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Economic Impacts of a Midwestern Earthquake

by Hal Cochrane

This article presents research conducted to date on the development of models to forecast the economic impacts of earthquakes. Comments and questions should be directed to Hal Cochrane, Colorado State University, at (970) 491-6493; email: hcochrane@vines.colostate.edu.

Introduction

The economic repercussions of earthquakes are often misunderstood and misrepresented. Much of what we think we know about post-disaster recovery is derived from case studies and computer simulations, both of which produce conclusions which should be viewed with a healthy dose of skepticism.

This brief summary begins by defining both real and financial indirect economic losses. Several important generalizations about regional economies are employed to explain why post-disaster recovery is a product of a unique combination of outside assistance and the preexisting state of the economy. The paper then assesses the indirect losses from a hypothetical large Midwestern earthquake, examines financial ripples and systemic losses, and evaluates claims about the vulnerability of the national insurance and financial markets.

Direct vs. Indirect Loss

Indirect loss is any loss other than direct loss. This seems tautological, however, it is important to begin with the obvious. Direct loss is a loss linked **directly** to an earthquake. It includes all damages, plus employment losses due directly to the closure of the damaged facility. Indirect losses/gains are anything else. Direct losses can produce dislocations in factories or commercial ventures (real ripple effects), banking, which causes uncertainty and a subsequent tightening of overall credit conditions (bank systemic risk), and insurance, thereby limiting coverage and triggering subsequent economic dislocations (insurance systemic risk).

Real ripple effects stem from supply shortages or sudden reductions in demand. The relative size of the ripple hinges on the geographic area of focus, and the time frame under scrutiny. Losses can be displaced both geographically and temporally. As will be shown in the following discussion, ripples must be negative for the nation, but can, with the receipt of outside assistance, prove positive for the impacted region.

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Research Activities

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Generalizations About Regional and National Indirect Losses

This simple presentation draws upon sound economic principles to portray the full range of possible outcomes in the post-disaster period. All losses, both direct and indirect, are scaled from 0 to 1, the scaling representing the percentage of the activity that is lost.

Figure 1 maps all combinations of direct and indirect loss for a region. The upper part of the diagram shows a ray from zero reflecting the income gains which occur as an unconstrained region rebuilds (100 percent financed by outside sources, i.e., insurance and federal aid). Economists will recognize this uppermost part of the envelope as simply the amount of reconstruction spending times the income multi-

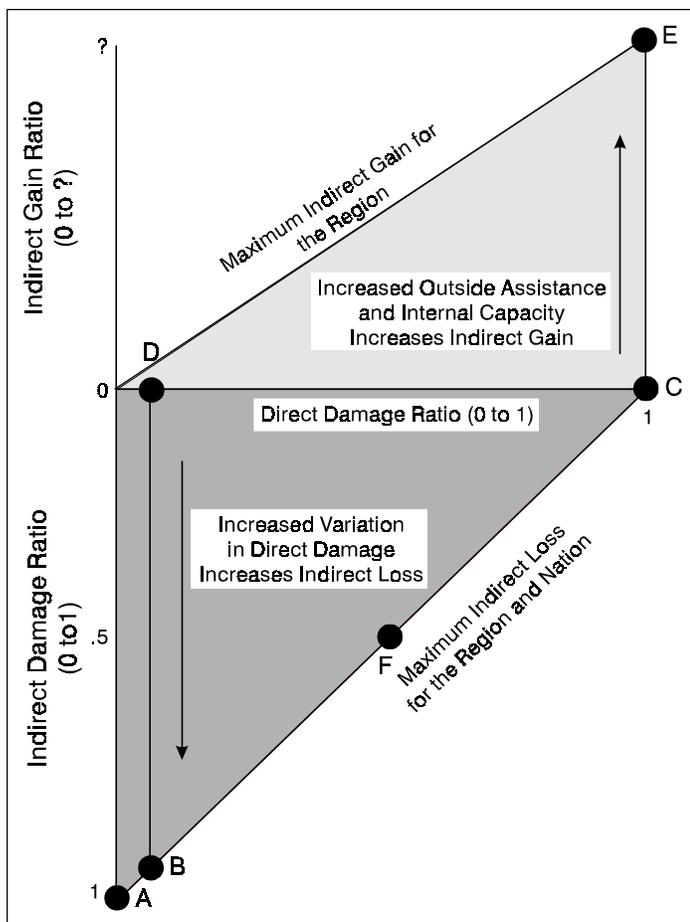


Figure 1: Relationship Between Direct and Indirect Damages and Gains: Regional Perspective

plier for construction. At the extreme, sufficient alternate supplies and markets void any bottlenecks. This is the best the impacted region can hope for. As more of the burden of financing reconstruction is shifted to the region's victims, the net positive effect of spending diminishes, and the ray rotates toward zero indirect gain. At the extreme, when all costs are borne internally, the gains from rebuilding are offset by reduced spending later on as households pay off disaster-related debt. This type of analysis is based on traditional input-output techniques and is all too familiar to regional economists.

The lower half of the diagram is not as simple to understand, at least initially. It reflects an economy with bottlenecks; the closer to zero, the less constraining these bottlenecks are. As in the explanation about indirect gains, the extremes are readily interpreted. Line segment A-C traces the outer edge of the loss envelope. Point B, the uppermost (where upper means the most negative) level of indirect loss, results from a maximum shock to the smallest sector, when no means of mitigating supply and demand shortages present themselves. At this point, the economy implodes to the level of output dictated by the constraining sector. Indirect loss can be a multiple of direct loss at B. Such an event is most likely when critical lifelines, such as power and water are lost. One might think of B as the terrorist's target of choice; the smallest amount of direct damage produces the greatest amount of economic disruption.

Point C on the indirect loss frontier shows no indirect loss when direct loss is total (100 percent). If all is lost then no forward or backward linked losses are possible. Line segment D-B shows the influence of (1) an increased variance in the pattern of loss (zero variance at D and maximum at B); and (2) reduced flexibility in the region's ability to mitigate shortages.

The line segment D-C shows the effect of a uniform damage pattern, which causes the economy to shrink proportionately. This occurs when all sectors are damaged proportionately, in which case forward and backwardly linked losses disappear. In this case, the economy remains balanced regardless of the amount of damage observed.

From a national accounting stance, indirect losses can be measured by deriving regional indirect impacts, adjusted for the liability the federal government incurs in providing disaster relief, and for offsetting increases in outputs elsewhere.

New Madrid Earthquake and the Memphis Economy

The following simple example is provided as an illustration of how constraints amplify indirect losses. Suppose that the Memphis economy is fully constrained, and there are no means for circumventing forward or backward linked losses. No excess capacity exists within the disaster stricken area, and trade with other regions cannot provide the needed supplies or markets. Something like this might result from the loss of high voltage transmissions towers, or a vital natural gas pipeline. Assume that only the region's sources of power, its lifelines, are damaged (30 percent destroyed). In such a situation, the output of transportation services, the sector which includes pipeline services, declines by 30 percent.

Table 1 demonstrates a solution to the problem based on the NIBS HAZUS indirect loss model. Since no adjustments were permitted in this example, the direct loss of lifeline services causes all sector outputs to decline by 30 percent. Indirect loss in such a situation is several times greater than direct loss.

Table 1: Losses Due to the Effect of a Pipeline Shock

Performance Measure	Direct	Indirect	Ratio
Output	-4.12%	-25.25%	6.13
Household Payments	-3.76%	-25.58%	6.80
Employment	-0.77%	-26.79%	34.79

In this simple example of a highly constrained economy, the 30 percent shock to transportation, produces 4.12, 3.76, and .77 percent change in *direct* output, income and employment, respectively. Because of the constraints assumed, **indirect** income and output losses are approximately six times the direct loss. Indirect employment losses are 35 times the direct employment effects.

Wider Regional and National Economic Consequences

The wider regional effects are easily modeled by tracing sector disruptions to import and export changes. National impacts are derived by reducing government spending by the amount of aid provided to the disaster stricken area. Table 2 provides *(Continued on Page 4)*

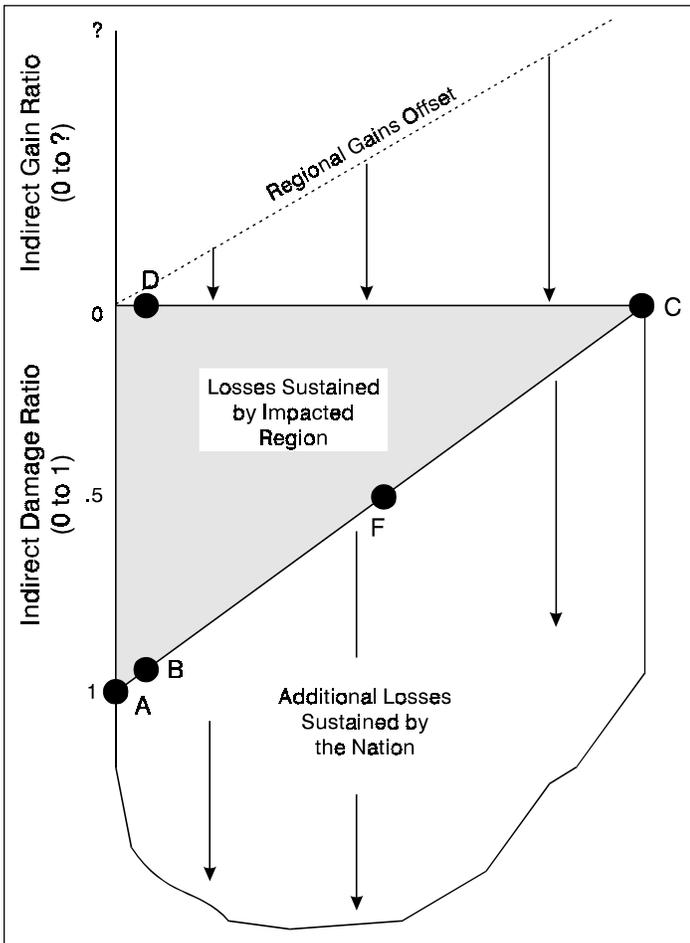


Figure 2: Relationship Between Direct and Indirect Damages and Gains: A National Perspective

The positive effects outside aid produces for the region are to some degree negated by the fiscal drag produced by debt financed federal relief. Figure 2 shows how the generalized loss envelope changes to reflect a national accounting stance. First, direct damage and subsequent indirect loss is transmitted to other regions via altered trading patterns (imports and exports). If the region produces critical materials for which ready substitutes are unavailable, then local indirect losses can spill over to affect the national economy. Hence, it is possible for indirect loss to exceed that sustained by the region alone. Second, the national economy is impacted in that external aid has to be financed. As a result, indirect gains disappear; the costs incurred outside the region negate local gains. So from the vantage point of the nation as a whole *indirect loss must exist*. Indirect gains are an illusion, a byproduct of focusing only on the stricken region.

Research Activities (Cont'd)

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Table 2: Distribution of Losses and Gains

Impacted Areas	Income Loss (-) or Gain (+) (\$ billions)	Computation
Other regions	8.67	Change in imports due to reconstruction.
Impacted region	14.32	Net effect of bottleneck effects and rebuilding expenditures. All outside assistance assumed.
Regional net gains	22.99	The sum effect on the local impacted area and the surrounding region.
National net gains	-2.57	The net effect on the region less the negative effect on the nation due to a reduction in government spending elsewhere.

an illustrative computation based on a hypothetical \$50 billion earthquake, where rebuilding is fully financed by outside sources. The results show that rebuilding stimulates not only the immediately impacted region but surrounding areas (through imports) as well. So, overall the wider region enjoys a \$22.99 billion gain. However, the implied reconstruction subsidy leaves the federal government with a budget shortfall which is assumed to be resolved by cutting spending elsewhere. As a result, incomes around the nation fall by more than the region gains, resulting in an overall reduction in income of \$2.57 billion.

So, what may appear to be a windfall gain for the region proves to be a wash or, in this case, an overall loss for the nation.

Dynamics of Loss and Gain

The solutions just presented are static, that is, they reflect an adjustment process which is presumed to last a fixed period of time, typically a year. Such a portrayal, although useful for some events, may produce misleading results for others, particularly for sizable events such as the Kobe earthquake, where dislocations are prolonged and the burden of reconstruction falls primarily on the victim. In such instances, time plays an important role in determining the ultimate costs

of an event. The severity of bottlenecks vary over the recovery period, and the financial burden indebtedness imposes on survivors lingers long past the event.

Financial Ripples

Much has been written about the fragility of the insurance industry and the potential for large systemic losses resulting from a sudden reduction in surplus. The industry's position regarding financial ripple effects is that a catastrophic earthquake will deplete the insurance industry's surplus. Surviving firms will be forced to ration coverage by: (1) restricting availability and (2) raising premiums. Without coverage, firms not suffering direct damage will be forced to shut down and substantial national indirect economic loss will result.

The evidence available thus far does not support the contention that surplus shocks produce general rationing and escalating premiums (aside from region specific adjustments motivated by factors other than supply considerations). Arguments that disasters, such as Andrew and Northridge, would drain industry reserves, forcing them to curtail other product lines, simply have not materialized. Premiums have not changed appreciably for property and casualty coverage in general (as opposed to earthquake and wind). It appears that supply restrictions are restricted to those risks which the industry feels are uninsurable. Their other lines do not appear to have suffered.

"Despite the massive losses caused by the California quake, rates for most lines of coverage remained flat throughout the year. Only some accounts with coastal properties or earthquake exposures experience significantly higher rates accompanied by shrinking capacity." (Business Insurance, December 26, 1994, p. 4).

It is highly likely that even if gaps in coverage were to emerge, they may be filled by alternate financial arrangements. Additional capacity offered by a maturing foreign insurance industry could help fill the void. So too, a more integrated and concentrated domestic financial sector is likely to weather surplus shocks more efficiently and smoothly than the current fragmented system. What is clear here is that predictions about the fallout from future earthquakes should not be grounded in outdated institutional arrangements.

From the little that can be gleaned from the literature, it is not at all clear that post-disaster financial repercussions will induce measurable real indirect loss. The insurance industry's vulnerability to the most recent string of catastrophes is debatable. The links between insurance and macroeconomic performance have not been credibly demonstrated. Lastly, financial institutions are in the throws of a revolution, one which is likely to cause us to rethink what we thought we already knew.

Summary

A differing set of pre-disaster conditions, along with a decentralized program of disaster relief without the involvement of the insurance industry, would have produced a dramatically different set of outcomes, where the region's economy might have deteriorated rather than turned sharply upward. The most important conclusion that can be drawn from this work on indirect loss is that it is difficult to generalize from any single event; real economic dislocations are a product of a complex set of forces. However, if forced to stand on a statement, it would be that the most important aspect of recovery is outside assistance. This is true for both the private and public sectors. Scenarios which others have painted regarding the national economic consequences of a string of catastrophic disasters should be viewed with a dose of skepticism. Financial markets are unlikely to collapse, regional bank failures will not produce contagion effects, and it seems unlikely that the economy will sustain sizable indirect losses if insurance has to be rationed. The word *if* is underscored in that recent events have not produced rationing. Lastly, trends in the financial sector to agglomerate and offer a full range of services is likely to invalidate much of what we thought we knew about the insurance industry and its response to natural disasters.

References

- Boisvert, R., (1992), "Indirect Economic Consequences of a Catastrophic Earthquake," Chapter 7, *Direct and Indirect Economic Losses from Lifeline Damage*, Development Technologies Inc. under FEMA Contract EMW-90-3598.
- Brookshire, D., and McKee, M., (1992), "Indirect Economic Consequences of a Catastrophic Earthquake," Chapter 8, *Indirect Loss Measurement and Computable Equilibrium Model*, Development Technologies Inc. under FEMA Contract EMW-90-3598.
- Development Technologies, Inc., (1992), "Indirect Economic Consequences of a Catastrophic Earthquake," Development Technologies Inc. under FEMA Contract EMW-90-3598.
- Doherty, N., Kleffner, A.E. and Kunreuther, H., (1991), "The Impact of a Catastrophic Earthquake on Insurance Markets," Philadelphia, Pennsylvania: University of Pennsylvania, Wharton School, Center for Risk and Decision Process.
- Ellson, R.W., Milliman, J.W. and Roberts, R.B., (1984), "Measuring the Regional Economic Effects of Earthquakes and Earthquake Predictions," *Journal of Regional Science*, 24 (4):559-79.
- Friesma, P., Caporaso, J., Goldstein, G., Lineberry, R., and McClearly, R., (1979), "Aftermath: Communities and Natural Disasters." Beverly Hills: Sage Publications.
- National Research Council, (1992), "The Economic Consequences of a Catastrophic Earthquake," Washington, D. C.: National Academy Press.
- Rose A., Benavides, J., Chang, S., Szczesniak, P. and Lim, D., (1995), "The Regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions," 42nd North American Meeting of the Regional Science Association Meeting International, Cincinnati, November 10.
- Roberts, R. Blaine, Milliman, Jerome W. and Ellson, Richard W., (1982), "Earthquakes and Earthquake Predictions: Simulating Their Economic Effects," Technical Report prepared for National Science Foundation under Grant PRF 80-19826.
- Wright, James D. et al., (1979), "After the Clean-up: Long-Range Effects of Natural Disasters," Beverly Hills: Sage Publications.
- Yezer, A. M., (1990), "Measuring the Effects of Catastrophic Earthquakes on Different Regions of the Country," *Proceedings of a Forum on the Economic Consequences of a Catastrophic Earthquake*, Washington, D. C.: National Academy Press.

Research Activities (Cont'd)

Performance-Based Specifications for the Seismic Design, Retrofit and Repair of RC Bridge Columns

by Andrew W. Taylor, William C. Stone and Sashi K. Kunnath

This article presents research resulting from NCEER's Highway Project, task 106-E-5.3. The article is taken from a task technical paper submitted for inclusion in an annual report to the Federal Highway Administration summarizing Research Year 3 of the Seismic Vulnerability of Existing Highway Construction project. Comments and questions should be directed to Andrew Taylor, National Institute of Standards and Technology, at (301) 975-6078.

Background

The objective of this project task is to develop performance-based criteria for the seismic design, retrofit, and repair of reinforced concrete bridge columns. Phase 1 of this task focused on the experimental behavior of typical California Department of Transportation (Caltrans) circular columns subjected to fatigue and random loading. The objectives of the current phase are to use the experimental data obtained in Phase 1 to evaluate and calibrate existing analytical damage models for reinforced concrete bridge columns, derive improved damage models, and develop methods using these damage models in practical design applications.

Research Approach

In earthquake engineering studies of reinforced concrete bridge columns, laboratory test specimens have traditionally been loaded with a controlled, cyclic lateral displacement pattern with increasing amplitudes. However, in actual earthquakes, bridge columns are exposed to random cyclic lateral loading patterns, which are much different from the typical laboratory loading patterns. Current American Association of State Highway and Transportation Officials (AASHTO) and Caltrans seismic design provisions are based almost entirely on tests in which traditional, controlled cyclic loading patterns at increasing levels of ductility have been applied. The differences in the effects of these two types of loading — controlled, cyclic lateral loads, and random earthquake type loads — have never been explored systematically. In this study, both types of loading were applied to a series of circular, cantilever flexural columns. Additionally, some specimens were subjected to constant-amplitude cycling to derive fatigue relationships for seismically-detailed columns.

The research is being conducted in two phases: Phase 1, now completed, consisted of monotonic, cyclic, constant-amplitude and random load tests on twelve quarter-scale circular bridge columns; and Phase 2, still in progress, is concerned with the utilization of the experimental results of the previous phase to develop damage-based seismic design guidelines. Several existing damage models are applied to observed data from the laboratory tests to verify their potential in damage prediction. A new fatigue relationship for seismically detailed flexural columns is being developed for use in performance-based design of bridge columns.

Summary of Phase 1 Tasks

The test program was designed to keep material, geometric and section variables to a minimum. Only flexural failure modes were considered in this study. Specimen and equivalent prototype details are listed in Table 1. A unique test

Table 1: Details of Prototype and Model

Item	Prototype	Model	Remarks
Long. Steel	24 # 11	21 # 3	$\rho = 2\%$
Spirals	# 5	wire = 4.04 mm dia.	
Spiral Pitch	76 mm	19 mm	
Spiral Yield Strength	414 mPa	379-448 mPa	
Column Diameter	1219 mm	305 mm	Scale 1:4
Column Length	5486 mm	1372 mm	"
Cover	51 mm	13 mm	"
Embedment Length	Tension = 1359 mm Comp. = 711 mm	Tension = 330 mm Comp. = 178 mm	Specimen Embedment = 864 mm
Axial Load	3218 kN	201 kN	0.1 f'c Ag
Lateral Load Capacity	1446 kN	90 kN	Vp = Mp/L
Spacing of Long. Steel	102 mm	31 mm	

facility was designed to expedite the testing process. Removable end-blocks which were anchored to the specimen base through post-tensioned bolts were used as shown in Figure 1. In keeping with the main objectives of the study, the primary variables considered were the amplitude, sequence and type of loading pattern. Specimens were labeled A1 through A12. Specimen A1 was loaded monotonically and unidirectionally up to failure; specimen A2 was subjected to a standard quasi-static cyclic load; Specimens A3 - A6 were subjected to constant amplitude cycles of 2.0, 3.0, 4.0 and 5.0 times the yield displacement, respectively.

Random displacement histories used on specimens A7 - A12 were developed from separate analytical simulation studies using IDARC (Kunnath et al., 1992). A summary of the imposed displacement histories is presented in Table 2.

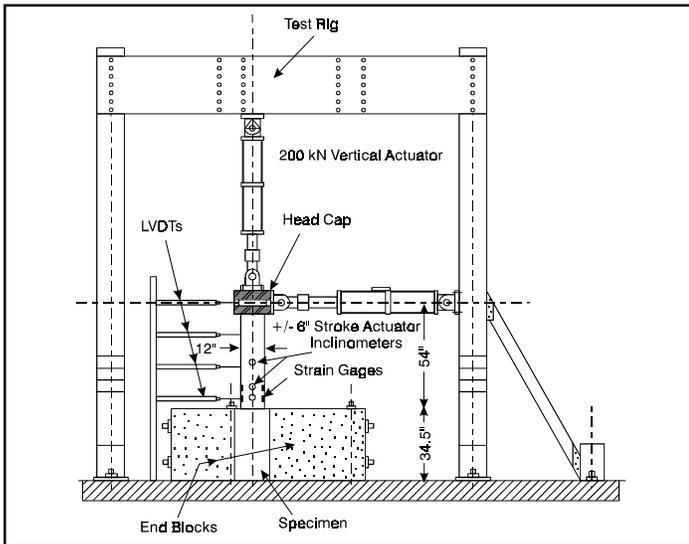


Figure 1: Test Setup

Summary of Phase 2 Tasks

The data generated in Phase 1 was used in a damage evaluation study to identify potential models for use in developing a damage-based design criteria. Four different damage models characterizing different damage measures were selected from the literature for detailed evaluation. The first model selected for evaluation is a modified form of the system softening index (Lybas and Sozen, 1977). This is representative of damage models that consider only a single structural parameter to quantify damage. The change in structural stiffness is associated with system degradation which alters the fundamental period of the system. An additional advantage of this model is that it can be monitored in actual structures. In the present study, the following normalized expression is used to quantify damage:

$$D = \frac{k_m - k_o}{k_f - k_o} \quad (1)$$

where k_m is the stiffness of the structure at the maximum induced displacement, k_f is the pre-established stiffness at failure of the system (typically under monotonic loads), and k_o is the initial stiffness prior to loading.

The second model considered in the evaluation is the Krazig model (Krazig, 1987), since it incorporates only energy-related terms in its formulation. In developing his model, Krazig defines a primary half cycle (PHC) as the energy contained in the half cycle at the maximum deformation point. Additional cycles with displacement amplitudes less than the peak deformation are accumulated as follower half cycles (FHC). Positive and negative deformations are treated separately. Accumulated damage for the positive portions of the response is defined as:

$$D^+ = \frac{\sum E_{p,i}^+ + \sum E_i^+}{E_f^i + \sum E_i^+} \quad (2)$$

where $E_{p,i}^+$ is the energy in a PHC, E_i^+ is the energy in an FHC and E_f^i is the energy absorbed in a monotonic test to failure. A similar expression is computed for negative deformations, and the two quantities are normalized as follows:

$$D = D^+ + D^- - D^+ D^- \quad (3)$$

The inclusion of the follower cycles in the numerator and denominator of equation (2) suggest that their contribution to damage is small, or less significant than deformations that extend the response envelope.

The next model considered in the study is the Park-Ang model (Park and Ang, 1985). This model represents a hybrid model, and was included in the evaluation partly because of its ease in implementation and partly because it is one of the most widely used damage models today. The model is used in its original form as follows:

$$D = \frac{\delta_m}{\delta_f} + \beta \frac{E_T}{F_y \delta_f} \quad (4)$$

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Table 2: Summary of Displacement Histories Used in Testing

Specimen Label	Load Description	Remarks
A1	Monotonic Load	
A2	Standard Cyclic Load	3 cycles at $\pm 1, 1.5, 2, 3, 4, 5,$ and $6 \Delta y$ with an intermediate small amplitude cycle at $\pm 0.5 \Delta y$ between each increase in amplitude
A3	Quasi-Fatigue	Constant amplitude cycling at $\pm 2.0 \Delta y$
A4	Quasi-Fatigue	Constant amplitude cycling at $\pm 3.0 \Delta y$
A5	Quasi-Fatigue	Constant amplitude cycling at $\pm 4.0 \Delta y$
A6	Quasi-Fatigue	Constant amplitude cycling at $\pm 5.0 \Delta y$
A7	Random Loading	Loma Prieta, Presidio (1989) @ 1.2g + Imperial Valley, Superstition Mt. (1979) @ 0.34 g + San Fernando, 2011 Zonal Ave. (1971) @ 0.1 g + San Fernando, 455 S Figueroa St. (1971) @ 0.54g to represent damaging event + two minor events + severe event
A8	Random Loading	Imperial Valley, Superstition Mt (1979) @ 0.34 g + San Fernando, 2011 Zonal Ave. (1971) @ 0.1 g + Loma Prieta, Presidio (1989) @ 1.2g + San Fernando, 455 S Figueroa St. (1971) @ 0.54g to represent two minor events and two major events, respectively
A9	Random Loading	San Fernando, Orion Blvd.(1971) @ 1.43 g + San Fernando, 2011 Zonal Ave. (1971) @ 0.1 g + El Centro (1940) @ 0.35 g + San Fernando, 455 S Figueroa St (1971) @ 0.15 g + San Fernando, Orion Blvd.(1971) @ 1.43 g to represent a damaging event, an after-shock, a moderate event, a minor event and a severe event.
A10	Random Loading	San Fernando, 2011 Zonal Ave. (1971) @ 0.1 g + El Centro (1940) @ 0.35 g + San Fernando, 455 S. Figueroa St (1971) @ 0.15 g + San Fernando, Orion Blvd.(1971) @ 1.43 g + San Fernando, Orion Blvd. (1971) @ 1.43 g to represent two minor events and a moderate event, followed by two severe events
A11	Random Loading	Northridge, VA Hospital (1994) @ 0.42 g + Northridge, Griffith (1994) @ 0.26 g + Taft (1952) @ 0.36 g + Mexico City SCT (1985) @ 0.17 g to represent a major event, two moderate events and a severe event
A12	Random Loading	Northridge, Griffith (1994) @ 0.26 g + Taft (1952) @ 0.36 g + Mexico City SCT (1985) @ 0.17 g Northridge, VA Hospital (1994) @ 0.42 g to represent two moderate and two severe events

Note: The terms minor, moderate and severe events are used to qualify the inelastic demands imposed by the earthquake on the bridge column and is not to be inferred as the energy content of the earthquake.

The constant β was identified directly from the standard cyclic test conducted on Specimen A2.

The final model selected for investigation was derived from principles of low-cycle fatigue. The fatigue behavior of the longitudinal steel under reversed cyclic loading is formulated in terms of the Coffin-Manson (Manson, 1953) equation:

$$\epsilon_p = \epsilon_f' (2N_f)^c \quad (5)$$

where: ϵ_p = plastic strain amplitude
 ϵ_f' = a material constant to be determined from fatigue testing
 $2N_f$ = number of complete cycles to failure
 c = a material constant to be evaluated experimentally

An experimental fit to this expression was obtained by Mander et al. (1994):

$$\epsilon_p = 0.08 (2N_f)^{-0.5} \quad (6)$$

Using fundamental relationships between curvature and strain, a relationship between curvature (or rotation) and cycles to failure (N_f) can be derived. If the plastic hinge length is defined as l_p , an expression for the plastic strain in terms of plastic curvature (or rotation) can be established (Paulay and Priestley, 1992) assuming that the plastic rotation θ_p takes place about the center of the plastic hinge:

$$\Phi_p = \frac{\theta_p}{l_p} = \frac{\Delta_p / (L - 0.5l_p)}{l_p} \quad (7)$$

which can be used directly to define the number of cycles to failure for a given plastic strain or a given plastic deformation. Cumulative damage is then defined as:

$$D = \sum \frac{1}{2N_f} \quad (8)$$

The four models described above were applied to the data obtained from the experimental testing of Phase 1. A comparative study of the damage models was carried out to assess their capability in seismic damage prediction.

Preliminary Results and Conclusions

There exists a so called “threshold” ductility level for well-confined flexural circular columns designed by current Caltrans specifications beyond which severe degradation of stiffness and strength take place. For the bridge columns tested in this study, this ductility level occurs between $2\Delta y$ and $4\Delta y$. Specimen A3, which was cycled 150 times at a ductility of $2\Delta y$, showed no significant signs of damage or deterioration. Specimen A5, which was cycled at a displacement ductility of $4\Delta y$, failed in less than 10 cycles. It may, therefore, be inferred that seismically detailed bridge columns subjected to earthquakes which impose ductility demands less than 2.0 can survive a series of similar events without undergoing any significant structural damage. When the ductility demand approaches 4.0, the likelihood of moderate to severe damage is high and depends on the number of such inelastic cycles experienced by the structure.

Under a sequence of low amplitude cycles, it is most likely that the confining spiral will fail prior to low-cycle fatigue failure of the longitudinal reinforcing bars. Conversely, if the bridge column is subjected to high amplitude inelastic cycles, it is most likely that the longitudinal bars will rupture before confinement failure occurs. In the present study of flexural columns, it was found the threshold “low-amplitude” cycle is approximately 2-3% drift, while high-amplitude cycles are those in excess of 4%.

A large database of displacement histories was produced for the bridge column specimens using dozens of recorded ground motions at different soil profiles. A significant finding of this research study, based on these numerous analytical simulations, is that typical earthquakes produce few large amplitude cycles, hence based on the preceding paragraph, failure is generally governed by confinement.

The constant amplitude and random cyclic testing clearly indicates that the energy capacity of a member at failure is strongly path dependent. Proof of this observation is shown in figures 2 and 3 which show plots of cumulative energy dissipated for all specimens tested in both phases of the study. If specimen A2, tested using standard cyclic displacement amplitudes, is referred to as the benchmark energy capacity, it is evident that the energy capacity of the columns varies considerably depending on the displacement amplitude and the path or previous load history.

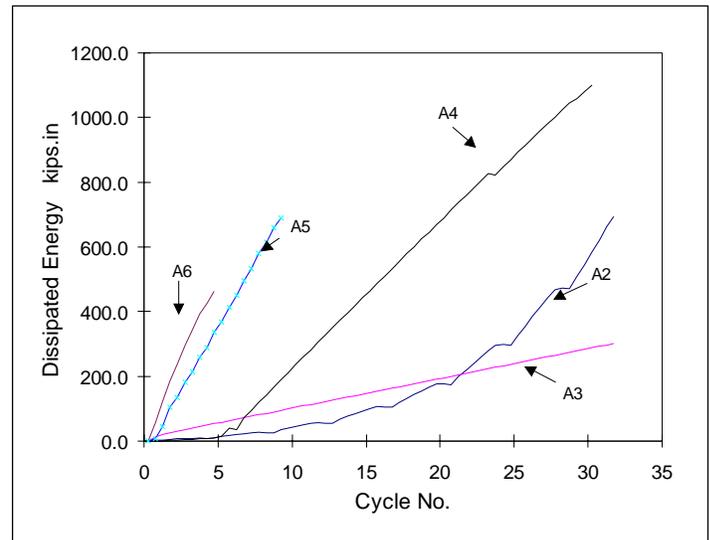


Figure 2: Cumulative Dissipated Energy to Failure for Bridge Columns Subjected to Constant Amplitude Loading (Specimen A2: Standard Cyclic Loading)

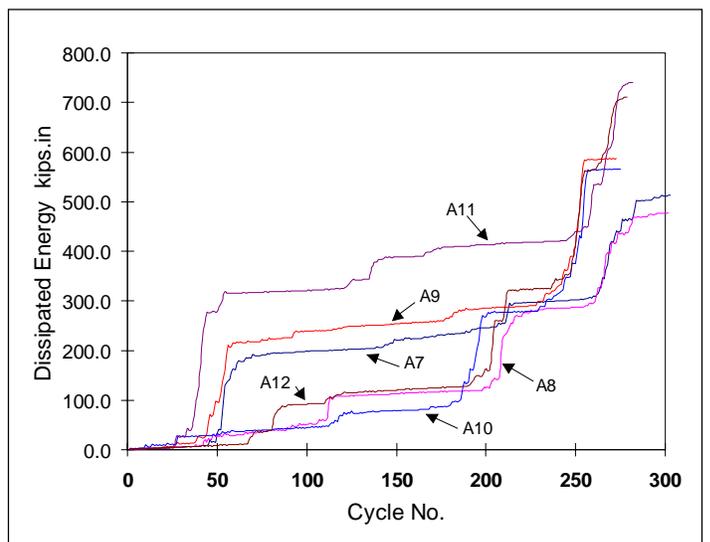


Figure 3: Cumulative Dissipated Energy to Failure for Bridge Columns Subjected to Random Cyclic Loading
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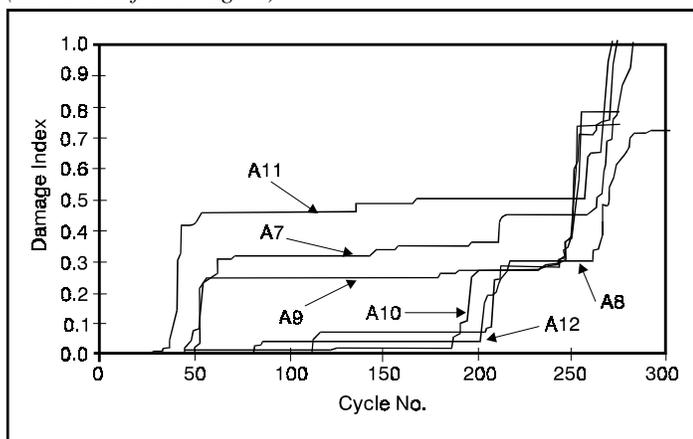


Figure 4: Proposed Fatigue-Based Damage Model Predictions for Specimens A7-A12

Damage models evaluated in this study indicate that most non-fatigue based theories are incapable of adequately reproducing observed damage. Models based on the degradation of a single structural parameter, such as the softening index evaluated in this study, are sensitive in the early stage of damage progression and show little variation beyond this point to failure, making them difficult to calibrate. Energy-based models which do not account for the level of ductility consistently over-predict damage. The Park-Ang model is essentially a ductility-based model since the energy term is not adequately represented: energy damage is sometimes overestimated at small inelastic amplitudes and underestimated at large inelastic cycles. On the other hand, existing fatigue theories, using a Coffin-Manson rule in combination with Miner's hypothesis, account only for low-cycle fatigue of steel. It appears that a model which combines low-cycle fatigue failure with confinement deterioration could yield excellent results.

A cumulative fatigue model was developed based on experimental fitting of the Coffin-Manson fatigue expression using results from testing of columns A3, A4, A5 and A6. As a result of evaluating the model coefficients for plastic strain vs. the number of half cycles to failure, the following expression is obtained:

$$\epsilon_p = 0.074(2N_f)^{-0.5} \quad (9)$$

The difference in the constant term that appears in the above expression to that obtained by Mander in equation (6) is due to the contribution of damage resulting from loss of confine-

ment and concrete fatigue. The predicted damage using the above fatigue expression in conjunction with the formulation described in equations (5) - (8) for specimens A7 - A12 is shown in figure 4.

In an attempt to correlate visually observed damage during testing with damage limit states, all of the recorded test data were evaluated carefully to develop a correlation chart to be used along with the proposed ATC-33 effort to define damage states. The summary is presented in table 3.

Concluding Remarks

This task is concerned with the development of performance-based guidelines for design and repair of highway bridge columns. Performance criteria will be based on damage limit states that have been correlated to observed experimental response. The guidelines can be utilized in seismic vulnerability assessment of existing highway bridge columns and can also be extended to evaluate repair and retrofit options for damaged columns.

Table 3: Correlation of Damage Limit States with Visual Observations

Damage Indicator	Damage State	Description	Visual Observation Based on Current Testing
N	None	No visible damage, either cosmetic or structural	No visible cracks
I	Insignificant	Damage requires no more than cosmetic repair. No structural repairs necessary	Hair-line cracks Minor spalling No exposed reinforcement
M	Moderate	Repairable structural damage has occurred. The existing elements can be repaired essentially in place, without substantial demolition or replacement of elements	Excessive spalling Exposed reinforcement <u>No</u> buckling of longitudinal bars <u>No</u> necking of spirals
H	Heavy	Damage is so extensive that repair of elements is either not feasible or requires major demolition or replacement.	Buckling/fracture of longitudinal bars Necking/rupture of spirals

References

Kratzig, W.B. and Meskouris, M., (1987), "Nonlinear Seismic Analysis of Reinforced Concrete Frames," *Earthquake Prognostics, Verlag Friedr. Vieweg and Sohn, Braunschweig*, 453-462.

Kunnath, S.K., Reinhorn, A.M. and Lobo, R.F., (1992), "IDARC Version 3.0 - A Program for Inelastic Damage Analysis of RC Structures," *Technical Report NCEER-92-0022, State University of New York at Buffalo*.

Lybas, J. and Sozen, M.A., (1977), "Effect of Beam Strength and Stiffness on Dynamic Behavior of RC Coupled Walls," *Report SRS 444, University of Illinois, Urbana*.

Mander, J.B., Panthaki, F.D. and Kasalanti, A., (1994), "Low Cycle Fatigue Behavior of Reinforcing Steel," *Journal of Civil Engineering Materials, ASCE*, 6 (4).

Manson, S.S., (1953), "Behavior of Materials Under Conditions of Thermal Stress," *Heat Transfer Symposium, University of Michigan Engineering Research Institute, Ann Arbor*, 9-75.

Park, Y.J. and Ang, A.H-S., (1985), "Mechanistic Seismic Damage Model for Reinforced Concrete," *Journal of Structural Engineering, ASCE*, 111, 722-739.

Paulay, T. and Priestley, M.J.N., (1992), *Seismic Design of Reinforced Concrete and Masonry Buildings, John Wiley and Sons, New York*, 744 pages.

Center Activities

Meeting Review

Highway Seismic Research Council and Highway Project Researchers Meeting

by Ian M. Friedland

The NCEER/Federal Highway Administration Highway Project Annual Meeting was held on November 19-20, 1996 in Buffalo, New York. The meeting was attended by more than 45 members of the Highway Seismic Research Council (HSRC) and project researchers.

The meeting provided an opportunity for the HSRC to review progress through the third year of research under the two Federal Highway Administration (FHWA) contracts comprising the NCEER/FHWA Highway Project (Seismic Vulnerability of New Highway Construction and Seismic Vulnerability of Existing Highway Construction) and to discuss the plan for the Year 4 research program. In addition, the draft strawmen reports for Volumes I and III of the proposed Seismic Retrofitting Manuals for Highway Systems ("Seismic Risk Analysis of Highway Systems" and "Screening, Evaluation and Retrofitting of Retaining Structures, Slopes, Tunnels, Culverts and Pavements") were discussed in detail.

Discussions during the meeting were grouped around the primary Highway Project technical areas: soils and foundations; design issues and details; performance criteria, design criteria, fragility and risk; seismic hazard and ground motion; and

analysis and earthquake protective systems. Meeting participants provided feedback on the specific objectives and research approach for each task and on the overall focus and scope for each of the two FHWA contracts. The two groups comprising the HSRC (the Coordination Group and Technical Group) also met in executive sessions during the meeting. They developed consensus recommendations regarding the scope of work for individual tasks, the proposed Seismic Retrofitting Manuals, other anticipated project products, coordination of research with other agencies, and technology transfer and implementation of project results. Formal written reports were submitted by the two HSRC groups following the meeting.

The meeting also provided an opportunity for the HSRC and project researchers to "brainstorm" on future research needs, in order to identify gaps in knowledge that may prevent the effective implementation of the Seismic Retrofitting Manuals. These needs will be discussed further by the project Research Committee during its next meeting in February 1997. At that time, a determination will be made as to whether and when some of these identified research needs should be initiated under the project.

Center Activities (Cont'd)

Workshop Review

U.S.-Italian Workshop on Seismic Evaluation and Retrofit

by Daniel Abrams

The *U.S.-Italian Workshop on Seismic Evaluation and Retrofit*, jointly sponsored by NCEER and the Italian Gruppo Nazionale per la Difesa dai Terremoti (National Group for the Defense Against Earthquakes - GNDT), was held on December 12-13, 1996 at Columbia University. The workshop reciprocated a previous NCEER-GNDT workshop on the same topic held at the University of Pavia in June of 1994. Both workshops were organized under the auspices of a Memorandum of Understanding between the GNDT and NCEER.

Chairs of the workshop were Dan Abrams of the University of Illinois and G. Michele Calvi of the University of Pavia. Klaus Jacob and Christian Meyer of Columbia University served as local hosts. Invited U.S. participants included Sashi Kunnath, Andrei Reinhorn, Mark Aschheim, Khaled Mosalam and Raimondo Betti. Italian participants were Ezio Faccioli, Luigi Gambarotta, Sergio Lagomarsino, Mauro Dolce, Edoardo Cosenza, and Paolo Pinto.

The focus of the meeting was on seismic evaluation and rehabilitation of buildings and bridges, with an emphasis towards basic issues for conducting research and implementing research results. Invited papers presented state-of-the-art summaries on:

1. Mitigating Earthquake Hazards
2. Estimating Ground Motions for Assessment of Existing Structures
3. Improvements in Seismic Evaluation through Advanced Computational Methods
4. Vulnerability Evaluation and Damage Scenarios
5. Seismic Evaluation and Rehabilitation of Concrete and Masonry Buildings
6. Seismic Evaluation and Rehabilitation of Transportation Networks

Discussions at the bilateral workshop helped identify common technical problems and solutions, research gaps and

needs, implementation issues, future directions of seismic codes, and ideas for technology transfer for improving future collaborative research. Based on these discussions, a set of resolutions were formulated, and grouped with respect to ground motion modeling, computational modeling of seismic response, evaluation and retrofit research, vulnerability studies and future actions. These resolutions will be published along with the technical papers as an NCEER report in 1997.

PACE Update

PACE Program Expands Topics and Locations of Short Courses

by Andrea Dargush

NCEER's PACE (Professional and Continuing Education) program is planning to extend its series of short courses on *Passive Energy Dissipation for Seismic/Wind Design and Retrofit*, with tentative offerings planned for Japan, Korea and Taiwan in the summer of 1997. A new course on the use of base isolation technology in seismic design is under development for winter 1997-98. To be placed on a mailing list for further information about these courses or the PACE program, please contact Andrea Dargush, Assistant Director for Research and Education, phone: (716) 645-3391, fax: (716) 645-3399, or email: dargush@acsu.buffalo.edu.

Instructional materials which have been used for the *Passive Energy Dissipation for Seismic/Wind Design and Retrofit* course are also presently being further developed for publication as one of a series of NCEER monographs. For further information on the monograph, please contact Jane Stoye, Publications Manager, at the number given above or via email: jestoye@acsu.buffalo.edu.

U.S.-Japan Workshops on Seismic Retrofit and Earthquake Protective Systems for Bridges

by Ian M. Friedland

The *Third U.S.-Japan Workshop on Seismic Retrofit of Bridges* was held in conjunction with the *Fourth U.S.-Japan Workshop on Earthquake Protective Systems for Bridges* in Osaka, Japan, on December 9 through 11, 1996. The U.S.-side co-sponsors for the workshops were the National Science Foundation and the NCEER/FHWA Highway Project; the Japan-side sponsor was the Public Works Research Institute (PWRI) of the Japan Ministry of Construction. Both workshops were held under the auspices of the UJNR Panel on Wind and Seismic Effects.

The organizers for the U.S. side were Ian G. Buckle and Ian M. Friedland. The U.S. delegation consisted of 20 participants representing academia, research institutions, engineering consultants, and State highway departments. Invited U.S. participants in the workshop included Kathleen Almand, Ahmed-W Elgamal, Gregory Fenves, Roy Imbsen, Anne Kiremidjian, H.S. Lew, John Mander, Masanobu Shinozuka, Andrew Taylor, Peter Clark, Serafim Arzoumanidis, Saad El-Azazy, Ahmad Itani, Roberto Lacalle, Nicos Makris, Andrew Whittaker and Yan Xiao.

The first and second bridge seismic retrofit workshops were held in Tsukuba, Japan, in 1990 and Berkeley, California, in 1994. Based on the success of these workshops, the third



Study tour participant Peter Clark, University of California at Berkeley, is shown examining a girder from the Rokko Island Bridge which was damaged during the Kobe earthquake.

workshop was oriented towards examining the performance of existing bridges during the 1994 Northridge and 1995 Hanshin-Awaji earthquakes, the development of new evaluation techniques, and research-in-progress related to innovative retrofitting strategies. Topics covered during the workshop included: (1) screening and prioritization for bridge retrofitting; (2) methods of analysis to assess the strength of existing bridges and the effectiveness of various retrofit schemes; (3) methods for retrofitting concrete and steel bridge columns; (4) methods for retrofitting bearings, foundations, and superstructures; and (5) performance of retrofitted bridges in recent earthquakes.

Similarly, the first three earthquake protective systems workshops were held in Buffalo, New York, Tsukuba, Japan, and Berkeley, California, in 1991, 1992, and 1994, respectively. The fourth workshop focused on research and the application of technology. Topics covered included: (1) innovative protective systems; (2) design methods for seismic isolation of bridges; and (3) full-scale verification and validation of system performance. As passive protective systems are now

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As part of the study tour, participants visited the Trans-Tokyo Bay Tunnel, which is currently under construction.

Center Activities (Cont'd)

(Continued from Page 13)

being widely implemented in both countries, an added emphasis of the workshop was on active and hybrid systems, and the use of smart and high-performance materials and structural systems.

Following the workshops, the U.S. delegation participated in a study tour of transportation facilities in Kobe, Yokohama, and Tokyo on December 12 through 14. Among the facilities visited were the reconstructed Hanshin Expressway and National Highways in the Kobe region, the Bridgestone Rubber Factory (where lead-rubber and high-damping rub-

ber isolation bearings are constructed) in Yokohama, ongoing column retrofits on a number of highways owned by the Metropolitan Expressway Public Corporation in Tokyo, and the currently under construction Trans-Tokyo Bay Tunnel project.

Proceedings of the workshop will be published by the Public Works Research Institute (PWRI) in the spring of 1997, and a limited number of copies will be available from NCEER following publication.

Cooperative Research

Viscoelastic Damper Installation in RC Building

by T.T. Soong

The installation phase of the \$1.47 million design/build contract awarded to NCEER by the Naval Facilities Engineering Command was completed on August 31, 1996, about two months ahead of schedule. In this project, the Navy asked NCEER to analyze, design, install, and monitor the seismic upgrade of a Navy-owned, lightly-reinforced concrete building using viscoelastic damping technology developed at NCEER in cooperation with the 3M Company of St. Paul, Minnesota.

The architectural/engineering firm associated with the design and installation was The Crosby Group of Redwood City, California; the installation contractor was Douglas E. Barnhart, Inc. of San Diego, California; and the viscoelastic modules were fabricated by the 3M Company. Shown in figure 1 is one of the 64 viscoelastic damped braces, each incorporating four damping modules placed horizontally below the floor beams. Figure 2 is a group photo taken during the post-installation inspection tour on October 11, 1996.

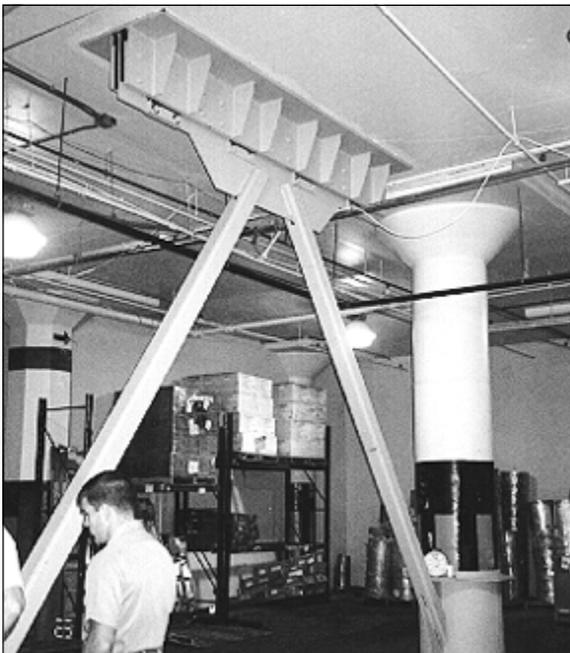


Figure 1: A viscoelastic damped brace as installed in the Naval Facility



Figure 2: Inspection tour of Naval Facility in San Diego. Those shown include representatives of the U.S. Navy, Douglas Barnhart, Inc., The Crosby Group, the 3M Company and NCEER. Shown from left are Lt. Jg. C. Costa, unidentified, B. Cahill, unidentified, M. Lysiak, L. Nelson, A. Reinhorn, P. Crosby, unidentified, C. Blaney, E.J. Neilson and T.T. Soong.

Center Resources

News from the Information Service *Overview of NCEER'S World Wide Web Site*

by Michael Kukla

NCEER's World Wide Web (WWW) site at URL: *http://nceer.eng.buffalo.edu* continues to be expanded with features and materials useful to the earthquake engineering and hazards mitigation community. The web site contains information about NCEER, as well as substantive materials dealing with the various phases of earthquake hazards mitigation. Information from and about other organizations in earthquake and natural hazards mitigation is also provided.

The site offers a variety of materials, including full text versions of both the **NCEER Bulletin** and the **NCEER Information Service News**, and two special publications: the **NCEER Research Accomplishments: 1987-94** and **NCEER Response**, a special supplement to the January 1995 issue of the **Bulletin** about the Kobe earthquake. The home page screen is shown in figure 1.

In addition to text materials, the NCEER web site features a *Data Resources* section. This section provides access to a large collection of computer literature search reprints, a comprehensive listing of upcoming conferences in natural hazard mitigation, and links to a variety of other Internet re-

sources such as accelerograms, maps, earthquake motion catalogs, and other such information. Links to the web sites of other major organizations working in earthquake engineering and hazards mitigation are also provided.

The site also features a *Databases and Software* section which offers access to a number of interactive databases providing bibliographic citations to the literature of earthquake engineering and natural hazards mitigation. It also provides access to information about software developed by NCEER and others for earthquake engineering analysis. Of particular note in *Databases and Software* is an experimental version of the Information Service's Quakeline® database. The approximately 30,000 records in the Quakeline® database have been integrated into a native WWW database environment with the implementation of a new search engine, Excite for Web Servers v1.1. This experimental version of Quakeline® allows for flexible searching of keywords, authors, names, etc. It dispenses with the requirement that one configure their browser to work with a telnet client — something which was necessary with earlier versions of the database.

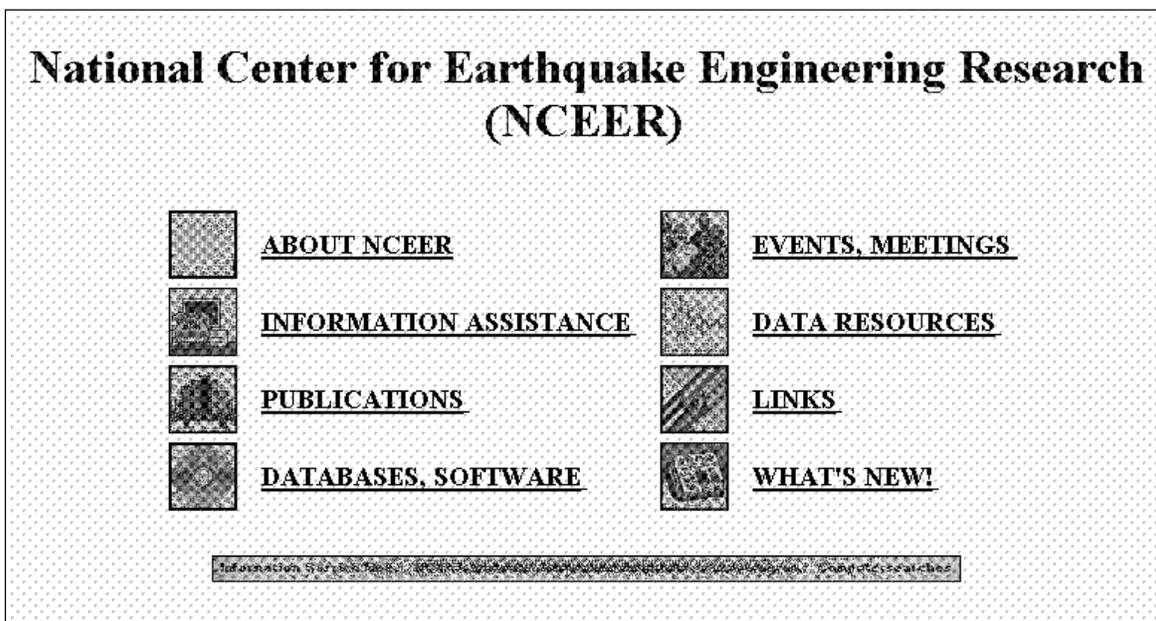


Figure 1: NCEER's Home Page on the World Wide Web

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Center Resources (Cont'd)

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Links to two new databases have also been added to *Databases and Software*: the **Earthquake Spectra** database, which provides bibliographic coverage of papers published in **Earthquake Spectra**: the Professional Journal of the Earthquake Engineering Research Institute (EERI); and the Civil Engineering database (CEDB) of the American Society of Civil Engineers (ASCE), which covers ASCE publications from 1975 to the present. Both databases can now be searched at no charge via the web.

The NCEER web site has for some time offered summaries, pricing and ordering information for the NCEER Technical Report Series. Improvements to this section of the site are now underway and nearing completion. One will soon be able to search the technical reports by subject, title, author and keywords. Additionally, the title listings and order form which are currently in a number of separate files on the web site will soon be integrated into a single file. Employing some simple automation, this single file should help to simplify the process of ordering NCEER technical reports via the web site. In the near future, the full text of selected NCEER technical reports and papers presented in proceedings volumes published as part of the NCEER Technical Report Series may be provided.

Finally, a *What's New* section has been added to the web site. This section provides users with announcements of recent uploads, such as new issues of the **News** and the **Bulletin**, notices of upcoming courses in the PACE (Professional and Continuing Education) program, additions to the NCEER Technical Reports List, notices of new conferences of special note and an entry for the "Bibliography of the Month." Frequent users of the web site may find that a quick glance into this section saves valuable time, as newer resources are made immediately available.

The Information Service staff is continually working to revise and improve the NCEER web site. It is hoped that the user community benefits from these efforts. Suggestions or questions are welcome. Contact the webmaster, Michael Kukla, at phone: (716) 645-3377; fax: (716) 645-3379; email: nceeris@acsu.buffalo.edu.

NCEER Technical Reports Six 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. In addition, NCEER's World Wide Web site offers a complete list of technical reports and their abstracts. The World Wide Web address is <http://nceer.eng.buffalo.edu>.

Dynamic Response of Unreinforced Masonry Buildings with Flexible Diaphragms

A.C. Costley and D.P. Abrams, 10/10/96, NCEER-96-0001, 324 pp., \$20.00

The overall objective of the research was to provide recommendations for the evaluation and rehabilitation of unreinforced masonry buildings. An experimental study was performed to investigate nonlinear dynamic response of two-story building systems with flexible floor diaphragms. Two reduced-scale test structures were subjected to a series of simulated earthquake motions on the University of Illinois shaking table. The experimental parameters were the relative lateral strengths of the two parallel shear walls and the aspect ratios of piers between window and door openings. The accuracy of several computational methods were examined by contrasting estimates with measured response. These methods included procedures that are prescribed in building code requirements for new construction and guidelines for rehabilitation of existing buildings, as well as more complex finite element and dynamic analysis methods. A nonlinear dynamic analysis model was developed to estimate large-amplitude displacements. This report includes descriptions of the experimental and analytical investigations, and provides a number of recommendations for evaluation and rehabilitation of unreinforced masonry buildings.

Ductility of Rectangular Reinforced Concrete Bridge Columns with Moderate Confinement

N. Wehbe, M. Saiidi, D. Sanders and B. Douglas, 11/7/96, NCEER-96-0003, 116 pp., \$15.00

This study examines the ductility and behavior of rectangular reinforced concrete bridge columns with moderate confinement. The research comprised experimental and analytical investigations of the response of such columns when subjected to lateral loading. Four half-scaled rectangular bridge columns were built and tested. The specimens were divided into two groups, based on the amount of lateral steel. The transverse reinforcement ratios in the long direction for the two groups corresponded to 42 percent and 54 percent of the minimum lateral reinforcement required by AASHTO for seismic detailing. The specimens exhibited moderate displacement ductility ratios ranging between 4 and 7. In the analytical study, several existing models pertaining to the concrete stress-strain relationship and the plastic hinge length were utilized and compared. For unconfined concrete, the Kent and Park model was used; the modified Kent and Park model and the Mander et al. model (as modified by Paulay and Priestley) were utilized to represent the constitutive relationship of confined concrete. The equivalent plastic hinge length was calculated using two different models, the Baker model and the model by Paulay and Priestley. The analytical study revealed that for rectangular bridge columns with relatively low axial loads and moderate confinement, it is possible to predict with reasonable accuracy the response of the columns to lateral cyclic loading.

Proceedings of the Sixth Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction

Edited by M. Hamada and T. O'Rourke, 9/11/96, NCEER-96-0012, 782 pp., \$40.00

This sixth Japan-U.S. workshop provided a forum for new approaches to the earthquake resistant design and damage mitigation of lifelines, and advanced techniques for characterizing liquefaction, stabilizing hazardous sites and improving post-earthquake response and recovery. The proceedings volume contains 52 technical papers. Ten papers review lifeline performance during the Northridge and Hyogo-Ken Nanbu earthquakes, in particular that of buried pipelines pertaining to water supply systems. Another twelve papers deal with observed seismic performance of underground structures, quaywalls and foundations. Six papers concern observations of ground motion, displacement and strain during a number of recent Japanese earthquakes. Analytical and experimental studies of liquefaction mechanisms and prediction are the focus of a group of eleven papers. Ten papers concern a variety of techniques and approaches for the remediation and mitigation of liquefaction, as well as the earthquake resistant design and construction of lifelines. It is intended that research findings herein may be applied in engineering decision-making and that the workshop will help to promote the transfer of technology from research to practice.

Chemical Hazards, Mitigation and Preparedness in Areas of High Seismic Risk: A Methodology for Estimating the Risk of Post-Earthquake Hazardous Materials Release

H.A. Seligson, R.T. Eguchi, K.J. Tierney and K. Richmond, 11/7/96, NCEER-96-0013, 146 pp., \$15.00

The first significant step towards developing a constructive area-wide response and mitigation program for chemical facilities is to be able to quantify the seismic risk potential of hazardous materials release and its effect on surrounding communities. Thus, the objective of this project was to develop a methodology that would enable local jurisdictions to determine the magnitude of the problem and identify areas most susceptible to earthquake-induced hazardous materials release. The generalized methodology includes five major steps: inventory development, seismic hazard analysis, component vulnerability assessment, regional vulnerability assessment, and population risk assessment. The results enable local emergency managers to prepare for and mitigate potential earthquake-induced releases. This report illustrates the application of the methodology for assessing the risk of earthquake-induced hazardous materials release and its impact on surrounding population. The methodology is demonstrated on the Los Angeles area using data from a survey conducted by the South Coast Air Quality Management District, limited to 22 facilities using ammonia and/or chlorine within Los Angeles County.

Response of Steel Bridge Bearings to Reversed Cyclic Loading

J.B. Mander, D-K. Kim, S.S. Chen and G.J. Premus, 11/13/96, NCEER-96-0014, 232 pp., \$20.00

The seismic performance of low and high type steel bridge bearing specimens is investigated in this study. Experimental apparatus was developed to allow large cyclic horizontal loads and displacements to be applied to bearing specimens while keeping gravity loads constant. Simple seismic retrofit strategies are proposed and investigated experimentally to increase seismic performance. To increase the resistance in the longitudinal direction of the high type rocker bearings, retrofitting consisted of welding steel wedges to the masonry plate. It is shown that retrofitting the existing high type steel bridge bearings provides sufficient strength and displacement capability to withstand substantial ground shaking. The weak link thus becomes the anchor bolts and/or the reinforced concrete pedestal. To understand the influence of the reinforced concrete pedestal and mild steel anchorage on the overall behavior of a high type fixed bearing assembly, a full scale reinforced concrete cap beam with pedestals was constructed. The test results demonstrate the importance of considering the flexibility of the concrete pedestal-anchor bolt system. As a retrofit method for the damaged reinforced concrete pedestal, a steel jacket was wrapped around the damaged reinforced concrete pedestal.

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Highway Culvert Performance During Past Earthquakes

T.L. Youd and C.J. Beckman, 11/25/96, NCEER-96-0015, 96 pp., \$10.00

To assess performance of culverts during earthquakes, the authors reviewed reports from six earthquakes, interviewed highway officials in areas shaken by four earthquakes and conducted field investigations in epicentral regions of three earthquakes. Seventeen corrugated metal pipe (CMP), one thermoplastic pipe, five reinforced concrete pipe (RCP), and thirty reinforced concrete box (RCB) structures were specifically evaluated through field inspection of literature review. Five of these culverts (all CMP) were deformed into a dysfunctional condition; nine (three CMP, five RCP and one RCB) required major repairs or replacement; six RCB structures required minor repairs (epoxy of cracks). Thirty-five surveyed culverts suffered inconsequential or no damage. Lack of observed or reported damage to hundreds of additional unsurveyed culverts in strongly shaken areas indicated inconsequential effects to these structures. Primary causes of culvert damage were liquefaction-induced embankment penetration or spreading, slope instability, and fault rupture. Other causes of damage were increased lateral earth pressures and inertial forces generated from thick overlying fills. These findings indicate that culverts generally perform well during earthquakes except in areas affected by foundation failure or subject to large lateral or inertial forces.

1997 Technical Report Series Subscriptions Available

Subscriptions to the 1997 Technical Report Series are available. It is anticipated that the 1997 series will include 15-20 titles, many of which will be related to topics in bridge engineering.

The subscription rate is \$300 to organizations within the United States, and \$400 to international subscribers. A reduced rate is offered to nonprofit organizations.

The previous yearly series of reports (from 1987 through 1996), can be ordered as a set at the per year subscription prices. Abstracts of all published technical reports are included on NCEER's world wide web site at <http://nceer.eng.buffalo.edu>.

For more information, contact Jane Stoye, NCEER Publications Manager, at phone: (716) 645-3391; fax: (716) 645-3399; email: jestoye@acsu.buffalo.edu.

Bulletin Board

Upcoming Events

Second National Seismic Conference on Bridges and Highways

The Federal Highway Administration and the California Department of Transportation are hosting the *Second National Seismic Conference on Highways and Bridges* in Sacramento, California on July 8-11, 1997. The objective is to provide a national forum for the exchange of information on current practice and research for seismic design and retrofit of new and existing bridges. Although the main focus is national, an International Forum will feature invited speakers from countries which have implemented advanced earthquake mitigation technologies. To register, contact Barbara Murdock, Henderson Associates, 1000 Vermont Ave. NW, 6th Floor, Washington, DC 20005; phone: (202) 682-3739; fax: (202) 682-2535.

Fourth Turkish National Conference on Earthquake Engineering

The *Fourth Turkish National Conference on Earthquake Engineering* will be held September 17-19, 1997 in Ankara, Turkey. For more information, check the conference's web site at <http://www.metu.edu.tr/~wwwweerc> or contact Professor Haluk Sucuoğlu, Earthquake Engineering Research Center, Department of Civil Engineering, Middle East Technical University, 06531 Ankara, Turkey, phone: (+90) 312-210-5480; fax: (+90) 312-210-1328; email: eerc@rorqual.cc.metu.edu.tr.

Announcement

Nominations Sought for Geotechnical Award

The Shamsheer Prakash Foundation seeks nominations/applications for the 1997 Shamsheer Prakash Research Award. This award for Excellence in Geotechnical Earthquake Engineering is intended for young engineers (40 years or younger) by the deadline of May 31, 1997. For additional information, contact Sally Prakash, Shamsheer Prakash Foundation, "Anand Kutir," 1111 Duane Avenue, Rolla, MO 65401; fax: (573) 364-5572; email: prakash@novell.civil.umn.edu.

New Publication

ATC-35 Report: Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice

The Applied Technology Council (ATC) has announced the availability of the ATC-35 report, **Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice**. This 110-page report contains a recommended program for transfer of USGS research results into active engineering practice. Included are recommendations pertaining to management actions that enhance information transfer; communications, such as newsletter articles, technical briefs, seminars and workshops, that are targeted to practicing engineers; and research activities to enhance development of information that is vital to engineering practice. Copies of the report can 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@atcouncil.org. The cost is \$25.00.

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Call for Papers

1997 SEAOC Annual Convention

The Structural Engineers Association of California (SEAOC) issues this Call for Papers to be presented at its 1997 Annual Convention, held in San Diego, California on September 25-27, 1997. The main theme of "Practical Based Design" has been chosen for the technical program. Papers on interesting and informative topics relating to structural analysis, design, construction and rehabilitation of building structures, bridges, wharfs and piers, reservoirs, tanks, and towers are welcome. Speakers with topics in other areas of structural engineering, structural forensics or current professional practice issues are also encouraged to submit papers. Abstracts should be submitted to Craig Rush, Technical Program Committee, 1997 SEAOC Convention, R2H Engineering, Inc., 11545 W. Bernardo Ct., Suite 300, San Diego, CA 92127, phone: (619) 673-8416; fax: (619) 673-8418. Abstracts are due May 15, 1997.

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