Description of Work

TOPICAL INVESTIGATIONS ON PERFORMANCE, PREDICTION AND EVALUATION

Subtask 5.5.2 - Develop Predictive Elastic Models for Building Performance

Background: As part of Task 5.5, models for predicting the behavior of steel moment frames buildings must be developed. These models must be directly usable by practicing engineers, but they must also be of sufficient sophistication and complexity that they can incorporate all of the available data on the expected building performance. They must incorporate knowledge gained through the results of detailed analytical studies and experiments on connections, materials testing and model development, and all system performance analyses. As such, this task will be based in large part on the other topical investigations of Task 5 and the testing work in Task 7. In addition, data collected and analyzed from actual building performance in past earthquakes will be used to calibrate any models developed. Modeling procedures to be developed under this task must consider a performance-based design format. Subtasks 5.5.2, 5.5.3 are directed toward developing such procedures, the first addressing elastic approaches, and the other developing procedures for use in the context of nonlinear analyses. This work, along with other subtasks under Task 5.5, will be closely coordinated by the Performance Prediction and Evaluation Team Leader. Task 5.5.2 will focus on elastic methods. Later work may be required to verify the utility of the results of this work through design type calculations and application of this initial work. The results of Task 5.5.2 will contribute to the accomplishment of the following objectives specified in the Project Work Plan:

- Develop design and analytical procedures that will assure satisfactory steel moment frame performance during an earthquake, and
- Develop **Seismic Design Criteria for Steel Frame Construction**.

Objective: This task will develop and verify practical procedures for designing and evaluating various building configurations in a performance based format. The procedures must be practical since they will be used by engineers in design offices from all parts of the country, but must be of sufficient detail to address all of the major design and evaluation considerations. Issues of balancing the target reliability and performance of the structure to the uncertainty in the seismic hazard, structural model, system force and deformation capacities and the design process will all be taken into account in the development of these models within the reliability framework developed for the SAC Phase 2 project.

While establishing these models, the investigator will consider the results of Task 3 on Past Performance of Buildings in Earthquakes, Task 5.1 on Materials and Fracture, Task 5.2 on Joining and Inspection, Task 5.3 on Connection Performance and Task 5.4 on System Performance, as well as experimental work in Task 7 and applicable past and ongoing experimental and analytical work on connections, including, but not limited to, Phase 1 of the SAC program. The work must assure that the models are consistent with the results obtained in past studies, and at the same time this work must be directly useful to the practicing engineer.

A systematic evaluation and development of elastic methods for performance prediction and evaluation of steel moment frame buildings will be conducted with the following objectives:

1. Determine the reliability of available elastic methods for predicting local and system strength and deformation demands for various performance goals or limit states. Develop bias coefficients for each elastic method in accordance with the reliability framework established for the SAC Phase 2 project. Instructions on how to develop these coefficients will be provided to the investigator to the Team Leader.

2. Modify, if needed, these elastic methods to obtain and enhance the capability of these procedures to provide accurate performance prediction.

3. Based on results from previous work and other efforts within the SAC Phase 2 Project, evaluate the ability of the elastic procedures to predict the location of fractured beam-column connections. This evaluation will be based on comparison between predicted and observed behavior from case studies of actual buildings that have been subjected to strong earthquake ground motions.

4. In conjunction with other SAC Phase 2 investigators and the Performance Prediction and Evaluation Technical Advisory Panel (TAP), develop specific information for incorporation into both the State of the Art Report on Performance Prediction and Evaluation and the Seismic Design Criteria for Steel Moment Frames.

Task Description: This investigation will focus on elastic methods for predicting steel moment frame performance. It will focus on available methods, for both static and dynamic analyses. So-called "strength-based" methods, typical of building codes for new construction, which incorporate system based reduction factors and drift limits, but do not explicitly define performance limits, such as the 1997 NEHRP provisions, will be included. In addition, "deformation-based" methods, which incorporate element based reduction factors and deformation limits, and explicitly define deformation standards, such as the FEMA 273-274 procedure, will be evaluated. Further, dynamic methods such as standard elastic response spectrum and time history procedures will be considered.

The nine model buildings designed as part of the Phase 2 project will be used as a basis for the investigation. The three buildings (3-story, 9-story and 20-story) at the Los Angeles site will be the primary focus of the study, but application of the procedures to the other sites will also be considered (conclusions drawn from studying the Los Angeles site structures will be confirmed for those at other two sites). These nine buildings are being studied in detail using both linear and nonlinear techniques as part of the System Performance (SP) team efforts. Since the investigator for this task will require data from the results of the SP studies (mean, standard deviation, range of response, etc.) for various performance parameters, close communication and coordination must be carried out with the SP team, and specifically the SP Team Leader.

This study will be broken up into two parts. The first part of this study will use various elastic methods to investigate steel moment frames with ductile connections and compact sections. As such, the effects of fracturing connections will not be considered in this portion of the effort. The second part of the project will address frames with connections that are susceptible to fracture.

In coordination with the PPE Team Leader and TAP and the Phase 2 Guideline Writers, the Investigator will select the various input parameters (design spectra, local and global strength and deformation acceptance criteria, etc.) for each of the performance limit states identified. The evaluation of the different elastic procedures and the performance and/or evaluation of the buildings will be investigated within the reliability based framework developed as part of Task 5.5. Calculated responses from the inelastic dynamic time histories performed as part of the SP Team studies will be considered as "exact" for the purposes of comparison with the results of this investigation.

The following questions should be among those addressed by the Investigator:

- Should the various limit states be defined in terms of strength, deformation or a combination of both of these quantities?
- What provisions are required for calculating story drifts, floor deflections and other deformation based quantities?
- For modal response analyses, are there special rules (number of modes, e.g.) needed to ensure that appropriate accuracy is achieved?
- What modeling rules should be followed to assure acceptable response predictions? Can simple models that use centerline dimensions with no joint modeling be used?
- What are the effects of non-moment frame columns in combination with the composite floor slab on the predicted performance?
- Are time history methods significantly more accurate than modal or static methods?
- Under what conditions are special design and/or evaluation methods required for predicting connection response (connections susceptible to fracture, e.g.)?
- Are there conditions when elastic methods should not be allowed? Potential issues could include special site effects (soft soils or near field effects, e.g.), structural irregularities (mass, strength, stiffness, geometric, e.g.), number of stories, etc.
- How should the force and deformation demands in columns, column splices and base plates be estimated?

Objective 1 - As noted above, this part of the study will focus on systems which are not impacted by connection fracture (compact sections are assumed). The three model buildings developed for the Los Angeles site as part of the SAC Phase 2 will be used in these studies. In addition, two other low-rise (less than six stories) buildings, likely taken from previous case study analyses, will be evaluated in this part of the study. Complete descriptions of the important structural characteristics of the model buildings will be provided to the investigator by the SP Team. Each of the five buildings will be evaluated at the various limit states to be considered. The accuracy of the various procedures will be assessed by comparison with the inelastic analyses. At least four analysis procedures will be investigated, equivalent static procedures that are strength-based such as NEHRP 1997, deformation-based procedures such as FEMA 273, multi-mode response spectrum and time history dynamic methods. In addition, design of one or two buildings will also be performed to satisfy the various performance objectives. Inelastic response quantities for this building consistent with those generated by the SP Team will be developed for these designs, using a set of ten to twelve of the ground motions included in the SP analyses. These will be done in accordance with the probability framework established for the SAC Phase 2 project and under the close coordination by the PPE Team Leader.

Objective 2 - After assessing the predictive capabilities of the procedures evaluated in *Objective 1*, where possible, improvements will be made to these procedures. The buildings studied in *Objective 1* will be used as the basis of making the necessary modifications. Proper consideration of all pertinent response parameters will be considered throughout this process, so that the predictive capability for one parameter is not to be achieved at the expense of others. This objective will also be accomplished within the reliability framework. Bias factors will be developed for each method in coordination with other Task 5.5 subtasks.

Objective 3 - In the second part of the study, two buildings that experienced fractured connections will be evaluated using the procedures recommended as a result of *Objectives 1 and 2*. The two buildings selected will have as complete documentation (damage descriptions, ground motion information, inelastic analysis models and results, etc.) as possible. The ability of the proposed elastic (both static and dynamic) procedures to predict connection fracture will be studied. One goal of this effort is to determine if an elastic analysis method in combination with other pertinent data, can be used to reliably predict the connections that should be inspected after an earthquake.

Objective 4 - The investigator will supply recommendations and supporting data to other members of the Phase 2 Project, including the Guidelines Writers and Team Leaders, to be considered for use in the development of project deliverables, such as the Seismic Design Criteria, as well as the State of the Art Report on Performance Prediction and Evaluation. Close coordination with the appropriate Guidelines Writers will be required throughout the development of such recommendations.

Deliverables: A final report will be written that will summarize the results of this investigation. It will address the theoretical and practical basis for the various procedures developed and proposed for use in other parts of the project. Issues of balancing target reliability and performance of the structure to the uncertainty in the seismic hazard, structural model, system forces and deformation capacities and the design or evaluation process will be addressed. Interim reports to the Performance Prediction and Evaluation TAP will also be required.

Task Management and Review: This subtask is supervised by James Malley, Project Director for Topical Investigations. The Performance Prediction and Evaluation (PPE) Team Leader and TAP will provide oversight and an advisory role on the conduct of the research and will review, provide specific comments and evaluate all reports and recommendations. Team leaders and selected members of the Systems Performance TAP and Connections Performance TAP will also review and evaluate this work. It is expected that the subcontractor/consultant selected for this subtask will be responsive to issues and concerns raised by the Project Director, TAP and other reviewers. The subcontractor shall be responsible for regularly reporting progress and difficulties to the PPE Team Leader and the Project Director for Topical Investigations.

Target Audience: The work products of this subtask will be directly used by Performance Prediction and Evaluation Team and the guideline writers working on the SAC Phase 2 project.

There will also be a need to integrate these results with the various other investigations throughout the progress of the program. They will also be of interest to Topical Investigation Team Leaders for System Performance and Connection Performance. The results of this sub-task will be used to develop the State of the Art Report on Performance Prediction and Evaluation. It is expected that the results will also be of great interest to the general profession and research community.