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The John A. Blume Earthquake Engineering Center

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THE BLUME CENTER BIDS FAREWELL TO ASSOC. DIRECTOR

On June 30, the Blume Center said goodbye to Dr. Stephanie King, the Center's Associate Director for the past three and a half years. Stephanie received her Master of Science degree from Stanford in 1990 and her Ph.D. in 1994. She continued on at the Blume Center as a postdoctoral researcher and on January 1, 1996 became Associate Director. Stephanie will be joining the private sector, but will keep her affiliation with Stanford and the Blume Center as a Consulting Professor. All of us at the Blume Center extend our thanks to Stephanie for her help and service through the years. Her enthusiasm, organizational skills, willingness to help and smiling face will be missed. We wish her all the best in her new endeavers.

OPEN FORUM SHOWCASED AT AFFILIATES' MEETING

On April 30, 1999, The John A. Blume Earthquake Engineering Center held its bi-annual Affiliates' Meeting. The meeting brought together affiliates of the Blume Center, experts in earthquake engineering, students and faculty for a day of presentations, an open forum, and a dinner celebrating the 90th birthday of **Dr. Blume**.

The presentations began with an introduction by **Professor Anne Kiremidjian**. **Professor Gregory Deierlein** spoke on "Evaluating Fracture Toughness Requirements for Welded Steel Structures" (**Wei-Ming Chi**, Research Assistant), followed by **Professor Laura Lowes** speaking on "Analysis of Reinforced Concrete Beam-Column Bridge Connections". "Modeling Nonlinear Ground Response Including SSI Effects" was presented by **Eric Lin** (**Professor Ronaldo Borja**, Advisor), and "Research on Health Monitoring Systems, Algorithms and Toolboxes" by **Professor Kincho Law** (**Jerome Lynch**, Research Assistant). **Akshay Gupta** (**Professor Helmut Krawinkler**, Advisor) presented findings on "Seismic Performance of Frame Structures", and **Nicolas Luco** (**Professor Allin Cornell**, Advisor) spoke on "Seismic Demand and Capacity". The final presentor was **Hjörtur Thráinsson** (**Pro-**

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BLUME CENTER NEWS

Structural Engineering and Geomechanics was delighted to graduate 23 students receiving master of science degrees, one receiving an Engineering degree and eleven students receiving a Ph.D. degree. **Hemant Shah** (MS '89) spoke at the CEE graduation and shared his experiences of the early years at Risk Management Solutions (RMS).

Professor Greg Deierlein presented results of a fracture mechanics investigation of welded connections at a meeting of the SAC Joint Venture Committee on Connection Performance on April 9.

On April 10, a group of 40 students, staff and faculty, led by **Professor Emeritus Jim Gere**, took a field trip to the Pinnacles National Monument for a 7-mile hike and a look at the creeping fault in Hollister, followed by dinner next to the San Andreas fault in San Juan Bautista.

At the ASCE Structures Congress in New Orleans (April 19-22) **Professor Helmut Krawinkler** and his former Ph.D. student **Dr. Pasan Seneviratna** received the 1998 Munro Prize for the best paper of Vol. 20 (year 1998) of the Journal of Structural Engineering.

On May 20, **Professor Greg Deierlein** presented at an invited seminar at CalTech entitled "Fracture Toughness Demands in Welded Moment Concrete".

Professor Helmut Krawinkler received an AISC Special Achievement Award for "his lasting contributions in developing new steel seismic design and analysis methods" at the North American Steel Construction Conference in Toronto (May 19-21).

Professor Greg Deierlein participated in meetings of the AISC task force on future planning of performance-based design standards for steel structures in Chicago on April 13; a BSSC task force to plan a NEHRP initiative to develop improved sysstem response parameters for linear seismic design procedures in San Francisco in May 26; and the PEER/PG&E Joint Management Committee in San Franciso on May 24.

Professors Helmut Krawinkler and **Greg Deierlein** and **Dr. Stephanie King** participated in the CUREe Board Meeting hosted at Stanford University on May 21.

Stanford was well represented at the PEER Annual Meeting held in Richmond on June 16. Attending and making presentations were **Professors Anne Kiremidjian**, **Helmut Krawinkler**, **Allin Cornell**, **Kincho Law**, **Laura Lowes**, **Greg Deierlein** and

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RESEARCH SPOTLIGHT

A Building Damage Estimation Method for Business Recovery

Keith Porter, Ph.D. Candidate
Anne S. Kiremidjian, Professor

INTRODUCTION

Owners of buildings that are subject to earthquake damage make high-value decisions regarding earthquake preparedness, risk management, and planning for business recovery. These decisions involve investment choices, seismic retrofit, purchase of earthquake insurance, etc. Other parties with an interest in a building's seismic risk (tenants, insurers, and government agencies) make similar decisions and likewise would benefit from high-quality seismic risk information.

The quality of earthquake risk information depends on a good seismological model of earthquake occurrence and attenuation, and on a vulnerability model that accurately reflects the building's susceptibility to damage and loss of use. The seismological parts of seismic risk analysis are well developed compared with models of building vulnerability to ground shaking. However, existing approaches to seismic vulnerability suffer from significant shortcomings.

Empirical models are typically based on aggregated insurance loss data. They offer ability to postdict past earthquake losses accurately. However, their data are typically proprietary, sparse at high shaking intensities, fail to distinguish between repair and upgrade, and most notably are insensitive to design detail and to technological innovation subsequent to the earthquakes from which they spring.

Heuristic models such as ATC-13 [Applied Technology Council, 1985] and HAZUS [NIBS/FEMA, 1995] are based in large part on expert judgment. They offer the advantages of general availability and a comparatively open technical approach. But because they rely on opinion, these models are often seen to offer less assurance of accuracy. They also face the problems of verification and insensitivity to design detail and to technological innovation.

New approach: assembly-based vulnerability. The present research proposes to remedy these shortcomings by breaking the vulnerability problem into smaller, more tractable pieces. Instead of treating a building as a monolithic entity identified solely by its location and structure type, the building is treated as a collection of parts or *assemblies*, each of which is subjected to probabilistic demand that may be modeled using ground-motion simulation and structural analysis. Each assembly is modeled as having a probabilistic capacity to resist damage. If demand exceeds capacity, an assembly fails and must be repaired (or demolished and replaced). Gantt scheduling can then be used to estimate loss-of-use duration. Equation 1 gives the general formulation for the loss computations.

$$P[C|O] = \sum_{\substack{All \\ assemblies}} \int\int\int\int\int P[C|X]P[X|Z]P[Z|S] P[S|M,R,k,O]P[M,R,k|O]\,dx\,dz\,ds\,dm\,dr \quad [1]$$

P[*] represents the probability of argument *. C is cost of repair, labor, or revenue loss. Physical damage is generically given as X. Parameters Z, S, M, R and k are respectively structure response, ground shaking, event magnitude, distance from the rupture zone to site O, and faulting mechanism. Loss for a given (M, R, k) scenario is determined by removing the integration over magnitude and distance. The integral is readily solved by Monte Carlo simulation.

The approach is summarized in Figure 1. The chart in Figure 1 is known as an influence diagram (or alternatively as a relevance or decision diagram) and describes the relationship of the various components [e.g., Howard and Matheson, 1981]. The generic models that are required for the overall approach are listed in the vertical block at the left of the diagram. The horizontal block on the top right describes the relationship between these components. The overall model pertains to a single building at a specified site, O. The five models listed on the left side of the diagram are: seismicity, ground motion, structural response, assembly fragility (actually a collection of many fragility models, one for each assembly type), and repair (again, one for each assembly type). These models are represented by conditional probability distributions. The horizontal block at the upper right represent the parameters of true interest: ground shaking at the site; structural response of the building in question; damage conditions of individual assemblies within the building, repair cost, loss-of-use duration, and finally, total economic value.

Seismicity, ground motion, and structural response models. The seismicity model in Figure 1 is readily available, e.g., from US Geological Survey fault data [USGS, 1999]. Ground shaking intensity, in terms of $S_a(T_1)$, is simulated using an appropriate ground motion attentuation [e.g. Boore et al., 1997]. In the present research, a ground-motion time history $a(t)$ matching this $S_a(T_1)$ is simulated using an ARMA (2,1) approach [Polhemus and Cakmak, 1981]. Structural response is determined using the simulated ground motion, e.g., with DRAIN-2DX. Resulting peak responses Z (drift, floor acceleration, etc.) are recorded for later use. Figure 2 shows peak 3rd story drift for a demonstration building subjected to each of 2400 simulated ground motions. The figure also shows the fitted lognormal distributions of Z conditioned on two $S_a(T_1)$ values.

Figure 1 – ABV influence diagram for retrofit design decision situation

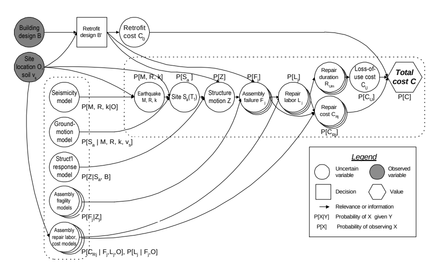
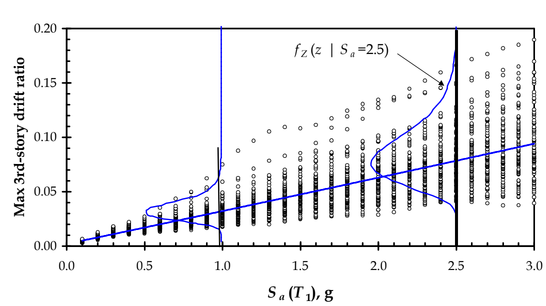


Figure 2 – Sample peak structural response using DRAIN-2DX



Assembly fragility. $P[X_j|Z_i]$ represents assembly fragility: X_j refers to failure of a particular type of assembly j; Z_i to peak structural response to which the assembly is exposed. Such a model is established for every assembly in the building. Figure 3 shows a sample fragility model for drywall partitions, using laboratory test data by Rihal [1982]. Where laboratory or earthquake experience data are unavailable or inadequate to develop assembly fragility, a theoretical model may be created using reliability analysis methods.

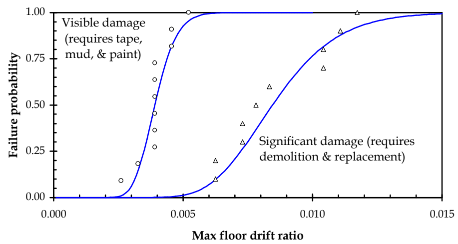


Figure 3 – Sample assembly fragility model: 8'x8' drywall partition on 3-5/8" metal stud

Unit cost. Assembly labor and repair-cost models are represented by $P[L_j|X_j,O]$ and $P[C_{R,j}|X_j,L_j,O]$, respectively, where L_j refers to the labor (in laborer-hours) required to repair a single instance of assembly type *j*. $C_{R,j}$ refers to cost in dollars to repair an instance of assembly type *j*. $C_{R,j}$ is determined using Equation 2, in which material cost per unit assembly *j* is represented by $C_{m,j}$; labor cost (dollars per laborer hour) by $C_{l,j}$; productivity, by $C_{p,j}$ (units of type *j* repaired per labor hour). Mean values for each parameter are published by RS Means [1997] and others; statistical distributions and variances are assumed. Total unit repair costs are then simulated using Monte Carlo methods, and a distribution fit to the result. Figure 4 shows a sample repair-cost model for drywall partitions. The total repair cost is calculated by multiplying unit costs with the number of damaged units, and summing overall assembly types. Figure 5 shows preliminary results for 600 simulations of total repair cost for a sample building.

$$C_{R,j} = C_{m,j} + C_{l,j} / C_{p,j} \qquad [2]$$

Figure 4 – Sample repair-cost model: demolish and replace 8'x8' drywall partition

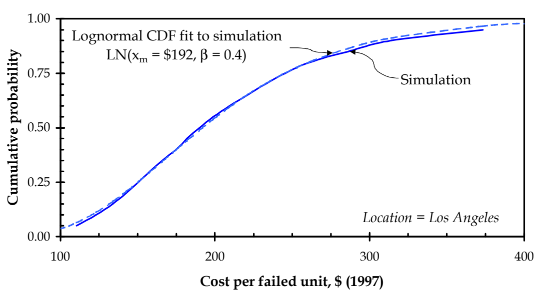
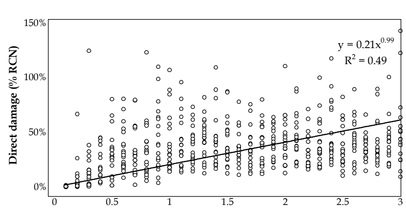


Figure 5 – Preliminary direct-damage simulations for demonstration building



Repair scheduling. Given a damage state determined in the previous step, repairs may be scheduled using standard Gantt scheduling techniques. Figure 6 shows preliminary results for 600 simulations using fast-track repair schedule, in which enough repair crews are hired so that repairs of all operational areas may are made in parallel, with minimal delays for change of trade.

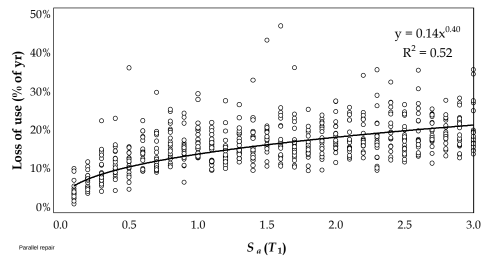


Figure 6 – Preliminary fast-track loss of use simulations for demonstration building

CONCLUSIONS

The most notable challenge of the ABV approach is to create a fragility model for each building assembly. Its advantages over existing models are several. The new approach treats each building as a unique structural system supporting a distinct configuration of architectural, mechanical, electrical, plumbing, and furnishing assemblies. Retrofit and other decisions may be evaluated in terms of cost and benefit to that particular building. Further, ABV provides insight into the vulnerability of particular assemblies and operational areas, offering opportunities to assess targeted retrofit and recovery decisions. Finally, ABV may be incrementally improved using published empirical or theoretical data. In summary, it is hoped that the proposed approach will allow more accurate, dependable, and building-specific earthquake risk analyses to be performed than are currently possible.

ACKNOWLEDGMENTS

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FELLOWSHIPS AWARDED

Four students have been awarded fellowships starting in the Fall Quarter.

A Stanford Graduate Fellowship (3 years) was awarded to **Bhanu Gotluru** to work in Structural Engineering. The Stanford Graduate Fellowship provides support for 300 graduate students each year in Sciences and Engineering. **Kossi Sama** recieved a National Science Foundation Fellowship to work in Geomechanics. **Blaise Duvernay** received the Blume Center Fellowship. The Blume Center Fellowship is awarded to graduate students for study and research in earthquake engineering. And **Keith Porter** was awarded one of six Stanford ARCS (Achievement Rewards for College Scientists Foundation) Fellowships.

Congratulations to all of the fellowship award recipients.

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several graduate students.

During the Spring Quarter, **Professor Allin Cornell** gave his EERI Distinguished Lecture at the University of Michigan, University of Illinois, Cornell University and at the Mid-America Chapter of EERI at Washington University (St. Louis).

Professor Kincho Law attended the Model-Based Simulation workshop sponsored by the National Science Foundation, June 24-25.

AFFILIATES' MEETING - continued from page 1

fessor Anne Kiremidjian, Advisor) on "Ground Motion Simulation with Complete Fourier Transform".

The attendees then enjoyed refreshments and a tour of the Blume Center before heading to Tressider Memorial Union for the Open Forum. The forum, entitled "Shake, Rattle and Retrofit", discussed how Stanford has managed its earthquake risk and the implications to the surrounding communities. The panel included **Anne Kiremidjian** (Stanford During the 1906 and Loma Prieta Earthquakes); **Maurice Power** of Geomatrix Consultants (Earthquake Hazard Exposure at and around the Stanford Campus); **William Holmes** of Rutherford & Chekene (Historical and Other Special Structures on the Stanford Campus); **Norm Abrahamson** of Pacific Gas & Electric (Experience of Utilities and What We Can Expect); **Craig Comartin** of Comartin-Reis (Risk Management History at Stanford); and **Michael Rosenthal**, Associate Vice Provost for Capital Planning and Management (Current Risk Management Policies at Stanford). Dr. Stephanie King moderated the question and answer period.

The afternoon festivities continued with cocktails and dinner at the Faculty Club, in honor of **John Blume's** 90th Birthday. Following a delightful meal, Dr. Blume listened in on the phone to tributes to him by **Joe Nicolleti**, **Jim Gere**, and **Anne Kiremidjian**, regaled his exploits and adventures as a young man as well as his incredible contributions to the field of earthquake engineering and devotion to Stanford University.

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