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THE JOHN A. BLUME EARTHQUAKE ENGINEERING CENTER

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Letter from the Director

As I begin my term as director of the John A. Blume Earthquake Engineering Center, I think it is timely to reflect on the center's mission and future. John Blume and the founding directors, Jim Gere and Haresh Shah, created the center as a focal point for world class earthquake engineering research and to facilitate transfer of research into practice. While these basic objectives remain as valid today as at the center's founding in 1976, the maturation of earthquake engineering over the intervening years suggests that we consider how the center's past success should guide us in the future. Many ideas that were revolutionary in the 1970's have now become commonplace in engineering practice. New earthquake engineering design concepts first outlined in ATC 3 (R-factors, spectral hazard maps, etc.) are now codified in national design standards, such as ASCE 7-03. Concepts of probabilistic seismic hazard analyses, inelastic dynamic analysis, and loss modeling, many of which trace their development to Stanford University, are now widely accepted and applied for seismic hazard mapping, performance assessment, and regional loss modeling. These are just a few examples of the many ideas that began as innovative research and are now routinely applied in practice. Apart from the research itself, today there are many more research centers and professional organizations involved in earthquake engineering, than existed thirty years ago. Thus, researchers and engineers must continually imagine new ideas and reassess the important research challenges in earthquake engineering. And, the Blume Center must adapt to continually foster innovative research and facilitate its transfer into engineering practice.

In October, I invited our professional affiliates to Stanford for an advisory meeting to discuss these topics with the Blume Center faculty. In general, the affiliates supported our current research initiatives in the areas of performance-based engineering, development and utilization of sensors for damage detection and health monitoring, numerical modeling and multi-scale simulations, and probabilistic methods to characterize uncertainty and risk. They also highlighted several additional areas worthy of inquiry. These included suggestions to (a) collaborate with researchers outside of engineering to explore the socio-economic aspects of earthquake hazard mitigation and raise understanding and awareness of these issues within the socio-political arena, (b) place greater emphasis on characterizing losses from non-structural components, including consideration of how losses are calculated by insurance companies (c) develop frameworks for more consistent data collection and utilization from tests, field reports, and post-earthquake reconnaissance, and (d) development of new materials and devices for protective systems. Finally, the affiliates reiterated John Blume's vision for the center by emphasizing the need for researchers and engineers to incorporate research findings into codes and standards for engineering practice.

Being the first director who has only known Dr. Blume by reputation, I feel a particular commitment to maintain his vision with the next generation of faculty and students beginning their careers in the Blume Earthquake Engineering Center. To help achieve this, I welcome the input, advice, and support from our professional affiliates and the many dedicated alumni, past directors, and friends of the Center. I urge you all to stay involved and in touch. Check out our web site, send an e-mail to ggd@stanford.edu, call or visit -- we would like to hear from you.

Otani Named John A. Blume Distinguished Lecturer

The John A. Blume Earthquake Engineering Center of Stanford University is pleased to announce the John A. Blume Distinguished Lecturer for 2002-2003 will be Professor Shunsuke Otani, University of Tokyo. This year's lecture, "Japanese Seismic Design of High-Rise Reinforced Concrete Buildings - An Example of Performance-Based Design Code and State of Practices", will be held on January 23, 2003, at 4:30pm in Building 420, Room 041.

Otani's lecture will discuss an example of performance-based regulations for structural design according to the 1998 revision of the Building Standard Law of Japan. The state of practices to satisfy the performance-based regulations is presented in the design of high-rise buildings for gravity loads, snow loads, wind forces and earthquake forces with emphasis on design of reinforced concrete structures. Earthquake resistant design includes generation of artificial earthquake motions, static pushover analysis of frames, nonlinear response analysis of simple models, estimate of member response.

Summer 2002 Graduates

Ilchan Ahn and **Chung-Chuan Chang** graduated with a Master's Degree in Structural Engineering and Geomechanics in the Summer. **Jerry Lynch** and **Dimitrios Vamvatsikos** received their Ph.D. degrees. Jerry is continuing at Stanford for a Master's Degree in Electrical Engineering and Dimitrios is in Greece serving in the military.

Alumni News

Patrick J. Ryan (MS '92) was promoted to Senior Associate at Rutherford & Chekene and **Mark Moore** (MS '93) was promoted to Associate.

Abhijit Kakhandiki (PhD '99) and his wife **Bimba** are proud to announce the birth of their **Pranav**. Born on August 5, he weighed 8lbs and was 21" long.

RESEARCH SPOTLIGHT

Shake-Table Experiments and Nonlinear Dynamic Analyses to Estimate Collapse Limit States of Structures

By Amit M. Kanvinde, Burak Tuncer and Prof. Greg Deierlein

Introduction

In theory, the current state of nonlinear dynamic structural analysis has the ability to evaluate the performance of structures until collapse, ideally tracing the path of the structure down to the ground. However, performing shake table tests of a structure to collapse can be dangerous and often expensive, so this ability of the analysis methods has not been extensively verified. Also, since test data for such collapse situations is sparse, understanding of such behavior has not been adequately studied. An important problem is to define the concept of dynamic collapse and to relate this phenomenon to simpler design guidelines and seismic demands, such as a critical interstory drift.

A series of nineteen small-scale shake table tests were run on structures in the Blume Center lab to investigate the behavior of structures near collapse, as well as evaluate the analytical abilities of the nonlinear dynamic analysis software (OpenSees). The structures had a heavy, 320-pound mass supported by flat steel replaceable columns and a time period of roughly 0.5 second and a stability coefficient $\theta = 0.17$. Two different structural details were used - one with holes at the column

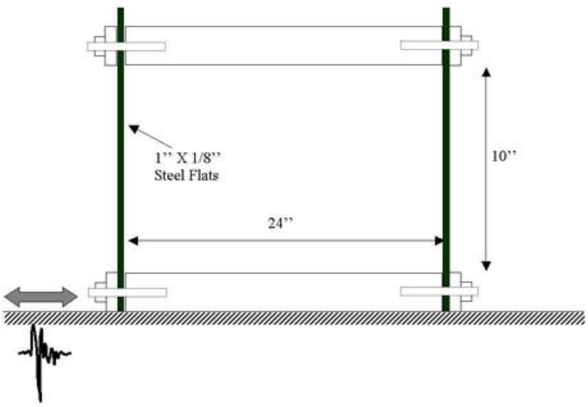

Figure 1. Schematic Elevation View of the Test Structure

plastic hinge locations, and another without, to study the effect of the strength of the structure on the collapse behavior. Figure 1 shows a schematic of the test specimen. Two earthquake records were used to study the different damaging characteristics of different ground motions. These were (1) The Northridge earthquake at Obregon Park in Los Angeles and (2) The Northridge Earthquake at the Pacoima Dam recording station. Figure 2 shows the unscaled response spectra of the two earthquakes for 1% damping (observed in the structure from free vibration tests). As can be seen from the records, the Pacoima Dam record is a much stronger record than the Obregon record. The choice of the records was made considering the demand requirements to collapse the structure, as well as the stroke limitations of the shake table, which prevented extreme scaling.

The Obregon Earthquake formed the primary testing series of 16 tests, which included both the types of structures, and two different scaling levels for each of the structures (with Sa(T1) ranging from 1.4 to 3.8g). The aim was to sandwich the collapse level between these two scaling factors, such that the structure would just survive the

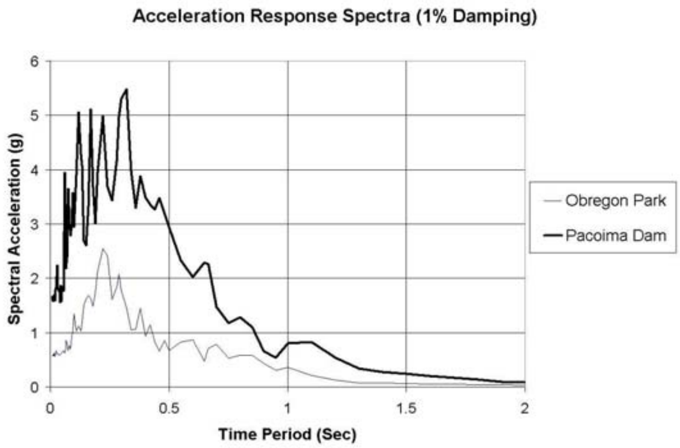

Figure 2. Response Spectra for 1% damping for both the earthquake records

first level, and collapse during the higher-level earthquake. The second test series, conducted only on the stronger structure employed the Pacoima Dam earthquake at a single intensity level of Sa(Tl) = 5.3g, to evaluate the accuracy of the analysis model.

Overall, it was found the large-displacement, nonlinear dynamic analyses formulations, and software like OpenSees are very effective in estimating the behavior of the structure to the point of collapse. It was also observed that using a static-pushover based estimate of collapse drift is a good indicator of the dynamic collapse condition.

Analytical Model and Comparison to Tests

The analytical model was designed to be as accurate as possible and to pick up all the effects and sources of nonlinearity in the structure. The structure was modeled as a 2-dimensional structure (this assumption was verified by test data from eccentric accelerometers that showed virtually no 3-dimensional torsional effect). A concentrated mass formulation (with two mass degrees of freedom) was used with elastic, large rotation beam-column elements modeled by the Corotational formulation in OpenSees. To model the plastic hinge behavior, single

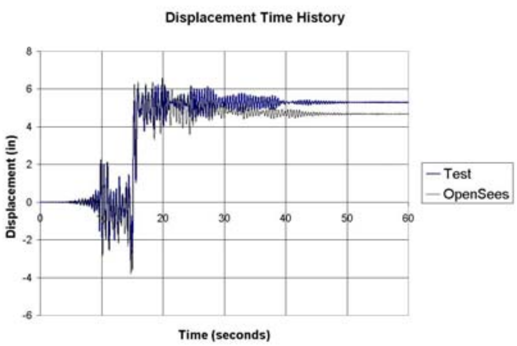

Figure 3. Displacement Time History Comparison between Test and Analysis

degree of freedom rotational springs were attached at the end of the columns. The Menegotto-Pinto nonlinear plasticity model was used to calibrate the spring response, and static cyclic tests of the column section were conducted to calibrate the model. It is important to note that a non-degrading material model is used, which works well for our situation, but some of the observations of this study might not be applicable to degrading materials like concrete.

As described earlier, two different structures were used, and two different earthquakes (one of them scaled at two levels) were used as the testing parameters. This results in three sets of tests - (1) the stronger structure with the Obregon Record at two levels (2) the weaker structure with the Obregon Record at two levels, and (3), the stronger structure with the Pacoima Record at one level. The stronger structure never collapsed completely, and this structure was an ideal test case for the analytical model which needs to exercise its large displacement capabilities. Thus, test sets (1) and (3) demonstrate the capabilities of the analysis. Test set (2), on the other hand, is visually more exciting, since the structure collapses forcefully. This provides us with valuable insight

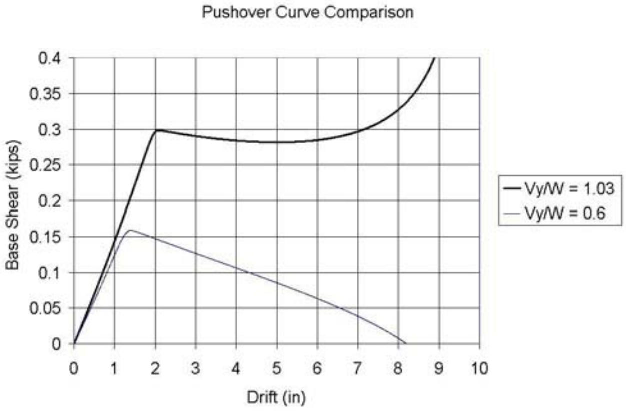

Figure 4. Pushover curves for both the structures

into the collapse mechanism of the structure, and enables us to relate dynamic collapse to static estimates of collapse drift. However, it was felt that since the weaker structure would not provide a very stringent test for the analysis model, since instability of the structure would be the dominant phenomenon. Figure 3 shows the analysis results superimposed on the time history recorded from the tests for a test on the stronger structure, and there seems to be excellent agreement (note that the drift angle is 37 degrees - more than anything we might ever expect to see in a real structure).

The stronger structure, with a V_y/W ratio of 1.03 would never "collapse", even if the drift angle reached 90 degrees, since the column strength was very large, thus the structure never actually collapses during any earthquake. This was predicted in the predictive dynamic analyses as well as in the pushover analyses. In sharp contrast, the pushover and dynamic analyses for the weaker structure (with V_y/W ratio of 0.6), both predicted a point of instability, which corresponds to complete loss of base shear capacity and consequent collapse. Figure 4 shows a comparison of the two pushover curves.

Interestingly, the point of instability predicted by the pushover curve for the weaker structure is a drift value 8.2 inches. In the dynamic tests, all (weaker) structures that exceed this drift value eventually collapse (on the same excursion), whereas all the structures that do not exceed this value survive. This leads us to believe that an estimate of the collapse drift from a pushover analysis is a good indicator of whether the structure will collapse during dynamic loading. The main difference between the static and dynamic case is the presence of inertial effects in the dynamic case. Once the structure is near the collapse state, its effective time period is almost infinity, and moreover the floor mass has dropped through a significant height. This makes it very difficult for the ground motion to exercise sufficient influence on the structure to keep it from collapsing. So if the ground motion gets a structure to the collapse drift predicted by the pushover analysis, in all likelihood the structure will collapse. Reinforcing this fact is that among those structures that traveled beyond this "collapse" drift, no structure showed any signs of returning, and the collapse beyond this drift level was monotonic, sudden and on the same excursion.

Incremental dynamic analyses (IDAs) were run on each of the structures for each of the earthquakes to investigate the accuracy of the analysis at different earthquake levels, and observe any trends, especially with respect to determining the collapse limit state. Figure 5 shows a plot of the IDA curves for maximum displacement of the Obregon Record for both the structures, which shows good agreement

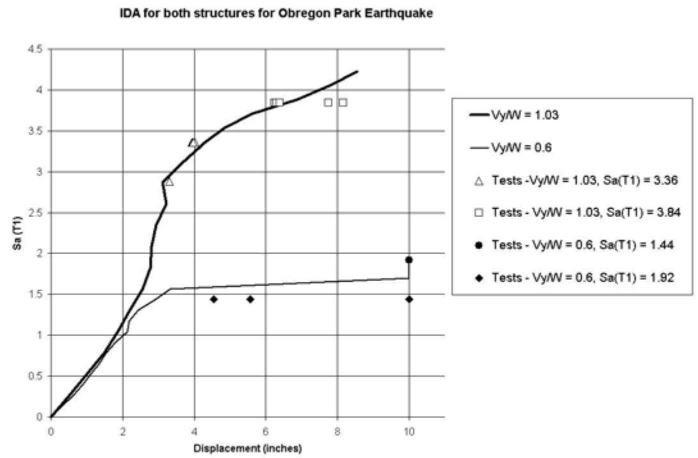

Figure 5. IDA Curves for the Obregon Park Record (both structures)

between test results and analysis.

In general, the analysis model does a good job of predicting the maximum as well as the residual drifts of the structure. However, the scatter seems to be larger in the higher level earthquakes, which leads us to believe that the collapse limit state might be more sensitive to slight variations in the ground motions, material properties, or analysis assumptions.

Conclusions and Observations

The important conclusions that can be drawn from this study are

1. Current analysis tools and formulations if calibrated carefully provide a reliable means of determining structural response to the point of collapse. This study traced some structures until they hit the ground (drift angle of 90^{o}), demonstrating the accuracy of the analysis well above the commonly encountered collapse limit state at roughly 8% to 10% drift.

2. The pushover analysis can be effectively used to estimate the collapse drift limit of a non-degrading structure during earthquakes.

3. The scatter in the structural response is greater at loading levels nearer collapse, than it is at lower levels. This is probably due to a combination of factors, including imperfections and variations in the structures and ground motions, as well as sensitivities to the model parameter calibration, which are not as significant at smaller load or displacement levels.

Blume Center News

Prof. Anne Kiremidjian was invited to participate in the EERI sponsored workshop on the NEES Consortium, June 18-20, in San Diego.

Dr. Christoph Adam (PostDoc) gave a presentation, “Moderately Large Flexural Vibrations of Composite Plates with Thick Layers”, at the Fourteenth US National Congress of Theoretical and Applied Mechanics, June 23-28, at Virginia Tech.

Dr. Renate Fruchter and Ph.D. Candidate, **Peter Demian**, presented a paper on “Knowledge Management for Reuse” at the CIB W78 Distributing Knowledge in Building conference sponsored by the International Council for Research and Innovation in Building and Construction at Arhus, Denmark in June. **Dr. Fruchter** also met with Mr. J. Keinanen CEO of the Association of Finnish Civil Engineering (AFCE) gave a presentation on PBL and A/E/C Global Teamwork at the AFCE in Helsinki, Finland.

Dr. Renate Fruchter presented a paper on the "Impact of multi-cultural dimensions and multi-modal communication in global teamwork" at the annual National American Society of Engineering Education (ASEE) convention in Montreal, Canada, in June.

From August 26-28, **Prof. Anne Kiremijdian** participated in a NSF supported workshop on Sensor Technologies for Structural Health Monitoring in Lake Tahoe.

7th US National Conference on Earthquake Engineering

Several of the Blume Center’s faculty, students and alumni attended the 7NECEE in Boston in July. **Prof. Greg Deierlein** organized and chaired a panel discussion on “Performance-Based Engineering”; **Prof. Allin Cornell** was a panelist. Papers were presented by **Dimitrios Vamvatsikos** (PhD ‘02), **Nico Luco** (PhD ‘02), **Paolo Bazzurro** (MS ‘91,ENG ‘93, PhD ‘98), **Prof. Eduardo Miranda**, PhD Candidates **Hesameddin Aslani** and **Shahram Taghavi**, **Prof. Charles Menun**, and **Prof. Anne Kiremidjian**.

At the conference thirty faculty, students, and alumni of the Blume Center met for a reunion dinner. The reunion provided a fun opportunity to visit old friends, introduce some of the new younger faculty, and gossip about those who weren't there. We are indebted to alumni **Stephanie King** (MS ‘90, PhD ‘94) and **Sarah Wadia-Fascetti** (PhD ‘91) who organized the event and picked some fantastic wines!

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