Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	*Parameterization of Non-Stationary Acceleration Time History*—**1G00**		
Start/End Dates	12/1/01 – 6/30/04	Budget/ Funding Source	$142,839 / PG&E/CEC
Project Leader (boldface) and Other Team Members	**Bazzurro (AIR Worldwide),** Luco (AIR Worldwide), Sjoberg (AIR Worldwide), Cornell (Stanford Univ.)		

1. Project goals and objectives

This project consists of the primary task (1G00) and three addendum tasks (denoted here as AT1, AT2, and AT3). The goals and objectives of each of these tasks are …

1G00: To investigate whether "non-stationary" characteristics of seismograms, in addition to more conventional ground motion intensity measures (e.g., spectral values), may improve the accuracy in the prediction of structural seismic performance.

AT1: To provide the quantitative technical basis to establish the threshold limits beyond which ground motion record scaling introduces bias in the nonlinear response of structures.

AT2: To provide the tools necessary for validation of ground motion simulation methods, addressing the issue of nonlinear structural response.

AT3: To provide a technical basis for assumptions made in the "Advanced Seismic Assessment Guidelines" study (PEER Lifelines 507 Project supervised by Prof. C.A. Cornell) regarding (i) whether the ultimate capacity of a structure damaged by an earthquake mainshock can be accurately estimated by applying a Nonlinear Static Pushover technique to mimic the effect of the mainshock, followed by a SDOF-based Nonlinear Dynamic Analysis technique to estimate its residual capacity to withstand aftershocks, and (ii) the distribution of the structure's residual roof drift angle after a mainshock excitation that results in a given peak roof drift angle.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

The results of the first three tasks (1G00, AT1, AT2) provide guidance in selecting, scaling, and simulating earthquake ground motion recordings for nonlinear dynamic analysis during vulnerability-mitigating design and/or damage evaluation of structures. The results of the fourth task (AT3) were used to update the "Advanced Seismic Assessment Guidelines" for existing structures that are common in the PG&E building inventory. Predicting the post-earthquake functionality of such structures is a crucial step in evaluating the likelihood that the PG&E power distribution network will not be able to provide power to customers. The Guidelines are also applicable to a more general class of structures that are not limited to those owned by PG&E.

3. Brief description of the accomplishments of the project

1G00: The use of the Empirical Mode Decomposition algorithm (developed by Norden E. Huang) is explored in search of ground motion record characteristics that induce severe structural responses, but it is found that the damageability of a record can only be measured in relation to a particular vibration period and specific strength. (This is evidenced by the low correlation between the nonlinear responses to structures of differing strengths, as illustrated in Figure 1). Hence, using record characteristics that do not account for the period and strength of the structure (e.g., characteristics of the velocity pulse, duration) are not likely to be "good" predictors of its response. In contrast, the inelastic displacement of an elastic-perfectly-plastic SDOF system with similar period and strength as the MDOF structure of interest, and, more innovatively, the first "significant" peak displacement of the elastic oscillator with the same fundamental period as the MDOF structure appear to be promising candidate predictors.

AT1: Dependent on the period and strength of the structure, as well as on the nature of the ground motion recordings (e.g., near- versus far-field), it is discovered that scaling recordings by factors greater or less than unity can result in, respectively, significant positive and negative biases in (median) nonlinear structural response relative to un-scaled recordings (as demonstrated in Figure 2). This is found to be true for both "intra-bin" scaling (i.e., same magnitude and distance for scaled and un-scaled recordings) and "inter-bin" scaling, as well as for SDOF and MDOF structures.

AT2: The differences between the median and dispersion of nonlinear structural response to recorded earthquake ground motions (from Northridge) versus those simulated by 7 different seismologists for the same earthquake and site conditions as the real recordings are compared. So seismologists can also validate other simulation methods, an SDOF nonlinear structural analysis code and, in a spreadsheet, nonlinear structural responses for all of the records in the Next Generation Attenuation (NGA) database are provided.

AT3: A nonlinear-static-pushover-based procedure for estimating the (median) residual capacity against aftershocks of a mainshock-damaged structure is developed that is consistent with the results of back-to-back (mainshock-aftershock) nonlinear dynamic analyses. From the dynamic analyses it is observed that the residual capacity is not much different than the intact capacity before the mainshock, particularly if the post-mainshock residual drift is small.

4. Describe any instances where you are aware that your results have been used in industry

Some aspects of the "Advanced Seismic Assessment Guidelines" (revised for AT3) have been applied to the analysis of a 8-story building located in San Jose, CA, by two local engineering companies. PG&E intends to adopt the guidelines for assessing the functionality of their structures after future earthquakes.

5. Methodology employed

In very general terms, all four of the tasks involve numerous nonlinear dynamic analyses of SDOF and MDOF structures of various fundamental periods of vibration and strengths under un-scaled (1G00, AT1, AT2), amplitude scaled (1G00, AT1, AT3), and response-spectrum-matched (1G00) earthquake records. The spectrum-matched records employed in Task 1G00 make it possible to focus on characteristics beyond the elastic response spectrum that influence the nonlinear structural responses. For Task AT3, back-to-back nonlinear dynamic analyses to iteratively scaled earthquake records are performed.

6. Other related work conducted within and/or outside PEER

"Correlation of Damage of Steel Moment-Resisting Frames to a Vector-valued Ground Motion Parameter Set that includes Energy Demands: Collaborative Research with the University of Texas at Austin, and AIR Worldwide" (Funded by USGS NEHRP External Research Program, 2003).

7. Recommendations for the future work: what do you think should be done next?

1G00: The spectrum-matched earthquake records used in this task were created via only one of several available approaches. It is possible that the observed bias in nonlinear structural response introduced by these records (relative to un-scaled records) is particular to the spectrum-matching approach; hence, other approaches should be considered.

AT1: For practical applications, it is important to understand whether the scaling-induced bias in nonlinear structural response observed in this task can be reduced, e.g., by only scaling earthquake records that have an elastic spectral shape similar to the target.

AT2: Further research into the reasons behind the observed differences between recorded and simulated ground motions is warranted. The dataset used here was limited to 20 stations and one earthquake.

AT3: Further studies of the effect of residual drift and damage on residual capacity (both median and dispersion) are important for generalizing the conclusions reached in this task to, e.g., other building types.

8. <u>Author(s), Title, and Date</u> for the final report for this project

1G00: Bazzurro, P. & Luco, N. "Parameterization of Non-Stationary Acceleration Time Histories" (Dec., 2003)

AT1: Luco, N. & Bazzurro, P. "Effects of Ground Motion Scaling on Nonlinear Structural Response" (Sept., 2004)

AT2: Sjoberg, B., Bazzurro, P., & Luco, N. "Post-Elastic Response of Structures to Synthetic Ground Motions" (Aug., 2004)

AT3: a) Bazzurro, P., Cornell, C.A., Menun, C., Luco, N., & Motahari, M. "Advanced Seismic Assessment Guidelines" (Aug., 2004)

b) Luco, N., Bazzurro, P., & Cornell, C.A. "Dynamic versus Static Computation of the Residual Capacity of a Mainshock-Damaged Building to Withstand and Aftershock" (Aug., 2004)

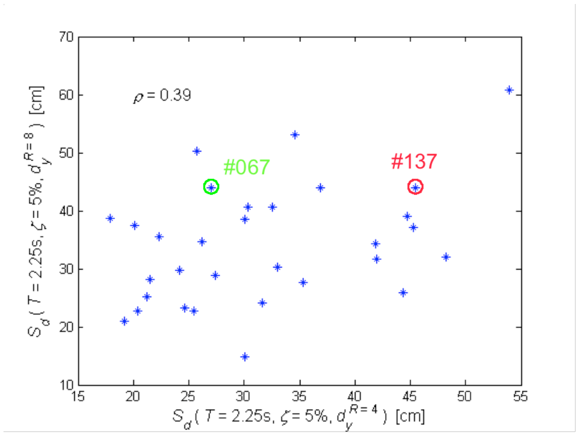

Figure 1. Example of the low correlation between the nonlinear drift responses of structures (SDOF oscillators) with the same fundamental period, but with different strengths. The two earthquake records identified (#067 and #137) both result in relatively large inelastic spectral displacements for oscillator with a strength reduction factor (R) of 8, but only #137 induces a relatively large response when R=4.

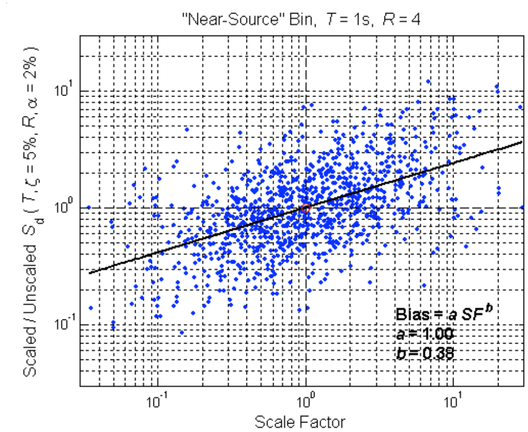

Figure 2. Example of the bias in nonlinear structural response induced by scaling (in amplitude only) earthquake records, as compared to un-scaled records. The records are scaled to match the elastic spectral acceleration of the un-scaled at the fundamental period of the structure of interest (in this case T=1 second).