## Description of Work

# *Topical Investigations on Performance Prediction and Evaluation*

### Sub-task 5.5.1 - Develop a Statistical and Reliability Framework for Comparing and Evaluation Predictive Models for Evaluation and Design

**Background**

Detailed technical issues related to materials and fracture, joining processes and procedures, connection performance and systems are being specifically addresses in various topical investigations as part of Task 5 of the SAC Phase 2 Project. A number of additional investigations are being undertaken as part of Sub-task 5.5, to support development of professionally oriented methods for use in the development of various guidelines documents. These relate to methods to reconcile the estimates of demands for various types of systems obtained with sophisticated simulation programs with predictions based on design-oriented analysis methods and estimates of connection strength, stiffness and deformation capacities. Uncertainties generated from estimating the seismic loading, structural response and deformation capacity must be considered in a consistent manner. In addition, performance criteria beyond substantial life safety must be developed. Finally, difficulties in predicting the distribution and intensity of damage in buildings subjected to the Northridge earthquake suggest the need to examine further methods for identifying and inspecting at-risk steel moment frame buildings.

Task 5.5.1 will evaluate and develop models for accurate prediction of overall building performance within a performance-based format. Results of other topical investigations will be utilized, such as the following: 5.4.1 through 5.4.7 on System Performance; 5.3.1 and 5.3.2 on Connection Performance; 3.01 through 3.07 on Damage from Past Earthquakes; 5.1.1 through 5.1.5 on Materials and Fracture. The results of this task will contribute to the accomplishment of the following specific project objectives (See Section 1.3 of the Project Work Plan):

- " Develop design and analytical procedures that will assure satisfactory steel moment frame performance during earthquakes."

- "Develop **Seismic Design Criteria for Steel Moment Frame Construction**."

The models to be developed are to be consistent and usable by practicing engineers from all parts of the country. 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 design process will be taken into account. The models to be developed are to be consistent, and usable by practicing engineers.

This sub-task is intended to organize and conduct a workshop to develop a reliability based framework for comparing and evaluating predictive models for building evaluation and performance prediction and to recommend how to compare relative safety of different systems. Such a framework must explicitly account for uncertainty and attempt to quantify performance and safety. 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 design process, will be taken into account. As such, it is the first step in the process of developing the predictive models.

**Objectives:** It is important that a statistical and reliability based framework be established in order to develop predictive models for evaluation and design. Establishing such a framework will help to identify parameters that are expected to be critical components of the predictive models. Identification of these parameters will provide direct focus for the necessary information being developed in other topical investigations and data collection efforts. A one-day workshop will be conducted for with the following objectives:

(1) Propose a framework for comparing the relative safety of one building system to another at the four performance levels.

(2) Propose a framework for estimating the absolute level of safety of a building at the four performance levels.

(3) Suggest how performance goals will be stated within the context of the project.

(4) Propose a criteria for accepting test specimen results.

(5) Propose a method for calibrating analysis methods.

(6) From a safety and reliability point of view, propose a framework for evaluating the relative effects of reducing the uncertainty in various design parameters.

**Task Description**: The Investigator will organize a one-day workshop to develop a statistical and reliability based framework for building response studies that will be conducted as part of the SAC Phase 2 project. The Investigator must be a recognized expert in the areas of probability and reliability approaches in the context of seismic design. Three workshop participants who are also experts in these areas will be invited by the Investigator to attend the workshop. The SAC Phase 2 Project Director will select several other participants from the Topical Team Leaders and Lead Guideline Writers who are familiar with these concepts, and/or whose work will be directly impacted by this effort. The Investigator will prepare a "White Paper" on these issues and a "Straw Person" framework that will be distributed to the workshop participants approximately two weeks before the workshop is held. The results of the workshop will provide valuable information to the Connection Performance (CP), System Performance (SP), and Performance

Prediction and Evaluation (PPE) Teams. The results will also be used by the Guideline Writers in the development of project documents.

The underlying motive for this task is to propose a consistent and universally acceptable framework, based on the information obtained from many of the other tasks of the SAC Phase 2 program, of handling the uncertainties that are revealed through these other studies. Two basic concerns to be addressed, along with others mentioned below, are the development of rational means for handling gaps in knowledge and engineering judgment. It would also be desirable for this effort to develop a mechanism to incorporate new knowledge into the process as it becomes available.

A number of specific issues need to be addressed as part of this task. These issues include the following:

**Issue 1**: Is there a procedure available that will allow for determining the relative reliability or safety among several alternatives? These alternatives might include various configurations or design approaches for a new building, a damaged building without repair vs. a damaged building with repair, various existing buildings not yet subjected to an earthquake, etc. Similarly, a procedure to assess the relative safety among building frames whose connections might have hysteretic loops that are pinched, fractured and/or degrading in strength and/or stiffness is needed. The safety or reliability under different seismic environments and ground motions should also be assessed. A means of determining if the differences identified are significant is also needed.

**Issue 2**: Is it possible, given a lack of some information, to determine if a building is "safe" in an absolute sense? The building in question may be exposed to a seismic hazard that includes long recurrence intervals, long duration motions, near fault pulses, etc. What is the best way to evaluate effects of different repair or modification schemes?

**Issue 3**: What is the best way to state performance or reliability goals? We will have suites of accelerograms for three sites and for four hazard levels: 50% probability of exceedance in 30 years, 50% in 50 years, 10% in 50 years and 10% in 250 years. Is this the best format for discussing safety in general? What are the practical and important issues that must be addressed within the proposed reliability and safety framework?

**Issue 4**: How should a criteria for accepting test specimen results for new or existing connection types be developed? Currently in areas of high seismicity a connection detail is considered acceptable if it can reach a plastic rotation of 0.03 radians under a specific test protocol. This value was established during a series of meetings of "experts" that participated in the Phase 1 project. How should this value be set? In some instances, only one test will be available and in cases where more tests are available there is great scatter. There is also great scatter in seismic demand based on analytical studies. As a result, confidence in the accuracy of experimental data is low. Finally, demand on a structural system is not well understood as it relates to local connection failures. What is the effect on overall safety if some percentage of all connections will fail? Is the overall safety tied closely to the connection behavior after fracture? What is the impact of composite behavior of the connections?

**Issue 5**: How can analysis methods be calibrated to provide the same level of safety or reliability? Four possible analysis procedures for design and evaluation are presently available: equivalent static elastic (single or multi-mode), time history dynamic elastic, nonlinear pushover and nonlinear time history. Each method will give different results. How does one determine if these different results are significant? Perhaps the other uncertainties are so great that differences in analysis results are not important. If they are important, can a penalty function or other device be developed to ensure the same level of reliability for each method?

**Issue 6**: Means to improve the reliability and safety of steel frame buildings must be developed. The uncertainty in the seismic hazard is large in many areas of the country. What can be done to increase the overall safety of a building? What will be the effects on the overall safety of a building of reducing the uncertainty in analysis procedure, analytical model complexity, structural configuration including redundancy, proportioning of members and connections, test results, connection type, quality controls of materials and workmanship, etc.?

The nonlinear time history response of a large number of structures will be computed as part of other investigations as part of the Phase 2 project. Specific instructions must be provided to these investigators in order that information that is the most appropriate and beneficial to calibration of the reliability based frame work be collected. In this regard, it is currently planned that the mean, standard deviation, minimum and maximum, etc., of the following global and local responses will be generated and tabulated for these analyses:

**Linear State and Dynamic Analyses**

* total displacement at each floor
* story drift at each level
* force applied at each level (Static)
* shear in each story
* M/Mp for beam ends in each story
* M/Mp for column ends in each story
* P/Py for each column in each story (compression and tension)
* V/Vy for panel zones
* base shear
* overturning moment
* mode shapes and frequencies of first three modes
* cumulative energy effects

**Nonlinear Dynamic Analyses**

* maximum displacement at each floor
* story drift index for each story
* maximum shear in each story
* $I_p$ plastic rotation of beam ends
* I total rotation of beam ends
* $I/I_y$ of beam ends
* $I_p$ and I of column ends
* $I/I_y$ of column ends
* cumulative energy effects

**Deliverables**: Deliverables for this sub-task include:

1) Preparation of a "White Paper" discussing each of the six issues noted above. A "Straw Person" framework will also be developed. These must be mailed to each workshop participant by approximately two weeks before the workshop is held.

2) Chair the Workshop that will be held to address the White Paper and Framework. A report describing the discussions that took place at the workshop will be prepared. This report should clearly state any resolutions and decisions that were made at the workshop. The theoretical basis for these decisions and resolutions should be explained. Issues of balancing the 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.

3) Based on the results of the Workshop, the final version White Paper and the Reliability Based Framework will be modified and submitted to the SAC Project Management Committee for review and acceptance.

**Task Management and Review:** This sub-task is supervised by James Malley, Project Director for Topical Investigations. The sub-contractor will be part of the Topical Investigation Team on Performance Prediction and Evaluation and participate in its meetings during the duration of the sub-task. As such, the Technical Advisory Panel (TAP) for Performance Prediction and Evaluation will provide review of the specific work activities recommended as well as on all reports and communications. The Team Leaders for System Performance, the Project Director for Product Development and the Guidelines Writers will also review the content of this work.

The sub-contractor shall be responsible for regularly reporting progress and difficulties to the Team Leader for Connection Performance and the Project Director for Topical Investigations.

It is expected that the sub-contractor will be responsive to issues and concerns raised by the Team Leader, Project Director, TAP and other reviewers.

**Target Audience:** The work products of this sub-task will be directly used by other consultants and subcontractors working on the FEMA/SAC Phase 2 project. The results will help provide tools and assessments that can be used during the remainder of the project.

The results of the reliability based framework and the issue paper will be used directly by investigators conducting case study analyses of actual buildings and those performing system performance analyses. Thus, the Topical Investigation Teams on System Performance and Connection Performance will have keen interest in reviewing and using the results of this sub-task, as will the Guidelines Writers.

It is expected that the results of this sub-task will also be of great interest to the general professional and research community.