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TESTING AND EVALUATION OF CFS L-HEADERS

J. Pauls[1], L. Xu[2], and S. Fox[3]

Abstract

Recently there has been an increased interest in cold-formed steel L-headers, in part due to their ease of installation and low material cost. Design guidance for L-headers is currently provided by the AISI *Standard for Cold-Formed Steel Framing – Header Design* in combination with the *North American Specification for Design of Cold-Formed Steel Structural Members*. The current AISI – Header Design provisions are, however, particularly limiting and lack certain design criteria for double and single L-header assemblies, primarily due to limited research.

Presented in this paper are the results from an extensive test program carried out at the University of Waterloo on both single and double cold-formed steel L-headers. A total of 48 single L-header assemblies and 56 double L-header assemblies were tested under gravity loading. The objective of the research was to develop improved design expressions for determining the flexural capacity and vertical deflections. A comparison between the flexural test data and the nominal flexural resistance calculated according to the current AISI Header Design standard is provided. The theory of semi-rigid connections is introduced to model the vertical deflections.

Introduction

L-shaped cold-formed steel headers are becoming more common in residential construction, since they are lighter and more economical compared to conventional built-up cold-formed steel headers. However, due to limited

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testing designers are still restricted to the size of L-headers that can be used. The current AISI Header Design standard (AISI 2007) is especially restrictive for single L-headers.

In 1998 the NAHB Research Center conducted 71 tests under gravity loads and 38 tests under uplift load on double L-headers (NAHB-RC 1998). In 2003 the NAHB Research Center carried out an additional 18 tests on single L-headers (NAHB-RC 2003). A paper summarizing both sets of tests was submitted to the AISI Committee on Framing Standards in 2005 by R.A. LaBoube (LaBoube 2005). Based on the analysis, LaBoube proposed a new design approach for double and single L-headers. In addition to the proposed new design methodology, LaBoube recommended additional testing to better assess the deflection performance of both single and double L-headers. LaBoube's proposed design approach has been adopted into the 2007 edition of the AISI Header Design. Currently there are no explicit design criteria for deflection determination of either single or double L-headers.

Summarized in this paper are the results obtained from the testing conducted at the University of Waterloo, and comparison of the test results to the nominal flexural capacity obtained using the current AISI Header Design. An analysis and evaluation of the vertical deflections is also presented.

Experimental Setup

The experimental investigation was conducted in two phases: short span tests and long span tests. Short span tests consisted of L-header assemblies with a clear span of three feet to six feet. Long span tests consisted of spans ranging between eight feet to sixteen feet.

Test Specimen Assemblies

The header assemblies were fabricated to simulate a typical opening in a 3-5/8" (92mm) wide steel stud wall assembly. One or two L-shaped cold-formed steel sections were added over the opening with the short leg lapping over the top track section and the long leg extended down the side of the cripple stud, as shown in Figure 1. Self-drilling screws (no. 8) were used to connect the L-shapes to the track sections, cripple studs, and king studs. The track sections used (362T125-33) had a minimum thickness of 33mils (0.84mm). Back-to-back cold-formed steel studs (362S162-43) were attached to each end of the L-header, to simulate king studs. The cripple studs were also 362S162-43 sections.

Clear spans chosen for the tests were based on common spans used in construction and were the same as previous tests conducted by NAHB, for comparison purposes. For the double L-headers five different span lengths were tested: three feet, six feet, eight feet, twelve feet, and sixteen feet. For single L-header assemblies three different span lengths were tested: four feet, six feet, and eight feet.

All assemblies were constructed based on general materials and methods appropriate for framing cold-formed steel light-commercial or residential structures. Construction and testing was entirely performed at the University of Waterloo.

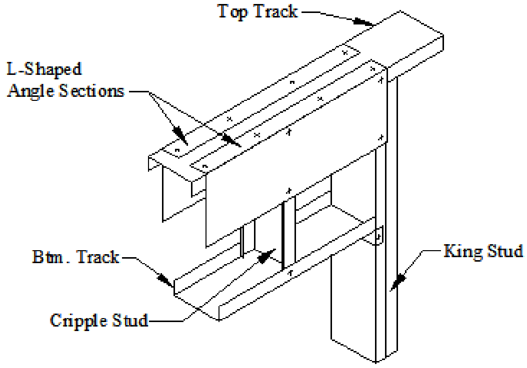

Figure 1: Double L-header Assembly

Material Properties

Mechanical properties for the L-header assemblies were based on tensile coupon tests and base steel thickness measurements, conducted in accordance with ASTM A370 and ASTM A90 respectively (ASTM 2003). Three coupons were cut from the long leg of the L-shaped angle sections. Galvanized coatings were removed by dipping the coupons in a sulfuric acid solution. Table 1 summarizes the mechanical properties for all the material.

Section Properties

Section properties for each specimen were calculated based on the North American Specification (CSA 2004). Section properties for the header assemblies were based entirely on the L-shaped angle(s), the top track or bottom track sections were not included in the calculation. Section properties calculated for serviceability determination were based on reduced yield stress ($0.6F_y$), which is commonly used for serviceability computations.

Short Span Test Setup

All short span tests were conducted using a universal testing machine (UTM) and were loaded at a constant rate of 1/20 inch per minute until failure. The 3ft (0.91m) and 4ft (1.22m) assemblies were loaded with a single point load applied at midspan over a cripple stud. Midspan deflections were recorded using a linear variable differential transformer (LVDT). The 6ft (1.83m) assemblies were loaded by two point loads at one-third span. A spreader beam was attached to the universal testing machine and distributed the loads equally to the two cripple studs. An LVDT measured the deflection at the location of the applied load (one-third span), while the midspan deflection was recorded using a linear motion transducer (LMT) attached to the bottom track.

The king studs on either end of the assembly were positioned in fabricated base supports. The supports allowed the assembly to rotate in the plane of bending, while restraining the assembly from out of plane bending and lateral movement.

Long Span Test Setup

The long span L-headers were tested using a Large Scale Hydraulic Truss Test Frame, which applied loads at multiple points along the L-header assembly. This frame utilized load control of the hydraulic actuators, rather than displacement control which was used for the short span tests. An equivalent rate of loading of 1.1 kip per minute was used. The king studs were positioned in the same fabricated base supports as the short span tests, and the assemblies were fully laterally braced.

The testing procedure used for the short span tests (six foot and less) was based on the procedure used at the NAHB Research Center. However, for the long span tests a different loading approach was implemented. The NAHB tests used a two-point loading at one-third span for all their long span tests, whereas the tests conducted at the University of Waterloo were loaded with multiple loads at 24 inches (610mm) on center. Applying loads at 24 inches on center is a much closer simulation of the actual loading experienced in typical residential construction.

One of the main differences between the loading configurations is that with two-point loading the maximum moment is larger than multi-point loading under the same total load. For the 12ft (3.66m) and 16ft (4.88m) assemblies under the same total load, the midspan moment is larger by 11% and 17% respectively. Furthermore, two-point loading results in a shear force of zero at midspan, while multi-point loading results in a non-zero shear force at midspan.

Results / Data Analysis

Gravity Loading - Ultimate Strength

Failure of both single and double short span L-header assemblies was observed to be a combination of flexure and web-crippling. For the 3ft (0.91m) and 4ft (1.22m) assemblies web-crippling was more pronounced; however, for the 6ft (1.83m) assemblies the effect of web crippling became less apparent. Assemblies longer than 6ft were observed to fail purely under flexure.

For the short span tests (3ft to 6ft) the ultimate load applied at failure of each assembly was determined directly from the data acquisition output, from which the ultimate test moment (M_t) was computed. For the long span tests the ultimate load was determined as the sum of the individual loads applied at each cripple stud, at failure. The ultimate test moment was calculated based on the individual loads applied to each cripple stud.

The ultimate test moment was compared to the nominal gravity flexural capacity (M_{ng}) of each header assembly as determined using the AISI Header Design standard (AISI 2007). The standard assumes the nominal gravity flexural capacity is solely based on the L-section(s) and that the track sections do not add to the capacity.

For double L-headers with a vertical leg dimension of 8” (203mm) or less the nominal flexural capacity under gravity loading is calculated according to Eq. 1.

$$M_{ng} = S_{ec} F_y \qquad \text{(Eq. 1)}$$

For L-header assemblies with a vertical leg dimension of greater than 8” and with a span-to-vertical leg dimension ratio equal to or greater than 10, Eq. 1 shall is used directly. However, for header assemblies with a vertical leg dimension greater than 8” and a span-to-vertical leg dimension ratio less than 10, the nominal flexural capacity calculated using Eq. 1 is multiplied by 0.9.

For single L-headers, the nominal flexural capacity under gravity loading of assemblies with a vertical leg dimension of 6” (152mm) or less is calculated according to Eq. 1. For single L-headers with a vertical leg dimension greater than 6” but not greater than 8”, the nominal flexural capacity is multiplied by 0.9. Single L-headers with depths greater than 8” or spans of greater than four feet are not covered in the AISI Header Design. Tested assemblies which exceeding this criteria were calculated based on Eq. 1 with no modification factor.

The AISI Header Design uses different resistance factors based on the vertical-leg dimension of the L-shaped section when calculating the actual design moment capacity (M_a).

Actual measured mechanical properties were used in the calculation of the nominal gravity flexural capacities. Summarized in Tables 2 and 3 are the results of the gravity tests for both double and single L-header assemblies respectively.

(a) Double L-headers

The 3ft (0.91m) header assemblies resulted in the lowest M_t/M_{ng} ratios. The nominal flexural capacity calculated as per the AISI Header Design over estimated the strength of these assemblies. Even after applying the 0.9 modification factor for short deep L-headers, the nominal flexural capacity is still over-estimated. It is probable that web-crippling and shear forces are influencing the behavior of these assemblies. The lowest M_t/M_{ng} ratios were seen for 3ft assemblies with the largest vertical leg-to-thickness ratios. As the vertical leg-to-thickness ratio of the assembly decreased the M_t/M_{ng} ratios increased closer to unity.

As the span lengths increased the M_t/M_{ng} ratios also increased. Assemblies with a span-to-vertical leg ratio of 9 had M_t/M_{ng} ratios of approximately unity. For assemblies with a span-to-vertical leg ratio of less than 9, M_t/M_{ng} ratios were consistently less than unity. Furthermore, as the span-to-vertical leg ratio increased beyond 9 the nominal flexural capacities calculated based on the AISI Header Design become conservative.

Conservative nominal flexural capacities could be due to the fact the ultimate test moment was calculated based on pinned end connections, which means the end connection rotational stiffness is zero. However, in reality the end connections would provide some rotational stiffness, therefore acting as semi-rigid connections. This added rotational stiffness would cause end moments, lowering the midspan moment and reducing the M_t/M_{ng} ratios closer to unity.

(b) Single L-headers

The results from the single L-header assemblies follow the same trends as the double L-header assemblies. The short spans had low M_t/M_{ng} ratios and as the span increased the M_t/M_{ng} ratios increased. As with the double L-headers, assemblies with a span-to-vertical leg ratio of 9 had M_t/M_{ng} ratios of approximately unity. Assemblies with a span-to-vertical leg ratio of less than 9 consistently have M_t/M_{ng} less than unity. Assemblies with span-to-vertical leg ratio greater than 9 have conservative nominal flexural capacities.

The 0.9 modification factor used in the AISI Header Design reduces the nominal flexural capacity, yet M_t/M_{ng} ratios are still less then unity.

Comparing the tested ultimate moment capacities of the single L-headers to the double L-headers, the single L-headers consistently had capacities of just over half the capacity for the same size double L-header assembly. With the nominal flexural capacity of the assemblies calculated based solely on the section modulus of the L-headers alone, doubling the section modulus for a double L-header assembly resulted in exactly double the nominal flexural capacity. However, since the track sections do somewhat influence the capacities of the assemblies, adding a second L-shaped section to the assembly did not exactly double the tested capacity. For this reason the single L-header assemblies resulted in slightly higher M_t/M_{ng} ratios compared to the same size double L-header assembly.

(c) Comparison to Previous NAHB L-header Tests

In general the results from the double L-headers tests conducted at the NAHB Research Center were similar to those conducted at the University of Waterloo. However, for the short span headers the average total load and average maximum moment at failure vary considerably between the tests conducted at the NAHB Research Center and the University of Waterloo. Nonetheless, if the differences in mechanical properties are taken into consideration the ratios of M_t/M_{ng} are fairly consistent, typically within 10% of each other. For longer span headers the average ultimate load at failure were particularly close in comparison, although the maximum moment capacities tend to be higher for the tests conducted at the NAHB Research Center (two-point loading configuration).

The single L-header tests conducted at the NAHB Research Center resulted in higher ultimate loads and maximum moments compared to those tested at the University of Waterloo. In addition, the mechanical properties of the material used for the NAHB tests were generally lower than those of the University of Waterloo tests. With lower tested capacities and higher calculated nominal flexural capacities, all tests conducted at the University of Waterloo resulted in noticeably lower M_t/M_{ng} ratios.

Gravity Loading – Deflection

Previous testing of L-header assemblies has provided limited deflection data. As a result, the current AISI Header Design does not provide any guidance with regards to vertical deflection computations. In an effort to provide design guidance, the current L-header testing measured the vertical deflection for each of the L-header test assemblies.

Generally headers are designed to meet a minimum deflection criterion of L/240 under service loads. Therefore, the vertical deflection results were compared to the L/240 limit at 60% of the ultimate applied load used as an approximation of the service load. Summarized in Table 4 are the deflection results for the double and single L-header assemblies.

(a) Deflection of Short Span L-Headers Assemblies

The maximum tested span deflection at 60% of ultimate load, for each 3ft (0.91m) and 4ft (1.22m) L-header assembly were less than L/240. The midspan load-deflection curve for each assembly was compared to a predicted curve based on a simply supported system, Eq.2.

$$\Delta_{midspan} = \frac{PL^3}{48EI_e} \qquad \text{(Eq. 2)}$$

The effective moment of inertia (I_e) used in the simply supported prediction model was computed at $f = 0.6F_y$ which is typically used for serviceability calculations. With using a constant effective moment of inertia the simply supported model produces a linear load-deflection curve. Generally, the deflections from the tested assemblies were larger than the predicted simply supported deflections. The common trend for the load-deflection curve of the L-header assemblies is as shown in Figure 2.

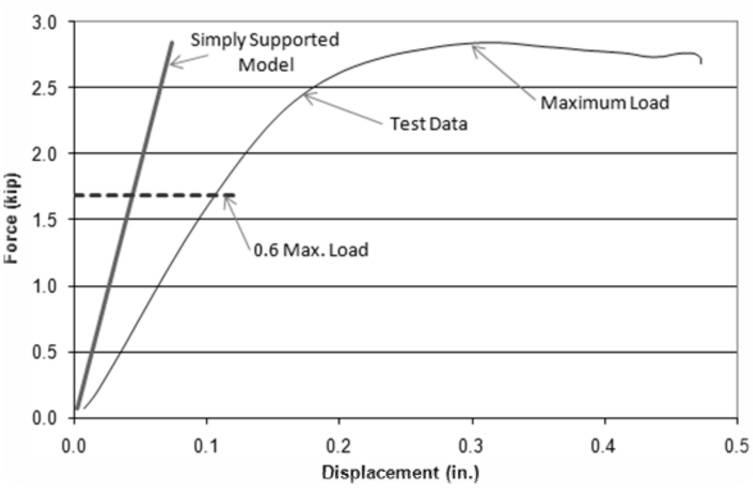

Figure 2 Typical Load-Deflection Curve for Short Span Assemblies

Since the midspan deflection of the tested assemblies is consistently greater than the simply supported model, other factors than just flexural stresses are influencing the vertical deflection. It was observed that for the short spans the assemblies failed in a combination of web-crippling and flexure. Consequently, a deflection predictor equation for short span assemblies needs to incorporate web-crippling and shear deformation.

(b) Deflection of Long Span L-Headers

The maximum span deflections under service load for the long span L-header assemblies (single and double) were found to be typically less than L/240. As with the short span L-headers, a simply supported beam model was used to predict the midspan deflection for the long span L-headers. However, it was found that the simply supported model over-estimates the midspan deflection for these assemblies, as illustrated in Figure 3.

The simply supported model is based on pinned end connections. However, the end connections of the L-header assemblies do provide end rotational restraint to some extent, therefore behaving as semi-rigid members. For semi-rigid members the end-fixity factor as defined below reflects the relative stiffness of the end connections (Xu 2001).

$$r = \frac{1}{1 + \dfrac{3EI_e}{RL}} \qquad \text{(Eq. 3)}$$

Where EI_e/L is the effective flexural stiffness of the L-header(s) and R is the end connection rotational stiffness. For pinned connections the end-fixity factor is zero ($r = 0$), while rigid end connections have an end-fixity factor of one ($r = 1$). Semi-rigid members have end-fixity factors ranging between zero and one.

A semi-rigid prediction model was needed to take into consideration the rotational stiffness of the assemblies for evaluating the span deflection. An ideal model would pass through the test data curve at 60% of the ultimate load, which is typically used as the ultimate service load. Consequently, the semi-rigid prediction model was calibrated with the 60% ultimate test load as shown in Figure 3. The corresponding end-fixity factor was calculated based on deflection equations for semi-rigid members (Xu 2001).

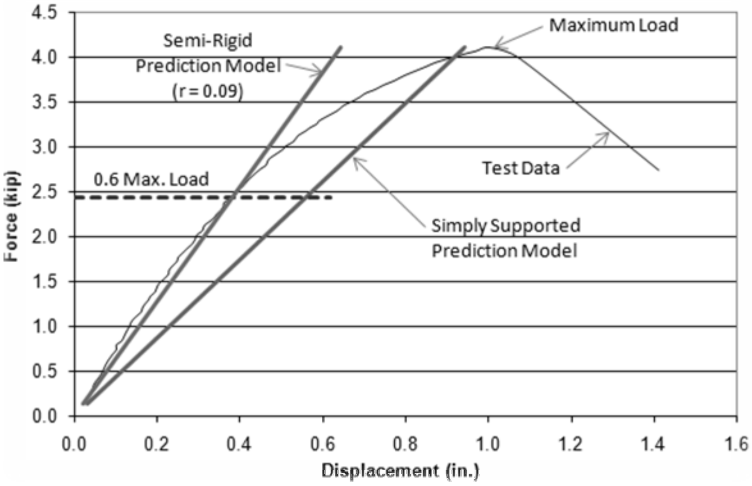

Figure 3 Typical Load-Deflection Curve for Long Span Assemblies

The tested header assemblies were found to have end-fixity factors ranging between 0 and 0.3 as summarized in Table 4. In general as the header assembly stiffness increased the end-fixity factor decreased. For a given header length increasing the depth or thickness results in increased assembly stiffness. As a result, the deepest and thickest 6ft (1.83m) and 8ft (2.44m) L-header assemblies tested, had insignificant end-fixity factors. For these header assemblies the simply supported model works well at predicting the midspan deflection under service loads.

Conclusions

1) Failure of short span single and double L-header assemblies is influenced by additional failure modes other than flexure alone. As the span increases flexural failure becomes predominate and the assembly tends to act as semi-a rigid member.
2) The current AISI – Header Design over-estimates the nominal gravity flexural resistance for short span L-header assemblies. However, predicts conservative results for long span assemblies.
3) Midspan deflections for short span assemblies are larger than predicted using the simply supported beam equation alone. Shear and web-crippling deformation influence the overall displacement of these short assemblies.
4) Assemblies with spans greater than 6ft (1.83m) act as semi-rigid members with rotational stiffness' greater than zero, causing midspan deflections to be less than that predicted by a simply supported system.

Future Work

1) Develop a revised ultimate limit states (ULS) design methodology for single and double L-headers, which accounts for the additional failure modes acting on short span assemblies, and takes into account the influence of the semi-rigid connections for the long spans.
2) Develop a new serviceability limit states (SLS) design methodology for midspan deflection determination.
3) Conduct uplift tests for both single and double L-header assemblies. Evaluate current AISI – Header Design uplift design approach for double L-headers.
4) Propose a new ultimate limit states (ULS) design approach for the flexural capacity of single L-headers under uplift loads.

Appendix - References

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Appendix - Notations

E = modulus of elasticity (29,000 ksi)
F_y = design yield strength (ksi)
I_e = effective moment of inertia, computed at $f = 0.6F_y$ (in.^{4})
L = clear span (in.)
M_{ng} = nominal gravity flexural capacity (kip*in.)
P = load (kips)
r = semi-rigid end-fixity factor
R = end connection rotational stiffness (kip*in./rad.)
S_{ec} = effective section modulus calculated relative to the extreme compression fiber (in.^{3})

TABLE 1 Mechanical Properties

	Material Designation[1]	Base Steel Thickness (in.)	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (%)
3' / 4' / 6' Spans	600L150-33	0.0334	51.8	55.7	33.7
	600L150-43	0.0437	54.5	59.5	29.4
	600L150-54	0.0541	58.5	78.0	30.1
	800L150-33	0.0341	58.5	67.2	28.2
	800L150-43	0.0434	51.2	61.4	30.3
	800L150-54	0.0541	58.5	78.0	30.1
	1000L150-33	0.0341	58.5	67.2	28.2
	1000L150-43	0.0434	51.2	61.4	30.3
	1000L150-54	0.0541	58.5	78.0	30.1
8' / 12' Spans	600L150-43	0.0438	50.4	55.4	30.8
	600L150-54	0.0543	55.0	71.2	31.1
	800L150-43	0.0438	50.4	55.4	30.8
	800L150-54	0.0543	55.0	71.2	31.1
	800L150-68	0.0695	55.6	72.7	30.8
	1000L150-43	0.0438	50.4	55.4	30.8
	1000L150-54	0.0543	55.0	71.2	31.1
	1000L150-68	0.0695	55.6	72.7	30.8
16' Span	800L150-54	0.0542	55.7	72.0	30.2
	800L150-68	0.0698	55.8	73.5	29.8
	1000L150-54	0.0542	55.7	72.0	30.2
	1000L150-68	0.0698	55.8	73.5	29.8

SI Conversion: 1 in. = 25.4 mm, 1 ksi = 47.9 kPa

[1] Material designated is as per the Steel Stud Manufacturers Association (SSMA). For example an 800L150-43 designation refers to an L-shaped angle with an 8" long leg (1/100 inches), 1.5" short leg (1/100 inches) and a 43 mil nominal thickness

TABLE 2 Double L-Header Results (ULS)

Assembly Designation[1]	**No. of Tests**[2]	**Leg / t**	**L / Leg**	**Ultimate Load**[3] **(kip)**	**Moment M_t (kip*in)**	**M_n (kip*in)**	**M_t/M_n**	**$M_t/(0.9M_n)$**
D6-33-3	2	182	6	3.61	32.5	27.5	1.18	
D6-43-3	3	140	6	4.15	37.3	40.0	0.93	
D6-54-3	2	111	6	6.00	54.0	55.7	0.97	
D6-54-6	3	111	12	5.30	63.6	55.7	1.14	
D6-43-8	2	140	16	4.05	64.2	37.5	1.52	
D6-54-8	2	111	16	5.09	81.2	53.0	1.53	
D8-33-3	3	242	4.5	4.30	38.7	52.5	0.74	
D8-43-3	3	186	4.5	5.90	53.1	61.9	0.86	
D8-43-6	2	186	9	5.88	70.5	61.9	1.14	
D8-54-6	2	148	9	7.10	85.3	91.3	0.93	
D8-43-8	2	186	12	5.47	87.1	61.8	1.41	
D8-54-8	2	148	12	6.83	108.9	86.7	1.26	
D8-54-12	2	148	18	5.21	114.1	86.7	1.32	
D8-68-12	2	118	18	7.38	161.2	118.6	1.36	
D8-54-16	2	148	24	4.32	122.2	87.6	1.40	
D8-68-16	2	118	24	5.90	165.0	119.5	1.38	
D10-33-3	2	303	3.6	4.84	43.5	78.9	0.55	0.61
D10-43-3	2	233	3.6	5.97	53.8	92.3	0.58	0.65
D10-43-6	2	233	7.2	7.18	86.1	92.3	0.93	1.04
D10-54-6	2	185	7.2	9.22	110.6	135.3	0.82	0.91
D10-43-8	2	233	9.6	6.87	109.4	92.1	1.19	1.32
D10-54-8	2	185	9.6	8.57	136.6	128.3	1.06	1.18
D10-54-12	2	185	14.4	7.40	161.9	128.3	1.26	
D10-68-12	2	147	14.4	9.14	199.3	174.2	1.14	
D10-54-16	2	185	19.2	5.17	144.5	129.7	1.11	
D10-68-16	2	147	19.2	7.19	200.7	175.6	1.14	
						Mean	1.10	0.95
						Std. Dev.	0.28	0.27
						COV	0.25	0.29

[1] Assembly designation is as follows: The first letter "D" or "S" represents double or single L-shape section. The first number is the vertical leg dimension (in.). The second number is the thickness of the angle (in.), followed by the clear span (ft).

[2] Tabulated values are based on the average of the No. of tests conducted for each assembly. A minimum of two tests were conducted for each identical assembly, if the ultimate load at failure of the two tests were not within 10% of each other further tests were performed.

[3] Ultimate load is the summation of the individual loads applied at 24" o.c.

TABLE 3 Single L-Header Results (ULS)

Assembly Designation[1]	No. of Tests[2]	Leg / t	L / Leg	Ultimate Load[3] (kip)	Moment M_t (kip*in)	M_n (kip*in)	M_t/M_n	$M_t/(0.9M_n)$
S6-33-4	3	182	8	1.50	18.0	13.7	1.31	
S6-43-4	4	140	8	1.80	21.6	20.0	1.08	
S6-33-6	3	182	12	1.72	20.6	13.7	1.50	
S6-43-6	3	140	12	2.48	29.7	20.0	1.49	
S6-43-8	2	140	16	2.26	35.6	18.8	1.90	
S6-54-8	2	111	16	2.68	42.3	26.5	1.60	
S8-33-4	4	242	6	1.73	20.7	26.3	0.79	0.88
S8-43-4	4	186	6	2.44	29.2	31.0	0.94	1.05
S8-54-4	2	148	6	2.81	33.8	45.6	0.74	0.82
S8-43-6	2	186	9	2.61	31.3	31.0	1.01	
S8-43-8	2	186	12	3.01	47.2	30.9	1.53	
S8-54-8	2	148	12	3.98	62.7	43.3	1.45	
S10-33-4	3	303	4.8	2.18	26.1	39.5	0.66	
S10-54-4	4	185	4.8	3.51	42.1	67.6	0.62	
S10-43-6	2	233	7.2	3.50	42.0	46.1	0.91	
S10-54-6	2	185	7.2	4.60	55.2	67.6	0.82	
S10-43-8	2	233	9.6	3.77	59.4	46.0	1.29	
S10-54-8	2	185	9.6	4.64	73.1	64.2	1.14	
						Mean	1.11	0.93
						Std. Dev.	0.37	0.11
						COV	0.33	0.12

[1] Assembly designation is as follows: The first letter “D” or “S” represents double or single L-shape section. The first number is the vertical leg dimension (in.). The second number is the thickness of the angle (in.), followed by the clear span (ft).

[2] Tabulated values are based on the average of the No. of tests conducted for each assembly. A minimum of two tests were conducted for each identical assembly, if the ultimate load at failure of the two tests were not within 10% of each other further tests were performed.

[3] Ultimate load is the summation of the individual loads applied at 24” o.c.

TABLE 4 Double & Single L-Header Results (SLS)

Assembly Designation[1]	No. of Tests[2]	Ultimate Load[3] (kip)	Load at L/240 (kip)	L/240 (in.)	Deflection at 60% Max Load[4] (in.)	Fixity Factor	End Stiffness (kip*in/ rad.)
D6-33-3	2	3.61	2.92	0.15	0.12	N/A	N/A
D6-43-3	3	4.15	3.43	0.15	0.10	N/A	N/A
D6-54-3	2	6.00	3.47	0.15	0.15	N/A	N/A
D8-33-3	3	4.30	3.97	0.15	0.08	N/A	N/A
D8-43-3	3	5.90	4.79	0.15	0.10	N/A	N/A
D10-33-3	2	4.84	4.13	0.15	0.10	N/A	N/A
D10-43-3	2	5.97	4.34	0.15	0.12	N/A	N/A
D6-54-6	3	4.92	3.78	0.30	0.25	0.21	885.2
D8-43-6	2	5.88	5.19	0.30	0.18	0.16	1132.9
D8-54-6	2	7.10	5.78	0.30	0.22	0.09	739.2
D10-43-6	2	7.18	6.58	0.30	0.17	0.04	482.4
D10-54-6	2	9.22	7.76	0.30	0.20	0.00	---
D6-43-8	2	4.05	2.43	0.40	0.40	0.08	178.9
D6-54-8	2	5.09	3.02	0.40	0.40	0.07	209.4
D8-43-8	2	5.50	4.42	0.40	0.26	0.07	329.9
D8-54-8	2	6.83	4.93	0.40	0.32	0.01	73.2
D10-43-8	2	6.87	6.21	0.40	0.22	0.02	134.5
D10-54-8	2	8.57	7.48	0.40	0.23	0.00	---
D8-54-12	2	5.21	3.36	0.60	0.55	0.05	185.0
D8-68-12	2	7.38	4.27	0.60	0.63	0.04	201.0
D10-54-12	2	7.40	5.61	0.60	0.44	0.04	307.6
D10-68-12	2	9.14	6.72	0.60	0.47	0.02	230.5
D8-54-16	2	4.32	2.39	0.80	0.89	0.04	130.6
D8-68-16	2	5.90	2.88	0.80	1.03	0.04	138.8
D10-54-16	2	5.17	3.86	0.80	0.60	0.04	224.7
D10-68-16	2	7.19	4.54	0.80	0.75	0.03	197.6
S6-33-4	3	1.50	1.38	0.15	0.12	N/A	N/A
S6-43-4	4	1.80	1.42	0.15	0.15	N/A	N/A
S8-33-4	4	1.73	1.63	0.15	0.12	N/A	N/A
S8-43-4	4	2.44	2.17	0.15	0.12	N/A	N/A
S8-54-4	2	2.81	2.54	0.15	0.12	N/A	N/A
S10-33-4	3	2.18	2.07	0.15	0.11	N/A	N/A
S10-54-4	4	3.51	3.17	0.15	0.12	N/A	N/A
S6-33-6	3	1.72	1.27	0.30	0.24	0.25	327.0
S6-43-6	3	2.48	1.95	0.30	0.24	0.26	484.5
S8-43-6	2	2.61	2.42	0.30	0.16	0.17	585.0
S10-43-6	2	3.50	3.24	0.30	0.16	0.05	301.6
S10-54-6	2	4.60	3.89	0.30	0.19	0.00	---
S6-43-8	2	2.26	1.23	0.40	0.45	0.08	89.8
S6-54-8	2	2.68	1.58	0.40	0.41	0.08	118.6
S8-43-8	2	3.01	2.18	0.40	0.31	0.05	113.0
S8-54-8	2	3.98	2.58	0.40	0.36	0.02	55.5
S10-43-8	2	3.77	3.13	0.40	0.24	0.01	28.6
S10-54-8	2	4.64	3.57	0.40	0.29	0.00	---

[1] Assembly designation is as follows: The first letter “D” or “S” represents double or single L-shape section. The first number is the vertical leg dimension (in.). The second number is the thickness of the angle (mils), followed by the clear span (ft).

[2] Tabulated values are based on the average of the No. of tests conducted for each assembly. A minimum of two tests were conducted for each identical assembly, if the ultimate load at failure of the two tests were not within 10% of each other further tests were performed.

[3] Ultimate load is the summation of the individual loads applied at 24” o.c.

[4] Represents ultimate service load.