Description of Work

Task 5.2: Topical Investigations on Joining and Inspection

Sub-Task 5.2.1 – Assess the effects of the relative strength of base and weld metal on weldment behavior at different strain rates

Background

Please see the attached document "Overview of Topical Investigations on Joining and Inspection" for the technical background to this sub-task and the relationship between this sub-task and the other Joining and Inspection sub-tasks and the overall Phase 2 project.

Objectives of Sub-task 5.2.1

Efforts will be undertaken in this sub-task to assess the effects of the relative strength of base metal, weld metal and heat affected zone on weldment behavior at different strain rates. This information will be used, along with other data, to identify desirable strength-related properties for FCAW-SS welded joints in steel moment-resisting frame connections subject to different strain rates. Tests will be used to establish and assess a relation between behavior observed in simple joint, welded plate and material tests. Data will be interpreted to help establish estimates of the strength, deformability and failure mode of welded joints as a function of strength-related material properties (including the yield-to-tensile strength ratio of each material) for different combinations of base and filler metal that might be encountered in new and existing construction.

Description of Sub-task

A series of experimental investigations will be conducted, analyzed and interpreted to accomplish the objectives of this sub-task. It is expected that these will include large scale test specimens, smaller scale welded plate tests and tests used to characterize base and weld metal properties.

The large scale specimens are expected to resemble a portion of the connection typically used between a beam and column flange in a steel moment-resisting frame connection. Specimens may resemble the T-stub tension specimen shown in Fig. 1, or approved alternative (see below).

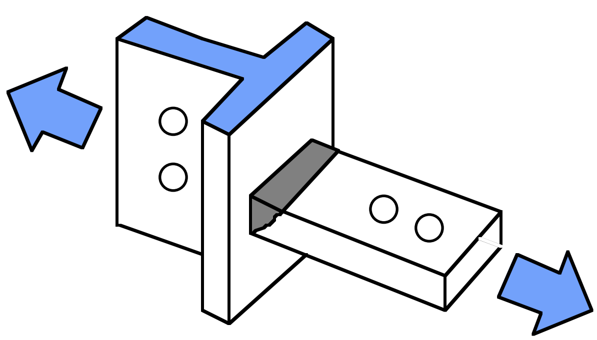

Fig. 1 – Simple T-Stub Tension Specimen

Basic considerations in designing, constructing and testing the large-scale connection specimens include the following:

- It is intended in this sub-task that the material used for the column should have metallurgical and other properties similar to those utilized in building construction, except that the strength should be selected to exceed the maximum strengths anticipated in the test series for the welds and for beam base materials. Thus, it is expected that failure will occur in the weld or in the beam flange. Sub-Task 5.1.2 examines the complementary situation where the column has a lower yield strength than the weld and beam.
- The column section of the T-stub tension specimen should be obtained from rolled shapes, because thick plates with chemical composition equivalent to structural shapes and not available. The "beam flanges" may have to be extracted from rolled shapes.
- Sizes of members used for the column and thickness employed for plate material used to represent the beam flange should result in flange thicknesses of at least 1 inch, and be selected in coordination with sizes used in the through-thickness property and other joint tests (Sub-tasks 5.1.2, 5.2.2, and 5.2.3) as well as in the subassemblage tests in Task 7.
- In addition, the test matrix developed should consider similar tests done in Phase 1 (Kaufmann and Fisher, *A Study of the Effects of Material and Welding Factors on Moment Frame Weld Joint Performance Using a Small-scale Tension Specimen*, SAC 95-08), and conducted in the U.S. (e.g., Kaufmann, *Dynamic Tension Tests of Simulated WMRF Weld Joints*, ATLSS Research Center, Lehigh University, Oct. 1996) and abroad. Unnecessary duplication of effort should be avoided.
- As described below, a range of strengths are to be utilized for the beam and weld to replicate overmatching, undermatching and matching strength conditions. In existing buildings, situations may occur where the strength of the weld metal undermatches that of the base material. Recent FEM analyses suggest potential benefits of having the weld metal overmatch the strength of the base metal by a significant margin. Additionally, low carbon structural steel weld metals in general exhibit different yield-to-tensile strength ratios than the base metals and as a result, in cases of matching, over- and undermatching, the behavior of welded joints may not necessarily be what is expected.
- It is essential that one or more benchmark specimens be utilized in this test series having similar characteristics related to material strength, welding procedures, member sizes and so on as those utilized in the various investigations undertaken in Sub-tasks 5.1.2, 5.2.2, and 5.2.3 as well as in the subassemblage tests in Task 7. These benchmarks will be established in coordination with the Project Director for Topical Investigations.
- The detail utilized by the sub-contractor for the CJP weld is to be established with the Project Director for Topical Investigations including toughness and other characteristics of the consumables, the welding procedures, and the method for removal of the backing and repair of the root pass. No "significant" fillet reinforcement of the weld root or face is desired.
- It is desired that the welds and materials be essentially free of defects or discontinuities that would significantly contribute to the failure (see acceptance standards stipulated below). Thus, thorough NDE of the welds and base metals (and documentation of results) is required prior to load testing.

Tests of similar welds in butt configuration as shown in Figure 2 will be performed. Details of these specimens, and the method of loading are to conform to AWS D1.5-95 (Bridge Welding Code). Various tests will be conducted to fully characterize the strength (stress-strain relationship), hardness and toughness of the weld metal. Dilution and heat affected zone size will be controlled to produce results similar to those obtained in the CJP welds. To facilitate comparison of results, and minimize the efforts needed to conduct material tests, efforts should be made to coordinate fabrication and inspection of specimens to be used in different parts of this project (e.g., Sub-tasks 5.1.2, 5.2.2, 5.2.3 and so on). Ideally, specimens in different subtasks having matched base metal and weld properties would be fabricated from the same heat of steel stock and welding consumables and utilize the same welder and inspectors.

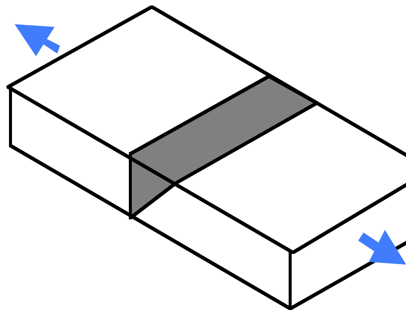

Figure 2 - Simple Welded-Plate Specimen

Efforts will be undertaken to compare and correlate results obtained in these three types of tests, including analysis of the metallurgy, chemistry, fracture surface, and so on. The controlling strength-related parameters as affecting joint performance, whether yield strength, tensile strength, yield-to-tensile ratio, or other properties, will be determined through these experiments.

The data obtained in the investigation will be used to help establish the weld quality acceptance criteria for steel moment resisting frames in sub-task 5.2.6. As noted previously, in some circumstances, conditions of use may result in the weld having only to develop a specified strength (essentially elastic behavior) so that the plastic hinge can develop at another location; in other situations, the weld region may have to contribute significantly to the overall plastic deformation capacity of the connection; in still other conditions, behavior of the welded region may be affected by the need to develop substantial yielding in the beam material immediately adjacent to the weld.

Scope of Work

To achieve the objectives of the sub-task, the sub-contractor is expected to develop and submit for approval to the Project Director for Product Development a detailed Sub-task Work Plan. It is anticipated that this Work Plan will address, among other issues, the following items:

1. The contractor must attend necessary meetings during the period of the subcontract (e.g., the project kickoff and quarterly team meetings with the Project Director of Topical Investigations and the Technical Advisory Panel). The sub-contractor is expected to provide regular verbal and written reports to the Team leader for Joining and Inspection and to the Project Director for Topical Investigations and be responsive to their requests related to the work.

2. Establish an experimental matrix of steels with three strength levels (yield and tensile), as well as filler metals with three different strength levels to be evaluated. The range of base metal yield strengths to be considered should vary between 30 to 70 ksi and that of the filler metal tensile strengths, between 60 and 90 ksi. To eliminate weld metal toughness as a variable from this set of experiments, the electrodes selected will all be high toughness grade filler metals. The relation of the proposed matrix to related tests in Sub-tasks 5.1.2, 5.2.2, and 5.2.3 should be established in the sub-task work plan. Details of the planned specimen configurations, testing methods, loading rates, instrumentation and other features of the experimental program will also be included for consideration by the Technical Advisory Panel as well as the SAC Project Management Committee, and approval by the Project Director for Topical Investigations.

3. Using a test configuration similar to the T-stub tensile test specimen shown in Fig. 1 (used in SAC Phase 1 research), three sets of test specimens will be welded. Each set will replicate low, medium and high strength beam flange steels being welded with low, medium and high strength welding consumables. It is thus anticipated that a total of at least 27 large weld specimens will be fabricated and inspected. Note that standard welding materials and procedures specifications will be provided, prior to start of work, to the sub-contractor and must be strictly adhered to by the sub-contractor. The welds will be inspected by the sub-contractor of Task 5.2.4 using ultrasonic and other acceptable technique to determine the quality of the joint. While weld repair is allowed in the preparation of these specimens, the finished weldment must meet QA and QC requirements according to AWS D1.5-

95 Section 12.17 on Critical Weld Repair. However, only UT is required for quality assurance. The size, location and orientation of defects shall be carefully mapped. All inspection records must be presented for the final reporting of the program.

4. The welding shall be performed by an experienced welder, qualified in accordance with AWS D 1.1 for each electrode used.

5. The first set of nine welded joint specimens will be tested quasi-statically (at a pre-selected strain rate, $\dot{\varepsilon}_1$) bringing the specimens to "failure." The presence of extensive plastic deformation will indicate a "passing" condition, while the absence of plastic deformation will represent a "failing" condition. The selected strain rate, $\dot{\varepsilon}_1$, should be comparable to that observed in seismic conditions. Consider time to maximum load at the order of seconds.

6. Those samples that pass the static tensile test will undergo similar tests, but at a higher strain rate ($\dot{\varepsilon}_2$). The strain rates to be used in these tests will be proposed by the subcontractor prior to the initiation of testing and submitted to the Project Director for Topical Investigations for approval prior to the test.

7. The weldments that "fail" the first round of quasi-static tensile tests will be re-tested. Specimens failing to achieve at least 85% of the nominal capacity of the joint should be re-tested, giving attention to the possibility of reducing the width of the beam plate away from the weld to assess the ability of the weld to support yielding of the beam away from the welded section. Otherwise, the original width specimen should be re-tested to confirm the initial result. Criteria and details used to reduce the beam section shall be submitted to the Project Director for Topical Investigations well prior to beginning these tests.

8. Depending on the outcome of these two sets of testing, a third set of test welds will be tested. Those that "passed" the second round of tests will be subjected to tests at an higher strain rate, $\dot{\varepsilon}_3$, than employed in the second set of tests. Those that failed the second round will be re-tested at the same strain rate as used in the second set in order to confirm these failing results (or, as in Item 7 above, re-tested with a reduced beam section). The loading rate must be approved by the Project Director for Topical Investigations.

9. To evaluate loading conditions that include bending moment, six additional tests utilizing overmatching (three specimens) and undermatching (three specimens) weldments will be conducted. Details on test specimen fixturing and loading condition to generate the bending moment shall be submitted to the Project Director for Topical Investigations well prior to beginning these tests.

10. The strength-displacement data, details of the measurements such as location, gage length, etc., will be recorded for documentation and subsequent correlation.

11. The fracture surface of the specimens will be examined, documented and analyzed for subsequent correlation with the base metal/filler metal strength/failure mode data. Assessment will include microstructure analysis and chemical analysis performed on transverse cross-sections of the welds.

12. A minimum of 27 sets of welds will be produced for the investigation.

13. Using the same combinations of steel and filler metal as described in Item 2 above, a variety of test plates similar to AWS D1.1 and D1.5 procedure qualification plates shall be fabricated. Reduced-section tensile coupons will then be extracted from the procedure qualification plates and tested. Details of these specimens and testing methods will be submitted for review and approval at the beginning of the sub-contract. The welding parameters used here will be provided to the sub-contractor for T-stub specimen preparation. The work described in item 13, 14 and 15 will be carried out prior to the tasks related to T-stub welds.

14. A series of material tests will be undertaken to characterize stress-strain, impact toughness, chemical and microstructural properties of the base material in the beam and column as well as in the welds.

All weld metal tensile coupons will be fabricated and tested. Charpy V-notch tests of the weld metals will be carried out at -20^{o}F. Weld heat affected zone hardness will be recorded. Material tests will be performed for the column in the longitudinal and through-thickness direction.

15. It is expected that the sub-contractor will cooperate with other SAC sub-contractors who will perform NDE tests during or following tests of the various test specimens. Where the test specimens do not fail in the weld region, it is the sub-contractors responsibility to re-inspect destructively and/or non-destructively the weld region and compare indications with those observed prior to load testing.

16. The results from the previous tests will be analyzed and an attempt will be made to correlate the performance of the "small-size" tensile plate and "large-size" T-stub tension tests, as described in item 13 and 14. Trends of acceptable behavior and the relationship between the weld metal and the base metal strength levels will be established.

17. A final report will be prepared outlining the test methodology, test results, analysis and interpretation of the results, and comparison between the large-scale and small-scale tests and characterization of material properties.

18. Preliminary test and analysis results are to be supplied to other investigators working within the Phase 2 project. Regular and prompt communication of results to investigators working on other sub-tasks in Task 5.2 is expected. Test specimens are to be archived for at least 3 months following the conclusion of the sub-contract and made available to other investigators as requested. Fracture surfaces are to be preserved using a suitable protective coating.

Project Deliverables

The subcontractor will submit the following items as deliverables:

1. Revised and detailed work plan based on kick-off meeting discussions, within 2 weeks of the kick-off meeting.

2. Completed experimental weld matrix as outlined in the work plan, and considering sub-task technical requirements as well as section sizes and material properties used in other sub-tasks, stipulated welding consumables and procedures, and the benchmark specimens established for the sub-task. Other information related to the test specimen configuration, test methods and rates, instrumentation, and inspection methods should also be included in the sub-task plan.

3. Results of completed inspections to ascertain the acceptability of the test specimens, as well as changes in inspection indications occurring as a result of testing.

4. Results of mechanical testing used to determine the passing and failing conditions of the weldments. Detailed results in printed and electronic form are to be provided.

5. Completed chemical analysis of the "small size" welds to determine the recovery of the alloying elements from the welding consumable and base metal to the weld metal.

6. Completed microstructural analysis and mechanical testing of the "small size" welds performed to determine the effect of base metal and weld metal strength on weld performance.

7. Completed simple fracture analysis of the "large size" welds to determine the failure mode and relationship with heat affected zone and weld properties.

8. Regular written progress reports and updates.

9. Final report on the results of the project, including necessary revisions required by the Technical Advisory Panel and Project Director for Topical Investigations. Numerical data and photographic documentation of the test results shall also be provided.

Format requirements for submission of reports and data are to be specified by the Project Director for Topical Investigations.

Task Management and Review

This subtask is supervised by James Malley, Project Director for Topical Investigations. The Joining and Inspection Technical Advisory Panel (TAP) will provide oversight and an advisory role on the conduct of the research and will review and evaluate reports and recommendations. The Team Leaders and selected members of the Materials and Fracture TAP and the Connection Performance TAP, as well as the Guideline Writers for In-Process Inspection, New Construction, and Repair will also review and evaluate this work. It is expected that the subcontractor/consultant selected for this task will be responsive to issues and concerns raised by the Project Director, TAP and other reviewers.

Target Audience

The work products of this task will be directly used by consultants and sub-contractors working on the SAC Phase 2 project. The general results and the interpretation of these results will be of interest to Topical Investigation Team Leaders for Materials and Fracture and Connection Performance, as well as Guideline Writers and other general users.