Center Spotlight, continued from page 3

provisions. These assessments are enabled by research to improve understanding of ground motions and their effects on structural response, nonlinear behavior and computer response simulation of structures, and practical probabilistic approaches to account for the inherent uncertainties in design and analysis. The ATC-63 project has implemented these advancements in a practical framework to assess the collapse safety of buildings and their underlying design basis.

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In Remembrance: Eric Elsesser

With great sadness do we communicate the passing of our friend, colleague, and mentor Eric Elsesser, who died peacefully at his home in Sausalito after a six-month battle with a brain tumor. The facts about Eric are that he graduated from Stanford University in 1955 with a B.S. degree and followed with an M.S. degree in 1956, started his career with John Blume in San Francisco, and opened his own structural design office in 1960. He has been at the forefront of creative structural engineering for half a century and inspired a cadre of talented colleagues at his firm, Forell/Elsesser. Behind these facts is a great personality whose interests spanned from structural engineering to architecture and the arts. Eric was a friend to many of us on the faculty and a great mentor to our students. In 1999 Eric was appointed to the prestigious Shimizu Visiting Professorship, and he has continued to lecture in several of our graduate and undergraduate courses that involve practical and creative design concepts

Eric’s input to our structural engineering curriculum was invaluable, and so was his influence on the philosophy and knowledge of engineering many of us practice and communicate today. He was involved in teaching at Stanford till the day he found out that he has an incurable brain tumor. Even thereafter he shared his excitement about the art of structural engineering with some of us. Perhaps the most successful seminar series ever in our program was a series of five lectures given by Eric a few years ago on “How to conceive, design, and build beautiful structures”. This title reflects the passion Eric always had for our profession and for making it the best it can be. We will miss his influence very much, and we will remember Eric for what he represented, which is the best of our profession in every respect.

Blume Distinguished Lecture - April 2008

We are happy to announce that William Baker of SOM will be presenting the 2008 John A. Blume Distinguished Lecture in April. We will be sending out more information of date and location soon.

Blume Center News

Eduardo Miranda has been named as a Thomas V. Jones Faculty Scholar in the School of Engineering. This is a term appointment that includes unrestricted funds over the next two years to support his research and teaching.

PhD Candidate Renee Lee and **Anne Kiremidjian** presented a paper on "Efficient Seismic Risk Assessment and Retrofit Prioritization Model for Transportation Networks" at the Risk Assessment and Risk Communication Workshop held on March 26-27, 2007 at Stanford University.

Anne Kiremidjian gave an invited lecture at the 4th International Conference on Earthquake Geotechnical Engineering, Tessaloniki, Greece on "Issues in Seismic Risk Assessment of Transportation Networks". The paper was co-authored with graduate students **Evangelos Stergiou** and **Renee Lee**.

On June 13, Blume Center faculty and students participated in the Summative Meeting of the Pacific Earthquake Engineering Research (PEER) Center to mark completion of PEER’s 10th year of funding as an NSF Research Center. **Greg Deierlein** and **Helmut Krawinkler** gave presentations to highlight PEER’s accomplishments.

Helmut Krawinkler, **Sarah Billington** and **Greg Deierlein** and **PhD Candidates Dimitrios Lignos** and **Xiang Ma**, attended the NEES Annual Meeting in Snowbird, Utah, June 19-21.

Dr. Renate Fruchter gave a keynote talk entitled "A2D2A2D… Seamless Transformations from Analog to Digital Worlds in Support of Global Teamwork" at the International CIB W78 Conference, Maribor, Slovenia, June 26-29, 2007.

On July 19, **Helmut Krawinkler** presented an invited lecture on "Performance-based Assessment and Design of Buildings" at the LESSLOSS Final Workshop in Belgirate, Italy. The LESSLOSS Project was a multi-year R&D Project of the European Union on risk mitigation for earthquakes and landslides, involving 46 partners from universities and industry.

Jack Baker co-authored a presentation with alum Jose Andrade (PhD '96) entitled “Stability of Granular Media with Random Porosities” at the 9th U.S National Congress on Computational Mechanics, July 22-26, 2007 in San Francisco

Dr. Renate Fruchter received the ASCE Appreciation Award at the ASCE Computing in Civil Engineering Conference, held at CMU, Pittsburgh, PA, July 24-27, 2007.

In July, **Greg Deierlein** spent a week in Pakistan with a team organized by GeoHazards International (GHI) who are collaborating with faculty at NED University in Karachi and other universities to improve earthquake engineering education, research and practice in Pakistan. A highpoint of the trip was a meeting with officials at the Earthquake Rehabilitation Authority in Islamabad and a visit to reconstruction sites in areas devastated by the earthquake in October, 2005.

Jack Baker coauthored four papers at the 10th International Conference on Applications of Statistics and Probability in Civil Engineering, July 31-August 1 in Tokyo, Japan. He also participated in the Southern California Earthquake Center Annual Meeting, August 7-12, in Palm Springs.

RESEARCH SPOTLIGHT

ASSESSING THE RISK OF EARTHQUAKE-INDUCED COLLAPSE IN REINFORCED CONCRETE FRAME SYSTEMS

Abbie B. Liel, Curt B. Haselton and Gregory G. Deierlein

Introduction

Building code provisions for earthquake safety have largely been developed based on judgment informed by observed performance of buildings in past earthquakes, laboratory testing of structural components, and analysis of idealized models. While building codes imply that code-conforming structures have a low likelihood of collapsing, the actual safety of modern code-conforming buildings is unknown, as is the safety of structures built according to earlier out-dated building codes.

Recent developments in earthquake engineering research have enabled simulation of structural collapse under seismic loading, providing quantitative measures of collapse risk. Using these tools, we examine the seismic collapse risk of reinforced concrete (RC) frame structures in the U.S. By assessing the collapse safety of modern code-conforming structures, we "benchmark" the safety provided by current code provisions. These assessments are useful in quantifying the relative safety of different building systems and the impact of changes to design requirements, and to quantify the effectiveness of retrofitting to reduce the collapse risk of older, non-ductile structures.

As part of this research, the authors have worked closely with researchers and practitioners involved in the ATC-63 project of the Applied Technology Council. The ATC-63 effort has developed a systematic method to assess collapse safety, for the purpose of assessing the adequacy of newly proposed structural design standards and building code provisions (ATC 2007). The collapse performance assessments described here have contributed to the development and validation of the ATC-63 methodology.

Methodology for Performance-Based Collapse Assessment

To evaluate structural collapse performance we use the performance-based earthquake engineering (PBEE) methodology developed by the Pacific Earthquake Engineering Research (PEER) Center, which provides a overall framework for relating ground motion intensity to the structural response through analytical models and structural simulation, and finally to potential dollar losses, deaths and downtime (Deierlein 2004). This study focuses on collapse prediction, accomplished through inelastic dynamic analysis to directly simulate sidesway collapse.

Simulation of global sidesway collapse is based on the incremental dynamic analysis technique (Vamvatsikos and Cornell, 2003). In incremental dynamic analysis, an analysis model is subjected to a recorded ground motion, and the motion is scaled to increased intensity until the building becomes dynamically unstable and collapse occurs. This process is repeated for a suite of ground motion records. Collapse performance is represented by a cumulative distribution function, which describes the probability of collapse as a function of ground motion intensity. This collapse distribution is corrected to account for the spectral shape of rare ground motions (Haselton and Deierlein 2007) and the effect of uncertainties in modeling parameters (Liel et al. 2007).

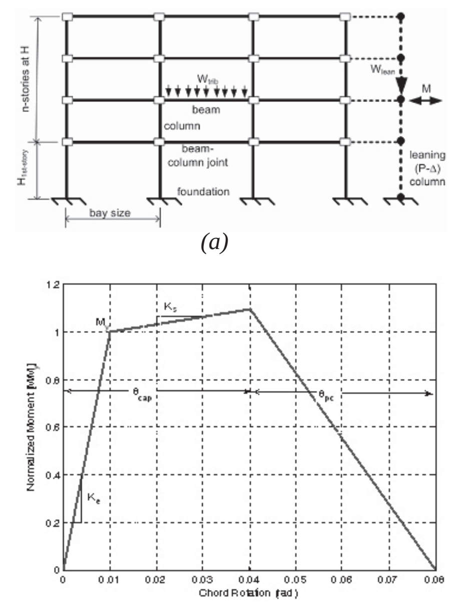

Figure 1. Analytical model for frame structures, showing (a) generalized 2D model configuration and (b) nonlinear material features of beam-column hinges.

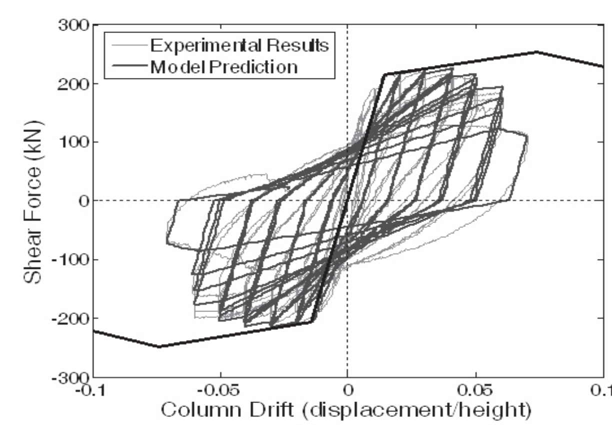

Figure 2. Calibration of RC beam-column model to experimental test by Saatcioglu and Grira (1999) [specimen BG-6].

Nonlinear Modeling of Reinforced Concrete Frames

Nonlinear time-history analysis is a central ingredient of the collapse assessment, the accuracy of which depends on how faithfully the model captures the strength and stiffness degradation that causes structural collapse. In this study, the reinforced concrete frames are modeled using the two-dimensional, three-bay model shown in Figure 1a. The beams, columns and beam-column joints are modeled using hinge models developed by Ibarra et al. (2005) that capture the post-peak softening branch of the monotonic backbone curve and the degrading hysteretic response. These features are essential to simulating collapse due to the combined effects of inelastic softening and P-Δ effects. To determine the modeling parameters for reinforced concrete beam-columns, Haselton et al. (2007) calibrated the concentrated spring model to results from more than 250 experimental tests. A comparison of the cyclic test data with model predictions for one of these columns is illustrated in Figure 2.

Collapse Assessments, and Building Code Applications

Collapse Predictions for Code-Conforming Reinforced Concrete Moment Frames

Using the method and models described above, Haselton and Deierlein (2007) assessed the collapse risk of 30 code-conforming reinforced concrete special moment frame structures, designed for a high seismic site in California. All structures are office buildings, and were fully designed according to the governing code provisions (2003 IBC, ASCE 7-02 and ACI 318-02). Haselton examined both space and perimeter frame systems with heights ranging from 1 to 20 stories. The results are illustrated in Figure 3a in terms of the conditional probability of collapse, that is the probability of collapse of the structure given that a rare ground motion (with 2% likelihood of being exceeded in 50 years) occurs. The collapse results are relatively consistent over structures of different heights, though the 1-story and mid-rise (8- and 12-stories) have slightly worst performance. It is clear that perimeter frame structures have consistently higher collapse risk than the space frame structures. Space frames tend to have higher lateral overstrength because the relative dominance of gravity and lateral loads in the design. In addition, perimeter frames are more flexible, which increases P-Δ effects, causing deformations to concentrate in a smaller number of stories.

The collapse assessment methodology also allows us to directly evaluate the effects of changes to building code provisions. In ASCE 7-05, the minimum base shear requirement was changed from the previous 2002 edition, leading to a significant reduction in design base shear for tall buildings at some sites. To examine the impacts of the revised provisions, Haselton redesigned the 12- and 20-story

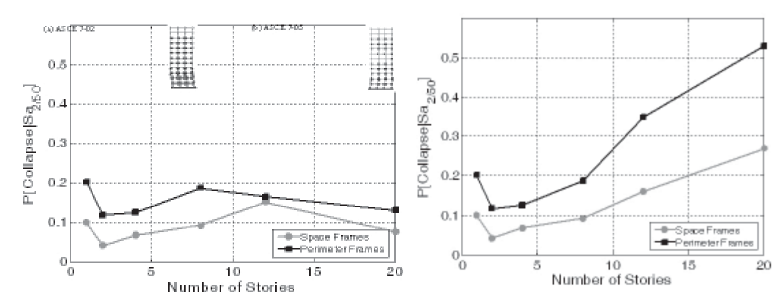

Figure 3. Predicted collapse performance of reinforced concrete special moment frames, measured in terms of probability of collapse for a 2% in 50 year ground motion. Comparison of figures (a) and (b) illustrates the minimum base shear requirements change between ASCE 7-02 and ASCE 7-05. The building images show the predominant collapse mechanism for the 12-story structure, which is more localized for the weaker ASCE 7-05 designs.

buildings according to ASCE7-05. Because of the reduced minimum base shear requirement, these structures have a lower design base shear than their ASCE 7-02 counterparts (eg. the design base shear of the 20-story building decreased from 0.044g to 0.022g). Figure 3b shows the collapse safety predictions for these redesigned (ASCE7-05) structures. Under the 2% in 50 year ground motion, the buildings designed according to ASCE 7-05 have a significantly higher probability of collapse. We also observe that the collapse safety of the ASCE 7-05 buildings reduces significantly as building height increases, and the predominant collapse mechanism tends to be more localized for the weaker ASCE 7-05 designs. These findings suggest that the minimum base shear requirement in ASCE 7-02 are an important component of ensuring relatively consistent collapse risk for buildings of varying height. Based largely on this study, the ASCE 7 committee has recently issued an addendum to reinstitute the minimum base shear requirement of the previous 2002 edition.

Comparison of Modern and Older RC Moment Frames

This collapse assessment procedure can also be used to evaluate the performance of structures designed according to out-dated building codes. Liel has assessed the seismic collapse risk of California's older (pre-1975) reinforced concrete frame structures, whose deficiencies, principally the lack of ductile detailing of reinforcement and potentially brittle failure modes, have been exposed by damage in past earthquakes. This study is based on the design, modeling and assessment of 26 non-ductile reinforced concrete frame structures designed according to the 1967 Uniform Building Code. These structures are designed for the same Los Angeles site as the code-conforming structures. We also use the same model (Figure 1), though the parameters defining the monotonic and cyclic behavior of beams and columns reflect the reduced ductility of these systems, and possible joint shear failure is explicitly modeled. In addition, we examined and modified results of the dynamic analysis account for column shear failure. As shown in Figure 4, the 1967 moment frames have a significantly larger probability of collapse than the code conforming structures. When collapse safety is measured instead in terms of collapse rate (mean annual frequency of collapse), we find that the older reinforced concrete frame structures are approximately 40 times more likely to collapse than the code-conforming reinforced concrete frame structures. These metrics can be used to explicitly evaluate the costs and benefits of retrofitting these deficient structures.

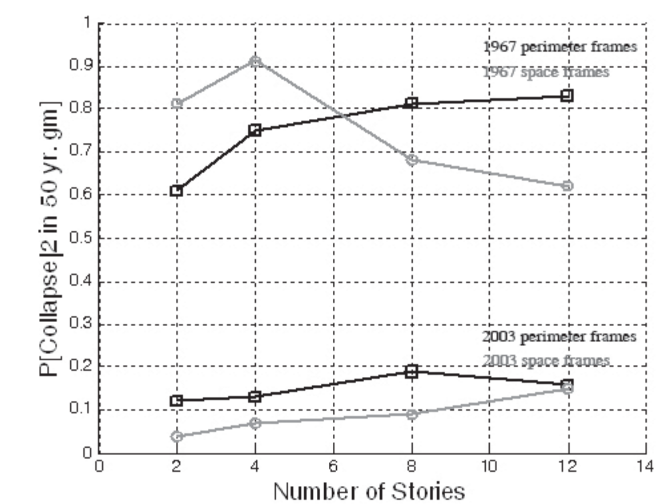

Figure 4. Predicted collapse performance of code-conforming (2003) and existing (1967) reinforced concrete moment frames. Due to changes in building code provisions, particularly related to reinforcement detailing and capacity design, the 2003 structures are much safer.

Conclusions

As described here, quantitative assessment of collapse performance for the first time allows us to compare the collapse safety of different structures and structural systems in order to systematically examine the implications of design standards and

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