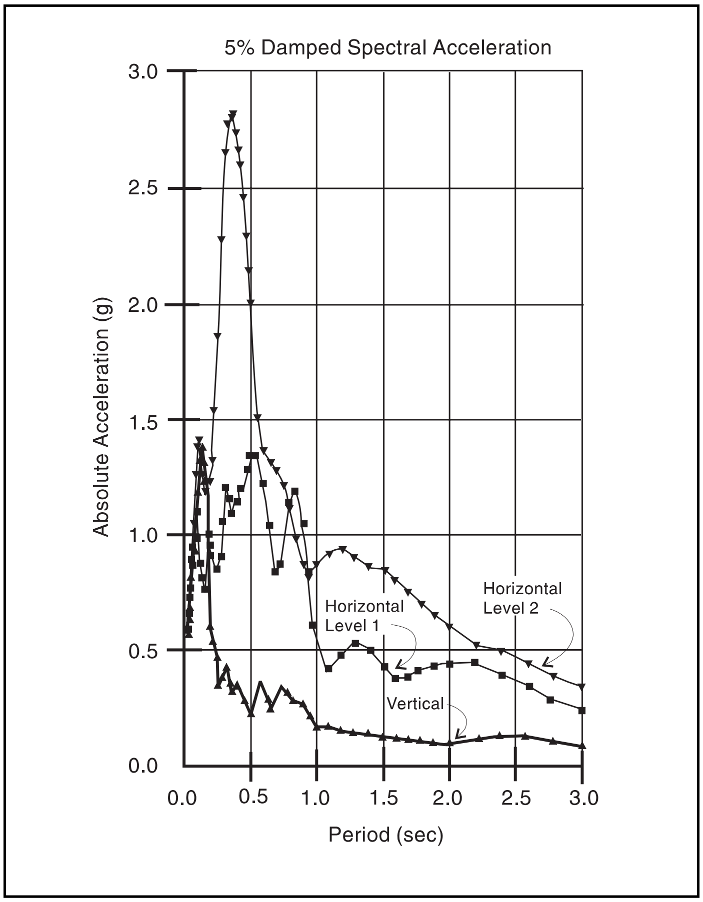

Figure 2: The peak horizontal and vertical acceleration recorded at the Sylmar County Hospital parking lot during the Northridge earthquake indicated that the energy in the vertical component is concentrated in the short period range of 0.1 to 0.2 seconds.

Specifying Near-source Ground Motions

The workshop examined both the characteristics of near-source horizontal ground motions and the effects of near-source ground motions on bridge response. As the distance to an earthquake source decreases, the intensity of ground motions increases, and this increase in ground motion intensity is incorporated in new USGS maps. However, in addition to their higher intensity, near-source ground motions have certain unique characteristics that are not found at greater distances. The most significant characteristic appears to be a large pulse of long-period ground motions when an earthquake rupture propagates toward a site. Furthermore, this pulse is larger in the direction perpendicular to the strike of the fault than in the direction parallel to the strike. This characteristic of near-source ground motions has been observed in many earthquakes, including most recently in the Northridge and Kobe earthquakes. Preliminary analyses of bridge response presented at the workshop indicate that near-source ground motions may impose unusually large displacement demands on bridge structures. The workshop concluded that traditional ground motion characterizations (i.e., response spectra) may not be adequate in describing near-source ground motions, because the pulsive character of these motions may be more damaging than indicated by the response spectra of the motions. The workshop recommended that additional research be carried out to evaluate more fully the effects of near-source ground motions on bridge response and to incorporate these effects in code design procedures. Until adequate procedures are developed, consideration should be given to evaluating bridge response using site-specific analyses with representative near-source acceleration time histories.

Specifying Spatial Variations of Ground Motions

Spatial variations of ground motions along a horizontally-extended structure such as a bridge include (1) spatial incoherency in ground motions due to scattering of the propagating seismic waves by the geologic media as well as spatial variations in wave superposition from seismic waves arriving from an extended earthquake source; (2) wave passage effects, in which non-vertically incident seismic waves arrive at different locations along the structure at different times (time-lag effects); (3) attenuation effects, in which ground motion amplitudes decrease with increasing distance from the earthquake source; and (4) differential site response due to variations in the geologic conditions along the structure (which can include two- and three-dimensional site response effects in basin environments, as well as simple one-dimensional site response effects). For important long-span bridges, procedures are available and have been employed in many cases which take these effects into account in relatively sophisticated site-specific analyses. The issue addressed at the workshop was whether there are classes of structures (e.g., related to bridge span length and other characteristics) for which spatial variations of ground motions may safely be neglected in design or the effects of these variations incorporated using simplified code-type design procedures.

Results of analyses were presented through which the effects of spatial variations of ground motion were systematically examined. Generally, these analyses indicated that in the absence of strong differential site response effects, the response of "ordinary" highway bridges was not greatly affected by spatial variations of ground motion. However, the workshop concluded that we cannot yet adequately define those categories of bridges for which spatial variations of ground motions can be neglected, even for the case of relatively uniform soil conditions along the bridge. Further research is needed to define the importance of spatial variations of ground motions as a function of bridge characteristics and to develop simplified procedures for incorporating the effects of these variations in design.

References

NEHRP, (1994), Recommended Provisions for Seismic Regulations for New Buildings, FEMA 222A/223A, May, Vol. 1 (Provisions) and Vol. 2 (Commentary).

Friedland, I.M., Power, M.S., and Mayes, R.L., editors, (1997), "Proceedings of the FWHA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities," Burlingame, California, May 29-30, 1997, NCEER-97-0010.

UBC, (1997), Uniform Building Code.

Overview of the NCEER/EERC Short Course on Passive Energy Dissipation

by T.T. Soong

"Passive Energy Dissipation for Seismic / Wind Design and Retrofit" is the first short course offered by NCEER under its Professional and Continuing Education (PACE) Program. It is designed primarily for structural engineers and design professionals who seek an in-depth understanding of the working principles of energy dissipation systems. The course provides design procedures for a variety of systems incorporated into new or existing structures for retrofit under wind or seismic load.

The basic function of passive energy dissipation devices, when installed in a structure, is to absorb or consume a portion of the input energy. They reduce the energy dissipation demand on the primary structural members and minimize possible structural damage. While this concept has been studied for quite some time, it is only in recent years that serious efforts have been made to develop the concept of energy dissipation or supplemental damping into a workable technology, and a number of these devices have been installed in structures in the U.S. and elsewhere. This course introduces the basic concepts of passive energy dissipation, and discusses current research, development, design and code-related activities in this exciting and fast-expanding field. At the same time, the fact that this entire technology is still evolving is emphasized. Many challenges remain and significant improvements in both hardware and design procedures will certainly continue for a number of years to come.

The following sections describe the course content. The material is taken from the draft text of an upcoming NCEER monograph titled *Passive Energy Dissipation Systems for Structural Design and Retrofit*, co-authored by M.C. Constantinou, T.T. Soong and G. Dargush. The monograph is currently being developed by NCEER and will be available later this year.

Passive Energy Dissipation for Seismic/Wind Design and Retrofit

Sponsorship:
NCEER PACE Program in cooperation with EERC of University of California at Berkeley

Duration:
2-1/2 days plus half-day field trip

Technical Coordinators:
Dr. T.T. Soong (NCEER) and Dr. A. Whittaker (EERC)

Instructors:
Dr. I.D. Aiken, Research Engineer, EERC, UC/Berkeley
Dr. F.A. Charney, President, Advanced Structural Concepts, Inc.
Dr. M.C. Constantinou, Professor, University at Buffalo
Dr. G. Dargush, Assistant Professor, University at Buffalo
Dr. J.M. Kelly, Professor, UC/Berkeley
Dr. J.B. Mander, Associate Professor, University at Buffalo
Dr. A.M. Reinhorn, Professor, University at Buffalo
Dr. T.T. Soong, Professor, University at Buffalo
Dr. A. Whittaker, Associate Director, EERC, UC/Berkeley

Locations:
Seattle (September, 1996)
San Francisco (October, 1996)
Los Angeles (February, 1997)
Seoul, Korea (Spring, 1998)
Hong Kong (Spring, 1998)

Basic Principles

A number of innovative technologies are currently available for structural applications in new design and retrofit against wind or earthquakes. In this section, the unique role that passive energy dissipation plays in this application area is delineated and contrasted with other techniques such as seismic isolation and active control.

A performance-based classification of passive energy dissipation systems is employed in the discussion of their basis principles. As shown in Table 1, they are

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Table 1: Passive Energy Dissipation Systems

Classification	**Hysteretic**			**Viscoelastic**			**Compressible Fluid**	**Tuned Systems**	
Principal of Operation	Friction	Yielding metal	Phase transformation of metals	Deformation of viscoelastic solids	Deformation of viscoelastic fluid	Fluid orificing	Fluid orificing and pressurization	Tuned mass damper	Tuned liquid damper
Materials/ Technologies	Metal-to-metal or non-metal contact	Steel, lead	Shape-memory alloys	Viscoelastic polymers	Highly viscous fluids	Fluids/ advanced orifice designs/ fluid sealing	Fluids/ advanced orifice design/high pressure sealing	Mass-spring damper	Vessels, liquid columns
Characteristics	Energy dissipation/ strength enhancement	Energy dissipation/ strength enhancement	Energy dissipation/ strength enhancement	Energy dissipation/ stiffness and damping enhancement	Energy dissipation/ stiffness and damping enhancement	Energy dissipation	Preload, constant restoring force, energy dissipation	Enhancement of damping	Enhancement of damping
Development in U.S.	Devices developed, recently marketed	Devices developed, recently marketed	Some research conducted	Developed and marketed for over 25 years	None	Available since 1925, significant developments for military applications	Available since 1955, significant developments for military applications	Developed and originally applied in U.S.	Some research conducted
Applications in U.S.	Seismic hazard mitigation	Seismic hazard mitigation	None	Wind vibration control, seismic hazard mitigation	Vibration and seismic isolation systems	Seismic hazard mitigation/ elements of seismic isolation systems	Military and industrial/ designs developed for seismic hazard mitigation	Wind vibration control	None
U.S. Industry*	Fluor Daniel and Independent Fabricators	Independent fabricators	None	3M	None	Taylor Devices, Enidine	Taylor Devices	MTS Systems	None
Potential Contributions of Center	Study of longevity/ reliability, design procedures, verification	Design procedures, verification	Large-scale testing, designs for reduced cost	Improved dependency on temperature, testing of new materials	Technology assessment	Development of alternate testing procedures, testing as elements of isolation systems, semi-active development	Development of alternate testing procedures, testing as elements of isolation systems, semi-active development	Multiple tuned mass dampers, development of semi-active and active systems	Large-scale testing, development of active systems

* Companies whose products have found applications in the field

Research Activities (Cont'd)

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classified as hysteretic, viscoelastic and others. Examples of hysteretic systems include devices based on yielding of metals or through sliding friction. Figure 1 shows typical force-displacement loops of hysteretic energy dissipation systems. The simplest models of hysteretic behavior involve algebraic relations between force and displacement. Hence, hysteretic systems are often called displacement-dependent. Viscoelastic energy dissipation systems include devices consisting of viscoelastic solid materials, devices operating on the principle of fluid orificing (e.g., viscous fluid dampers) and devices operating by deformation of viscoelastic fluids. Figure 2 shows force-displacement loops of these devices. Typically, these devices exhibit stiffness and damping which are frequency-dependent. Moreover, the damping force in these devices is proportional to velocity, that is, the behavior is viscous. Accordingly, they are classified as viscoelastic systems.

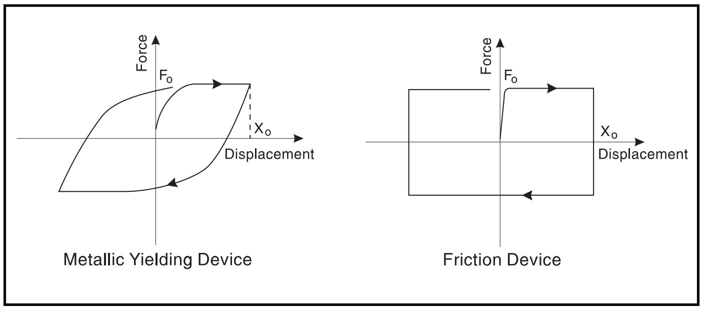

Figure 1: Idealized Force-displacement Loops of Hysteretic Energy Dissipation Devices

Energy dissipation systems which cannot be classified by one of the basic types depicted in Figures 1 and 2 are classified as other systems. Examples are friction-spring devices with re-centering capability and fluid restoring force and damping devices. Figure 3 illustrates the behavior of these devices. While the illustrated loops appear very different from those of Figures 1 and 2, in reality these devices originate from either hysteretic devices (a friction device with a re-centering mechanism) or fluid viscous devices (a pressurized device to develop pre-load and re-centering capability, together with fluid orificing for energy dissipation).

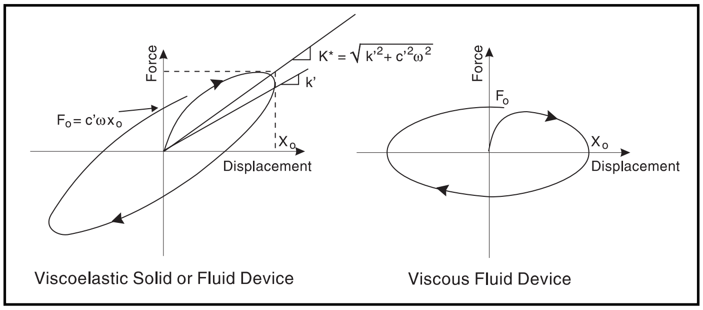

Figure 2: Idealized Force-displacement Loops of Viscoelastic Energy Dissipation Devices

Discussions on basic principles are followed by illustrative examples of application of these systems on a structural frame. Through qualitative arguments, some general conclusions are established for the range of applicability of these systems and for the effects they have on the response of the frame. Subsequently, a treatment of linear viscoelastically damped structures is presented. The lack of nonlinearity in these structures allows for a formal treatment of the problem and prepares the ground for presentation of simplified nonlinear methods of analysis, which are presented next.

Finally, the use of energy dissipating devices as elements of seismic isolation systems and the use of seismic isolation bearings to primarily absorb seismic energy rather than lengthen the period are briefly discussed.

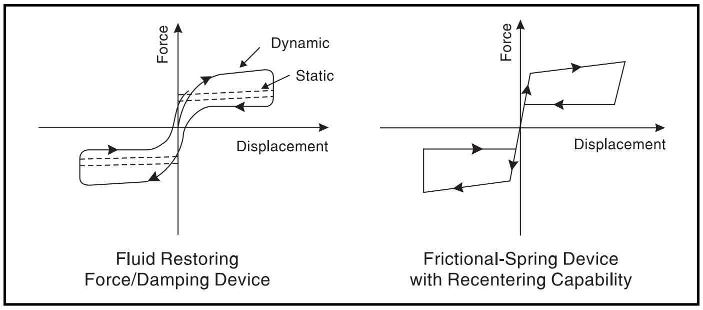

Figure 3: Idealized Force-displacement Loops of Other Energy Dissipating Devices

Mathematical Modeling

Broadly speaking, energy dissipation may be achieved either by the conversion of kinetic energy to heat or by the transferring of energy among vibrating modes. The first mechanism incorporates both hysteretic devices that dissipate energy with no significant rate dependence, and viscoelastic devices that exhibit considerable rate (or frequency) dependence. Included in the former group are devices that operate on principles such as yielding of metals and frictional sliding, while the latter group consists of devices involving deformation of viscoelastic solids or fluids and those employing fluid orificing. As shown in Table 1, a third classification consists of re-centering devices that utilize either a pre-load generated by fluid pressurization or internal springs, or a phase transformation to produce a modified force-displacement response that includes a natural re-centering component. An idealized single-degree-of-freedom structure is shown in Figure 4a with a passive hysteretic, viscoelastic or re-centering device operating in parallel. A macroscopic model defining the stiffness and damping characteristics of the device is needed in order to determine the overall structural response.

The second mechanism mentioned above, pertaining to the transfer of energy between modes, is utilized in dynamic vibration absorbers. In these systems, supplemental oscillators involving mass, stiffness and damping are introduced, as illustrated in Figure 4b. In order to significantly enhance performance, the dynamic characteristics of the supplemental oscillators must be tuned to those of the primary structure. Tuned mass dampers and tuned liquid dampers are included in this category.

Each major type of passive system is examined in some detail in this section. Emphasis is placed on the physical basis for their behavior and on the mathematical model appropriate for characterization of their response. In many cases, models with varying levels of sophistication are provided. For preliminary design and analysis, rather simple approximations are often desirable, while for final detailed design, more precise representations may be required.

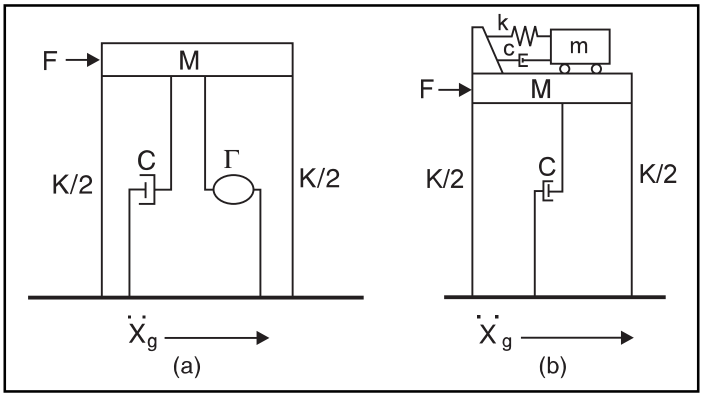

Figure 4: Idealizations for Passively Damped SDOF Structures (M,K,C); (a) with Passive Hysteretic, Viscoelastic or Re-centering Device (Γ) *(b) with Dynamic Vibration Absorber (m,k,c)*

Recent Development and Modern Applications

Advances in terms of research and development of passive energy dissipation devices are presented. Each device is reviewed from the point of view of theoretical and experimental research, analysis of device-added structures, development of design guidelines, and implementation-related considerations. Recent full-scale installations of passive energy dissipation devices in buildings and bridges in North America, which now total approximately 50, are discussed. One of these installations is usually chosen as a detailed case study in each offering of the short course. These sessions also feature demonstrations of computer software used for dynamic analysis and design of device-added structures.

Codes and Regulations

Recent activities in the development of standardized design guidelines, codes and regulations related to structures equipped with passive energy dissipation systems are summarized in this section, which include the following topics.

(Continued on Page 14)

(Continued from Page 13)

Tentative Requirements of SEAONC

In 1993, the Energy Dissipation Working Group of the Base Isolation Subcommittee of the Seismology Committee of the Structural Engineers Association of Northern California (SEAONC) developed a document on seismic design requirements for passive energy dissipation systems. This early document established a terminology for energy dissipation systems similar to the one used in this short course, and prescribed analysis procedures for buildings and testing procedures for devices. Buildings incorporating rate dependent devices may be analyzed by equivalent linear procedures provided that all structural elements remain elastic. For buildings incorporating rate independent devices, nonlinear dynamic analysis is mandated. Moreover, the document promotes the use of dual lateral force resisting systems, consisting of the frame carrying the energy dissipation devices and a supplemental moment frame. The latter must be detailed as a special moment-resisting frame if the analysis predicts that the frame will experience inelastic deformations.

1994 NEHRP Recommended Provisions

The 1994 edition of the *National Earthquake Hazard Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings* contains an Appendix on “Passive Energy Dissipation Systems.” The appendix is loosely based on the SEAONC Tentative Requirements. It requires nonlinear dynamic analysis for all buildings incorporating energy dissipation devices except for the case of linear viscous devices and provided that the fundamental mode damping ratio is not more than 30% of critical. For buildings incorporating linear viscous devices with damping more than 30% of critical, the equivalent lateral force procedure for seismic analysis is permitted.

However, it has since been recognized that this procedure is not appropriate, since it will allow significant reduction in lateral forces due to both inelastic action in the building and viscous damping provided by the energy dissipation system. The Technical Subcommittee 12 of the Building Seismic Safety Council is currently in the process of revising the *NEHRP Recommended Provisions on Passive Energy Dissipation Systems.* Scheduled to be included as a subsection on “Provisions for Passive Energy Dissipation Systems,” these revised provisions will appear in the *1997 NEHRP Recommended Provisions for Seismic Regulations for New Buildings.*

Applied Technology Council Project 33

The Applied Technology Council is in the process of developing *Guidelines and Commentary for the Seismic Rehabilitation of Buildings* for the Building Seismic Safety Council. When completed in 1997, this document will be available as *FEMA 272, NEHRP Guidelines for the Seismic Rehabilitation of Buildings* and *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings.*

Semi-active Control Systems

The concept of semi-active control systems is introduced as a logical extension of passive energy dissipation systems. Semi-active systems generally originate from passive systems which are modified to allow for adjustment of their mechanical properties through the application of a power source. Referring to Figure 4a, the added feature of a semi-active device over a passive one is that the mechanical properties of the device element, Γ, can be adjusted in real time in response to the external load, or to the structural response, or to both. Semi-active systems require nominal amounts of energy to adjust their mechanical properties and, unlike fully active systems, they cannot add energy to the structural systems as no active forces are applied directly to the structure.

The working principles of semi-active systems are illustrated through the consideration of semi-active mass dampers and semi-active fluid dampers. There have been limited structural applications of these devices and several of them are discussed in some detail.

Center Activities

Center News

Interim Deputy Director Appointed

Dr. Tsu-Teh Soong, Samuel Capen Professor of Engineering Science and professor in the Department of Civil, Structural and Environmental Engineering, has been named interim deputy director of the National Center for Earthquake Engineering Research. Dr. Soong was one of NCEER's co-founders, serving on both its original Executive Committee and later on the Research Committee. He replaces Dr. Ian Buckle, who left earlier this year to take an administrative post at the University of Auckland, New Zealand. A national search for a permanent deputy director is underway.

Dr. Soong is a leading researcher in engineering structural dynamics, reliability and control. His research focuses on developing and implementing passive and active control systems for protecting structures against potential damage resulting from earthquakes, strong winds and waves. His research has been applied to structures in the U.S., Japan and China. He is a primary developer of NCEER's short course titled "Passive Energy Dissipation for Seismic / Wind Design and Retrofit" and co-author of an NCEER monograph on this subject (see article on page 10).

In addition to research support from NCEER, Dr. Soong's work has been funded by the National Science Foundation, the U.S. Navy, the U.S. Environmental Protection Agency, the National Institute of Standards and Technology, The 3M Company, IBM Corp., MTS Systems Corp., Takenaka Corp. and Samsung Corp., among others.

Dr. Soong has authored six books and approximately 250 technical publications. He was twice awarded the Humboldt Foundation Senior U.S. Scientist Award.

A faculty member at the University of Buffalo since 1963, Dr. Soong previously held positions at the Jet Propulsion Laboratory at California Institute of Technology and at Purdue University. A graduate of the University of Dayton, he earned master's and doctoral degrees in engineering science from Purdue University.

Honors and Awards

NCEER's Assistant Director Chairs TCLEE Transportation Technical Committee

NCEER Assistant Director for Bridges and Highways Ian M. Friedland has been appointed as chair of the Transportation Committee of the ASCE Technical Council on Lifeline Earthquake Engineering (TCLEE). Ian replaces NCEER affiliate Jim Roberts of Caltrans who led the Committee for the past three years. TCLEE's stated objective is to elevate the state-of-the-art and practice of lifeline earthquake engineering through the participation of its members in the development of guidelines, pre-standards, and standards for seismic design and construction of lifelines; to serve as a primary resource for establishing broad consensus on lifeline seismic issues; to identify and prioritize research needs related to lifeline seismic planning, design, construction, and operation; and to support and conduct programs for education and technology transfer.

The Transportation Committee is charged with studying problems of planning, design, construction, and operation of transportation lifelines, including highways, railroads, airports, and rapid transit, and coordinates with the TCLEE Ports and Harbors Committee to mitigate the effects of earthquakes and develop procedures through which sound design can be achieved for all transportation facilities.

The Transportation Committee is currently looking to add members with expertise in all transportation modes. Anyone interested in joining the Committee should contact Ian Friedland via email at *imf@acsu.buffalo.edu* or fax to (716) 645-3399.

Short Course

Seismic Retrofitting of Highway Bridges

As part of its Professional and Continuing Education (PACE) series, NCEER will offer a short course on the "Seismic Retrofitting of Highway Bridges" in April, 1998 at a location to be determined. This course is based on the Federal Highway Administration (FHWA) guidelines which were updated by NCEER under contract to FHWA. The course will provide a comprehensive overview of the issues of preliminary screening, detailed evaluation, and retrofit measures for highway bridges, with an emphasis on bridges in moderate and low seismic hazard regions. Attendees can expect to learn about the behavior of bridges in earthquakes and methods for improving this performance. Emphasis will be placed on older bridges that are typical of the inventory in the central and eastern U.S.

Specific topics to be discussed include seismic hazard in the central and eastern U.S., seismic performance of bridges, preliminary screening and ranking of bridges, detailed evaluation using both the capacity/demand method and the push-over method, retrofitting strategies for bearings, joints, columns, foundations and soils. Attention will also be given to the use of earthquake protective systems such as seismic isolation and energy dissipators.

This course is intended for design and construction engineers from departments of transportation and consultants in the private sector who have an interest in seismic retrofitting. The length of the course is 2-1/2 days, with an optional field tour tentatively scheduled for the afternoon of the third day. Dr. Ian Buckle, former deputy director of NCEER, is the principal course instructor.

For additional information, watch NCEER's web site at: *http://nceer.eng.buffalo.edu*, or contact Andrea Dargush, phone: (716) 645-3391; fax: (716) 645-3399; email: *dargush@acsu.buffalo.edu*.

Workshop Review

Earthquakes! A Seminar to Explore Earthquakes, Information Resources and Activities for Grades 7-12

by Andrea Dargush

For the second year, NCEER has offered a day-long seminar for local high school teachers to learn more about earthquake lesson options for their classrooms and the informational resources which exist to assist both students and teachers alike. Held Saturday, October 25, 1997 on the University at Buffalo campus, an overall objective of the annual session is to promote discovery methods of learning among pre-college level students.

The seminar consisted of mulitmedia presentations and demonstrations, with a prominent emphasis on accessing earthquake information electronically and adapting information into classroom lessons and projects. Discussions of hands-on activities and individual opportunities for Internet "surfing" concluded the day.

The seminar was organized by Andrea Dargush, NCEER's Assistant Director for Research and Education, and Dorothy Tao, Acting Manager of the Information Service, with additional presentations by Marsha Flett, Carol Kizis, and Michael Kukla, of the Information Service Staff. A revised packet of lessons and exercises for secondary teachers which incorporates lessons presented at the seminar is being completed and will be available from NCEER both in paper and electronic versions. Watch the NCEER web site for additional information or contact Andrea Dargush at (716) 645-3391, or via email at: *dargush@acsu.buffalo.edu*.

Center Resources

NCEER Technical Reports

Four New Reports Reviewed

NCEER technical reports are published to communicate specific research data and project results. Reports are written by NCEER-funded researchers, and provide information on a variety of fields of interest in earthquake engineering. The proceedings from conferences and workshops sponsored by NCEER are also published in this series. To order a report reviewed in this issue, fill out the order form and return to NCEER. To request a complete list of titles and prices, contact NCEER Publications, University at Buffalo, Red Jacket Quadrangle, Box 610025, Buffalo, New York 14261-0025; phone: (716) 645-3391; fax: (716) 645-3399; or email: *nceer@acsu.buffalo.edu*.

NCEER's world wide web site offers a complete list of technical reports and their abstracts. The publications section allows users to search the report list by subject, title, author and keywords. The web site address is *http://nceer.eng.buffalo.edu*.

Cumulative Seismic Damage of Reinforced Concrete Bridge Piers

S.K. Kunnath, A. El-Bahy, A. Taylor and W. Stone, 9/2/97, NCEER-97-0006, 192 pp., $15.00.

This report describes a comprehensive experimental study to investigate cumulative damage in reinforced concrete circular bridge piers subjected to a series of earthquake excitations. Twelve identical quarter-scale bridge columns were tested. They were designed and fabricated in accordance with current AASHTO specifications. Testing was in two phases. Phase I testing consisted of benchmark tests to establish the monotonic force-deformation envelope and the energy capacity under standard cyclic loads; and constant amplitude tests to determine the low-cycle fatigue characteristics of the bridge column. Phase II testing was composed of a series of analytically predicted displacement amplitudes representing the bridge response to typical earthquakes. Test observations indicate two potential failure modes: low cycle fatigue of the longitudinal reinforcing bars; and confinement failure due to rupture of the confining spirals.

An analytical study of cumulative damage was also conducted. A simple fatigue-based model was used to predict cumulative damage in flexural bridge piers. Critical damage measures, such as stiffness degradation, dissipated hysteric energy, ductility, and fatigue were evaluated against observed behavior. It was found that none of these damage measures consistently predict observed damage limit states, although fatigue-based models demonstrated better reliability. It was further observed that the energy-dissipation capacity of members is path-dependent; models of seismic damage that rely only on measures of energy dissipation cannot predict failure if it is not related to ductility. Findings from this study will provide additional input into the development of performance-based design specifications.

Structural Details to Accommodate Seismic Movements of Highway Bridges and Retaining Walls

R.A. Imbsen, R.A. Schamber, E. Thorkildsen, A. Kartoum, B.T. Martin, T.N. Rosser and J.M. Kulicki, 9/3/97, NCEER-97-0007, 154 pp., $15.00.

This report describes detailing for structural movements for bridges and retaining walls for new construction in the western and eastern U.S. Bridge retaining devices such as longitudinal joint restrainers, vertical motion restrainers, shear keys, and integral superstructure to substructure connections are described. Many of these details are traditional methods that have been used in new bridge construction to limit displacements for seismic events. Sacrificial elements, which include abutments and joints, are also described. These types of details have been used in new seismic designs within the last two decades. An introduction to passive energy dissipating devices and isolation bearing systems is provided as well as recommendations for detailing. Both devices are relatively new as a method to limit displacements in bridges within the U.S. In fact, isolation bearing systems have just emerged for new bridge construction within the last few years. The minimum support length requirements are reviewed. The current practice for designing earth retaining systems for seismic displacements is reviewed and some recommendations for detailing are provided. The effects of substructure flexibility on the isolation system are documented. Examples are provided to illustrate the impact of substructure flexibility.

A Method for Earthquake Motion-Damage Relationships with Application to Reinforced Concrete Frames

A. Singhal and A.S. Kiremidjian, 9/10/97, NCEER-97-0008, 244 pp., $20.00.

The research presented in this report provides a general method for developing relationships between earthquake ground motion and damage. The motion-damage relationships were presented as fragility curves and damage probability matrices. The major components of the methodology consist of: (a) characterization of the potential ground motions; (b) characterization of the nonlinear response of the structure when subjected to extreme dynamic loads; (c) application of the methodology to reinforced concrete frames; (d) sensitivity studies for different structural attributes; and (e) development of a Bayesian technique to update the motion-damage relationships.

Seismic Analysis and Design of Bridge Abutments Considering Sliding and Rotation

K. Fishman and R. Richards, Jr., 9/15/97, NCEER-97-0009, 88 pp., $10.00.

Current displacement-based seismic design of gravity retaining walls utilizes a sliding block idealization, and considers only a translation mode of deformation. However, recent studies demonstrate the possibility of seismic loss of bearing capacity and subsequent rotation or mixed mode of deformation. It has previously been proposed that this more complex scenario be described with coupled equations of motion cast in terms of relative acceleration between the retaining wall, and the foundation soil. Here, the authors update and extend the coupled equations of motions that appear in the literature. A newly developed fundamental theory on seismic bearing capacity of soils was used to compute the seismic resistance of bridge abutments and the resisting moment offered by the foundation soil. Also, the equations presented have been extended to consider the case of bridge abutments and load transfer from the bridge decks. Algorithms for predicting permanent deformations were applied to a number of test cases that were modeled in the laboratory. Model bridge abutments were constructed within a seismic testing chamber, and seismic loading was applied to the models via a shaking table. Compared to previous studies described in the literature, the models were unique in the sense that they were not constrained to a particular mode of failure. Failure was possible by sliding, tilting or a combination of both. The mode of failure could be accurately predicted and depended on model parameters and properties of the backfill and foundation soil. Comparisons between observed and computed model responses serve to verify the ability of the proposed algorithms to predict sliding, tilting or mixed modes of deformation. Displacement-based seismic design is now possible for all modes of wall movement and not just translation.

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New Publications

ATC-20-3 and ATC-40 Reports Available

The ATC-20-3 report, **Case Studies in Rapid Post-earthquake Safety Evaluation of Buildings**, illustrates 53 case studies using the ATC-20 rapid evaluation procedure, including 21 from the 1989 Loma Prieta earthquake, 12 from the 1994 Northridge event, and 20 from other events. Rapid evaluation is the first, and many times, the only, safety evaluation performed. Each case study is illustrated with photos and describes how a building was inspected and evaluated for safety, and includes a completed safety assessment form and placard. The cost is $48.00.

The ATC-40 report, **Seismic Evaluation and Retrofit of Concrete Buildings**, is a two-volume, 612-page report which provides a recommended methodology for the seismic evaluation and retrofit of older concrete buildings. The document provides information on emerging techniques applicable to most building types, specifically focusing on concrete frame buildings constructed from the 1940s to the mid-1970s, and on concrete frame buildings with concrete walls constructed from the early 1900s to the mid-1970s. The cost is $65.00 for this two-volume set.

Copies of these reports may be obtained from: Applied Technology Council, 555 Twin Dolphin Drive, Suite 550, Redwood City, California 94065, phone: (415) 595-1542; fax: (415) 593-2320; email: *atc@council.org*.

Passive Energy Dissipation Systems in Structural Engineering

Passive Energy Dissipation Systems in Structural Engineering provides a unified treatment for passive energy dissipation systems. Written by T.T. Soong and G.F. Dargush of the University at Buffalo, the 450 page book is organized to address a wide range of behavior characteristics associated with passive energy dissipation devices, ranging from basic principles to implementation issues and design. The price of the book is £60.00 (about $100.00 U.S.). For order information, contact Tina Moore, John Wiley & Sons Ltd., Baffins Lane, Chichester, West Sussex, PO19 1UD, UK; phone: +44 (0) 1243-770102; fax: +44 (0) 1243-775878.

The Northridge Earthquake of January 17,1994: Report of Data Collection and Analysis, Part B: Analysis and Trends

The Northridge Earthquake of January 17, 1994: Report of Data Collection and Analysis, Part B: Analysis and Trends, is the second publication resulting from a joint effort between the California Governor's Office of Emergency Services and EQE to quantify and analyze information on economic and social losses caused by the Northridge earthquake. The emphasis is on key lessons learned in the administration of several important assistance programs, including individual assistance and sheltering. To obtain copies, send a check or money order to: EQE International, Inc., Attention: Ms. Lisa Saunders, Lakeshore Towers, 18101 Von Karman Ave., Suite 400, Irvine CA 92612-1032, phone: (714) 833-3303; fax: (714) 833-3391. The cost is $48.00.

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email: *nceer@acsu.buffalo.edu*
World Wide Web site*: http://nceer.eng.buffalo.edu*

Editor: Jane Stoyle
Illustration and Photography: Hector Velasco
Production and Mailing List: Jennifer Caruana

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Contributors:

A. Dargush, NCEER
A. El-Bahy, University of Central Florida
I.M.Friedland, NCEER
S.K. Kunnath, University of Central Florida
M. Power, Geomatrix Consultants, Inc.
T.T. Soong, University at Buffalo
D. Tao, NCEER Information Service

New Agreement Focuses on Reducing Property Loss from Earthquakes

Better ways to protect people and property from earthquakes will be the focus of a public-private partnership that has been formed by the Insurance Institute for Property Loss Reduction (IIPLR) and the U.S. Geological Survey. Under the new agreement, the IIPLR and the USGS will work together to improve earthquake loss computer modeling, develop earthquake education programs and sponsor research projects.

IIPLR is a Boston-based organization created by the property-casualty insurance industry to reduce deaths, injuries, suffering, property damage and economic loss from natural disasters. For more information, contact Kathleen Gohn, U.S. Geological Survey, phone: (703) 648-4732.

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CENTER FOR
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State University of New York at Buffalo
Red Jacket Quadrangle
Box 610025
Buffalo, NY 14261-0025