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Load-resistance Behavior of Connections with Welds and Bolts in Combination

1. Abstract

Situations such as repair and strengthening of existing structures sometimes make it unavoidable to use connections with both welds and bolts. These combined connections behave differently from bolted or welded connections and it is known that adding the strengths of individual components of a combined connection does not equal its ultimate strength (Manuel and Kulak). This can be attributed to the difference in ductility and load-resistance mechanism of welds and bolts. The AISC specifications give some instructions on designing combined connections by specifying

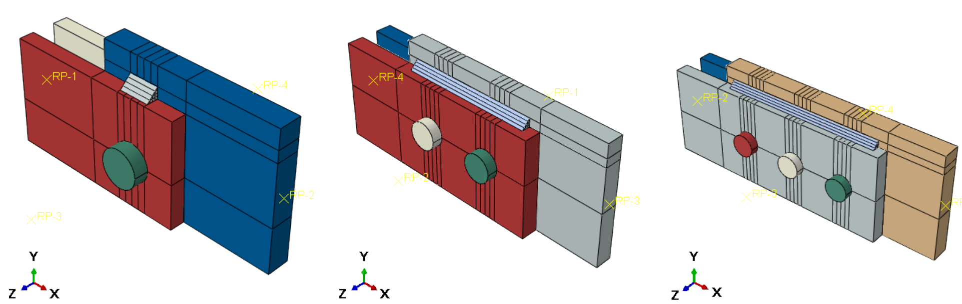

Figure 1: Different groups of combined connections

lower limits on strengths of welds and bolts in a combined connection but these limits ignore the action of bearing forces, leading to high factors of safety ranging from 3.01 to 3.94 for friction-type connections and up to 4.53 for bearing-type connections (Holtz and Kulak). The use of finite element analyses (FEA) can be helpful in simulating combined connections under a variety of loads.

2. Background and Significance

Kulak and Holtz pointed out limitations of existing design methods and developed an analytical model to calculate the ultimate strength of combined connections and validated it with experiments. The consideration of angle of welds which is missing from design specifications was included in development of analytical model. Behavior of tension splices and moment connections was evaluated in this work. This work was the most important in developing the FEMs (Finite Element Models) for combined connection[1]. The material properties and modeling methods from the work by Adkins (Adkins) and Wurzelbacher (Wurzelbacher) were used for this research.

2.1 Objectives of this Research

The main objectives of this work were:

1. To develop methodology of modeling prestressed bolts in a connection in ABAQUS with the prestressing force as specified in Table J3.1 of AISC 360-16 (Code-Steel) which, on application of load in tension, produces the correct load response with correct slip plateau as predicted from calculations.

2. To correctly simulate the load-resistance behavior and failure initiation of longitudinal and transverse welds applied with a tensile load in ABAQUS and comparing obtained results with Adkins' results.

3. To use the know-how of modeling welds and bolts from objectives (1) and (2) to create FEA for combined connection loaded in tension to simulate fracture initiation and know the percentage contribution of welds and bolts in resisting total load.

[1] Holtz' and Kulak's work is the main source of experimental results for comparison with FEA.

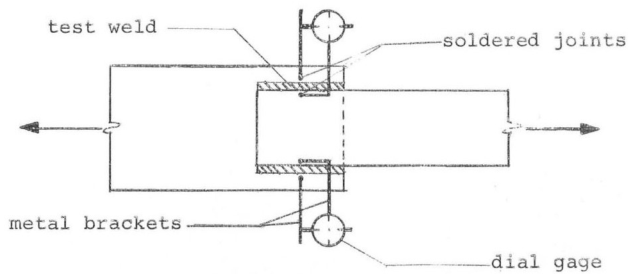

Figure 2: Position of dial guages for measuring displacement (Holtz and Kulak)

3. Procedure

3.1 Simulating Experiments by Holtz and Kulak

The research done by Holtz and Kulak on combined connections in 1970 provided a foundation for creating the FEM for a combined connection. The specimens were fabricated from ASTM A36 plates, welds from E60 electrodes and bolts were ASTM A325 grade. These specimens were fabricated in three groups:

1. Longitudinal welds in combination with bearing-type snug-tight bolted connection
2. Longitudinal welds in combination with friction-type bolted connection.
3. Transverse welds in combination with friction-type bolted connection.

For this research, only connections in the second group were chosen to compare results from FEA. The reason for this is the recommendation by Holtz and Kulak that connections belonging to the remaining two groups should be avoided. This finding was also verified through FEA in this research. After successfully modeling and replicating Holtz' and Kulak's experiment, several models were analyzed for connections with different combinations of strengths of bolted and welded components as shown in Figure 1. The displacements were measured as per the position of dial gauges as shown in Figure 2.

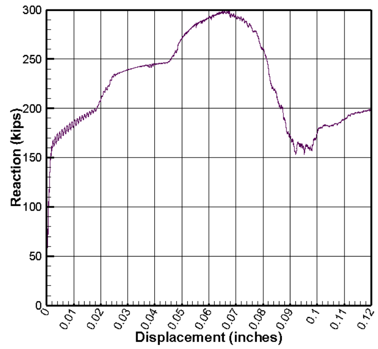

Figure 3: Results from FEA of experiments by Holtz and Kulak

4. Analysis Results

4.1 FEM for Holtz' and Kulak's Experiments

To replicate the experiments by Kulak and Holtz (Specimen BW-L-1-3) in ABAQUS, the modeling procedure from Adkins' work and Wurzelbacher's work was used and the results are shown in Figure 3. From this plot, it can be seen that the ultimate displacement occurs at 0.09 inch and ultimate load is 298 kips, which are close to the experimental values. For this model, a scaling factor of 0.5 for Hooputra's aluminum data(Hooputra et al.) was used.

4.2 Relation between Ultimate Strengths

From the data obtained, the following relation can be established between the ultimate strengths of individual components of the combined connection:

$$r_{u(combined)} = (1.50 - 0.002 \cdot r_{u(bolt)}) \cdot r_{u(weld)} + (6.5 - 0.024 \cdot r_{u(weld)}) \cdot r_{u(bolt)}$$

4.3 Proposed Method to Calculate Design Strength

After looking at the force-displacement response of combined connections, it was realized that a systematic method to find their design strengths was necessary which is as outlined below:

1. Find the line that closely represents the linear elastic response of the combined connection.

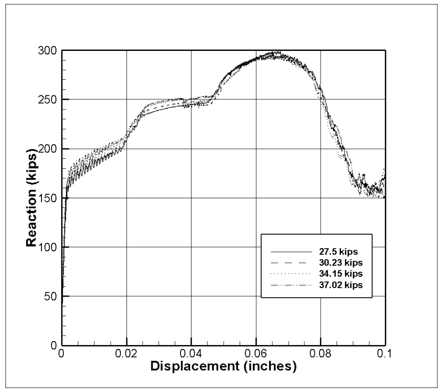

Figure 4: Force-displacement results for different values of bolt pretension

2. With a slope equal to that of line obtained, draw another line intersecting the X-axis (displacement) at a value of 20% of ultimate displacement.

3. The ordinate of the point on the graph that intersects the line in (2) gives the value of the ultimate strength of a combined connection.

5. Conclusions

5.1 Effect of Pretension on Combined Connections

Combined connections with different pretensioning force in the bolts were analyzed for the force-displacement response. The responses are shown in Figure 4. It can be seen from the graph that the load-displacement response of combined connection remains unchanged with change in bolt pretension force. It must also be stated here that the minimum value of pretension specified by AISC is required for combined connections. Pretensioning the bolts causes the external force to be resisted by both the welds and friction between the plates.

5.2 Proposed Ratio for Nominal Strengths of Welds and Bolts

In order to come up with a ideal ratio of nominal strengths of the welded components and bolted components of a combined connection, several connection designs were analyzed with different varying strength of each component. The two major groups of connections analyzed had

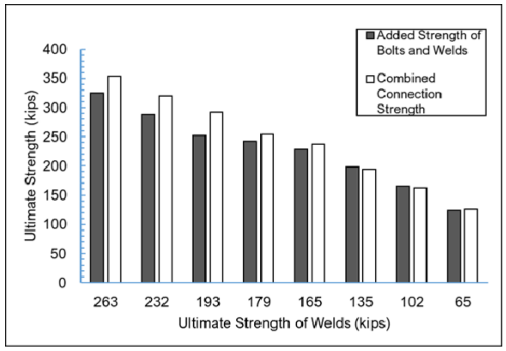

Figure 5: Ultimate strength for connections with one bolt

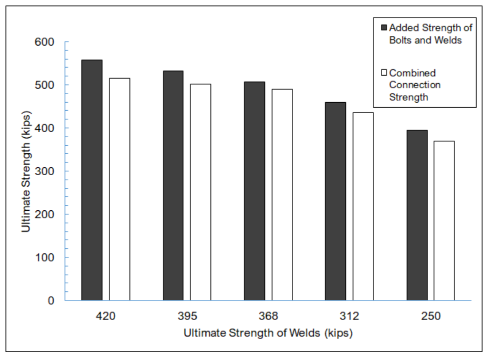

Figure 6: Ultimate strength for connections with two bolts

one and two ¾ inch bolts respectively and the length of the weld was varied in each group. Figure 5 shows the results for connections with a single bolt and Figure 6 shows results for two bolts. Based on the results, it was concluded that for a tensile load, a ratio of 1.45 for the nominal strength of welded component to the nominal strength of bolted component ensures maximum ultimate strength.

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