Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	*Advanced Seismic Assessment Guidelines*—**507**		
Start/End Dates	1/1/01 – 12/31/03	Budget/ Funding Source	$266,301 / PG&E/CEC
Project Leaders (boldface) and Other Team Members	**C. A. Cornell. and P. Bazzurro,** C. Menun, M. Motahari, G. L. Yeo, (Stanford); N. Luco AIR		

1. Project goals and objectives

The objective of this project was to develop a practical professional tool to estimate "tagging fragility curves" which could be used by PG&E to assess the likelihood that a specific building their electrical distribution system would be closed to occupancy (i.e., tagged "yellow" or "red") and hence rendered inoperable after being exposed to a given level of earthquake ground motion.

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 tool will aid in a proposed probabilistic system assessment of the seismic vulnerability of PG&E production and distribution network. By-products have been (1) an explicit way to evaluate a damaged structure after an earthquake to help judge whether it poses a life threat, and (2) a tool to help assess whether a building should be up-graded prior to an earthquake.

3. Brief description of the accomplishments of the project

The project developed a procedure based on the standard NSP (Nonlinear Static Procedure) professional tool, but extended to include application to the post-earthquake damaged structure. This procedure leads the way to the desired fragility curves. The method was put into a draft guideline in the first year of the project. In subsequent years the method was tested by two engineering firms and the procedure was further studied by the investigators to improve the analysis scheme. The final report reflects the results of all these efforts. The following papers were prepared for the 13th World Conference on Earthquake Engineering: (1) Bazzurro, P., Cornell, C.A., Menun, C. And Motahari, M., "Guidelines for Seismic Assessment of Damaged Buildings"; (2) Yeo, G.L. and Cornell, C.A., "Building Tagging Criteria Based on Aftershock PSHA"; and (3) Luco, N. , Bazzurro, P., and Cornell, C. A., "Dynamic Versus Static Computation Of the Residual Capacity of a Mainshock-Damaged Building to Withstand an Aftershock".

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

The procedure has been used on three PG&E structures which were used as tests of the methodology. These cases studies were conducted by Rutherford and Chekene and by Degenkolb and Associates. In addition another application is currently under way for PG&E by Drs. J. Mafei and R. Hamburger.

5. Methodology employed

The NSP is applied to the intact structure to assess the likely damage state as a function of ground motion (IM) level. For each of several such damage states (as indexed by roof drift), another NSP analysis is applied as shown in the first figure below. It is this damaged structure that is the potential life-safety threat and whose status dictates closure or not. The damaged-structure static pushovers are transformed by D. Vamvatsikos' SPO2IDA tool into (median) Incremental Dynamic Analyses (IDAs), as illustrated by the left side of the second figure. These produce estimates of the collapse capacity of the damaged structure. Based on this capacity to resist aftershocks the "tagging-state" is determined by one or more "tagging rules" developed by the project. The original intact structure (right side of the second figure) is assessed to determine the (median) ground motion amplitude necessary to put it into the each of these damage states. To this median are "added" estimates of the "dispersion" – both aleatory and epistemic. The former is provided by SPO2IDA and the latter by tables develop through interviews with three practicing engineers.

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

The efforts of this project led to the sponsorship by the NSF portion of the PEER Center in 2003-2004 of a project on the roll of aftershock assessment in the larger PEER PBEE context. This project will lead to a PhD thesis by Mr. Gee Liek Yeo. Also Prof. Stojadinovic with student Kevin Mackey has been studying aftershock capacity of bridges.

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

At the implementation end it is suggested that there be a workshop and other follow up to disseminate to professionals the new procedures proposed in the guidelines. At the research end there is need to understand still better the connection between earthquake damage in a mainshock and its effect on the capacity of the structure to withstand aftershocks without collapse and life loss. These studies should involve (1) nonlinear dynamic analyses of the type initiated in this project (varying levels of mainshock damage followed by aftershock collapse capacity assessment via IDAs); (2) further study of the role of residual displacement to aid in rapid post-quake evaluation of building safety; and (3) improvement in practical nonlinear static procedures to mimic the damage and residual capacity

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

Paolo Bazzurro, C. Allin Cornell, Charles Menun, Maziar Motahari, and Nicolas Luco, "Advanced Seismic Assessment Guidelines", July, 2004. (To be submitted for publication as a PEER report.)

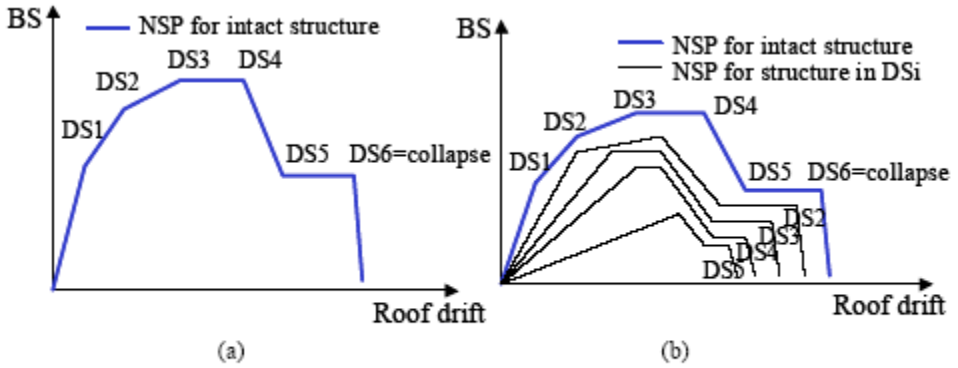

Figure 1: (a) NSP curve for the example building in its, intact, pre-earthquake condition. (b) NSP curves for the building in the pre-earthquake intact condition and in the four most relevant of all the post-earthquake damage states. For simplicity, all the curves for the damaged building have had the residual offset removed.

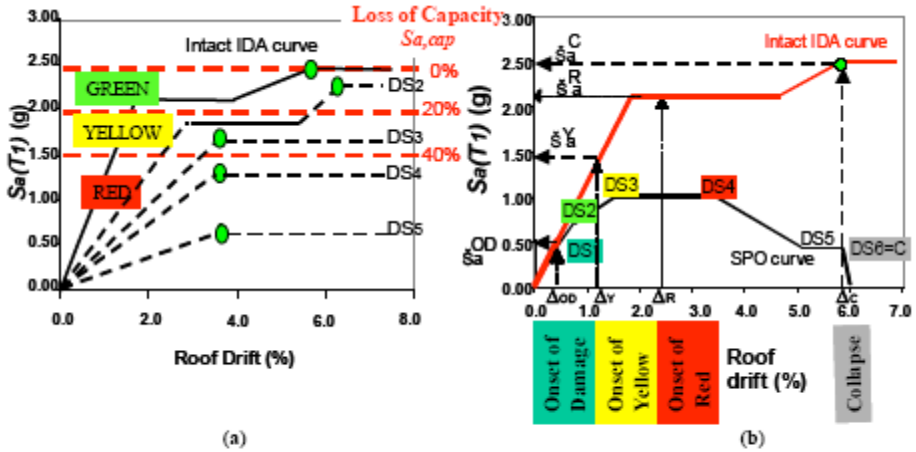

Figure 8: (a) Onset of yellow and red tagging according to the criteria in Figure 4 for a structure with P_θ less or equal to about 2×10^{-4}. (b) Median estimates of the mainshock $S_a(T_1)$ that takes the intact structure to the onset of OD, Y, R, and C. Note that, in general, the onset of a limit state may not occur exactly at the roof drift of any