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THE JOHN A. Blume EARTHQUAKE ENGINEERING CENTER

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING, STANFORD UNIVERSITY

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BLUME AND SHAH NAMED TOP SEISMIC ENGINEERS OF THE CENTURY

On April 17, 2006 design professionals from around the nation joined the Applied Technology Council and Engineering News Record for an awards dinner celebrating 100 years of seismic structural engineering and construction in the United States.

Honored at the event were **Dr. John Blume** and **Professor Emeritus Haresh Shah** who were recognized as two of the "top seismic engineers of the 20th Century". Dr. Blume was recognized for his major contributions to earthquake engineering research and practice, beginning with his pioneering work to characterize inelastic dynamic response of structures through his professional leadership in building codes and practice. Professor Emeritus Shaw was selected for his pioneering research which has revolutionized the practice of seismic loss assessment and risk management.

100TH ANNIVERSARY 1906 EARTHQUAKE CONFERENCE

Stanford University and the Blume Center were well represented at the 100th Anniversary 1906 Earthquake Conference held in San Francisco on April 18-22, 2006. Stanford alumnus, **Chris Poland**, chaired the conference and gave the opening address where he introduced **Governor Arnold Schwarzenegger** and **Senator Dianne Feinstein** to address the assembly. Stanford Geophysics Professor **Greg Beroza** and Blume Center Alumnus **Charlie Kircher** gave plenary talks describing the scenario if the 1906 earthquake were to re-occur today, including a probabilistic assessment of damage and fatalities in the Bay Area. Professor **Greg Deierlein** presented another plenary lecture on looking toward the future - "Earthquake engineering challenges and innovations for a sustainable world" (see http://www.1906eqconf.org/). The conference featured over thirty papers co-authored by current Blume Center faculty and students, and many more by Stanford Alumni. The Blume Center also hosted a reunion dinner attended by 70 current and former students, faculty, staff, affiliates and friends.

PUBLISHED PAPERS

Baker J.W. and **Cornell C.A.**, 2006. *Spectral shape, epsilon and record selection*, Earthquake Engineering & Structural Dynamics, 35 (9), 1077–1095.

Baker J.W. and **Cornell C.A.**, 2006. *Which spectral acceleration are you using?*, Earthquake Spectra, 22 (2), 293-312.

BLUME CENTER NEWS

Professor Jack Baker gave a talk *"Accounting for soil spatial variability when assessing liquefaction risk"* at the Second International Forum on Engineering Decision Making in Lake Louise, Canada, April 26-29, 2006.

PhD Candidate Renee Lee presented a joint paper with **Professor Anne Kiremidjian** at the Second International Forum on Engineering Decision Making held April 26-29, 2006 at Lake Louise, Canada. The paper was on *Component Loss Uncertainty for a Spatially Distributed Transportation Network*.

On May 18, **Professor Greg Deierlein** outlined the basis of new design provisions for steel structures in the 2005 edition of the AISC Specification in talk entitled "Design for Frame Stability: Direct Analysis Method" at the ASCE Structure's Congress held in St. Louis.

Professor Jack Baker gave two presentations at the 25th International Conference on Offshore Mechanics and Arctic Engineering (OMAE), in Hamburg Germany, June 4-9.

On June 22, **Professor Greg Deierlein** made a presentation at the NEES Annual Meeting in Washington, D.C. on a NEES-SG project entitled, "Controlled Rocking of Steel-Framed Buildings with Replaceable Energy Dissipating Fuses". Supported by a $1.4M grant from the National Science Foundation, Deierlein is leading this project with co-investigators, **Professors Sarah Billington**, **Helmut Krawinkler**, and **Jerome Hajjar** (University of Illinois) and collaborators from industry and Japan. Blume Center students involved in the project include **Paul Cordova** (PhD 2005), **Eric Borchers**, **Xiang Ma** (Blume Fellow), and **Alejandro Pena**.

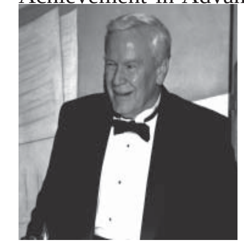
PhD Candidate **Krishan Nair** and **Professor Anne Kiremidjian** participated in the 4th World Conference on Structural Control and Monitoring where Krishan presented their joint paper on *A Wavelet based damage detection algorithm based on Gaussian mixtures modeling*. The conference was held July 11-13, 2006 in San Diego California.

Professor Jack Baker gave a talk *"Geostatistics for modeling of soil spatial variability in Adapazari, Turkey"* at the Interdisciplinary workshop on Management of Earthquake Risks in Zurich, Switzerland, August, 28-29. Also attending the conference were **Professor Anne Kiremidjian** and PhD Candidate **Pooya Sarabandi**. They presented a talk titled *"Building Information Extraction from Satellite Imagery for Regional Risk Assessment"* .

Professor Anne Kiremidjian and PhD Candidate **Renee Lee** participated in the 1st European Conference on Earthquake Engineering and Seismology, September 3-8, 2006 Geneva, Switzerland. The presented a poster on *A Loss Analysis Method and Evaluation of Correlated Bridges in a Transportation Network.* **Professor Helmut Krawinkler** also attended and presented a paper on *"Facilitating the Selection of Effective Structural Systems in Performance-Based Design"*.

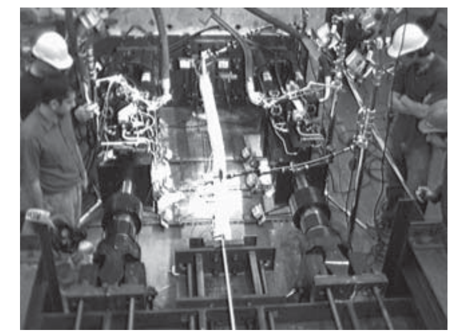
AWARD WINNERS

Professor Helmut Krawinkler, pictured at the ATC Awards Dinner on April 17, 2006, received the ATC Award of Excellence for Extraordinary Achievement in Advancing Knowledge on the Seismic Performance of Buildings.



Professor Eduardo Miranda received the ASCE Moisseiff Award for two papers that appeared in the February 2005 issue of the ASCE Journal of Structural Engineering, "Approximate Floor Acceleration Demands in Multi-Story Buildings, Parts I & 2."

PhD Candidate **Abbie Liel** captured the top prize in EERI's student paper competition with her paper, "Using Collapse Risk to Inform Seismic Safety Decisions: California's Existing Reinforced Concrete Structures."



Prof. Greg Deierlein *and* **Andy Myers** *(right) collaborate with UC Davis* **Prof. Amit Kanvinde** *and* **Ben Fell** *(left) on a NEESR project. The photo was taken at the Berkeley NEES facility during the first experiment of nineteen representative SCBF braces to investigate Ultra-Low Cycle Fatigue (ULCF) and fracture in full-scale steel structures.*

SPRING 2006 GRADUATES

Congratulations to our recent graduates. Master of Science degrees in Structural Engineering and Geomechanics were awarded to **Whitney Armbrust, Allen Au, Jiffy Bennett, Steve Bono, Katy Briggs, Jimmy Chan, Gopal Chandramouli, Shawn Earp, Kevin Haas, Joan Hanson, Josh Hooker, Sarah Morrisroe, Kevin Nadolny, Cole Olsen, Mary Turnipseed, Kevin Wang,** and **Nick Wann.** Master of Science degrees in Design/Construction Integration were awarded to **Eileen Aghnami, Steve Carrillo, Matt Casey, Tao Lin, Josh Odelson, Harry Tam** and **Lan Yu**. **Yao-Hung Yang** was awarded an Engineer degree in Design/ Construction Integration.

Doctorate degrees in Structural Engineering and Geomechanics were awarded to **Jose Andrade**, **Craig Foster**, and **Farzin Zareian**.

2006 Shah Family Symposium

Gerald Galloway and Carel Eijgenraam respond to a question during the press conference held in the Blume Center.

On May 10, Consulting Professor **Dr. Martin McCann** hosted the 2006 Shah Family Symposium on "A KATRINA LEGACY: Addressing Levee Safety and Public Policy in the U.S. and California." The symposium featured a panel discussion with Brigadier General (retired) and Professor Gerald Galloway (University of Maryland), Professor Jeffery Mount (U.C. Davis) and Mr. Carel J.J. Eijgenraam (CPB Netherlands Bureau for Economic Policy Analysis) addressing the issues for looking forward to developing effective strategies for managing levee risks in the California Delta and the U.S.

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RESEARCH SPOTLIGHT

Sidesway Collapse of Deteriorating Structural Systems Under Seismic Excitations

Dimitrios G. Lignos, Helmut Krawinkler and Andrew Whittaker

Introduction

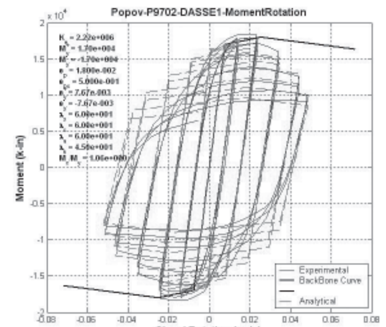
Understanding, predicting, and preventing collapse has always been a major objective of earthquake engineering. From the perspective of financial losses, collapse constitutes a limit state associated with complete loss of the building, its content, and its function. This may not be a critical consideration because similar losses likely will be encountered already at drifts significantly smaller than those associated with collapse. But collapse is the main source of injuries and loss of lives, which makes it a limit state of paramount importance to society. The main obstacles to reliably predict collapse have been our inability to predict deterioration properties of structural components, to incorporate these properties into our analysis and design tools, and to account for all important sources of uncertainty ranging from hazard to ground motion to structural modeling uncertainties that may affect collapse prediction. Moreover, there has not been a comprehensive physical experiment that demonstrates that prediction of collapse is indeed feasible and reliable.

The main objective of this research project is to prepare the road for predicting one critical mode of collapse, namely that associated with sidesway (incremental) collapse in which an individual story (or a series of stories) displaces sufficiently so that the second order P-delta effects fully offset the first order story shear resistance and dynamic instability occurs, i.e., the structural system loses its gravity load resistance. The research project is build on a thorough evaluation of available methods of component deterioration and structure collapse prediction, on improved analytical tools that will be incorporated in the open source analysis platform OpenSees, and on concepts and data of uncertainty propagation and performance assessment that have been developed recently. It will also take advantage of the availability of an advanced shaking table and the associated infrastructure at the SUNY University at Buffalo NEES facility to demonstrate the feasibility of collapse prediction by means of a comprehensive shaking table experiment in which a scale model of a 4-story frame structure will be tested to collapse.

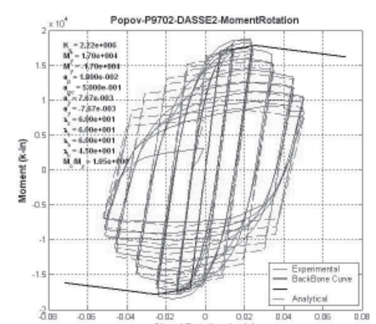
Databases and Component Deterioration Models – Available Tools

To fill in the missing aspect of comprehensive modeling of deterioration properties we are in the process of developing two databases of monotonic and cyclic component experiments that have been conducted worldwide, for steel and reinforced concrete (RC) components. Both databases include information of detailing criteria that control deterioration of the tested components. One of the major issues that makes this effort very time consuming is the existence of many tests in a non digitized format. To establish a digitization procedure we have developed a software in JAVA programming language that assists in digitizing the loading histories of interest, provides energy dissipation per excursion and associated peaks of loading histories of the testing component. The database effort is also supported by the CUREE/Kajima Phase VI Research Program.

To calibrate the deterioration parameters a modified version of the Ibarra – Krawinkler deterioration model (Ibarra, 2003) is used. The modifications are based on observations from the two databases. The model calibration is controlled through an interactive software that we developed in MATLAB, which simplifies the calibration procedure and provides the deterioration parameters for each test. Figures 1a and 1b illustrate the calibration of the deterioration model for two identical steel specimens with reduced beam sections (Popov et al 1997) for 2 symmetric loading histories.



(a)



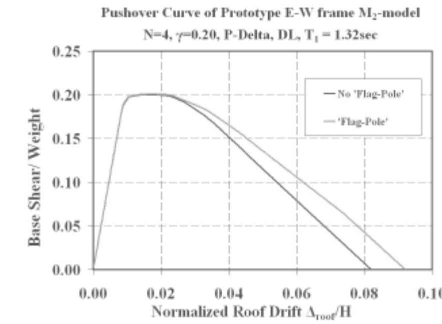
(b)

Figure 1: Calibration of deterioration model for identical specimens using the interactive software for symmetric loading histories (a) specimen DASSE1 and (b) specimen DASSE2

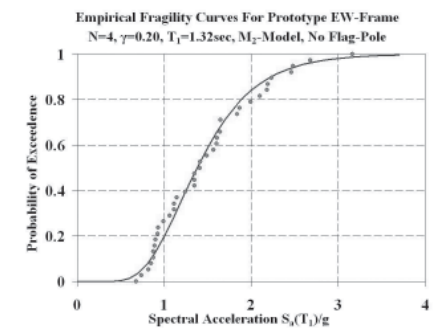
Shaking Table Collapse Testing

The major challenge for this research project is the execution of a collapse test using the shaking table NEES facility at the University at Buffalo. For this purpose a prototype office building was designed in accordance to IBC (2003) specifications. The structural system is a special moment resisting frame (SMRF) with fully restrained reduced beam section (RBS) moment connections designed based on FEMA-350 (2000) guidelines. The east-west (EW) perimeter frame has been evaluated using a mathematical model that includes deformations of the panel zones and takes into account material nonlinearity with concentrated plasticity. Target deterioration parameters are extracted from the steel database described earlier, based on the characteristics of each structural section, and are assigned to the modified version of the Ibarra-Krawinkler deterioration model.

The performance of the structure has been evaluated based on a nonlinear static analysis, as illustrated in figure 2a, investigating the effect of the gravity columns on the lateral strength and stiffness. Dynamically, a set of 40 ground motions was used to evaluate the collapse capacity of the structure for the individual ground motions based on a so-called incremental dynamic analysis (IDA) proposed by Vamvatsikos and Cornell (2002). Based on these dynamic analyses results we developed the fragility function for collapse evaluation of the 4-story structure. This curve provides the probability of collapse for the 4-story structure given a spectral acceleration, and is illustrated in figure 2b for the selected deterioration parameters.



(a)



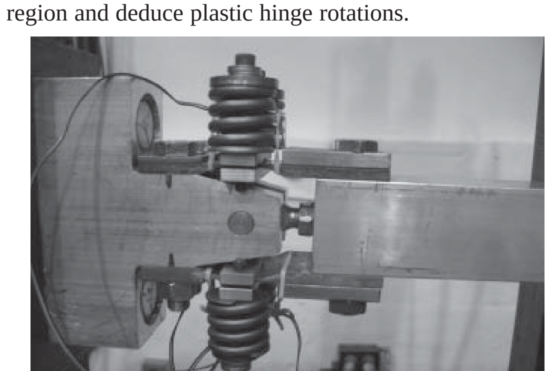
(b)

Figure 2: (a) nonlinear static analysis including/not including the effect of 'flag-pole', and (b) fragility function for collapse of the EW special moment resisting frame based on dynamic analysis for a set of 40 ground motions

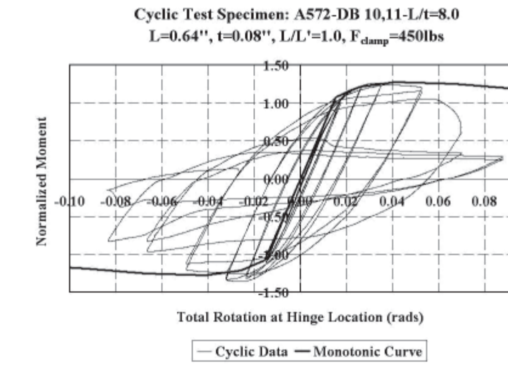
To investigate the capability of reliably predicting the collapse capacity of the 4-story steel structure we will replicate half of the prototype structure on the Buffalo shaking table, using a 1/8 scale model of a two bay EW moment resisting frame (MRF) of the structure. An auxiliary frame will be used to simulate the gravity load.

Experimental Studies on Structural Components

Deterioration modeling for the shaking table test structure necessitates a series of monotonic and cyclic experimental tests on structural components. The type of component detail used to simulate the plastic hinge region, shown in figure 3a, is fabricated using two flange steel plates. The ratio of length over thickness (L/t ratios) of a reduced region of the plates controls deterioration properties of the plastic hinge location. In support of the experimental work, finite element studies are conducted using ABAQUS in order to quantify the effect of various parameters controlling deterioration. For cyclic tests (e.g. figure 3b) the SAC loading protocol is used (Krawinkler et al 2000). All the plastic hinge locations are instrumented with strain gages attached on the steel plates. In addition, part of the instrumentation involves clip gages (home-made extensometers, see figure 3a) to measure plate elongation over the plastic hinge region and deduce plastic hinge rotations.



(a)



(b)

Figure 3: (a) Clamped specimens to control early local buckling gages attached on the steel plates, (b) cyclic behavior of plastic hinge region with length to thickness of reduced section equal to 8

Summary and Discussion

This research spotlight summarizes the framework and steps taken in our project to reliably predict sidesway collapse of structural systems. For this purpose we have developed a comprehensive database to model deterioration of steel and RC components under cyclic bending moments. Loading histories of individual components are calibrated using a modified version of the Ibarra Krawinkler deterioration model. Based on realistic deterioration parameters the collapse capacity of a 4-story steel structure is quantified, and the methodology to predict collapse will be evaluated through an upcoming shaking table collapse experiment of a scale model of the structure. To justify the deterioration characteristics for each plastic hinge region of the model we use a combination of experimental tests and finite element predictions. Our future work will include developing simplified methods of collapse prediction that will be based on widely available engineering prediction tools. Ultimately, the greatest benefit of this research work will be the development and dissemination of design recommendations for collapse safety.

Acknowledgements

This research is supported by a research grant of NSF's Network for Earthquake Engineering Simulation Research (NEESR) Program. Additional support is provided by the CUREE/Kajima Phase VI Research Program. The financial support is much appreciated by the authors.

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