

Load Bearing Clip Angle Design

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Load Bearing Clip Angle Design

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ABSTRACT

The report presents a comprehensive research project aimed at developing design methods for three limit states of cold-formed steel clip angles: shear, compression, and pull-over of the screw connections. For each limit state, a test program was conducted to investigate the behavior, strength, and deflection of the clip angles. The test results were compared with existing design methods for members similar to, but not exactly the same as, cold-formed steel clip angles. It was found that none of the existing methods worked well for the tested clip angles, therefore new design methods were developed for each of the three limit states studied in the project. LRFD and LSD resistance factors and ASD safety factors were provided to apply to the proposed design equations for nominal strength.

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1 OBJECTIVES

The objective of this project was to investigate the behavior of load-bearing cold-formed steel (CFS) clip angles and then develop appropriate design methods for their use when subjected to three different loading conditions. Three limit states were considered in the research: (1) transverse shear capacity of the cantilevered leg; (2) axial compression capacity of the cantilevered leg; and (3) pull-over strength of fasteners on the anchored leg.

2 SHEAR STRENGTH OF CLIP ANGLES

The shear test program was aimed at identifying the failure mechanism and determining the shear strength of the cantilevered leg of CFS clip angles subjected to in-plane transverse shear forces. The test setup ensured the failure would occur in the clip angle, and fastener failures were prevented. The test results were initially compared with the double coped beam design procedure found in the AISC Steel Construction Manual (AISC, 2011). It was found that large variations existed between the test results and those determined using the AISC methodology. A new design method was proposed that would more accurately predict the shear strength of the CFS clip angles than other previous methods. To address the deflection limit, a design method with consideration of the deformation limit was also developed.

2.1 Test Setup and Test Procedure

The test programs were performed in the Structural Testing Laboratory at the Discovery Park of the University of North Texas. The entire test apparatus was constructed on a structural reaction frame. Figures 2.1 and 2.2 show the overall view and close-up view of the shear test setup respectively.

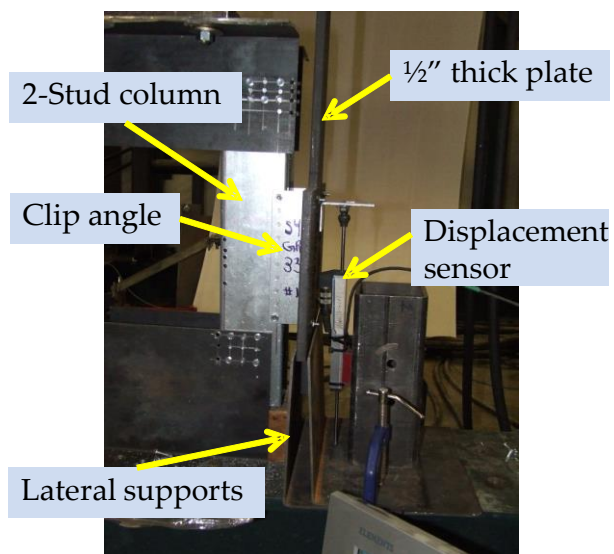
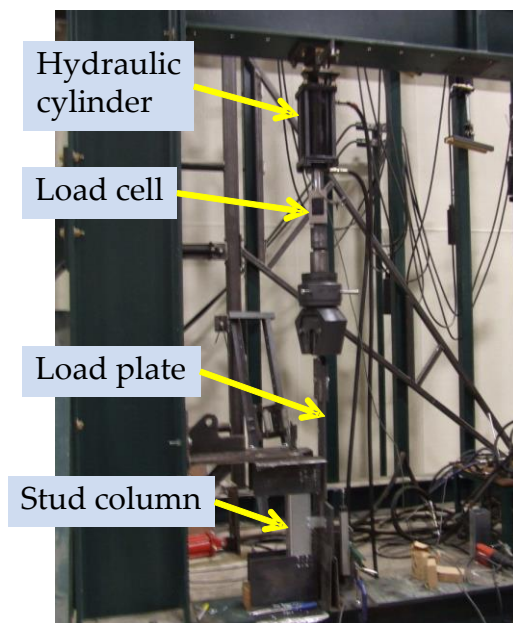


Figure 2.1: Overall view of shear test setup Figure 2.2: Close-up view of shear test setup

In each shear test, two identical clip angles were used in the specimen assembly. The cantilevered leg of each clip angle was fastened to a 54 mil or 118 mil 20 in. long CFS stud column (one clip on each side of the column) using No. 14-14×1 self-drilling self-tapping screws. The other leg of the clip angle (anchored leg) was fixed to a loading plate by No. 10-24×1 Button Head Socket Cap (BHSC) screws. The loading plate was made of ½ in. thick structural steel which had pre-drilled holes to accommodate the BHSC screw connections. The 20 in. long CFS stud column was fixed to a set of specially designed steel fixtures on both ends by No. 14 screws as shown in Figures 2.1 and 2.2. The stud column was made of two identical CFS stud members face-to-face welded together by spot welds along the flanges. For 54 mil and thinner clip angles, a 54 mil stud column was used. For 68 mil and thicker clip angles, a 118 mil stud column was used. The upper end of the loading plate was attached to a mechanical grip via a pin connection. The other end of the loading plate was constrained by two lateral supports, as shown in Figure 2.2, so that the out-of-plane movement of the loading plate was prevented.

A 50 kip universal compression/tension load cell was installed between the hydraulic rod and the mechanical grip. A position transducer was used to measure the vertical displacement of the loading plate. The data acquisition system consisted of a PC with Labview and a National Instruments® unit (including a PCI6225 DAQ card, a SCXI1100 chassis with SCXI1520 load cell sensor module and SCXI1540 LVDT input module). The applied force and the clip angle displacement were measured and recorded instantaneously during the test. An 8 in. stroke hydraulic cylinder was used to apply the shear load to the clip angle. The cylinder was supported by a hydraulic system with a built-in electrical servo valve to control the hydraulic flow rate.

The shear tests were conducted in a displacement control mode. In each test, the hydraulic cylinder moved the loading plate upwards at a constant speed of 0.3 in. per minute. The selected loading speed was found satisfactory for achieving the desired failure mode of test specimens meanwhile allowing accurate readings of displacement and load measurement devices. The testing speed was slow enough to have no effect to the test results.

2.2 Test Specimens

The research focused on failures in the clip angles, therefore the tests that failed in other modes such as fastener failures were not included in the analyses. The shear test program included a total of 33 valid shear tests with the thickness range of the clip angles between 33 mil and 97 mil. The failure modes of invalid tests are provided in Appendix 1. All the clip angles in the research project had pre-punched holes for screw installation. For the shear tests, No. 14-14×1 self-drilling self-tapping screws were used on the cantilevered leg of clip angles. No. 10-24×1 BHSC screws were used on the anchored leg of clip angles. The screws were placed uniformly along the line of the holes and the two end holes were always used for screws. Table 2.1 lists the measured dimensions related to the proposed shear design method, tested material properties, and the number of screws used in each clip angle. The detailed dimensions of the clip angles are provided in Appendix 2. The test specimens were manufactured by Simpson Strong-Tie Company. The test specimen designations used in this test program were the same as the original product labels from the manufacturer. In Table 2.1, the L measures the flat length of the cantilevered leg between the center of the first line of screws and the bend line. The thickness, t, is the uncoated thickness of materials. The yield stress F_y , and tensile strength, F_u , were obtained from coupon tests following

ASTM A370 Standard Test Method and Definitions for Mechanical Testing of Steel Products (2014). Figure 2.3 illustrates the measured dimensions.

Table 2.1: Properties of clip angles in the shear test program

Test Label	L (in.)	B (in.)	t (in.)	F _y (ksi)	F _u (ksi)	No. of Screws C-leg ¹	No. of Screws on A-leg ²
S1 #4	1.394	3.020	0.0584	45.7	50.1	4	4
S1 #5	1.394	3.020	0.0584	45.7	50.1	4	4
S3 #1	1.391	5.230	0.0584	45.7	50.1	3	7
S3 #2	1.391	5.230	0.0584	45.7	50.1	3	7
S4 #3	1.401	7.497	0.0349	49.9	55.8	3	10
S4 #4	1.401	7.497	0.0349	49.9	55.8	3	10
S5 # 3	1.415	7.520	0.0465	46.4	51.2	3	5
S5 # 4	1.415	7.520	0.0465	46.4	51.2	3	5
S6 #1	2.422	3.004	0.0465	46.4	51.2	2	4
S6 #2	2.422	3.004	0.0465	46.4	51.2	2	4
S7 #1	2.362	3.021	0.1006	45.6	60.0	8	8
S7 #3	2.362	3.021	0.1006	45.6	60.0	8	8
S8 #3	2.387	5.254	0.0465	46.4	51.2	3	7
S8 #4	2.387	5.254	0.0465	46.4	51.2	3	7
S8 #5	2.387	5.254	0.0465	46.4	51.2	3	3
S9 #2	2.389	7.540	0.0349	49.9	55.8	3	10
S9 #3	2.389	7.540	0.0349	49.9	55.8	3	10
S10 #1	2.387	7.497	0.0584	45.7	50.1	3	10
S10 #2	2.387	7.497	0.0584	45.7	50.1	3	10
T1a #1	2.418	1.747	0.0349	49.9	55.8	2	2
T1a #2	2.418	1.747	0.0349	49.9	55.8	2	2
T1b #1	2.038	1.747	0.0349	49.9	55.8	2	2
T1b #2	2.038	1.747	0.0349	49.9	55.8	2	2
T1b #3	2.038	1.747	0.0349	49.9	55.8	2	2
T3 #1	1.523	1.753	0.0584	45.7	50.1	2	2
T3 #2	1.523	1.753	0.0584	45.7	50.1	2	2
T3 #3	1.523	1.753	0.0584	45.7	50.1	2	2
T4 #2	2.394	1.751	0.0698	54.8	66.7	2	4
T4 #3	2.394	1.751	0.0698	54.8	66.7	2	4
T5a #1	2.431	1.751	0.0349	49.9	55.8	2	2
T5a #2	2.431	1.751	0.0349	49.9	55.8	2	2
T5b #1	2.276	1.751	0.0349	49.9	55.8	2	2
T5b #2	2.276	1.751	0.0349	49.9	55.8	2	2
Note: 1- the cantilevered leg; 2- the anchored leg							

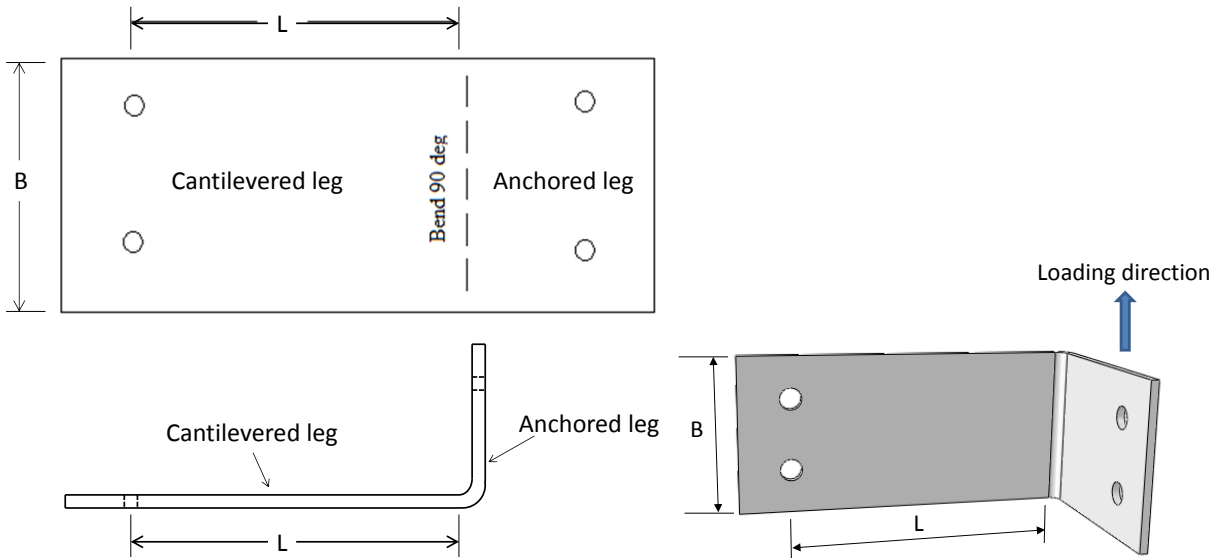


Figure 2.3: Measured dimensions

2.3 Test Results

For each specimen configuration, a minimum of two tests were conducted. If the difference in the peak load between the first two tests was greater than 10% of the average result, a third test would be performed. In the shear test program, two failure modes were observed. For thin clip angles with large aspect ratios ($L/B > 0.8$), a lateral-torsional buckling mode dominated the behavior and failure mechanism. Figure 2.4 shows the test curve and the lateral-torsional failure mode of a 33 mil clip angle (T5a#2). For thick clip angles with small aspect ratios ($L/B < 0.8$), a local buckling failure could be observed. The observed failure mode for each test is provided in Table 2.2. Figure 2.5 shows the test results of a 33 mil clip angle with an aspect ratio of 0.45. Figure 2.6 shows the test results of a 97 mil clip angle. Local buckling failure can be observed in Figures 2.5 and 2.6. In Figure 2.4, the test label was later revised from T5#2 to T5a#2.

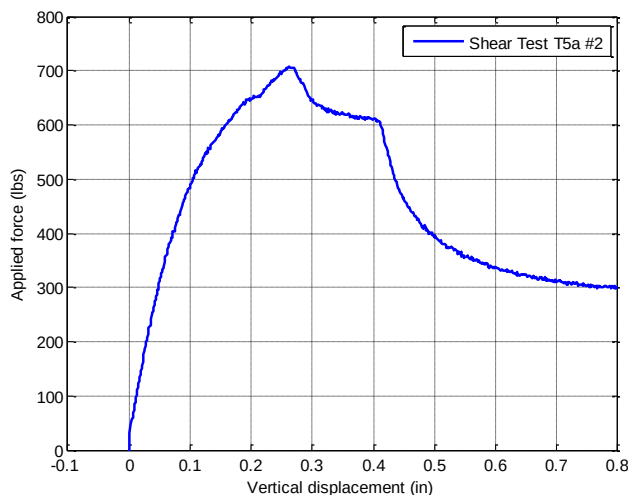


Figure 2.4: Test result of clip angle T5a #2

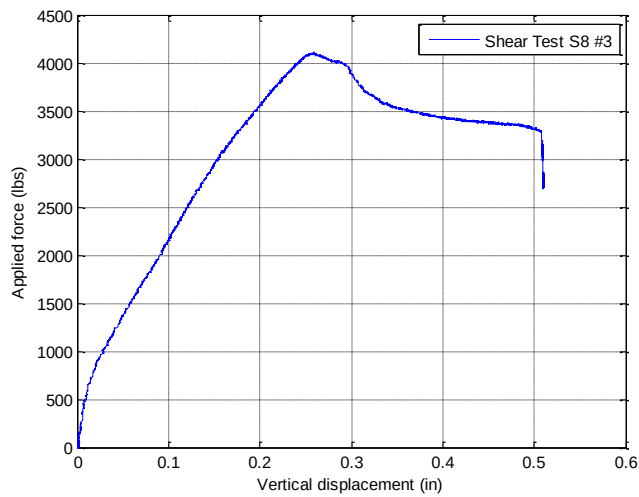


Figure 2.5: Test result of clip angle S8 #3

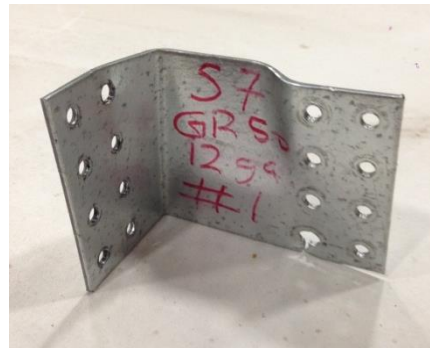
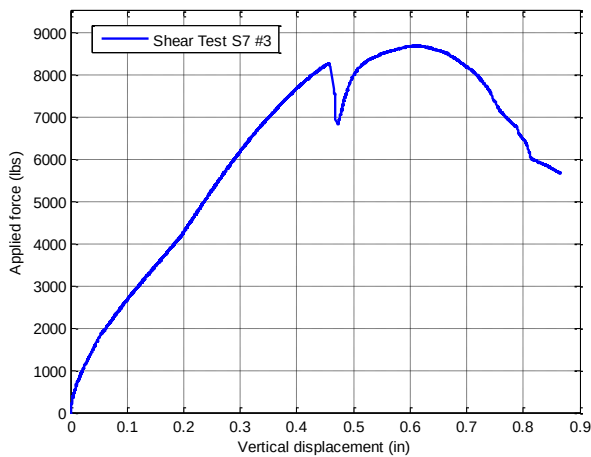


Figure 2.6: Test result of clip angle S7 #1

The test results are provided in Table 2.2 in which V_{test} is the peak load per clip angle and $V_{1/8}$ is the maximum load per clip angle in the deflection range between 0 and 1/8 in. The deflection, Δ , is the displacement of the loading plate at the peak load. Δ can be considered as the average vertical deflection of the clip angles as two identical angles were used in each test.

Table 2.2: Results of shear tests

Test Label	V_{test} (lbs)	Δ (in.)	$V_{1/8}$ (lbs)	Failure Mode
S1 #4	2594	0.523	1102	L
S1 #5	2767	0.685	781	L
S3 #1	3794	0.401	1521	L
S3 #2	3753	0.343	1710	L
S4 #3	2581	0.198	2230	L
S4 #4	2445	0.098	2445	L
S5 # 3	3534	0.294	2344	L
S5 # 4	3488	0.318	1936	L
S6 #1	1050	0.362	586	L
S6 #2	983	0.297	665	L
S7 #1	4339	0.608	1540	L
S7 #3	4319	0.532	1066	L
S8 #3	2054	0.259	1284	L
S8 #4	1912	0.236	1236	L
S8 #5	2048	0.286	1182	L
S9 #2	1787	0.225	1429	L
S9 #3	1670	0.197	1293	L
S10 #1	3268	0.359	1521	L
S10 #2	3421	0.256	2051	L
T1a #1	288	0.119	288	LTB
T1a #2	328	0.198	280	LTB
T1b #1	358	0.211	307	LTB
T1b #2	315	0.198	261	LTB
T1b #3	373	0.225	261	LTB
T3 #1	845	1.248	421	LTB
T3 #2	967	1.264	495	LTB
T3 #3	932	0.831	462	LTB
T4 #2	1028	1.109	429	LTB
T4 #3	993	0.904	476	LTB
T5a #1	319	0.109	319	LTB
T5a #2	359	0.260	279	LTB
T5b #1	250	0.100	250	LTB
T5b #2	303	0.228	237	LTB
Note: L – local buckling failure; LTB – lateral-torsional buckling failure				

2.4 Comparison with AISC Design Method

The AISC Steel Construction Manual (AISC, 2011) does not provide a design method for clip angles, however the double coped beam, shown in Figure 2.7 has similar loading and boundary conditions as those for the CFS clip angles. Therefore the AISC design provision for the double coped beam was adopted as a reference design method in this research. The nominal shear strength of a double coped beam, R , can be expressed as the following:

$$R = (F_{cr} S_{net})/e \quad (2.1)$$

where F_{cr} is the elastic buckling stress, S_{net} is the net section modulus, e is the width of the coped flange. The AISC design manual lists two methods for calculating F_{cr} .

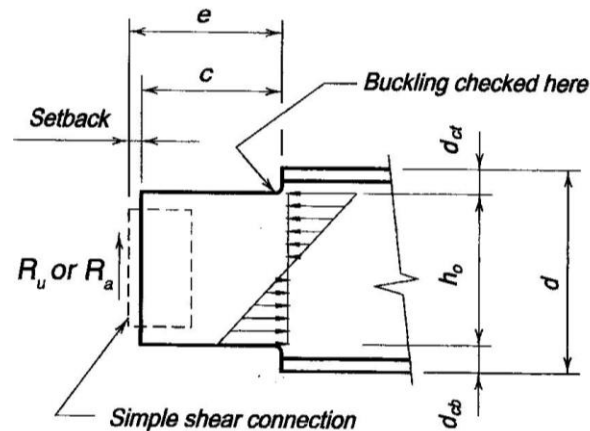


Figure 2.7: Loading and boundary conditions for a double coped beam (AISC Design Manual, Figure 9-3)

Method A:

$$F_{cr} = 0.62 \pi E \frac{t_w^2}{ch_0} f_d \leq F_y \quad (2.2)$$

where,

$$f_d = 3.5 - 7.5 \left(\frac{d_c}{d} \right) \quad (2.3)$$

d_c = cope depth at the compression flange

Method B:

$$F_{cr} = F_y Q \quad (2.4)$$

where,

$$\begin{aligned} Q &= 1 \text{ for } \lambda \leq 0.7 \\ &= (1.34 - 0.486 \lambda) \text{ for } 0.7 < \lambda \leq 1.41 \\ &= (1.30 / \lambda^2) \text{ for } \lambda > 1.41 \end{aligned} \quad (2.5)$$

$$\lambda = \frac{h_0 \sqrt{F_y}}{10 t_w \sqrt{475 + 280 \left(\frac{h_0}{c} \right)^2}} \quad (2.6)$$

The definitions of the notations used in above equations can be found in AISC (2011).

Method B was considered as more conservative than Method A. The shear test results were compared with the AISC double coped beam design methods. In Table 2.3, R_a is the AISC predicted shear strength using Method A for F_{cr} , R_b is the predicted strength using Method B for F_{cr} . Figure 2.8 illustrates the comparison between the shear test results and the AISC design methods. Both AISC methods do not provide good agreements with test results. On average, Method A yields unconservative predictions and both methods' predicted values have large variations from the test results. It can be concluded that the AISC double coped design provision was not appropriate for the shear strength of the CFS clip angles; a new design method was needed.

Table 2.3: Comparison of test results with AISC design methods

Test Label	V_{test}/R_a	V_{test}/R_b
S1 #4	0.992	1.057
S1 #5	1.058	1.127
S3 #1	0.483	0.537
S3 #2	0.478	0.532
S4 #3	0.515	0.502
S4 #4	0.488	0.476
S5 #3	0.304	0.355
S5 #4	0.300	0.350
S6 #1	0.829	1.367
S6 #2	0.776	1.279
S7 #1	1.602	1.602
S7 #3	1.635	1.635
S8 #3	0.706	1.312
S8 #4	0.657	1.222
S8 #5	0.704	1.309
S9 #2	1.002	1.498
S9 #3	0.936	1.400
S10 #1	0.399	0.599
S10 #2	0.418	0.627
T1a #1	0.825	1.275
T1a #2	0.941	1.453
T1b #1	0.873	1.280
T1b #2	0.768	1.126
T1b #3	0.911	1.335
T3 #1	1.039	1.039
T3 #2	1.189	1.189
T3 #3	1.146	1.146
T4 #2	1.350	1.380
T4 #3	1.304	1.333
T5a #1	0.911	1.416
T5a #2	1.030	1.601
T5b #1	0.674	1.021
T5b #2	0.817	1.238
Mean	0.550	1.110
St. Dev.	0.491	0.385
COV	0.893	0.346

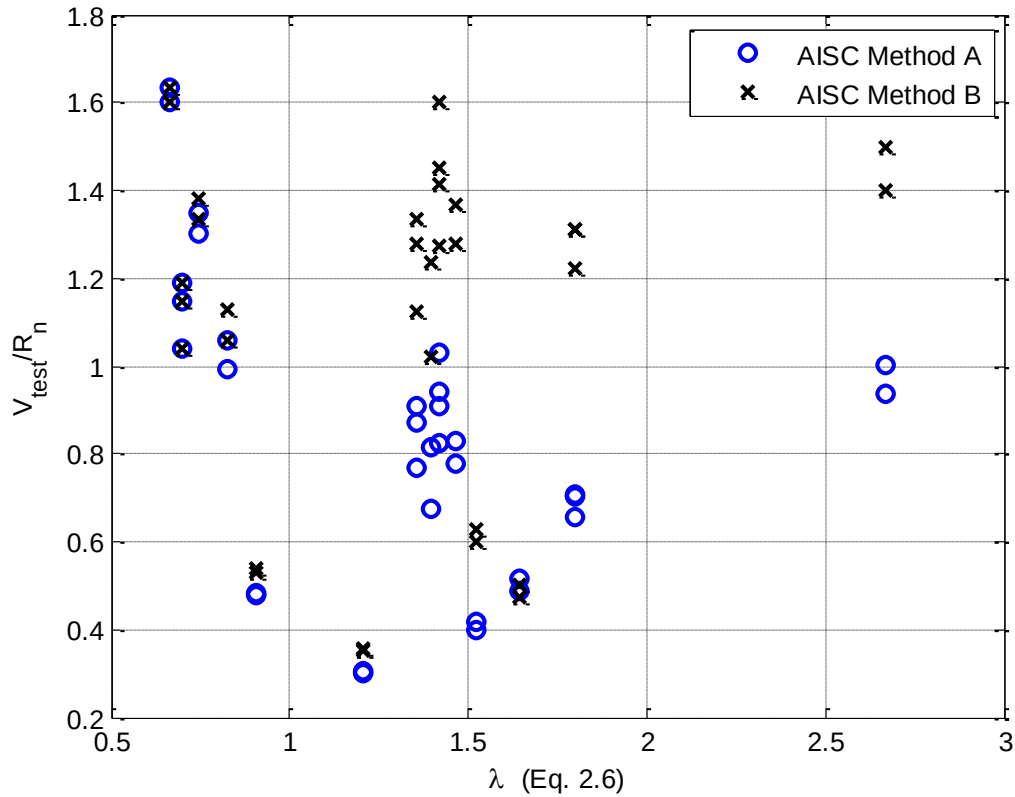


Figure 2.8: Comparison of shear test results with AISC design methods

2.5 Proposed Shear Design Method for CFS Clip Angles without Consideration of Deformation

A design method for determining the nominal shear strength without consideration of deformation of CFS clip angles was developed using the peak load results from the shear test program. The design method was based on the methodology of the Direct Strength Method (Schafer and Peköz, 1998) which used the yield strength and the critical elastic buckling solution of the entire CFS member to predict the ultimate strength. The proposed shear strength method without consideration of deformation is listed as follows:

Nominal shear strength

$$V_n = 0.17\lambda^{-0.8}F_y Bt \leq 0.35F_y Bt \quad (2.7)$$

$$\text{where } \lambda = \sqrt{\frac{F_y}{F_{cr}}} - \text{slenderness ratio} \quad (2.8)$$

$$F_{cr} = \frac{k\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{B}\right)^2 - \text{critical elastic buckling stress} \quad (2.9)$$

E - modulus of elasticity of steel, 29500 ksi

μ - Poisson's ratio for steel, 0.3

$$k = 2.569 \left(\frac{L}{B} \right)^{-2.202} \text{ - buckling coefficient} \quad (2.10)$$

t - design thickness of clip angle

B - depth of clip angle as shown in Figure 2.3

L - flat width of clip angle, distance between the center of first line of screws to the bend line as shown in Figure 2.3.

The above equations shall be valid within the following range of parameters and boundary conditions:

Clip angle design thickness: 33 mils to 97 mils,

Clip angle design yield strength: 33 ksi to 50 ksi,

L/B ratio: 0.18 to 1.40,

The fastener pattern shall allow full engagement of the cantilevered leg in bearing the shear load.

The comparison between the test results and the calculated nominal shear strength by the proposed design method is listed in Table 2.4 and illustrated in Figure 2.9. It can be seen that the proposed method has a good agreement with the test results, and it indicates that the concept of Direct Strength Method approach works for determining the shear strength of CFS clip angles.

The LRFD and LSD resistance factors and the ASD safety factors for the proposed shear design method were calculated following Chapter F of the North American Specification for the Design of Cold-Formed Steel Structural Members (AISI S100, 2012). Two types of components listed in Table F1 of AISI S100, Flexural Members – Shear Strength and Connections Not Listed Above, were chosen for the statistical analysis. The results are listed in Table 2.5.

Table 2.4: Comparison of shear test results with the proposed design method

Test Label	λ	V_{test} (lbs)	V_n (lbs)	V_{test}/V_y	V_{test}/V_n
S1 #4	0.570	2594	2146	0.322	1.209
S1 #5	0.570	2767	2146	0.344	1.289
S3 #1	0.538	3794	3893	0.272	0.975
S3 #2	0.538	3753	3893	0.269	0.964
S4 #3	0.914	2581	2389	0.197	1.080
S4 #4	0.914	2445	2389	0.187	1.023
S5 # 3	0.669	3534	3801	0.218	0.930
S5 # 4	0.669	3488	3801	0.215	0.918
S6 #1	1.328	1050	878	0.162	1.196
S6 #2	1.328	983	878	0.152	1.120
S7 #1	0.591	4339	3590	0.313	1.209
S7 #3	0.591	4319	3590	0.319	1.203
S8 #3	1.235	2054	1627	0.181	1.262
S8 #4	1.235	1912	1627	0.169	1.175
S8 #5	1.235	2048	1627	0.181	1.259
S9 #2	1.643	1787	1502	0.136	1.190
S9 #3	1.643	1670	1502	0.127	1.112
S10 #1	0.940	3268	3570	0.164	0.915
S10 #2	0.940	3421	3570	0.171	0.958
T1a #1	1.930	288	306	0.094	0.941
T1a #2	1.930	328	306	0.108	1.072
T1b #1	1.599	358	356	0.117	1.006
T1b #2	1.599	315	356	0.103	0.885
T1b #3	1.599	373	356	0.123	1.048
T3 #1	0.664	845	1103	0.181	0.766
T3 #2	0.664	967	1103	0.207	0.877
T3 #3	0.664	932	1103	0.199	0.845
T4 #2	1.002	1028	1137	0.154	0.904
T4 #3	1.002	993	1137	0.148	0.873
T5a #1	1.941	319	305	0.104	1.046
T5a #2	1.941	359	305	0.118	1.177
T5b #1	1.805	250	324	0.082	0.772
T5b #2	1.805	303	324	0.099	0.935
Mean					1.034
St. Dev.					0.148
COV					0.143

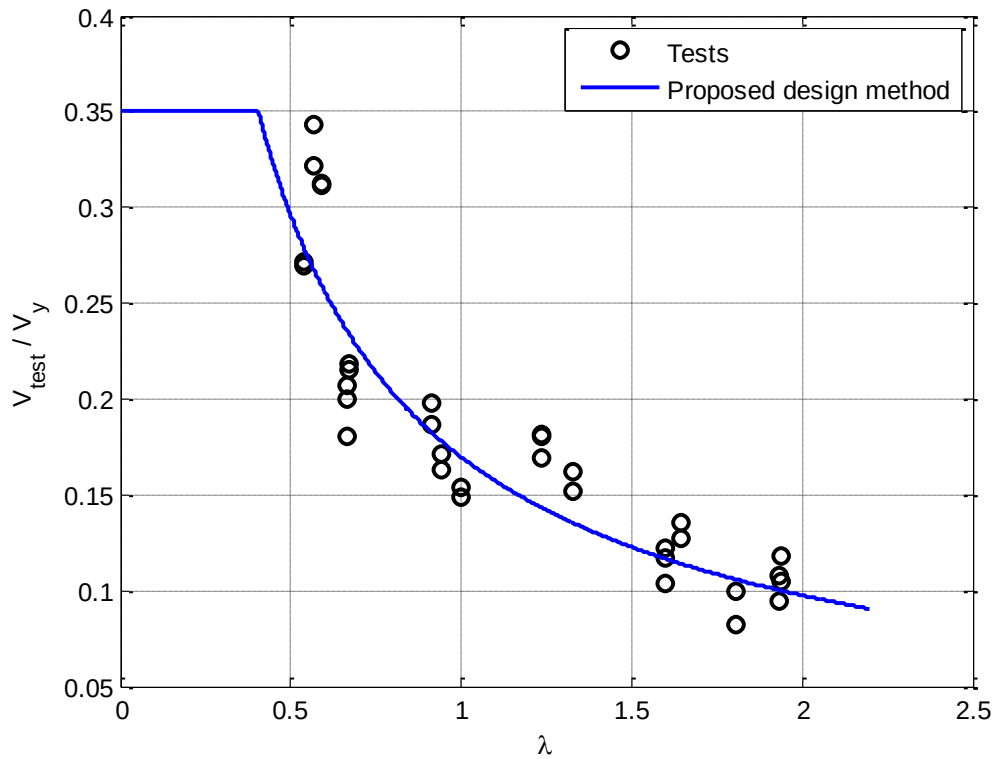


Figure 2.9: Comparison of shear test results with proposed design method

Table 2.5: Resistance factors and safety factors for the proposed shear design method

	Considered as Flexural Members – Shear Strength	Considered as Connections Not Listed Above
Quantity	33	33
Mean	1.034	1.034
Std. Dev.	0.148	0.148
COV	0.143	0.143
M_m	1.10	1.10
V_m	0.10	0.10
F_m	1.00	1.00
P_m	1.034	1.034
V_f	0.05	0.15
β (LRFD)	2.5	3.5
β (LSD)	3.0	4.0
V_Q	0.21	0.21
ϕ (LRFD)	0.86	0.57
ϕ (LSD)	0.70	0.46
Ω (ASD)	1.87	2.78