Understanding the Behavior of Steel Connections with Bolts and Welds in Combination

Christopher D. Waite, Ligang Shen, Mohamed Soliman, Ph.D., Bruce W. Russell, Ph.D., P.E., F.ACI
School of Civil and Environmental Engineering, Oklahoma State University

Project Description

The need for connections employing bolts and welds in combination may occur during the construction phase of a bridge when there are unforeseen difficulties in the matching of bolt holes, or in retrofit of existing structures. Due to the different load-deformation behavior, bolts and welds may not reach their maximum strength simultaneously. Accordingly, the maximum capacity of the connection cannot be easily predicted. Through full-scale experimental testing partnered with finite element analysis, the load-deformation behavior of connections utilizing bolts and welds in a single load sharing system has been investigated. This study has provided insight into how the various connection attributes can affect both its ultimate capacity, as well as its inherent ductility. These attributes include bolt grade, bolt size, bolt tightening method, condition of faying surface, and ratio between the strength of welds and bolts. The experimental results are then employed to calibrate the finite element model to predict the ultimate capacity under different variable combinations. These results will allow the evaluation of the current 2016 AISC Specification for connections utilizing bolts and welds in combination.

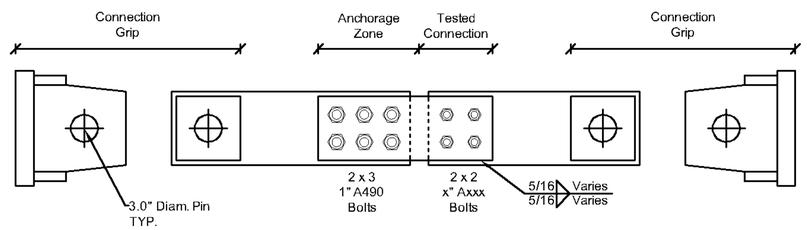
Project Goals

1) Determine the behavior of connections employing both pretensioned/slip-critical bolts and longitudinal welds in a single load-sharing system.
2) Quantify the uncertainties associated with the behavior of these joints.
3) Evaluate the provisions of the 2016 AISC Specification on using bolts in combination with welds and propose the necessary changes.
4) Provide design guidance for realistic connection configuration.

Test Specimen Details

Axial lap connections are currently being studied in 2x2 (45 specimens) and 2x3 (24 specimens) bolt patterns. Each test specimen utilizes A572 Gr. 50 steel and is made of three parts: the tested connection, the anchorage zone, and the connection grip. The specimen was designed to ensure failure in the tested connection zone under the highest load case of $(R_n)_{Bolt} + (R_n)_{Weld}$. The highest loaded connection is roughly 350 kips in capacity.

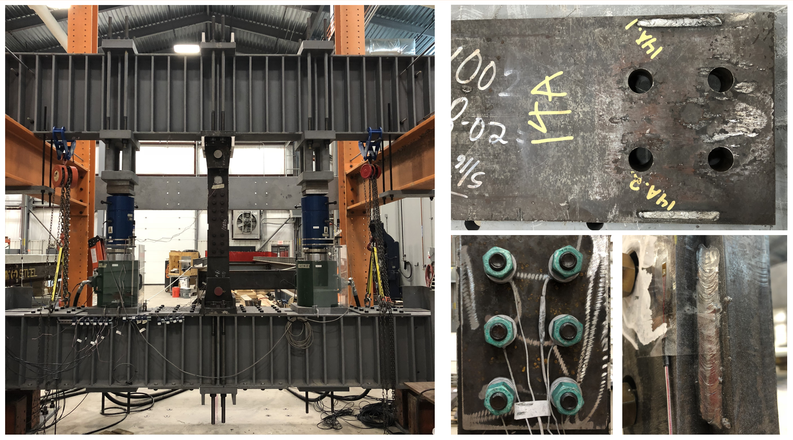
The bolts in the tested connection are pretensioned/slip-critical and are placed in oversized holes. During joint construction, these bolts are positioned in negative bearing, therefore to capture the bolt slippage during testing.



The specimens represent an extensive effort to analyze many different important test attributes. These attributes include:

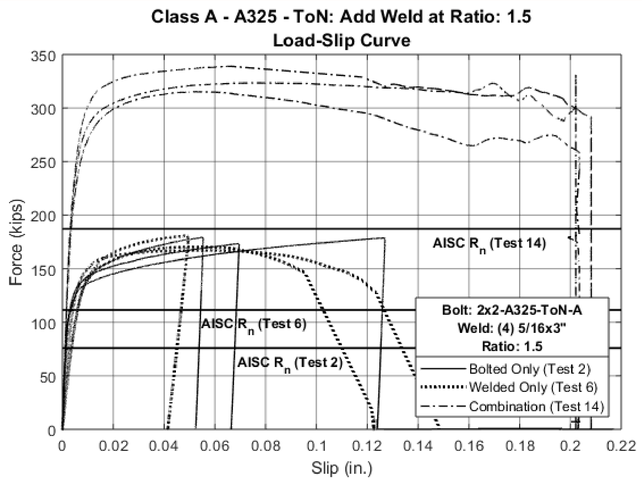
Connection Size: 2x2 & 2x3
Bolt Grade: A325 & A490
Bolt Size: 3/4" & 1"
Faying Surface: Class A & Class B
Tensioning Method: Turn of Nut (ToN) & Tension Control (TC)
Weld/Bolt Strength Ratio: 0.67, 1.0, 1.33, 1.5, & 2.0

Full-Scale Experimental Testing



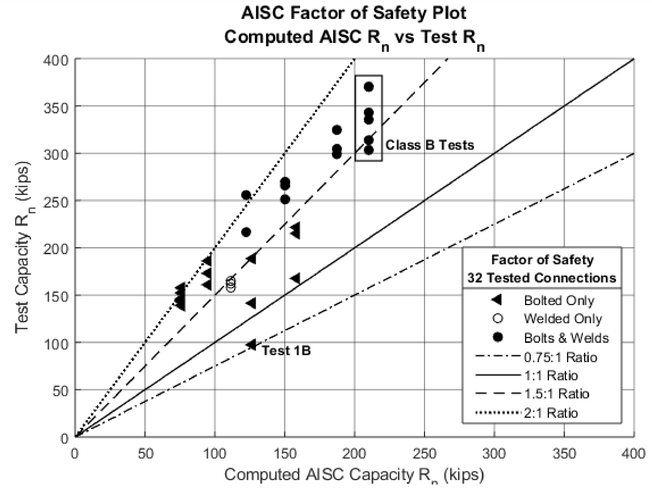
A custom 500 kip capacity test frame is utilized for the full-scale test. It is powered by a MTS SilentFlo 90 GPM pump and controlled using a MTS FlexTest 60 controller. The load is applied using two 565 ton Simplex actuators operating at 3000 psi. Each actuator is also accompanied by a 6'' stroke linear variable displacement transducer (LVDT) and a 250 kip load cell used for control and measurement. The force is applied at a displacement controlled rate until the system detects a force reduction of 50%. At this point, the hydraulic system slowly reduces load and ends the test. This type of test captures the load-deformation characteristics of the connection past the first yield. This includes when the test bolts "slip" from negative bearing to positive bearing. The slip distance is 0.375" and 0.50" for the 3/4" bolts and 1" bolts, respectively.

Test Results



Test 2 is a bolted only connection with a Class A surface utilizing A325-ToN bolts. Test 6 is a welded only test with four longitudinal fillet welds at 5/16 x 3.0". Test 14 has the bolt characteristics of Test 2 and the weld characteristics of Test 6, making it an ideal case to highlight the load-slip behavior of connections utilizing both bolts and welds.

Discussion



For each connection, the AISC R_n was plotted against its respective Test R_n to gain insight into the factor of safety that would be provided for the 32 tested connections. Aside from Test 1B, the tested connections meet or exceed the AISC Specifications for nominal strength. All Class A tests, both bolted only and combination have a factor of safety that exceeds the 1.5. The Class B bolted only connections do not reach a 1.5, but when combined with weld, some exceed this threshold.

Conclusion

Thus far, the test results have been promising and present a increase in stiffness through the elastic region of the connections utilizing bolts and welds sharing the load beyond the stiffness of either bolt only or welded only connections. This hypothesis is preliminary and will continue to be investigated with the remaining experiments and with utilization of a calibrated finite element model partnered with probabilistic analysis. The remaining experiments include additional 2x2 & 2x3 connections, as well as 4x6 connections which would be utilized in bridges.

Acknowledgements

This project is sponsored by the **American Institute of Steel Construction, AISC**. The research is a collaborative effort between **OSU** and **W&W/AFCO Steel Co.**, which provided the load frame and fabricated samples to be tested at the **Bert Cooper Engineering Laboratory.**

St. Louis Screw & Bolt supplied all fasteners for the project as well as valuable technical expertise throughout construction and testing.

GWY and **Skidmore Wilhelm** provided fastening and measuring equipment and supported the research group with equipment and construction training.