Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	Methods to Estimate Displacements of PG&E Structures - **505**		
Start/End Dates	5/1/00 – 8/30/01	Budget/ Funding Source	$65,000 / PG&E/CEC
Project Leader (boldface) and Other Team Members	**MacRae, Gregory A.** (PI), and Tagawa, Hiroyuki – Graduate Student, (UW)		

1. Project goals and objectives

The objectives of this applied research are to answer the following questions:

- What are the advantages, disadvantages and relative reliability of the CM and CSM methods for design?
- What modifications are required to the CM and CSM approaches to allow them to accurately predict the response of structures of different periods to near-fault shaking?
- How should PG&E structures be designed using the findings above?

2. Benefits of the results of this project

The following technologies were developed to mitigate the seismic vulnerability of PG&E mill-type structures:

- An assessment method for estimation displacements of structures located in the near-fault region resulted.
- A methodology for PG&E mill-type structures resulted.
- An alternative to the inadequate *m*-factor method in FEMA-356 was developed.

3. Brief description of the accomplishments of the project

The accomplishments of the project are as follows:

1) For short period structures, such as PG&E mill type structures, with fundamental periods less than about 0.8s, it was shown that directivity effects from NF shaking did not increase the demands above that found for FF shaking.

2) When comparing the Coefficient Method (FEMA 356) CM and the Capacity Spectra Method (ATC-40) CSM methods it was shown that:

(a) The CM is relatively simple to use, but it does not consider the influence of different types of damping or hysteretic loop shape easily, and results may be sensitive to the definition of yield displacement. The CSM is less sensitive to the definition of yield displacement and can take damping effects into account easily. However iteration is required to estimate the likely structural displacements, the method may require use of very long period response values which have dubious accuracy, three empirical relationships have to be assumed or calibrated, and an understanding of the structure's hysteretic shape is required to estimate the demand.

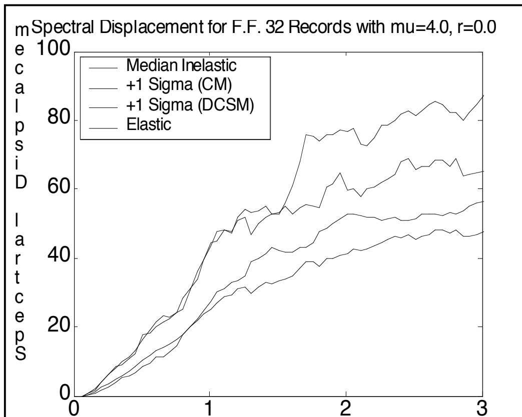

Figure 1. The Capacity Spectra Method (CSM) and the Coefficient Method (CM) have been calibrated to obtain the same median inelastic displacement. The scatter for a series of records, indicated by +1 Sigma, is different for the two methods.

(b) Both the CM and CSM can be calibrated to estimate the exact response. For the CM a bilinear approximation of lateral force reduction factor, *R*, vs. fundamental period, *T*, for a specific ductility is reasonable. The CSM effective damping, ζ_{eff}, for a specific ductility, , as well as the spectral reduction, *SR*, for a specific damping, ζ, are dependent on period, *T*.

(c) When both the CM and CSM are well calibrated, the scatter in displacement, , for oscillators with an effective (secant) period, T_{eff}, less than about 3.0s is similar. For structures with T_{eff} greater than about 3.0s, the CSM has more scatter as shown in Figure 1.

(d) When the CSM was calibrated according to ATC-40, ATC-40 significantly overestimated the average effective damping at periods greater than about 0.2s. ATC-40 non-conservatively estimated the median inelastic response over the majority of the period range from 0-3s and its estimation was as low as 60% of the median displacement for some periods. The CM calibrated according to FEMA356 conservatively estimated the median displacement over most of the period range. For some periods, FEMA356 estimated displacements more than 30% greater than the actual median displacements.

3) Oscillators with demands estimated by the CM, and with fundamental periods less than about 0.8s, were not affected significantly by near-fault shaking effects. For longer period oscillators, oscillator strengths may need to be increased by more than 60% to account for inelastic shaking effects from NF sites in the region of positive directivity compared to that for shaking from FF or NF near-epicenter sites for the same target displacement ductility as shown in Figure 2. NF shaking did not cause significant trends in the displacement demands of oscillators evaluated by the CSM method. Modifications to the existing FEMA356 CM nonlinear static procedure (NSP) C_1 factor, accounting for NF shaking effects when appropriate, was developed for structures with fundamental periods in the range of 0-3s.

4) For design of PG&E structures, it was determined in conjunction with PG&E/PEER that the FEMA356 CM Linear Dynamic Procedure (LDP) should be used to evaluate the demands of PG&E mill-type structures. The estimation of inelastic response should be made using the C_1 factor from the FEMA356 Nonlinear Static Procedure (NSP). While the C_1 factor may be modified for NF shaking effects, this is only required for structures with periods greater than 0.8s. NF shaking effects therefore do not need to be considered on the inelastic response of the majority of PG&E mill-type structures since their fundamental periods are less than 0.8s. The difference between member and system ductility demands is not considered in the FEMA356 LDP often resulting in non-conservative demand estimates. A method to show how it can easily be accounted for in assessment and in design is provided. A design procedure and example for assessing NF shaking inelastic displacement demands on a mill type structure using the CM was provided.

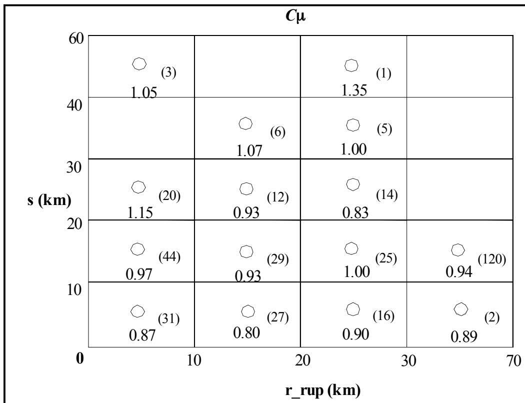

Figure 2. Average ratio of inelastic to elastic displacement demands for long period oscillators from a number of records in blocks s (km) in the fault direction and r_{rup} (km) from the fault surface with a ductility of 4.

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

Results of this project, and an previous project, have been used by PG&E and their consultants to assess the seismic vulnerability of their mill-type structures.

5. Methodology employed

Dynamic inelastic time-history analyses of single-degree-of-freedom (SDOF) bilinear oscillators were undertaken to determine the ability of the Coefficient Method (FEMA273/FEMA356) and the Capacity Spectrum Method (ATC-40) to predict the total displacement demands of simple structures. Both the Coefficient Method (CM) and the Capacity Spectrum Method (CSM) were calibrated to obtain the exact inelastic response displacements for near-fault (NF) and far-fault (FF) shaking.

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

Other related, but different types of studies, on displacement prediction methods for structures were carried out by Chopra and Goel, and more recently by Bill Iwan, ATC-55 and ATC-58 projects. Roeder and MacRae also conducted an earlier PG&E-PEER project on some related issues.

7. Recommendations for the future work

1. To obtain better procedures and calibration for near fault shaking effects, more records with known locations and orientations relative to the fault and epicenter, and on different soil conditions, are required. Studies should also be carried out using structures with different shaped hysteresis loops.
2. Methods have been developed to assess the near-fault (NF) demands at different locations relative to the epicenter and fault. However, in general location of the epicenter of the next earthquake on the fault is not known. Appropriate statistical procedures are required to account for the probable location of the site relative to the epicenter in a performance-based assessment/design context.

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

MacRae, G. A. and Tagawa H. "Methods to Estimate Displacements of PG&E Structures", Final Report to PEER, August, 2002.