Description of Work

Topical Investigations on Materials and Fracture

Subtask 5.1.2 - Assess the Influence of the Through -Thickness Properties of Columns and Joint Geometry Upon the Behavior of Beam to Column Flange Welds

Background: The standard beam to column connection used in moment frames relies upon the strength of the beam flange, beam flange to column flange weldment, and the through-thickness strength of the column flange to transmit the cyclic inelastic moments generated in the beam. There are few, if any, documented instances of fractures from the Northridge earthquake that could be specifically attributed to through-thickness base metal fractures, lamellar tearing. A significant number of fractures did propagate through the column base metal either as a “divot” from the column flange or completely through the column section. The through-thickness strength of rolled section flanges are not known. The industry has indicated that the through-thickness properties are likely to vary considerably. The proposed investigation is directed at determining the behavior of simulated moment frame connections which will not only determine the influence of column through-thickness strength upon the connection capacity but also the influence of joint geometry, weld heat input, and column stiffener size.

A sketch of a typical joint used in some post-Northridge designs is attached. The sketch is also intended to indicate the type of specimen to be tested in this investigation. Current practice is to leave the backing bar attached with continuous reinforcing fillet weld on the top flange. The original connection used the backup bar without the continuous reinforcing fillet weld. The fillet weld is used to reduce the crack like notch due to the lack of fusion of the back up bar. This weld reduces the effective crack size and changes the crack geometry from a surface to an internal crack. The bottom flange detail currently in use for some connection designs requires the removal of the back up bar, back gouging of the root of the weld to sound metal, followed by adding a reinforcing fillet weld to the root in the overhead position. This procedure is used on the bottom flange to insure that adequate fusion is attained at the weld root at the centerline of the weld. Lack of fusion defects caused by the difficulty in welding through the cope hole were found to initiate many of the fractures found after the Northridge earthquake. The original connection left the back up bar in place.

Objectives: The beam flange forces must be transmitted through the weld into the column flange and then dissipated into the column. Column stiffeners or continuity plates are often specified to aid in the transfer of force into the column and to reduce the bending of the column flanges. The design criteria for when these stiffeners are required in seismic design is different from that used in non-seismic construction. The influence of the stiffener size relative to the column dimensions on connection performance needs to be established. It is assumed that a stiffener will provide more uniform strain in the beam to column flange weld and therefore reduce the likelihood of a weld fracture. The stiffener size requirements are not directly based upon weld performance requirements particularly when the weld is subjected to dynamic cyclic plastic deformation. In addition, the size, type, and toughness required for the stiffener welds needs to be established. The fillet welds shown in the sketch are the simplest and cheapest method of construction. However, the correct sizing of these welds need to be established. Fillet welds have an inherent crack like defect at the weld root. It is not known whether this inherent root crack will initiate a fracture through the weld and it is uncertain what weld metal toughness is required to prevent a weld fracture with a fillet weld.

The through thickness strength of steel is dependent upon the distribution and size of non-metallic inclusions and the toughness of the steel. Three types of steel are used to make column sections, scrap based electric furnace steel, ingot production from integrated mills, and self quenching steel. The influence of the type of steel upon through thickness properties needs to be determined. In order to include each of these types of steels in the research, the column sections used in the testing program shall include sections from British Steel, Nucor-Yamato, and Trade ARBED. The table below gives the column sections to be used in this investigation and potentially in companion SAC topical investigation projects. All columns are to be grade 50 material. The mills will supply the 60 foot lengths of each section.

Shape	**Nucor-Yamato**	**TradeARBED-A572 Gr. 50**	**British Steel**	**TradeARBED-A913 Gr. 50**
W 14x257	**1**	**1**	**1**	**1**
W 14 x176	**1**	**1**	**1**	**1**
Totals	**2**	**2**	**2**	**2**

The cost of shipping of the material will not be paid by the producers. Proposals for this subcontract should include the cost of shipping for one 60 foot long section of each column size. The cost of shipping the other pieces will be borne by other SAC projects. The excess column section material shall be stored at the investigators site and each piece marked for identification, for use in other SAC projects.

The influence of weld heat input shall be investigated. The range of heat input shall be between 40 and 70 kJ/in. The weld metal is not a variable in this study. The researcher shall select a welding process and procedure which will produce welds with overmatching weld strength and high fracture toughness. Detailed welding procedures shall be developed and implemented. The welding shall be monitored to insure that the welding of each specimen is the same. The area of the column flange to be welded shall be inspected ultrasonically prior to welding to insure that no laminations exist in the flange at the location of the weld. The influence of the backing bar upon weld performance shall be determined. The influence of the continuous backing bar fillet weld and backing bar thickness shall be determined. The influence of root opening upon joint behavior should also be examined, since it is difficult to have consistent root openings in the field welding of these connections.

The test specimen shall simulate the actual field weld and geometry as closely as possible. The recommended geometry is shown in the attached figure. The material used to simulate the flange and web of the beam shall A514 steel or similar material. The purpose of using this high strength steel is to force the failure into the column. The influence of stiffener size and stiffener weld size and type, column flange bending, and stress distribution along the weld shall be investigated. A final set of specimens using grade 50 material for the beam flange component shall be tested to determine the influence of beam flange yielding on the performance of the connection. Monotonic loading is considered to be adequate for these tests. If the researcher includes reversed loading in the proposal, the loading protocol shall be given in the proposal. Dynamic testing of some of the specimens, loading rate on the order of 1-2 seconds to maximum load is desirable to determine the influence of the fracture toughness of the material at realistic earthquake loading rates.

Task Description: As part of this investigation, the sub-contractor will perform the following activities:

1) Development of Test Plan

The researcher shall prepare and present the proposed test plan (produced in coordination with the steel shape producers) to the Technical Advisory Panel (TAP) for Materials and Fracture. A meeting with the investigator, TAP, and producers will be held to finalize and approve the proposed plan. The coordination between the producers rolling schedule and availability of sections shall be the responsibility of the researcher. The welding process and procedures proposed for the fabrication of the specimens shall also be presented by the investigators for review by the TAP.

2) Column Base Metal and Weldment Characterization

The tensile strength of the column flange materials in the longitudinal and through thickness direction shall be measured for all sections included in the work plan. The longitudinal specimens shall conform to ASTM A6 and the through thickness specimens shall conform to ASTM A770. The through thickness strength and reduction in area of the column flange material shall be measured in three locations across each flange to determine the variation across the flanges and the difference between the flanges.

Test weldments using the flange of each section and both high and low heat input shall be made and then sectioned. The cross sections shall be macro-etched and the hardness of the weld metal, HAZ, and base metal measured. A tensile test of the weld metal shall also be performed. The Charpy V Notch toughness of the flange and weld metal shall also be determined. The chemistry of the weld and base metal shall be determined from these test weldments.

3) Simulated Bottom Flange Weld Tests

Test weldments using the procedure for a bottom flange weld shall be fabricated and tested. The simulated beam flange material shall be ASTM A514 or other suitable high strength material. The welds should be made using a back up bar which is then removed and the weld back gouged and welded. The bottom flange welds are to be used during this phase since they eliminate the consideration of the notch from the back up bar weld. Continuity plates shall be used in these specimens attached with full penetration welds. The weld procedure used shall be the highest heat input weld procedure. The tests should be monotonic tension loading to failure. They shall include one sample of each column flange, at least eight tests. The results of these tests should then be analyzed to determine which of the column flange material has the lowest and highest through thickness strength and the correlation of the performance of the weldment tested to the material tests performed in task 2 above.

The lowest and highest column flange strengths measured in the high heat input weld tests should then be tested with welds at the lowest heat input, for an additional two tests.

4) Influence of Joint Geometry and Other Variables

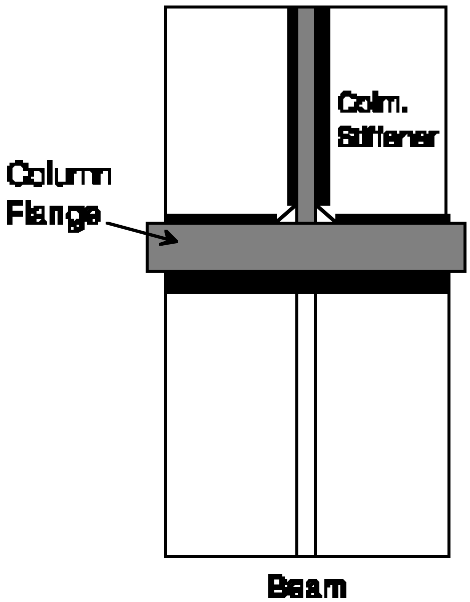
The influence of the back up bar, continuity plates, type of continuity plate weld, flange yield strength, root opening, loading rate, and column flange thickness on the connection strength shall be determined by a matrix of test specimens. The test matrix should be submitted to the Technical Advisory Panel for Materials and Fracture. A meeting with the TAP will be held to finalize and approve the proposed test matrix. The tasks 1-3 shall be summarized by the investigators in a short report submitted to the panel prior to the meeting along with the proposed test matrix. A minimum of 20 tests are envisioned to be included in this phase. If the project budget allows, additional tests will be included in the test matrix. Throughout this portion of the testing, the investigator will provide regular progress reports to the Materials and Fracture Team Leader.

5) Final Report

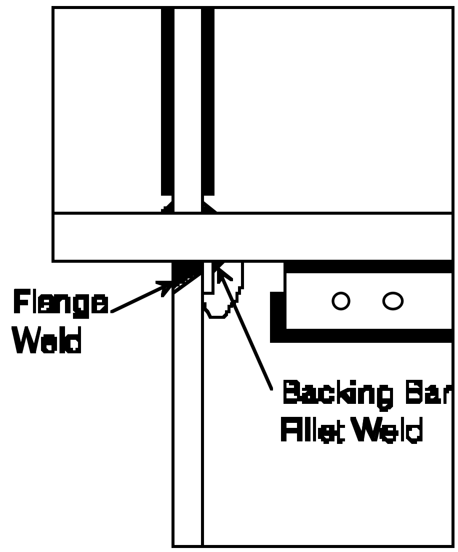
The final report shall document the test results and provide an estimated through thickness design strength for the moment frame connections beam to column connections. The design recommendations shall include the influence of heat input, base metal strength, joint geometry, and continuity plate details, loading rate, etc., upon the design stress. Draft reports shall be submitted in the format prescribed by SAC for review and comment by the TAP. Final reports shall be camera ready for publication by SAC. This report is the primary deliverable for this project.

Task Management and Review: This subtask is supervised by James Malley, Project Director for Topical Investigations. The Materials and Fracture Technical Advisory Panel (TAP) will provide oversight and an advisory role on the conduct of the research and will review, provide specific comment, and evaluate all reports and recommendations. Team leaders and selected members of the Connections Performance TAP and Performance Prediction and Evaluation TAP will also review and evaluate this work It is expected that the subcontractor/consultant selected for this subtask will be responsive to issues and concerns raised by the Project Director, TAP and other reviewers. The subcontractor shall be responsible for regularly reporting progress and difficulties to the Materials and Fracture Team Leader and the Project Director for Topical Investigations.

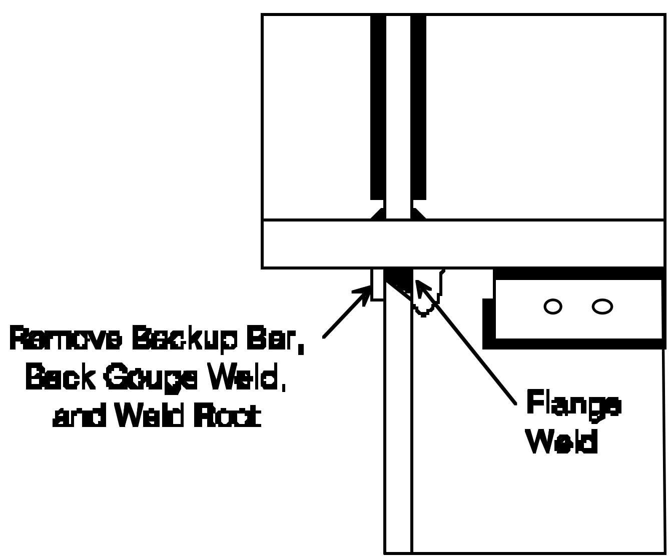
Target Audience: The work products of this subtask will be directly used by Materials and Fracture Team and the guideline writers working on the SAC Phase 2 project. There will also be a need to integrate these results with the various analytical and testing investigations throughout the progress of the program. They will also be of interest to Topical Investigation Team Leaders for Connection Performance and Performance Prediction and Evaluation. The results of this sub-task will be used to develop the State of the Art Report on Materials and Fracture. It is expected that the results will also be of great interest to the general profession and research community.



Top View



Side View
Simulated Top Flange



Side View
Simulated Bottom Flange