

5) DISCUSSIONS

Table 3 demonstrates that some specimens had test results as much as 20% lower than nominal strength calculated in accordance with AISC Specification. Results in Table 3 are rearranged into smaller groups based on parameters for further discussions.

An attempt to convert data from strain gauge into any meaningful stress did not materialize as the strain gauge itself was only suitable for straightforward normal stress. However, from Figure 7, it can be noticed that the maximum strain value always occurred on one of the corners, mostly at the top right corner (at the heel of the angle) which is located farthest away from the centroid of the weld group.

5.1 Effects of Unbalanced Arrangement on Angle Welded Connections

To appreciate the effects of unbalanced welding arrangement alone, only specimens with double angles are compared to exclude any involvement from out-of-plane bending in Table 4.

Table 4 Effects of unbalanced welds on shear rupture of angle welded connection

Specimen	Angle (mm)	Calculated Nominal Weld Rupture (kN)	Test Results (kN)	Ratios of Test Results/Nominal Strength
D1-B-G10	2-65x65x8	459	415	0.90
D1-U-G10	2-65x65x8	459	394	0.86
D2-B-G10	2-120x120x8	459	417	0.91
D2-U-G10	2-120x120x8	459	373	0.81

From Table 4, it can be clearly seen that strength of the welded end connection is 14% below calculated nominal strength in 65x65x8 mm-angle specimen and is 19% below in 120x120x8 mm-angle specimen. Use of larger angle means that the distance between the two welds, one at the heel and another at the toe, increases. This may worsen the shear rupture strength of the weld group. In addition, it should be notice that, even though the effects of unbalanced welds are conspicuous, rupture strength of balanced welds were 10% lower than the calculated nominal values.

5.2 Effects of Out-of-plane Bending on Angle Welded Connection

To demonstrate the effects of what out-of-plane bending due to the fact that the centroid of the angle does not lie in its own physical body has on strength of welds, Table 5 is created to consist of balanced welds so that the impact of unbalancing the connection does not include in the discussion. Because of the difference of the number of angles used in the specimens, a comparison on the effects of out-of-plane bending is made on the ratios of test results and nominal strength which normalizes the number of angles.

Table 5 Effects of out-of-plane bending on shear rupture of angle welded connection

Specimen	Angle (mm)	Calculated Nominal Weld Rupture (kN)	Test Results (kN)	Ratios of Test Results/Nominal Strength
D1-B-G10	2-65x65x8	459	415	0.90
S1-B-G10	65x65x8	230	232	1.01
D2-B-G10	2-120x120x8	459	417	0.91
S2-B-G10	120x120x8	230	200	0.87

From Table 5, the comparison of specimens with 120x120x8 mm angles shows that reduction of weld rupture strength due to out of plane bending is less than 5%, whereas there is no reduction at all in case of specimens with 65x65x8 mm angles when the calculated nominal strength and the test result of the welded connection were almost identical. Even though the member itself will experience out-of-plane bending under tensile load, the impact is not transferred onto its welded end connections.

5.3 Effects of Gusset Plate Thickness on Angle Welded Connections

To study the impact of gusset plate thickness on strength and behavior of welded end connections of angles, three thicknesses were used in the experiments. Results of specimens are summarized in Table 6.

Table 6 Effects of gusset plate thickness on strength and behavior of angle welded connection

Specimen	Gusset Plate Thickness (mm)	Calculated Nominal Weld Rupture (kN)	Test Results (kN)	Ratios of Test Results/Nominal Strength	Displacement of Gusset (mm)
S1-B-G10	10	230	232	1.01	6.72
S1-B-G16	16	230	223	0.97	9.82
S1-B-G22	22	230	223	0.97	12.49
S1-U-G10	10	230	202	0.88	4.25
S1-U-G16	16	230	225	0.98	7.71
S1-U-G22	22	230	223	0.97	4.64*

* denotes that the specimen was strengthened at the support to reduce lateral deformation.

In case of balanced welds, since the welded connection did not experience any strength reduction, an increase in a gusset plate thickness bears no discernable benefits. In case of unbalanced welds, thicker plates helped increase strength of the weld group significantly. However, it should be noted that an increase of plate thickness induced a huge amount of displacement of the plate itself. The displacement had become so large that the gusset plate had to be strengthened by adding a stiffener at the back of it (Mekpramual 2014). It is also noticeable that displacements in specimens with balanced welds were slightly greater than those in unbalanced welds in every comparable case. Even though an increase of gusset plate thickness may help maintain the full strength of the welded connection, the size required may not be practical as the use of a 65x65x8 mm should not require a gusset plate as thick as 16 mm.

5.4 Effects of Dimensions of Welded End Connections

The effects of dimensions of the connection, i.e., the width of the connection or the distance between the two welds; and the length of the welds, are investigated by making a comparison of weld rupture in specimens with different single angle sizes as shown in Table 7, and specimens with different weld lengths as shown in Table 8, respectively.

From Table 7, it can be seen that the width of the connection, which, invariably, is equal to the leg of the angle, has significant effects on shear rupture strength of the welds. In the case of balanced welds, the strength of the weld group is lower than the nominal value by almost 15%, whereas that of the unbalanced weld group is more than 20%.

Table 7 Effects of Width of Connection on Welded End Connection

Specimen	Angle (mm)	Calculated Nominal Weld Rupture (kN)	Test Results (kN)	Ratios of Test Results/Nominal Strength
S1-B-G10	65x65x8	230	232	1.01
S2-B-G10	120x120x8	230	200	0.87
S1-U-G10	65x65x8	230	202	0.88
S2-U-G10	120x120x8	230	181	0.79

Table 8 Effects of Length of Connection on Welded End Connection

Specimen	Lengths of Welds (mm)		Calculated Nominal Weld Rupture (kN)	Test Results (kN)	Ratios of Test Results/Nominal Strength
	L ₁	L ₂			
S2-B-G10	120	50	230	200	0.87
S2-B-G10-a	240	90	446	363	0.81
S2-U-G10	85	85	230	181	0.79
S2-U-G10-a	165	165	446	366	0.82

Since longer welds naturally possess greater strength than the shorter ones, use of ratios of test results and nominal strength again has to be employed to normalize the results. From results shown in Table 8, it is seen that use of long welds may have further reduced its strength up to almost 20% in the balanced weld case. However, in the unbalanced case where the weld shear rupture strength was already deducted by 20%, no further reduction was evident. It is also probable that strength reduction in any case may not be beyond approximately 20%. In addition, it should be noted that the length of the welds used in the research is substantially less than 100 times its own size, which is the limit that AISC (2010) suggests that the effective length be reduced.

6. CONCLUSIONS AND SUGGESTIONS

From results and discussions in the previous sections, the following conclusions can be drawn from the research:

1. Use of unbalanced welds may reduce the strength of welded end connection as much as 20%.
2. Out-of-plane bending due to the eccentric nature of the angle itself does not penalize the strength of the welded end connection.
3. An increase of a gusset plate thickness helps strengthen the welds, but it may not be a practical solution.
4. A large welding configuration, i.e., with a large distance between the welds or with long lengths, may result in strength reduction up to 20%. The length of the welds use in the research is substantially lower than the 100 times the weld size, which is the limitation that AISC suggests that the effective length be used.

Design suggestions are as follows:

1. If possible, always use the balanced welds for end connections of angles to avoid strength reduction.
2. Exercise use of large size welded end connections with at least 20% reserve for precaution.

7. REFERENCES

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