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Strength of Cold-Formed Steel Clip Angle in Combined Bending and Shear Loading

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Abstract

Thin-walled cold-formed steel (CFS) clip angles have been commonly used for connecting CFS framing members or attaching CFS members to the major building structure. The implementation of clip angles involves consideration of ultimate strength for combined bending moments and shear forces. Therefore, a test program of CFS clip angle was recently conducted to investigate the behavior and strength of cold-formed steel clip angle subjected to combined bending moments and shear forces at different boundary conditions. The research included connection tests on clip angle. The testing method was adopted from the AISI S914 Test Standard for Joist Connectors Attached to Clod-Formed Structural Framing. This paper presents the details of the test program, test results as well as recommendations for CFS clip angle configurations.

Introduction

Thin-walled cold-formed steel (CFS) clip angles have been commonly used for connecting CFS framing members or attaching CFS members to the major

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building structure. The cantilevered leg of the clip angle may subject to shear, axial (compression or tension), bending, or a combination of those three forces. A comprehensive test program was recently conducted at the University of North Texas to investigate the clip angles' behavior under shear, tension, and compression (Yu et al., 2015). The objective of this paper is to investigate the shear strength of the clip angles in actual loading and boundary conditions that exist in CFS framing. Therefore, CFS joist connectors are tested under combined bending and shear. Two types of boundary conditions, rigid and semi-rigid, for the cantilevered leg of clip angles are included. Details of the test program, test results as well as recommendations for CFS clip angle configurations are provided.

Test Setup and Test Procedure

The CFS joist connector tests used AISI S914 (2015) as a guide for the test setup as illustrated in Figures 1 and 2. In each test, a two identical CFS joists were connected using one structural steel tube at the mid span, shown in Figure 3. Steel angles were also used to connect the flanges of the two joists. The joist assembly was anchored to two supporting members at both ends by four identical CFS clip angles. A structural steel load transfer block was used to apply a vertical force to the steel tube. Four position transducers were used to measure the vertical deflection of the clip angles. A minimum gap of 1/8 was provided between the end of each joist and supporting members to avoid any contact during the test. The joist tests were performed in a displacement control mode at a constant speed of 0.3 in. per minute.

Figure 1 - Joist test setup

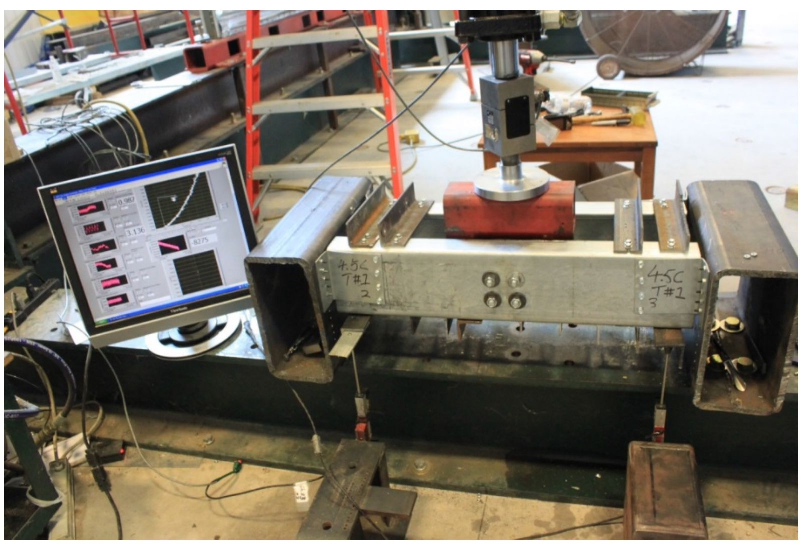

Figure 2 - Joist test setup

Figure 3 - Connection details of the two joists (photo taken after test)

Test Specimens

A total of 14 joist tests were conducted. The clip angle label was used as the joist test label. For all clip angles in this test program, single line of No. 14-14×1 self-drilling self-tapping screws were used to attach the cantilevered leg of the clip angle to the joist. The anchored leg of the clip angle was attached to the supporting members by No. 10-24×1 BHSC bolts. All the clip angles were 54 mil. All the joists were 28 in. long in this test program, the thickness was either 54 mil or 97 mil. Table 1 lists the measured dimensions, the tested material properties, joist specifications, and the number of screws used in each clip angle. Figure 4 illustrates the measured dimensions

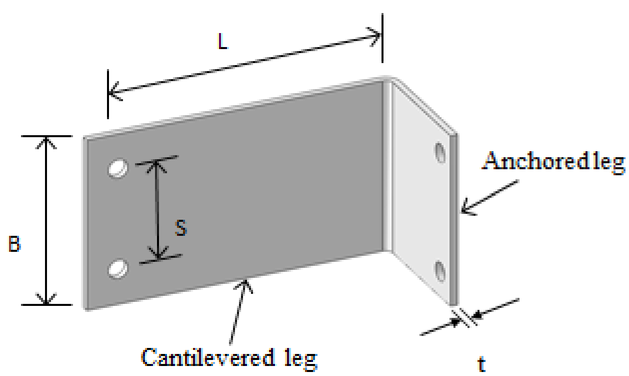

Figure 4 - Measured dimensions

Table 1 - Properties of clip angles in the joist tests

Test Label	B (in.)	L (in.)	t (in.)	F_y (ksi)	F_u (ksi)	# Screws on C-leg	S (in.)	Joist Spec.
4.5D T#1	4.492	3.157	0.0583	46.1	63.7	4	1.25	600S250-97
4.5F T#1	4.501	3.407	0.0583	46.1	63.7	4	1.25	600S250-54
4.5F T#2	4.501	3.407	0.0583	46.1	63.7	4	1.25	600S250-54
6.5A T#1	6.500	3.094	0.0583	46.1	63.7	5	1.44	800S250-54
6.5A T#2	6.500	3.094	0.0583	46.1	63.7	5	1.44	800S250-54
6.5B T #1	6.500	3.407	0.0583	46.1	63.7	5	1.44	800S250-54
6.5B T #2	6.500	3.407	0.0583	46.1	63.7	5	1.44	800S250-54
8.5B T #1	8.499	3.407	0.0583	46.1	63.7	5	1.94	1000S165-54
8.5B T #2	8.499	3.407	0.0583	46.1	63.7	5	1.94	1000S165-54
8.5B T #3	8.499	3.407	0.0583	46.1	63.7	5	1.94	1000S250-97
8.5B T #4	8.499	3.407	0.0583	46.1	63.7	5	1.94	1000S250-97
10.5B T#1	10.500	3.886	0.0583	46.1	63.7	14	0.75	1200S165-54
10.5B T#2	10.500	3.886	0.0583	46.1	63.7	14	0.75	1200S165-54
10.5B T#3	10.500	3.886	0.0583	46.1	63.7	14	0.75	1200S250-97
10.5B T#4	10.500	3.886	0.0583	46.1	63.7	14	0.75	1200S250-97

Test Results

Table 2 summarizes the joist test results. The P_{test} is the peak load per clip angle, which was calculated using the total force divided by 4. The deflection, Δ, is the vertical deflection of the controlling clip angle. The controlling clip angle was the one with most significant deformation in each joist test. P_n is the predicted shear strength using Eq. 2.6.

Table 2 - Results of joist connector tests

Test Label	P_{test} (lbs)	Δ (in.)	P_n (lbs)	P_{test} / P_n
4.5D T#1	1760	0.227	2107	0.835
4.5F T#1	1688	0.218	2046	0.825
4.5F T#2	1640	0.228	2046	0.802
6.5A T#1	3276	0.218	3404	0.962
6.5A T#2	3207	0.297	3404	0.942
6.5B T #1	2595	0.151	3268	0.794
6.5B T #2	2959	0.130	3268	0.905
8.5B T #1	3800	0.201	4269	0.890
8.5B T #2	3829	0.088	4269	0.897
8.5B T #3	4650	0.702	4269	1.089
8.5B T #4	5417	0.114	4269	1.269
10.5B T#1	4981	0.146	7857	0.634
10.5B T#2	4936	0.074	7857	0.628
10.5B T#3	8305	0.181	7857	1.057
10.5B T#4	9061	0.154	7857	1.153

Direct comparison can be made for the 4.5D clip angles which were tested in both the joist tests and the shear tests with the same configurations. Figure 5 shows the comparison of the test curves. Figures 6 and 7 show the failure mode for the 54 mil 4.5 in. clip angles in the joist and the shear test respectively. It can be seen that the 54 mil clip angle had similar peak load, deflection, and failure mode in the two test programs.

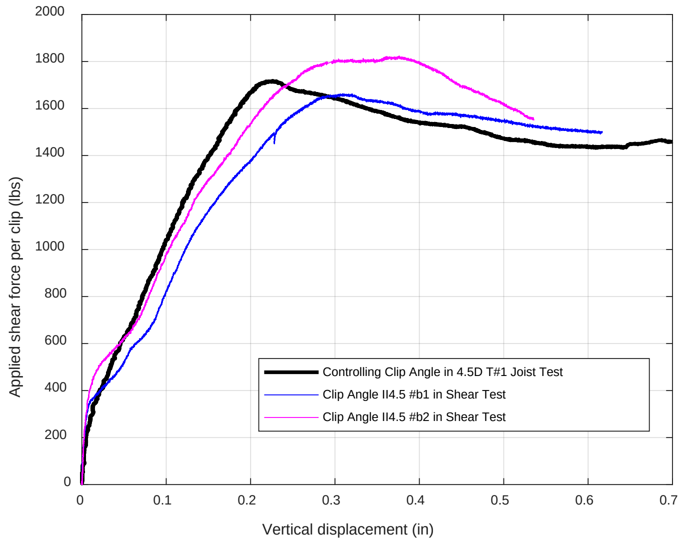

Figure 5 - T Comparison of 54 mil 4.5 in. clip angles in two test programs

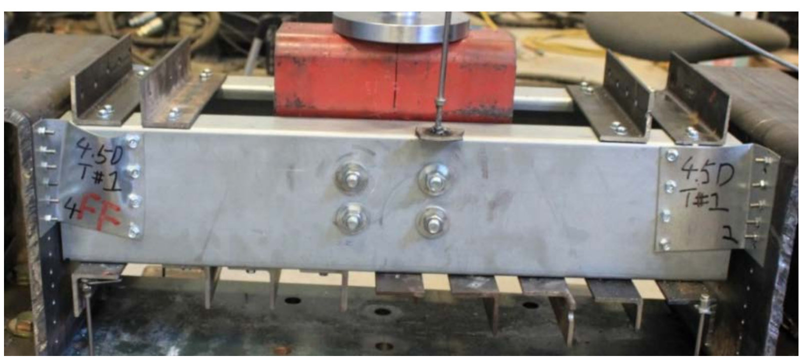

Figure 6 - Failure mode of joist 4.5D T#1

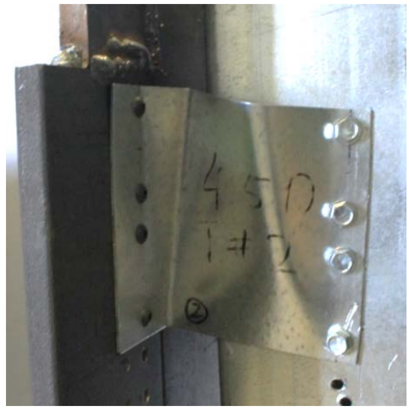

Figure 7 - Failure mode of shear test II4.5 #b2

Direct comparison can also be made on 54 mil 6.5 in. deep clip angles with 5 screws. The test curves are shown in Figure 8 and the failure mode is shown in Figures 9 and 10. The clip angles in both test programs showed similar failure mode. However the joist tests gave lower peak loads than those in the shear tests. In the joist tests, the controlling clip angle had significant deformation while the other three clip angles showed no observable deformation. It was believed that the load redistribution took place during the test and it lowered the ultimate load that the joist assembly could yield.

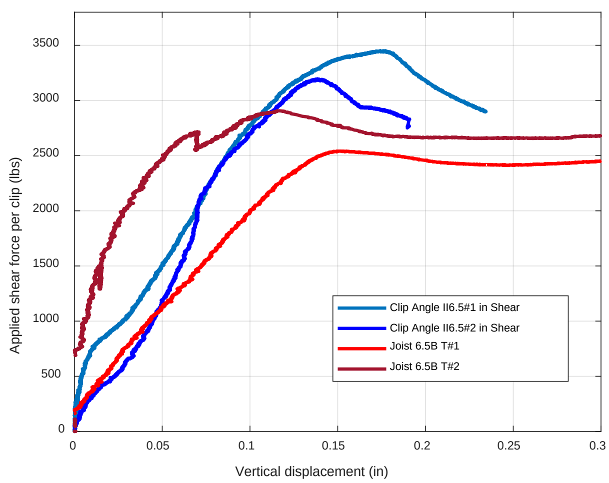

Figure 8 - Comparison of 54 mil 6.5 in. clip angles in two test programs

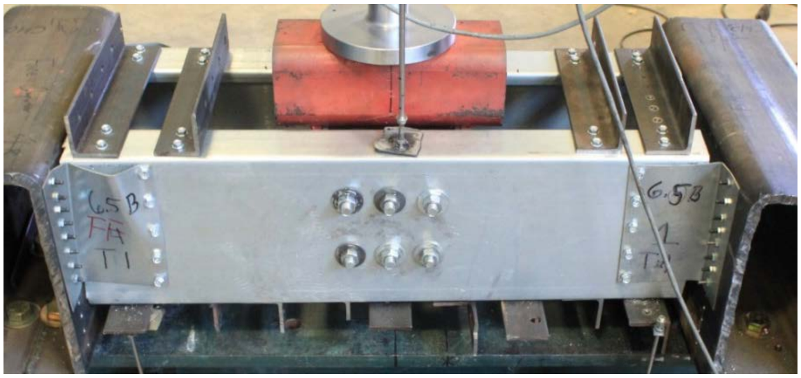

Figure 9 - Failure mode of joist 6.5B T#1

Figure 10 - Failure mode of shear test II6.5 #1

The joist test program discovered that for the deeper clip angles (8.5 in. and 10.5 in.) attached to 54 mil joists, significant deformation in the joist web was observed when the clip angle reached its capacity. Figures 11 and 12 respectively show the failure mode of 8.5B T#1 and 10.5B T#1 respectively where 54 mil joists were used. Shear buckling occurred in the web of CFS joists where the clip angles were installed. The clip angles in those two tests yielded lower strength than the predicted values mainly due to a weaker boundary condition that the joist's web provided to the cantilevered leg of clip angles. Particularly for the 10.5 in. deep clip angle, the clip angles only reached 63% of their predicted shear strength.

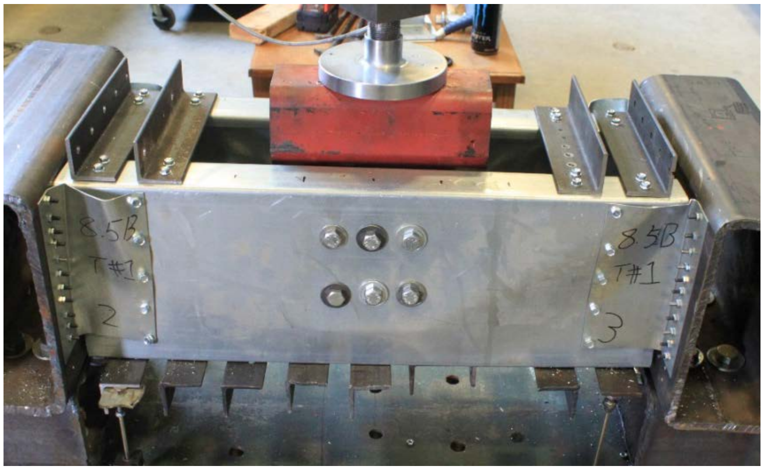

Figure 11 - Failure mode of 8.5BT #1

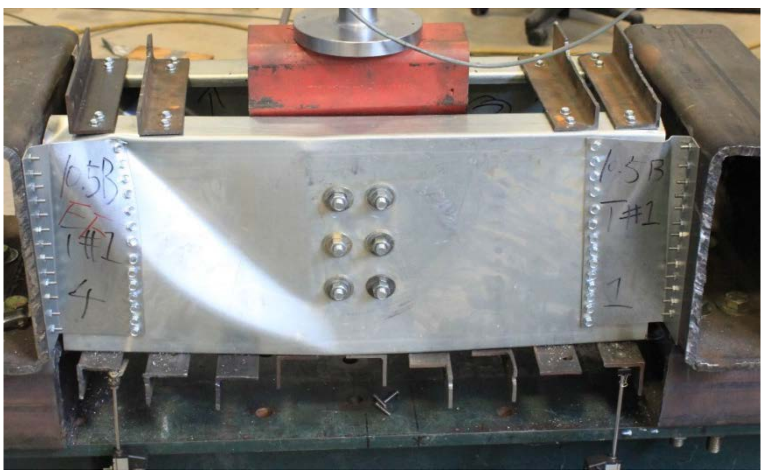

Figure 12 - Failure mode of 10.5B #1

The 8.5 in. and 10.5 in. clip angles were re-tested using 97 mil joists in order to avoid buckling in the web. Figures 13 and 14 show the failure of the joist test 8.5B T#3 and 10.5B T#3 respectively, no failure in the joist web was observed. The peak load was increased and comparable with the predicted values. The joist connector tests discovered that the boundary condition could have significant effect on the shear strength of the cantilevered leg of the clip angle. The proposed shear design method assumes a solid support to the cantilevered leg and the anchored leg. The CFS clip angle may not be able to provide full shear strength if the connecting members yield significant deformation. The shear strength of the connecting members shall be checked to ensure structural safety.

Figure 13 - Failure mode of 8.5B T#3

Figure 14 - Failure mode of 10.5B T#3

Conclusions

The CFS joist connector tests were conducted to investigate the shear strength of the clip angles when used in CFS framing. The test results found that the web stability could have significant impact to the shear strength of the clip angle. When the joist web could not provide adequate shear resistance, it could buckle at the locations where the clip angles were installed. In order to achieve the full shear strength of a clip angle, the connecting members shall be able to provide solid support to clip angle.

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