BLUME CENTER NEWS

Ph.D. Candidate Kerri Tokoro has won ASCE’s 2004 O.H. Ammann Research Fellowship in Structural Engineering. The fellowship was endowed in 1963 to foster advances in structural design and construction. Tokoro’s research is on developing a technique to predict response interactions in steel frame structures.

Dr. Renate Fruchter, in collaboration with Dr. Ichiko and Mr. Date from Obayashi Corporation, Japan, worked with Stanford OTL to license and deploy at Obayashi the ThinkTank web-based collaboration technology developed by Dr. Fruchter’s team in the PBL Lab at Stanford.

Ph.D. Candidate Jack Baker was awarded a fellowship to participate in the East Asia Summer Institutes in Japan program, sponsored by NSF, and the Japan Society for the Promotion of Science. He visited several major research centers as part of the National Hazards Mitigation in Japan program, and then spent two months as a visiting researcher at Nagoya University and Kyoto University.

Dr. Renate Fruchter gave three presentations at the 10th International Conference on Computing in Civil and Building Engineering (ICCCBEX), in Weimer, Germany this June. Dr. Fruchter also gave an invited lecture on "AEC Global Teamwork" at the Technical University Bochum in Germany.


Prof. Allin Cornell, Greg Deierlein, Helmut Krawinkler, and Eduardo Miranda presented papers at the International Workshop on Performance-Based Seismic Design - Concepts and Implementation, held in Bled, Slovenia, from June 28 to July 1. This workshop, organized by Profs. Fajfar (U. of Ljubljana, former Shimizu Visiting Professor at Stanford) and Krawinkler, brought together 44 of the leading researchers and engineers from 14 countries to assess the state of knowledge and practice related to performance-based earthquake engineering. The PEER Center was the main sponsor of the workshop.

Prof. Ronnie Borja presented a keynote lecture at the 4th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2004) held in Jyväskylä, Finland, on July 24-28, entitled "Deformation Bands in Multiphase Porous Materials".

In July, Prof. Sarah Billington led a half-day hands-on session for the Stanford Summer Engineering Academy introducing incoming freshmen to civil engineering. Students participated in a web-based activity where they worked as teams of civil engineers to decide if a certain dam should be repaired or decommissioned based on running fracture analyses and risk analyses as well as evaluating environmental impacts.

Prof. Sarah Billington attended the Planet-X Symposium titled...
### RESEARCH SPOTLIGHT

**The Role of Epsilon in a Vector-Valued Intensity Measure**

Jack W. Baker and C. Allin Cornell

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**Introduction**

As nonlinear dynamic analysis becomes a more frequently used procedure for evaluating the demand on a structure due to earthquakes, it is increasingly important to understand which properties of a recorded ground motion are most strongly related to the response caused in the structure. A value that quantifies the effect of a record on a structure is often called an Intensity Measure (IM). Spectral acceleration at the first-mode period of vibration, \( S(T_i) \), has commonly been used as an IM. But among records with the same value of \( S(T_i) \), there is still significant variability in response of a multi-degree-of-freedom, nonlinear structural model. Here we consider a two-parameter (i.e., vector-valued) intensity measure consisting of \( S(T_i) \) as before, and a second parameter termed \( \varepsilon \) (“epsilon”). It is found that this IM is significantly superior to the level. This result is referred to as a drift hazard curve, and is used for predicting the demand on a structure using a vector-valued IM as a function of \( \varepsilon \) for each \( S(T_i) \) level. In doing this, we must note that some records cause a collapse in the structure, and thus must be treated separately.

The probability of collapse as a function of \( \varepsilon \) is first estimated using logistic regression, which is a commonly used tool for analyzing binary data. Among a suite of records scaled to \( S(T_i) = x_i \), we designate \( C \) as an indicator variable for records that cause collapse and use the \( \varepsilon \) value of each record as our predictor. The logistic regression prediction is then:

\[
\hat{P}(C \mid S(T_i) = x_i, \varepsilon = x_\varepsilon) = \frac{\exp(\hat{\beta}_0 + \hat{\beta}_1 x_\varepsilon)}{1 + \exp(\hat{\beta}_0 + \hat{\beta}_1 x_\varepsilon)}
\]

where \( \hat{\beta}_0 \) and \( \hat{\beta}_1 \) are coefficients to be estimated from regression on a dataset that has been scaled to \( S(T_i) = x_i \). By performing this regression for a range of \( S(T_i) \) levels, one can obtain the probability of collapse as a function of both \( S(T_i) \) and \( \varepsilon \), as seen in Figure 1.

Among the remaining non-collapsing records, there tends to be a relationship between \( \varepsilon \) and EDP of the form \( \ln(EDP) = \beta_2 + \beta_3 \varepsilon \), where \( \beta_2 \) and \( \beta_3 \) are constant coefficients, and \( \varepsilon \) is the prediction error (“residual”). We can use linear least-squares regression to obtain estimates of the coefficients (denoted \( \hat{\beta}_2 \) and \( \hat{\beta}_3 \)) and the variance of the residuals (denoted \( \hat{\sigma}_\varepsilon^2 \)). We have verified that the residuals are well represented by a Gaussian distribution, so the probability of exceeding an EDP level \( z \) given \( S(T_i) = x_i \), \( \varepsilon = x_\varepsilon \), and no collapse can be expressed as:

\[
P(EDP > z \mid S(T_i) = x_i, \varepsilon = x_\varepsilon, \text{no collapse}) = 1 - \Phi \left( \frac{\ln z - (\hat{\beta}_0 + \hat{\beta}_1 x_\varepsilon)}{\hat{\sigma}_\varepsilon} \right)
\]

where \( \Phi(*) \) denotes the standard Gaussian cumulative distribution function.

The possibilities of collapse or no collapse are combined using the Total Probability Theorem and Equations 2 and 3 to compute the conditional probability that EDP exceeds \( z \):

\[
P(EDP > z \mid S(T_i) = x_i, \varepsilon = x_\varepsilon) = \Phi \left( \frac{\ln z - (\hat{\beta}_0 + \hat{\beta}_1 x_\varepsilon)}{\hat{\sigma}_\varepsilon} \right) + \left(1 - \Phi \left( \frac{\ln z - (\hat{\beta}_0 + \hat{\beta}_1 x_\varepsilon)}{\hat{\sigma}_\varepsilon} \right) \right) - \Phi \left( \frac{\ln z - (\hat{\beta}_0 + \hat{\beta}_1 x_\varepsilon)}{\hat{\sigma}_\varepsilon} \right)
\]

Although \( x_i \) does not appear in Equation 4, our estimate is implicitly a function of \( x_i \), because records are scaled to \( S(T_i) = x_i \), before generating the response data to estimate \( \hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3, \) and \( \hat{\sigma}_\varepsilon^2 \).

When performing the logistic and linear regressions needed for Equation 4, it has been found that \( \varepsilon \) is a statistically significant predictor of structural response for a range of structures and spectral acceleration levels considered. The important conclusion is that records with larger epsilon values tend to have a lower probability of causing collapse, and cause lower levels of structural response among records that do not cause collapse.

**Why Does Epsilon Affect Structural Response?**

When considering why \( \varepsilon \) could affect structural response, we consider current knowledge about nonlinear response of multiple-degree-of-freedom (MDOF) structures. For a given \( S(T_i) \) level, values of \( S_\varepsilon \) at periods other than \( T_i \) are known to affect the response of a nonlinear MDOF structure. This is because \( S_\varepsilon \) at shorter periods affect the response of higher
modes, and $S_a$ at longer periods affect nonlinear structures because of the effective lengthening of the first mode. Thus, given two records with the same $S_a(T_1)$ value, the record with higher $S_a$ values at periods other than $T_1$ will tend to cause larger responses in a nonlinear MDOF system.

A record with a positive $\varepsilon$ value is one that has a larger-than-expected $S_a$ at the specified period. But what does it tell us about the spectral acceleration at other periods? $S_a(T_1)$ is positively correlated with $S_a$ at other periods, but not perfectly correlated. Thus if $\varepsilon$ at $T_1$ is positive, then the expected values of $\varepsilon$ at other periods are positive but less than the $\varepsilon$ at $T_1$. The result is that a positive $\varepsilon$ value at $T_1$ tends to indicate a "peak" in the response spectrum at $T_1$, and a negative $\varepsilon$ value tends to indicate a "valley." Consider scaling a record with a peak and a record with a valley to the same $S_a(T_1)$ level. At $T_1$, the two records will have the same spectral acceleration by construction, but at other periods the valley record will tend to have larger spectral accelerations, which induce larger MDOF responses, than the peak record, as seen in Figure 2. Therefore, $\varepsilon$ is an indicator of spectral shape, and this is why it is effective in predicting the response of nonlinear MDOF models. Using a second-moment model for logarithmic response spectra, it is shown by Baker and Cornell [1] that $\varepsilon$ is a consistent estimator of peaks and valleys: the effect seen in Figure 2 is not unique to these two records.

**Epsilon and Drift Hazard**

The drift hazard methodology outlined above is now applied to a sample structure, to demonstrate the effect of adding $\varepsilon$ to the IM.

**Description of the structure:** The structure analyzed is a reinforced-concrete moment-frame building located in Van Nuys, CA, which is serving as a test-bed for PEER research. The model has a first-mode period of 0.8 seconds, and contains nonlinear elements that degrade in strength and stiffness, in both shear and bending. Forty historical earthquake ground motions from California are used to analyze structural response. Epsilon values were not considered as a criterion for selection of records, so that the $\varepsilon$ values of the record set are random.

**Ground motion hazard:** We consider the ground motion hazard at the site of the test structure. As the annual rate of exceedance decreases (and the $S_a(T_1)$ level increases) the epsilons contributing to the hazard shift to larger values. In general, for any hazard environment, it can be shown that the ground motion hazard at low mean annual frequencies of exceedance will be dominated by positive $\varepsilon$ events [1]. Because positive $\varepsilon$ records cause lower response levels on average, it is expected that neglecting to account for $\varepsilon$ will result in conservative estimates of the drift hazard, and this is verified for the sample structure.

**Drift hazard results:** The structural response calculations were combined with the ground motion hazard for the Van Nuys site to compute drift hazard curves as shown in Figure 3. The vector IM $\{S_a(T_1), \varepsilon\}$ is evaluated using Equation 1, and the scalar IM $S_a(T_1)$ is evaluated using an analogous procedure. We see that inclusion of $\varepsilon$ in the IM results in lower mean annual frequencies of exceedance at higher levels of drift. Analysis was also performed using a vector-valued IM $\{S_a(T_1), \text{magnitude}\}$ using the same procedure, and replacing $\varepsilon$ with magnitude. While the use of magnitude lowers the drift hazard, the effect is much less pronounced than when $\varepsilon$ is used, because magnitude’s impact on spectral shape is comparatively mild. (Using distance as a second parameter results in a negligible change in drift hazard.)

**Conclusions**

It is seen that $\varepsilon$ has a significant ability to predict structural response, because it tends to indicate whether $S_a$ at a specified period is in a peak or a valley of the spectrum. For a fixed $S_a(T_1)$, records with positive $\varepsilon$ values cause systematically smaller demands in structures than records with negative $\varepsilon$ values. In addition, by examining disaggregation of the ground motion hazard, it is seen that at low mean annual frequency of exceedance the ground motions are all positive-epsilon motions. Therefore, the practice of scaling up zero-epsilon (on average) records to represent records with positive epsilons is likely to result in overestimation of the demand on the structure at a given hazard level.

A vector-valued IM consisting of $S_a(T_1)$ and $\varepsilon$ has been proposed. This IM will account for the effect of $\varepsilon$ on structural response, correcting the bias seen when using $S_a(T_1)$ alone as an IM. Alternatively, one could correct for the effect of $\varepsilon$ on structural response by intelligently selecting records that have the proper $\varepsilon$ value (based on disaggregation results), and then using $S_a(T_1)$ as a scalar IM. In either case, it is important to consider the possible effect of $\varepsilon$ when estimating structural response.

**Acknowledgements**

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**References**


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Figure 1. Prediction of the probability of collapse as a function of both $S_a(T_1)$ and $\varepsilon$.

Figure 2. Scaling a negative $\varepsilon$ record and a positive $\varepsilon$ record to the same $S_a(0.8s)$: an illustration of the peak and valley effect.

Figure 3. Mean annual frequency of exceedance versus maximum interstory drift using scalar and vector-valued IMs.
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"Technology Innovations Toward a Sustainable Planet" held on the Stanford Campus in July. Ph.D. Student Molly Morse presented a poster at the symposium on the research she is conducting with Prof. Billington regarding bio-degradable composites for the building industry.

Prof. Krawinkler gave a presentation on “Sidesway Collapse of Frames with Deteriorating Properties” at the SEAOC Convention held in Monterey from August 25 to 28.

NSF NEES-R Awards

The Blume Center is represented well in the first round of NEES research grants, with Stanford faculty and alumni involved with five of the ten projects that were awarded by the NSF. Prof. Helmut Krawinkler is leading a project to investigate the sidesway collapse of deteriorating structural systems. Prof. Anne Kiremidjian will be working with the research team at the University of Nevada Reno dealing with seismic performance of bridge systems with conventional and innovative materials. Prof. Amit Kanvinde (PhD ’94), who recently joined the faculty at U.C. Davis, is leading a project on testing and simulation of ultra-low-cycle fatigue cracking in steel structures. Amit will be collaborating with his former adviser, Prof. Greg Deierlein, and a Stanford graduate student on this project. Prof. Luciana Barroso (PhD ’99) is co-PI on a project at Texas A & M concerning the in situ determination of soil modulus and damping as a function of induced strain. Prof. Jerome Lynch (PhD ’03) is co-PI on a project at the University of Michigan dealing with damage tolerant and intelligent slab-column frame systems, which combine advanced materials and embedded wireless sensors. Look for more developments on these and other projects in upcoming newsletters.

SPRING 2004 GRADUATES

Arash Altoontash and Gloria Ting Ting Lau received their Ph.D. degrees in Structural and Geotechnical Engineering during the Summer quarter. Arash is now working at Walter P. Moore and Assoc., in Los Angeles, and Gloria is with FindLaw, Inc. in Mountain View.

Published Papers


Alumni News

Pablo Sanz (MS ’02) and his wife, Alejandra, welcomed their first child, a daughter, on June 30. Emma weighed in at 6 lbs., 10 oz., and was 20” long. Proud papa returned to Stanford this Fall to study for his Ph.D.

Alumni, Affiliates and Friends of the Blume Center are encouraged to send news items about yourselves to racqueh@stanford.edu for inclusion in the next newsletter.

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