Description of Work

Topical Investigations on System Performance

Sub-Task 5.4.7 – Investigation of Alternative Framing Systems with partially restrained, bolted or energy dissipative connections.

Background: As part of Tasks 5.4 and 5.5, a large number of analytical investigations are carried out to assess the effect of various ground motion and structural characteristics on seismic demands. These investigations focus on a number of issues, including the effect of:

1. Building configuration, proportioning and analytical modeling,
2. Ground motion intensity and dynamic characteristics,
3. Deterioration of the strength and/or stiffness of plastic hinge regions,
4. Fracturing of beam to column and other critical connection regions,
5. Alternative moment-resisting connections, such as partially restrained, bolted or energy dissipative joints,
6. Alternative moment resisting frame systems that can be used in regions of lessor seismic hazard,
7. Simplifications and uncertainties introduced by the analytical methods used in design or evaluation, and
8. Targeted levels of performance, reliability and economy.

The brittle fractures of welded moment resisting frames during the Northridge earthquake suggests that alternative forms of connections should be investigated. This sub-task includes analytical investigations to assess the use of moment-resisting frames that contain partially restrained (PR), bolted, energy dissipative or other types of alternative connections.

Moment-resisting frames with partially restrained or bolted connections provide a feasible alternative to frames with rigid connections in most or perhaps all seismic zones. Various suggestions have been advanced for a variety of other alternative connection types intended to dissipate energy during severe earthquakes. Provided that alternative connections with reliable ductility capacity can be identified, the issues of concern are whether sufficient strength and stiffness of the connection or system can be realized to achieve acceptable performance. Within the present code context, this implies sufficient elastic strength and stiffness under code seismic loads so that code strength and drift limitations can be fulfilled. The 1994 UBC stipulates for seismic zones 3 and 4 that connections be able to develop the flexural strength of the beam (or the shear strength of the panel zone). However, there is no clear reason for this requirement and it should not be considered a constraint in this study. It has also been suggested by some that the use of partially restrained or other economical alternative connections at all beam to column connections in a building will result in a highly redundant system capable of tremendous energy dissipation, and that by proper selection of configuration (e.g., the numbers of frames, bay spacing, etc.) and proportions (e.g., the relative strength of beams, columns and connections) that adequate overall structural stiffness and strength can be achieved. On the other hand, concerns have been raised about the possible increased initial and post-yield flexibility of some types of alternative systems and the appropriateness of design rules developed on the basis of gravity and wind loading.

Thus, the focus of this sub-task is on how to tune alternative moment-resisting frame to achieve specified performance by:

1. Selection of the strength, stiffness and deformability of the PR, bolted or energy dissipative connections used, and by
2. Selection of the configuration and proportioning of the structural system.

In the planning of these studies and in the evaluation of the results obtained full advantage must be taken of information available in the literature from past studies as well as from other on-going investigations. In addition, several issues related to the first item immediately above are also addressed by Sub-task 5.4.4. In contrast to Sub-task 5.4.4, this sub-task will place more attention on hysteretic characteristics representative of realistic connection details of a type likely to be used in practice, on the effects of system configuration and proportioning, and on assessment of design approaches available for alternative frames. Sub-task 5.4.4 will use relatively simple analytical idealizations to mimic the general hysteretic behavior (degree of restraint, strength and post-yield deterioration) of a broad range of alternative connection types. Efforts in Sub-task 5.5, examine the specific design requirements of various alternative systems possessing limited ductility and that may be suitable for areas of lesser seismic risk (so called ordinary moment frames). Sub-task 5.4.3 examines the effects of configuration and proportioning on seismic demands for fully restrained connections. These Phase 2 sub-tasks must be carefully coordinated to avoid unnecessary duplication of effort.

Objectives: The objectives of this sub-task are to identify the effect on seismic performance of the strength, stiffness and hysteretic characteristics of realistic alternative connection types as well as of the system configuration and proportioning. Results obtained are to be interpreted to identify situations were response is comparable or equal to that of a system with conventional fully restrained connections, and where adverse effects occur. Where results indicate that performance deteriorates due to the use of alternative connections, analyses are to be conducted to assess what changes in the system or connection characteristics might be made to improve performance. Recommendations for design of systems with alternative connections and for predicting local deformation demands from simplified analyses are to be developed.

Task Description: Much information is available in the literature on the behavior of PR connection. This information, together with experimental evidence generated within the SAC program and other on-going or planned experimental studies, is to be synthesized, in conjunction with the Technical Advisory Panel, to identify suitable PR connection types and to quantify the moment-rotation characteristics of these connections.

Suitable alternative(partially restrained, bolted or energy dissipative) connections are to be used to redesign a sub-set of the model buildings (3, 9, and 20 story buildings designed for typical conditions in Los Angeles, Seattle, and Boston) as alternative frame structures. Inelastic time history analyses are to be performed, using the ground motion records developed under Task 5.4.1, in order to assess local and global seismic demands. Near-field ground motions and soft soil ground motions are to be considered in the studies.

The parameter and simulation studies in this sub-task are to be inelastic static(pushover) and dynamic (time history) analyses, based on two-dimensional frame configurations. Particular attention is to be paid to static and dynamic P-Δ effects, since these may have a significant influence on the performance of structures with flexible connections. Response parameters defined in Sub-task 5.4.2 will be monitored and entered into a database developed in that sub-task. These include but are not limited to connection rotations, panel zone shear distortions, interstory drifts, global displacements, and energy dissipation demands. The results of the analyses are to be evaluated in relation to the results obtained for rigid frames in other SAC projects.

Additional studies are to be performed by varying structure configuration (number of moment resisting frames in the structure), frame configuration (number of bays and bay width within a frame) and connection proportioning (relative strengths of beams, columns and connections and the degree of restraint and strength provided by an alternative connection relative to a fully restrained connection). The potential beneficial effect of redundancy is to be evaluated. Due consideration should also be given to the beneficial effects on performance and safety of the simple (shear) connections used in parts of the structural frame work assumed for design purposes not to be part of the lateral load-resisting system.

The results of the analyses, together with conceptual studies and results from Sub-tasks 5.4.3 and 5.4.4, are to be utilized to develop methods for the prediction of connection rotation and interstory drift demands, and to develop preliminary design recommendations for frames with alternative connections in all seismic zones.

It is essential that the work in Sub-task 5.4.7 build upon current knowledge and not unnecessarily duplicate previous work. Thus, the activities undertaken in this task must be based on the assessment of current knowledge undertaken as part of Task 4 and elsewhere. The detailed work plan developed for this sub-task must account for and take advantage of activities undertaken in other portions of the Phase 2 project. The electronic data base developed in Sub-Task 5.4.2 may provide a convenient mechanism for the investigators working on these parts of the project to exchange information. A meeting will be held early in project to allow sub-contractors working on Task 5.4 to establish liaison and to coordinate efforts.

This project must be closely coordinated with the project on seismic demands associated with configuration, proportions and models (Sub Task 5.4.3), deterioration of hysteretic characteristics (Sub-Task 5.4.4) and ground motion intensity and dynamic characteristics (Sub-Task 5.4.5) as well as on efforts being undertaken in Sub-task 5.4 related to design and evaluation of frames having limited ductility.

As part of this task the sub-contractors are to perform efforts to accomplish the above objectives and address the various issues mentioned above. Specific activities include:

1. Present a detailed work plan at a one day kick-off TAP meeting to be held in the San Francisco area. This shall delineate the analyses to be included in the parameter studies, milestones for delivery of preliminary and final reports, types of interpretations and analyses or results to be performed, and information needed from others. The plan shall be based on a review of information available on the relevant topics. It is anticipated that modifications of the proposed detailed work plan will be necessary to

coordinate the work effort with that of others, and to avoid unnecessary gaps in or duplication of the knowledge to be gathered. The plan should also identify the coordination of tasks between the two subcontractors - Bruce Maison and Kazuhiko Kasai (Lehigh University) - and establish the efforts to be undertaken by each of them.

2. Synthesize available information on frames with alternative connections and develop modeling rules for strength, stiffness, and ductility capacity of selected PR connections. Implement the rules developed in an appropriate computer program. Assess the realism of these rules through cyclic static and dynamic analyses and modify the rules or models, if necessary. The model used in this project are expected to differ from those used in Sub-task 5.4.4. However, efforts shall be undertaken in this sub-task to assess the implications of the differences between the models.

3. Validate the computer program along with the member and connection element (s)to be employed in the investigations using the Benchmark Frame developed in Sub-task 5.4.2. If it does not already exist, develop computer software needed to place information on the key response parameters obtained from the numerical simulations into the database developed as part of Sub-task 5.4.2.

4. Re-design a subset of the model buildings and perform and interpret the analysis studies described above. The effects of alternative connections shall be evaluated in the light of corresponding results obtained in a companion study for fully restrained connections and for comparable systems that respond elastically. Where potentially worse behavior is indicated, the results should be interpreted, or analyses should be undertaken, to assess methods for mitigating these adverse effects (improved detailing, modification of the proportions and strength of members, modification to the structural configuration, etc.).

5. Develop methods for the prediction of connection rotation and interstory drift demands, and develop design recommendations for frames with alternative connections in all seismic zones. These recommendations should address at a minimum strength, stiffness and hysteretic characteristics of connections, configuration and proportioning of frames, and possible design approaches.

6 Provide progress reports and attend meetings of the Technical Advisory Panel at regular intervals to be defined during the kick-off meeting.

7. Provide a final report that describes the results of the project in a manner that can be incorporated into a comprehensive report of the System Performance Team and that can be utilized effectively by the Guideline Writers. All reports need to be prepared in conformance with format guidelines specified by SAC.

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

1. Revised work plan, and schedule, for this sub-task based on the kick-off meeting discussion. This work plan must delineate the responsibilities of

the two subcontractors - Bruce Maison and Kazuhiko Kasai (Lehigh University) - outlining their responsibilities and the coordination between their efforts.

2. Summary reports on Items 2 through 5 of the Task Description.
3. A well organized computer-based database of the results of the analytical studies (for use in interpreting the results and for use by others involved in this program). This should be maintained throughout the progress of the project so that preliminary interpretations can be made.
4. Regular progress updates on the project status.
5. Final report on the results, findings, conclusions and recommendations of the sub-task.

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 System Performance and participate in its meetings during the duration of the sub-task. As such, the Technical Advisory Panel (TAP) for System Performance will review the specific work activities recommended by the sub-contractor, and evaluate and comment on the conduct of the research as well as on all reports and recommendations. TAP meetings are anticipated quarterly during the project. Funds necessary for attending these meetings are included as part of the budget for this sub-contract. The Team Leaders and selected members of the TAPs for Connection Performance and Performance Prediction/Evaluation will also review and comment on this work.

The sub-contractor shall be responsible for regularly reporting progress and difficulties to the Team Leader for System Performance and to the Project Director for Topical Investigations. It is expected that the sub-contractor will be responsive to issues and concerns raised by the Project Director, the TAP and other reviewers.

Target Audience: The work products of this sub-task will be directly used by other consultants and sub-contractors working on the Phase 2 project. The results will provide basic data on the effect of connection fractures on the performance of steel frame buildings and the implications of these effects for design and rehabilitation. The sub-task may indicate the need for special design methods, or details.

The other investigators in Sub-task 5.4 (and portions of Sub-task 5.5 related to systems with limited ductility)will be conducting closely related investigations. As such, other investigators working on Sub-task 5.4 need to be kept abreast of activities, results and difficulties within this sub-task, so that results from all sub-tasks can be combined, compared and interpreted for achievement of the overall goals of the project. Similarly, the Topical Investigation Teams on Connection Performance and Performance Prediction and Evaluation will have a keen interest in reviewing and using the results of this sub-task. Testing will be conducted in Task 7 related to bolted, partially restrained, energy dissipative and simple connections. The subcontractor shall monitor these results to assess their impact on the models used in this task or the recommendations developed.

The results of this sub-task will be used by others to develop a State of the Art Report on System Performance.

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