Description of Work

Topical Investigations on Connection Performance

Sub-Task 5.3.1 — Assess and Improve Finite Element/Fracture Models for Unreinforced and Cover Plated Connection Details

Background: As part of Task 5.3, a series of detailed analytical investigations are to be carried out to assess the sensitivity of moment connection response to various design parameters. Factors to be considered in these analytical investigations include the effects of:

1. connection detail and overall geometry.
2. mechanical properties of the steel, including yield and tensile strength in various directions, and toughness.
3. relative physical properties of the connecting elements, such as flange and plate thicknesses, beam depth, etc..
4. sensitivity to fracture.

It is desired to characterize the connection response to the various parameters listed above for a series of connection details, including both the unreinforced details that have been used in the past, as well as the many of the modified connections that have been developed and are being implemented in the wake of the Northridge earthquake. Reliable procedures to model and predict the response of these various details are needed to guide the Phase 2 experimental investigations and future designs. This initial effort in this area is to investigate the analytical response of the unreinforced “pre-Northridge” connection and the cover plated connection detail that became a popular choice in the months following the earthquake.

Objective: This first phase of Task 5.3.1 is intended as the initial effort to determine if effective analytical models can predict connection behavior including yielding and fracture. Since there is uncertainty as to how fully and effectively these objectives can be achieved with present technology and available funding, this initial effort will be a critical test of the effectiveness of present methods, and will help to better define directions and methods used during the remainder of the study. The ultimate objectives of the overall task also include the development of simple, rational procedures for a wide range of moment frame connections and of methods for establishing connection configurations that are not fracture critical under seismic loading. The objectives of the activities within this sub-task are to:

1. Evaluate the fracture sensitivity of unreinforced connections previously tested in Phase 1 of the project.
2. Assess the ability of existing analytical techniques to predict various fracture modes that may occur.
3. Develop a better understanding of the effect of varying design parameters to the expected response of the unreinforced connection detail.

4. Assess available two dimensional fracture models to predict three dimensional response through companion three dimensional finite element plasticity analyses.
5. Assess the fracture sensitivity of cover plated connection details, using previously tested connection performance as the initial study.
6. Extend the cover plated connection investigation by varying design parameters to assess the sensitivity of this configuration to fracture.

Task Description: The vast majority of detailed analytical investigations that have been performed on steel moment resisting connections since the Northridge Earthquake have not specifically addressed issues related to connection fracture. However, analytical procedures that explicitly consider crack initiation and propagation have been developed and used in research settings to address problems other than steel moment resisting connections. This sub-task will investigate the viability of these existing procedures to predict connection performance of unreinforced "pre-Northridge" connections that proved to be susceptible to fracture and exhibited a number of different fracture propagation paths.

The basis of these initial analyses will be a series of three connection tests that were performed as part of Phase 1 of the SAC Project. These tests simulated a large scale connection with a nominally A36 W36x150 girder and a A572 Grade 50 W14x257 column. These sections were connected using procedures that simulated those that would have been common prior to the Northridge earthquake (unreinforced connection, no notch toughness requirements on weld filler materials, weld backing left in place, etc.). It was learned during the testing, that beam material for each of the three tests came from different heats, with substantially different reported mill certification report values for yield stress. The column in all three tests were taken from the same heat. While the fracture that occurred in each of these tests occurred at approximately the same point in the standard loading history, the fracture propagation paths were significantly different, and reproduced the major fracture types that were found in buildings following the Northridge earthquake. The initial analyses will investigate the ability of the available analytical techniques to predict the observed performance. Since the initial analyses will be performed on the available two dimensional a (2D) analysis tools, three dimensional (3D) inelastic finite element method (FEM) models will be developed to assess the importance of 3D effects on the distribution of strains and stresses in critical regions.

Following these initial analyses, the models will be extended to observe the effect of various design parameters on the predicted performance. Parameters such as material yield strengths in various directions, material toughnesses, filler metal yield and toughnesses, weld flaw size, etc., will be varied over the range of expected available values to identify their importance to the connection performance. In addition items such as panel zone yielding, weld backing removal, weld run-off tab removal, web connection detail, residual stress distribution, etc., will also be investigated.

Following the Northridge earthquake, substantial attention has been given to cover plated connection details. These details have exhibited somewhat unreliable performance in recent laboratory testing, from excellent energy dissipation and plastic rotation capacity, to limited capacity and sudden brittle fracture. This sub-task will also begin an investigation of the fracture sensitivity of the cover plated connection detail using a previous analysis of a SAC Phase 1 test as the analytical basis. Parametric studies will also be performed on this model.

Upon completion of the analyses listed above, the subcontractor will perform a detailed assessment and evaluation of the analytical results to identify important parameters necessary to predict connection performance. Limitations of presently available techniques will be identified and recommendations for future development will be made, if applicable. Finally, recommendations for additional analyses that will further the results of this study will be made, and incorporated in the final report for the project.

As part of this sub-task, the subcontractor will perform the following activities:

1. Prepare a detailed work plan for distribution and review by the Connections Performance TAP, the Team Leader and the SAC Project Management Committee. This work plan shall delineate the analyses to be included in the study, milestones for delivery of preliminary and final reports, types of interpretations and analyses of the results to be performed, and information needed from others. It is anticipated that modifications of the proposed detailed work plan may be necessary to coordinate the work effort with that of others, and to avoid unnecessary gaps in, or duplication of knowledge to be gathered.
2. Perform analyses of the three combinations of large size of the unreinforced SAC Phase 1 tests that were completed at the University of Texas and the University of California at Berkeley. It is anticipated that these analyses will be performed using 2D models that include limited plasticity and crack initiation and propagation in critical regions. Actual test configuration, geometry of the connections and the available information on material properties will be used in these initial analyses. Assumptions regarding the best possible estimate of the dynamic fracture properties and initial imperfections of the weldments will be made in these analyses.
3. Extend the original analyses to evaluate the effects of the range of possible values for at least the following parameters: weld toughness, variation in yield stress of various components (beam flange, column flange, weldment, etc.) in various directions, size of weld imperfections, amount of column panel zone yielding, removal of weld backing, removal of weld run-off tabs, welded web connection vs. bolted web connection, and residual stresses.
4. Perform complementary 3D nonlinear FEM models that do not include crack initiation and propagation to assess the importance of 3D effects on the distribution of stresses and strains in the analyses. The 3D models will be developed to complement the initial analyses on the actual tested connections.
5. Assess and evaluate the results of the analyses described above to evaluate the accuracy and reliability of existing analytical methods for predicting crack initiation, crack propagation paths, failure modes, distribution of both elastic and inelastic strains and stresses in the connections, and ultimate deformations and resistance. Evaluate the importance of the varying specific connection parameters on these items, and identify other parameters that may also affect the connection response. Evaluate the importance of 3D effects in the ability to predict crack initiation and propagation, failure modes, etc.
6. Extend the model previously developed to analyze the cover plated connection test performed at the University of California at Berkeley Earthquake Engineering Research Center to assess the importance of the effective horizontal crack that occurs between the cover plates and beam flanges to the predicted performance of the connection detail. Perform limited parametric studies on items such as weld toughness, variation in yield stress of

various components (beam flange, column flange, weldment, etc.) in various directions, size of weld imperfections, and amount of column panel zone yielding.

7. Assess and evaluate the results of the cover plated analyses described above to evaluate the accuracy and reliability of existing analytical methods for predicting crack initiation, crack propagation paths, failure modes, distribution of both elastic and inelastic strains and stresses in the connections, and ultimate deformations and resistance. Evaluate the importance of the varying specific connection parameters on these items, and identify other parameters that may also affect the connection response. Assess potential importance of 3D effects in the ability to predict crack initiation and propagation, failure modes, etc.
8. Develop recommendations for future supplementary analytical investigations to augment the findings of this study. Identify limitations in presently available techniques and potential extensions that will improve predictive capability.
9. Provide progress reports, and attend meetings of the TAP at regular intervals to be defined at the start of the project.
10. Provide a final report that describes the results of sub-task activities in a manner that can be incorporated into a comprehensive report of the Connections Performance Tea and that can be utilized effectively by the Phase 2 Guideline Writers. Subcontractor will submit report draft for TAP and Team Leader review, and will address all substantive comments in the final report. All reports must be prepared in conformance with electronic and hard copy format guidelines specified by SAC.

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 Connection Performance and participate in its meetings during the duration of the sub-task. As such, the Technical Advisory Panel (TAP) for Connection Performance will provide review of the specific work activities recommended as well as on all reports and communications. The Team Leaders for System Performance and Performance Prediction/Evaluation 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 both the fracture sensitivity and parameter investigations for both the unreinforced and cover plated connections will be used by investigators conducting connection experiments and those performing system performance analyses. It is desirable that analytical investigations and/or experiments for subassemblage or structural capacity be reported in a manner consistent with methods used to report analytical estimates of demand. Thus, the Topical Investigation Teams on System Performance and Performance Prediction and Evaluation will have keen interest in reviewing and using the results of this sub-task.

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