Description of Work

Task 5.2: Topical Investigations on Joining and Inspection

Sub-Task 5.2.3 – Assess the Sensitivity of the Behavior of Welded Joints to Variations in Welding Procedures, Parameters and Conditions

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 5.2.3

Determine the sensitivity of the self-shielded flux cored arc welding and other commonly used welding process in structural fabrication to variations in welding procedures, parameters, and conditions for shop and field fabrication of new structural components for seismic applications. This data will help determine appropriate welding procedure specification (WPS) parameters and limits for delivering welds with the required mechanical property and quality levels. The relative sensitivity of the behavior of welded joints fabricated using different electrodes and procedures to variations in parameters and welding conditions will help establish the required limits on the quality of mechanical property. Data obtained will help evaluate existing AWS D1.1 requirements relative to pre-qualified WPSs and WPSs qualified by test to determine their limitations relative to achieving the required mechanical properties and quality levels for construction of structural welds subject to seismic loading.

Description of Sub-task

The sensitivity of various electrodes and welding procedures to welding parameters and workmanship will be established through a series of tests on simple mock-up joints and welded tension plates. In this sub-task a single combination of base and filler metal strengths will be specified. This would likely involve currently available Grade 50 base material and E70 consumables. Consumables will include at least two types of self shielded FCAW electrodes currently used in situations where high notch toughness is required (e.g., E70T-6 and E70TG-K2) and one gas shielded FCAW electrode (e.g., E70T-1) as well as benchmark tests utilizing an SMAW electrode (i.e., E7018). A complete set of welding procedure parameters and variations should be considered for one of the FCAW-SS electrodes and for the SMAW electrode. A reduced set of parameter variations may be considered for the other electrodes. Other variables such as base and filler metal strength may be considered provided that efforts within Sub-task 5.2.1 are not being unnecessarily duplicated. At least 48 sets of parameters and electrodes are anticipated as part of the tests in this sub-task.

The mock-ups should be designed to simulate actual fabrication joints. As such, a T-stub tension connection (like that shown in Fig. 1) might be utilized, but a simple, single bevel, butt welded CJP weld of two plates (see Fig. 2) might be more appropriate for comparison. These two types of specimens are utilized in Sub-tasks 5.2.1 and 5.2.2. It is desirable that the material used in the tests in sub-task 5.3.2 match those used in these other sub-tasks; if at all possible, it is desirable that the specimens be fabricated from the same stock. Loading of the welded plate specimen may be by tension, bending or other means to demonstrate the behavior of interest on a consistent basis. However, the loading need be compatible with loading methods used for similar specimens in Sub-tasks 5.2.1 and 5.2.2.

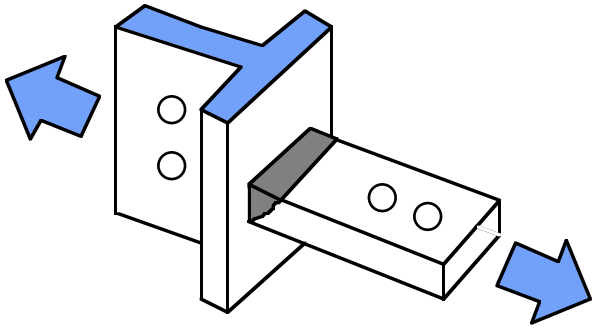

Fig. 1 – Simple T-Stub Tension Specimen

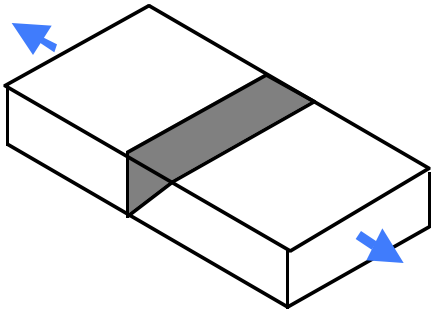

Fig. 2 – Simple Welded-Plate Specimen

A wide range of welding parameters should be investigated for a specific FCAW and SMAW electrode. Typically welding parameters will be as recommended by the consumable manufacturer consistent with AWS D1.1 requirements and conditions. This situation will correspond to the reference condition for each of the electrodes considered. Sensitivity to heat input should be investigated considering high and low travel speeds. Other issues related to electrode diameter, preheat, controlled post-heat, electrode stick out, and so on should be considered in a logical fashion in developing the final test matrix to assess the effects of these parameters and their variability on joint strength and toughness.

Basic considerations in designing, constructing and testing the T-stub and tension plate specimens include the following:

- It is intended in this sub-task that the material used for the base metal should have metallurgical and other properties similar to those utilized in new building construction. This material should in general be similar or identical to that used in Sub-task 5.2.1 for the beam flange material in the T-Stub test specimens. Care should be taken in these tests to insure that the longitudinal (rolling) direction of the base metal is oriented perpendicular to the weld. 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 "column" and "beam" flanges may have to be "extracted" from rolled shapes.
- Sizes of plate material used to represent the beam flange should result in flange thicknesses of at least 1 inch and a width of 6-inches, and be selected in coordination with sizes used in the through-thickness property and other joint tests (Sub-tasks 5.1.2, 5.2.1, and 5.2.2) as well as in the subassemblage tests in Task 7.
- In sub-tasks 5.2.1 and 5.2.2 a "single" welding procedure specification was utilized, but a wide variation in strengths and toughnesses were considered for the base material and welds. In this sub-task, a single set of material strengths is emphasized, but a range of welding electrodes and parameters are considered. The test matrix employed in this sub-task should reflect and take advantage of the tests being performed in these other investigations.
- The detail utilized by the sub-contractor for the T-stub and tension plate weld specimens, including the welding procedure specifications, and the method for removal of the backing and repair of the root

pass, must be similar to those used in sub-tasks 5.2.1 and 5.2.2 and approved by the Project Director for Topical Investigations.

- It is desired that the welds and materials be essentially free of defects or discontinuities that would significantly contribute to the failure. Thus, thorough NDE of the welds and materials (and documentation of results) is required prior to load testing. This inspection includes RT and UT inspection as well as in-process visual inspection while the welding is performed. Welds should conformance to quality standards of AWS D1.5-95 for fracture critical welds to assure that behavioral differences are due to the welding parameters investigated, rather than the presence of welding defects.

Tests of simpler fracture type specimens will be performed on the tension plate welds. It is envisioned that the welded plate and toughness specimens for a particular electrode/welding parameter set will be machined from a single long welded plate in order to simplify fabrication and help assure matching properties in the weld region. It is expected that CTOD or other standard fracture mechanics test specimens will be tested in addition to Charpy V-notch specimens. The fracture tests used must be compatible with those employed in Sub-task 5.2.2. Details of the impact toughness test specimens to be employed, and the method of loading them must conform AWS D1.5 specification. If new base materials are used (including the use of a different heat) than used in another sub-task for which stress-strain characteristics have been previously obtained, tests will also be conducted to fully characterize the uniaxial strength properties of these materials.

To facilitate comparison of results, and minimize the efforts needed to conduct material tests, it is recommended that fabrication and inspection of specimens used in different parts of this project (e.g., Sub-tasks 5.1.2, 5.2.1, 5.2.2 and so on) be fabricated from the same heat of steel stock and welding consumables and utilize the same welder and inspectors. Some of the materials to be tested will be provided by SAC from the Connection testing projects.

Efforts will be undertaken in this sub-task to compare and correlate results obtained in the T-stub specimens, welded tension plates, fracture and impact of tests, including analysis of the microstructure, chemical composition, fracture surface and so on. The sensitivity of joint behavior to variability in parameters contained in Welding Procedures Specifications and the need for improved WPS's or special inspection requirements will be determined based on information obtained in this sub-task. The data obtained in Sub-task 5.2.3 will be used to help establish the weld acceptance criteria for new steel moment-resisting frames in Sub-task 5.2.6.

Scope of Sub-Task

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

1. The contractor must attend necessary meetings during the period of the sub-contract (e.g., 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 as well as to the Project Director for Topical Investigations and be responsive to their requests related to the work.

2. The welding shall be performed by an experienced welder, qualified in accordance with AWS D 1.1 for each electrode used. Field-like welding conditions will be replicated, including windy conditions. Inspectors shall likewise be experienced and qualified to inspect fracture critical welds according to AWS D1.5.

3. Design a test matrix of welding processes, using recommended electrodes and procedures to evaluate the range of applicable parameters and conditions that may be encountered. See Sub-task description above regarding selection of electrode types and the parameters and variations to be considered. The sub-contractor will also recommend for the consideration and approval of the Project Director for Topical Investigations loading histories, deformation rates, testing temperature(s) for the welded plate and impact toughness specimens, instrumentation, methods used to simulate field conditions, and so

on. The sub-contractor must indicate the steps being taken to ensure that the salient features of this sub-task's test program are coordinated with tests undertaken in Sub-task 5.2.2.

4. It is envisioned that the T-stub test matrix will contain at least 16 combinations of electrodes (one FCAW-SS - not used in sub-tasks 5.2.1 and one SMAW) and parameter variations (two levels of heat input - travel speed, two wind speed conditions, and two preheat/interpass temperatures) to be tested. The welding current and voltage will be kept constant while the heat input is changed by varying weld travel speed. The electrode extension will also be fixed. These specimens will be tested at a selected loading condition to be provided by SAC to the Sub-contractor. The loading condition will be determined based on results from Sub-task 5.2.1 and 5.2.2.

5. The weld tension plate test matrix will consist of 32 combinations of electrodes (two FCAW-SS not used in sub-task 5.2.2, one FCAW-G and one SMAW) and parameter variations (two levels of heat input - travel speed, two wind speed condition, and two preheat/interpass temperatures) to be tested. The welding parameters will be similar to those described in item 4 for direct comparison of mechanical testing results. All weld metal tensile and CVN specimens will be prepared and tested, and the data correlated with the T-stub test results.

6. The strength-displacement data from item 5, details of the measurements such as location, gage length, etc., will be recorded for documentation and subsequent correlation.

7. At a selected set of heat input, wind speed and preheat/interpass temperature condition, six additional process variables tests will be conducted using clean and dirty plates, long and short electrode extension, flat and overhead positions for one FCAW-SS and one SMAW electrode.

8. The overall test matrix is to be submitted for review and revision by the Technical Advisory Panel at the sub-task "kick-off" meeting and the approval of the Project Director for Topical Investigations.

9. 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.

10. A minimum of 54 sets of welds (16 sets of T-stub specimens, 32 tension plate specimens and 6 additional process variables specimens) will be produced for the investigation. Note that some of the materials to be tested may be from the Connection testing projects.

11. A series of material tests will be undertaken to characterize stress-strain, impact toughness, chemical and microstructural properties as a function of variations of welding procedure, parameters and conditions. 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. It is anticipated that data will be obtained on the base material, and on the weld at : (a) the root pass, (b) mid-depth of the weld, (c) face of the weld, and (d) two locations within the heat affected zone(s) (identified by micro-etching).

12. Chemical analyses will also be performed to characterize the weld material. The tests in this Item need not be done, if such tests have been performed on identical specimens as part of other sub-tasks. Weld heat affected zone hardness will be recorded.

13. CTOD testing will be performed on selected weld tension plate specimens. A minimum of six sets of tests will be required.

14. 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.

15. The test results will be analyzed and compared to identify the sensitivity of joint performance to electrode and welding procedure, parameters and conditions. Potential causes of the observed sensitivities are to be identified from the results on testing of the welded plates and fracture toughness

specimens, analyses of fracture surfaces, and weld chemistry. Preferred electrodes and procedures will be determined in terms of their intrinsic toughness as well as their insensitivity to variations in welding parameters and conditions.

16. Existing controls in AWS D1.1-96 will be assessed with respect to their suitability for maintaining consistent weld quality for fabrication of steel structures subject to seismic loading. Prequalified conditions as well as limitation of variables for procedures qualified by test will be compared.

17. 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 preserved using a suitable protective coating.

18. The contractor shall prepare a written report that summarizes findings. The report shall include a report of test conditions, testing results, evaluation of results, conclusions regarding the most applicable welding electrodes, procedures and conditions, and recommended controls, if necessary, in addition to existing D1.1-96 requirements to ensure suitable quality levels.

Project Deliverables

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

4. Completed experimental weld matrix (54 combinations of electrodes and weld parameters). Fabrication procedures are to be presented as well as the testing and inspection/quality control protocols as outlined in the work plan. Correlation of materials and parameters selected to those utilized in other sub-tasks is to be included.

5. Design of T-stub and welded plate specimen, fracture toughness specimen and impact test specimens.

6. 54 sets of weld tests for procedure variability evaluation.

7. Regular progress reports and updates.

8. Final report on the results of the sub-task, 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.