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L-HEADER TESTING, EVALUATION AND DESIGN METHODOLOGY

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Abstract

Cold-formed steel L-shaped headers have gained popularity over the past few years due to their simplicity and cost effectiveness. While cold-formed steel conventional headers are widely used and can be designed for most applications, often it is necessary to reduce cost by using less material and labor hours. The L-shaped header provides both, a fast and economical solution to safely transfer applied loads to other structural elements in a building. As the name suggests, the main components of an L-shaped header is a piece of cold-formed steel formed into a shape resembling the letter L. An L-header assembly consists of a cold-formed steel angle with one short leg lapping over the top track and one long leg extending down the side of the wall above openings. The current design equations in the AISI Specification do not provide a reasonable design values for L-header assemblies. Testing of the assemblies was necessary to develop an easy to use design equations that can be used by designers. A total of 71 gravity tests and 38 uplift tests of L-header assemblies having variable sizes and thicknesses and spans were conducted at the NAHB Research Center. Results of the tests as well as a proposed design procedure is presented here.

Introduction

The recent increase in the use of lighter material and more economical headers led to the development of the cold-formed steel L-shaped header. However, designers and engineers still do not have the proper tools to properly design and specify those headers. Design practice for header beams has been based on the AISI Specification (1996). However, application of the AISI design provisions often results in limited span capability for the header beam. Because the current design specification (Specification 1996) does not explicitly address L-shaped headers, a comprehensive study was initiated at the NAHB Research Center in 1998 and 1999. This study, funded by the American Iron and Steel Institute and USS POSCO specifically addressed the maximum span limitations of double shaped-L-headers. The testing and evaluation program was completed in two phases. The first phase looked at the most practical shapes and configurations of L-headers, while the second phase concentrated on the most economical sections.

This paper will summarize the findings of the bending tests, and a modified design methodology that has been developed. The modified design methodology is based on the flexural capacity of the L-sections alone.

Experimental Approach

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Test Specimens

The L-header test specimens utilized construction materials and methods appropriate for residential construction using cold-formed steel framing. All steel materials used in the tests conformed to the dimensional requirements of Table 1 and had a minimum specified tensile strength of 33 ksi, which was verified by tensile tests in accordance with ASTM A370. Base steel thickness was measured in accordance with ASTM A90. Mechanical properties were based on coupons cut from the center of the web from a sample of the test specimens.

Each L-header assembly consisted of a cold-formed steel angle with one short leg lapping over the top track and one long leg extending down the side of the wall above window or door openings. Each angle was fastened to the top track above an opening with #8 (minimum) screws spaced 12-inches on-center. "L" angles can be placed on one side or both sides of the steel track to form either a single or a double L-header. A detail of the built-up L-header assembly is shown in Figure 1. Header spans for the tests were selected to cover a range of the most common construction opening sizes (i.e. 3'-0", 6'-0", 8'-0", 12'-0", and 16'-0"). All screws used were #8 or #10 self-drilling with low profile heads or hex heads. All screws protruded through steel a minimum of 3/8-inch with a minimum of three exposed threads.

Gravity Load Tests:

A total of 71 L-shaped header assemblies were constructed and tested in accordance with Table 2. Steel track sections had a minimum thickness of 33 mils. Eight L-header specimens were constructed and tested with 43 mil steel tracks to investigate the impact of the track thickness on the header's capacity. L-header assemblies with 3'-0" clear spans were tested utilizing one point loading to simulate the worst case scenario when truss members (or floor joists) spaced at 24 inches on-center are bearing on the headers. L-header assemblies with 6'-0" or greater clear spans were tested utilizing one-third point loading (two-point loading).

Uplift Load Tests:

A total of 38 L-shaped header assemblies were constructed and tested for uplift loads in accordance with Table 3. Steel tracks had a minimum thickness of 33 mils. L-header assemblies with 3'-0" clear spans were tested utilizing one point loading to simulate the worst case scenario when truss members, floor joists, or other structural members spaced at 24 inches on-center are bearing on the headers. L-header assemblies with 6'-0" or greater clear spans were tested utilizing one-third point loading (two-point loading).

Test Apparatus

Gravity Load Tests:
The header assemblies were tested using a universal-testing machine (UTM). The two-point or one-point loads were applied to the L-header specimen using heavy steel I-beam and 1.5 inch x 4 inch steel bearing plates as shown in Figure 1. Back-to-back steel studs (350S162-

54) were fastened to each end of the L-header. The load was applied at a load rate of 1/20 inch per minute until failure. The ultimate load constituted failure of the header material (buckling, bearing or crippling) or failure of the screws (shear or pull out). Deflections at each header's midpoint were recorded during the full range of loads using linear variable differential transformers (LVDTs). Each header assembly was restrained against weak axis rotation and lateral movement. Rotation of the header was allowed in the plane of bending. Rollers were not used at the reactions because rotation was provided by the configuration of the end studs.

Uplift Load Tests:
The header assemblies were tested using a universal testing machine. Two test set-ups were used:

1. A simply supported inverted L-header was subjected to a compressive load, applied through a 54 mil stud (350S162-54) fastened to one side of the L-header with 6 No. 10 screws, to simulate an uplift condition, as shown in Figure 3. The load was applied at a load rate of 1/20 inch per minute until failure.

2. The bottoms of the end studs (back-to-back studs) were fixed to prevent them from pulling out as shown in Figure 4. Each header assembly was subjected to an uplift (tension) load until failure. The ultimate load constituted failure of the header material (buckling or crippling) or failure of the screws (shear or pull out). The load (with a load rate of 1/20 inch per minute) was applied at two-point or one-point location depending on the header span.

Results

Tables 4 and 5 summarize the results of the gravity and uplift load tests.

Gravity Load Tests

Web crippling and bending failure mode was observed in all 3-foot, 4-foot, 6-foot, and 8-foot header tests and bending failure mode for the 12-foot and 16-foot headers. During one test, 2-800L150-54 (3-foot), the cripple stud at the load points was removed and as expected the specimen failed at a lower load (5,146 lb. compared with 6,386 for a standard header specimen) but with the same failure mode. This test confirmed that the typical practice of using a C-section web support fastened with screws to the track provides partial, not full, web crippling support.

Uplift Load Tests:

All test specimens behaved consistently during the test and at failure. The header's webs between the point loads and between the point loads and the reactions showed severe buckling failure at peak loads. High vertical deflections (between 0.5 in. and 1.0 in.) were observed for all headers at peak loads.

Header specimen tested under both configurations (Figure 3 and 4) resulted in similar ultimate capacities.

Data Analysis

Tests indicated that the failure mode was flexure or combination of flexure and web crippling. The tested moment capacity, M_t, was determined and compared with the computed moment capacity as defined by Section C3.1.1(a) of the AISI Specification. The nominal moment capacity was computed using the following equation:

$$M_n = S_{xc} F_y \quad (1)$$

(a) Gravity Moment Capacity

A comparison of the M_t/M_n yielded ratios that ranged from 0.78 to 1.67 with a mean of 1.11 (Table 6). Although a favorable mean value was achieved, the coefficient of variation was 0.21.

Although seven tested header sections have M_t/M_n ratios of 0.7 to 0.81, the remainder of the data has a ratio of 0.9 or greater. These seven test specimens are all 10 inch L-headers. Thus, the application of Eq. 1 appears questionable for the 10 inch L-header. Summary of the 10 inch L-header test results is given by Table 7. A review of the data indicates that the application of Eq. 1 is valid for test specimens having a span to leg dimension, L/leg, of 10 or greater. For the specimens having L/leg ratios less than 10 the M_t/M_n ratio ranged from 0.70 to 0.81 with a mean of 0.77 (Table 8). Table 3 presents the ratio of $M_t/(0.8\ M_n)$, which ranges from 0.89 to 1.02 with a mean of 0.97.

(b) Uplift Moment Capacity

A comparison of the M_t/M_n yielded ratios that ranged from 0.14 to 0.31 with a mean of 0.22 (Table 9). Further analysis of the moment ratio indicated that the behavior was influenced by the ratio of L_h / t. Therefore, uplift reduction factors, R, are given as a function of the L_h / t ratio. The 2-1000L150-54 section resulted in unexplainable behavior and thus this section is singled out for a lower reduction factor. Applying the appropriate uplift reduction factor resulted in M_t/M_n ratios that ranged from 0.82 to 1.30 with a coefficient of variation of 0.12.

Design Methodology

This design procedure is limited to double L-headers fabricated using cold-formed steel angles having the following limitations:

Minimum top flange width = 1.5 in.
Maximum vertical leg dimension = 10 in.
Minimum base material thickness = 0.033 in.
Maximum design yield strength, F_y = 50 ksi
Cripple stud located at all load points

Minimum bearing length 1.5 in. at load points
Minimum No. 8 self-drilling screws installed per Fig. 1.

(a) Gravity Moment Capacity

(i) For a double L-header beam having vertical leg dimensions of less than 8 in. or less, the design shall be based on the flexural capacity of the L-sections alone. The nominal flexural strength, M_n, shall be calculated as follows:

$$M_n = S_{ec} F_y \qquad (2)$$

(ii) For a double L-header beam having vertical leg dimension greater than 8 in., and having a span-to-leg dimension ratio greater than or equal to10, design shall be based on the flexural capacity of the L-sections alone, Eq. 2. For an L-header beam having a 10-in. vertical leg dimension greater than 8 in. and having a span-to-vertical leg dimension ratio less than 10 in., the nominal moment capacity shall be taken as 0.90 times Eq. 2.

(b) Uplift Moment Capacity

For a double L-header beam, design shall be based on the flexural capacity of the L-sections alone. The nominal flexural strength, M_n, shall be calculated as follows:

$$M_n = R\, M_{ng} \qquad (3)$$

Where

M_{ng} = gravity moment capacity determined by Eq. 1
R = 0.25 for $L_h/t \leq 150$
= 0.20 for $L_h/t \leq 170$
= use linear interpolation for $150 < L_h/t < 170$

(c) Design Moment Capacity

The allowable stress design moment is determined as follows:

$$M_a = M_n/\Omega \qquad (4)$$

Where for gravity load moment capacity, $\Omega = 1.67$ for members having vertical leg ≤ 8 in., and $\Omega = 2.26$ for members having vertical leg > 8 in. For uplift moment capacity, $\Omega = 2.0$.

The load and resistance factor design moment is determined as follows:

$$M_a = \phi M_n \qquad (4)$$

Where for gravity load moment capacity, $\phi = 0.90$ for members having vertical leg ≤ 8 in., and $\phi = 0.71$ for members having vertical leg > 8 in. For uplift moment capacity, $\phi = 0.80$.

Appendix - References

National Association of Home Builders (1998), "L-Shaped Header Testing, Evaluation, & Design Guidance," NAHB Research Center, Upper Marlboro, MD

Specification for the Design of Cold-Formed Steel Structural Members (1996), American Iron and Steel Institute, Washington, D.C.

Appendix - Notation

F_y = Design yield stress
L_h = Vertical leg dimension of the angle
M_a = Allowable design moment
M_n = Nominal moment capacity at section being investigated.
M_t = Tested moment capacity
R = Reduction factor
S_{ec} = Elastic section modulus of the effective section calculated at $f = F_y$ in extreme compression fibers
S_{xc} = Elastic section modulus of the effective section computed at $f = F_y$.
t = Base thickness of steel

TABLE 1 PHYSICAL AND MECHANICAL PROPERTIES OF TEST SPECIMENS[1]

L-Header Designation[2]	L-Angle Dimension (inches)	Average Yield Point[3] (psi)	Average Tensile Strength[3] (psi)	Average Uncoated Thickness[4] (inches)	Elongation[5] (percent)
600L150-33	6	34,900	40,100	0.0339	21.2
600L150-43	6	36,500	45,300	0.0459	22.7
600L150-54	6	51,500	60,600	0.0575	22.4
800L150-33	6	48,000	56,200	0.0342	23.5
800L150-43	6	37,500	43,700	0.0465	22.3
800L150-54	6	54,500	67,400	0.0550	23.5
800L150-68	6	53,450	62,890	0.0719	21.5
1000L150-33	6	46,550	54,500	0.0341	20.9
1000L150-43	6	50,500	59,100	0.0475	20.5
1000L150-54	6	51,800	63,800	0.0575	22.9
1000L150-68	6	53,450	62,890	0.0179	21.5

For SI: 1 in. = 25.4 mm, 1 psi = 0.0479 kN/m^2

[1] All track members had 3-1/2" webs and 1-5/8" flanges.

[2]Header designation is as follows: The first number is the size of the long leg of the angle in 1/100 inches (eg. 8" leg is indicated as 800). The "L" represents an angle. The 3-digits indicate the size of the short leg of the angle in 1/100 inches (eg. 1-1/2" leg is indicated as 150). The 2-digits represent the thickness of the angle in mils.

[3]Average yield point and average tensile strength shown are based on actual average yield point and tensile strength from coupons cut from a sample of three specimens tested per ASTM A370.

[4]Average uncoated thickness shown is based on actual average uncoated thickness from a sample of three specimens tested per ASTM A90.

[5] Tested in accordance with ASTM A370 for a two-inch gauge length.

TABLE 2 DOUBLE L-SHAPED HEADER TEST SPECIMEN FOR SIMULATED GRAVITY LOADS

No. of Tests	Header Designation	Angle Size (in.)	Angle Thickness (mils)	Header Clear Span	Track Thickness (mils)	Loading Configuration
2	2-600L150-33	6"	33	3'-00"	33	1 point
2	2-600L150-43	6"	43	3'-00"	33	1 point
2	2-600L150-54	6"	54	3'-00"	33	1 point
2	2-600L150-54	6"	54	6'-00"	33 & 43	2 point
2	2-800L150-33	8"	33	3'-00"	33	1 point
2	2-800L150-43	8"	43	3'-00"	33	1 point
2	2-800L150-43	8"	43	6'-00"	33	2 point
2	2-800L150-43	8"	43	8'-00"	33	2 point
2	2-800L150-54	8"	54	3'-00"	33 & 43	1 point
2	2-800L150-54	8"	54	6'-00"	33 & 43	2 point
2	2-800L150-54	8"	54	8'-00"	33 & 43	2 point
2	2-800L150-54	8"	54	12'-00"	33	2 point
2	2-800L150-54	8"	54	16'-00"	33	2 point
2	2-800L150-68	8"	68	12'-00"	33	2 point
2	2-800L150-68	8"	68	16'-00"	33	2 point
2	2-1000L150-43	10"	43	3'-00"	33	1 point
2	2-1000L150-43	10"	43	6'-00"	33 & 43	2 point
2	2-1000L150-43	10"	43	8'-00"	33	2 point
2	2-1000L150-54	10"	54	3'-00"	33	1 point
2	2-1000L150-54	10"	54	6'-00"	33 & 43	2 point
2	2-1000L150-54	10"	54	8'-00"	33 & 43	2 point
2	2-1000L150-54	10"	54	12'-00"	33	2 point
2	2-1000L150-54	10"	54	16'-00"	33	2 point
2	2-1000L150-68	10"	68	12'-00"	33	2 point
2	2-1000L150-68	10"	68	16'-00"	33	2 point
1	2-600L150-43[1]	6"	43	3'-00"	33	1 point
1	2-800L150-43[1]	8"	43	3'-00"	33	1 point
1	2-800L150-54[1]	8"	54	3'-00"	33	1 point
1	2-800L150-54[1]	8”	54	6'-00"	33	2 point
1	2-1000L-150-54[1]	10”	54	6’-0”	33	2 point

[1] No. 8 and No. 10 screws used for testing to investigate the impact of screw size on header’s capacity.

TABLE 3 L-SHAPED HEADER TEST SPECIMENS FOR SIMULATED UPLIFT LOADS

No. of Test	Header Designation	Angle Thickness (mils)	Header Clear Span (ft-in)	Track Thickness (mils)	Loading Configuration	Testing Configuration
2	2-600L150-43	43	3'-0"	33	1 point	Fig. 3
2	2-600L150-54[1]	54	3'-0"	33 & 43	1 point	Fig. 2
2	2-600L150-54	54	6'-0"	33	2 point	Fig. 2
2	2-800L150-43	43	3'-0"	33	1 point	Fig. 3
2	2-800L150-43	43	6'-0"	33	2 point	Fig. 3
2	2-800L150-43[2]	43	8'-0"	33	2 point	Fig. 3
2	2-800L150-54[2]	54	3'-0"	33	1 point	Fig. 2
2	2-800L150-54[3]	54	6'-0"	33 & 43	2 point	Fig. 3
2	2-800L150-54	54	8'-0"	33	2 point	Fig. 3
2	2-800L150-43	54	12'-0"	33	2 point	Fig. 3
2	2-1000L150-43	43	3'-0"	33	1 point	Fig. 2
2	2-1000L150-43	43	6'-0"	33 & 43	2 point	Fig. 3
2	2-1000L150-43	43	8'-0"	33	2 point	Fig. 3
2	2-1000L150-54[2]	54	3'-0"	33	1 point	Fig. 3
2	2-1000L150-54[3]	54	6'-0"	33	2 point	Fig. 3
2	2-1000L150-54	54	8'-0"	33 & 43	2 point	Fig. 2
2	2-1000L150-54	54	12'-0"	33 & 43	2 point	Fig. 3

[2] Tested with both 350T162-33 and 350T162-43 top tracks.
[2] Tested with both #8 and #10 screws.
[3] Tested with 350T162-33 and 33 mil king studs

TABLE 4 TEST RESULTS - GRAVITY LOADS

Test No.	L-Header Designation	Angle Size (inches)	Angle Thickness (mils)	Header Clear Span	Loading Config-uration	Ultimate Load [1] (lb.)	Load At L/240 Deflection (lb.)
1	2-600L150-43	6"	43	3'-0"	1 point	3,194	2,812
2	2-600L150-43	6"	43	3'-0"	1 point	3,282	3,073
3	2-600L150-54	6"	54	3'-0"	1 point	5,586	4,400
4	2-600L150-54	6"	54	3'-0"	1 point	4,878	4,066
5	2-600L150-54	6"	54	3'-0"	1 point	5,325	4,340
6	2-600L150-54	6"	54	6'-0"	2 point	5,652	4,142
7	2-600L150-54	6"	54	6'-0"	2 point	6,120	4,670
8	2-600L150-54	6"	54	6'-0"	2 point	7,112	5,140
9	2-600L150-54	6"	54	6'-0"	2 point	6,201	4708
10	2-800L150-33	8"	33	3'-00"	1 point	4,302	4,277
11	2-800L150-33	8"	33	3'-00"	1 point	4,634	4,235
12	2-800L150-43	8"	43	3'-00"	1 point	5,962	5,402
13	2-800L150-43	8"	43	3'-00"	1 point	5,516	3,606
14	2-800L150-43	8"	43	6'-00"	2 point	5.200	4,620
15	2-800L150-43	8"	43	6'-00"	2 point	5,150	4,414
16	2-800L150-43[2]	8"	43	8'-00"	2 point	5,136	4,375
17	2-800L150-43	8"	43	8'-00"	2 point	5,452	4,400
22	2-800L150-54	8"	54	3'-00"	1 point	6,147	5,600
23	2-800L150-54	8"	54	3'-00"	1 point	6,624	6,150
24	2-800L150-54	8"	54	6'-00"	2 point	7,154	5,600
25	2-800L150-54	8"	54	6'-00"	2 point	7,230	5,680
26	2-800L150-54	8"	54	8'-0"	2 point	7,244	5,818
27	2-800L150-54[2]	8"	54	8'-0"	2 point	7,252	5,990
28	2-800L150-54	8"	54	11'-6"	2 point	4,200	3,825
29	2-800L150-54	8"	54	11'-6"	2 point	4,200	3,825
30	2-1000L150-43	10"	43	3'-00"	1 point	6,014	5,200
31	2-1000L150-43	10"	43	3'-00"	1 point	6,072	5,600
32	2-1000L150-43	10"	43	6'-00"	2 point	6,986	6,150

TABLE 4 TESTED RESULTS - GRAVITY LOADS (continued)

Test No.	L-Header Designation	Angle Size (inches)	Angle Thickness (mils)	Header Clear Span	Loading Config-uration	Ultimate Load [1] (lb.)	Load At L/240 Deflection (lb.)
33	2-1000L150-43	10"	43	6'-00"	2 point	7,344	5,990
34	2-1000L150-43	10"	43	8'-00"	2 point	4,130	3,922
35	2-1000L150-43	10"	43	8'-00"	2 point	4.138	4,126
36	2-1000L150-33	10"	33	3'-0"	1 point	4,494	4,339
37	2-1000L150-33	10"	33	3'-0"	1 point	4,232	4,067
38	2-1000L150-33[2]	10"	33	6'-0"	2 point	4,742	4,492
39	2-1000L150-33[2]	10"	33	6'-0"	2 point	3,822	3,590
40	2-600L150-33	6"	33	3'-0"	1 point	2,238	1,811
41	2-600L150-33	6"	33	3'-0"	1 point	2,314	1,968
42	2-1000L150-54	10"	54	3'-0"	1 point	7,484	5,600
43	2-1000L150-54	10"	54	3'-0"	1 point	7,830	6,500
44	2-1000L150-54	10"	54	6'-0"	2 point	8,616	7,170
45	2-1000L150-54	10"	54	6'-0"	2 point	7,722	7,160
46	2-1000L150-54	10"	54	8'-0"	2 point	6,646	5,558
47	2-1000L150-54	10"	54	8'-0"	2 point	6,400	6,090
48	2-1000L150-54	10"	54	8'-0"	2 point	6,706	6,656
49	2-800L150-54	8"	54	16'-0"	2 point	3,248	1,450
50	2-800L150-54	8"	54	16'-0"	2 point	3,136	1,485
51	2-800L150-68	8"	68	12'-0"	2 point	7,711	2,800
52	2-800L150-68	8"	68	12'-0"	2 point	6,721	2,550
53	2-800L150-68	8"	68	16'-0"	2 point	5,578	1,700
54	2-800L150-68	8"	68	16'-0"	2 point	5,850	1,550
55	2-1000L150-54	10"	54	12'-0"	2 point	6,458	5,426
56	2-1000L150-54	10"	54	12'-0"	2 point	6,542	5,510
57	2-1000L150-54	10"	54	16'-0"	2 point	5,428	2,110
58	2-1000L150-54	10"	54	16'-0"	2 point	5,449	2,200
59	2-1000L150-68	10"	68	12'-0"	2 point	9,043	4,200
60	2-1000L150-68	10"	68	12'-0"	2 point	8,890	3,850
61	2-1000L150-68	10"	68	16'-0"	2 point	7,232	2,450
62	2-1000L150-68	10"	68	16'-0"	2 point	6,857	2,600
63	2-800L150-43[3]	8"	54	3'-0"	1 point	6,800	6,500

TABLE 4 TESTED RESULTS - GRAVITY LOADS (continued)

Test No.	L-Header Designation	Angle Size (inches)	Angle Thickness (mils)	Header Clear Span	Loading Config-uration	Ultimate Load [1] (lb.)	Load At L/240 Deflection (lb.)
64	2-600L150-43[3]	3"	43	3'-0"	1 point	3,190	2,898
65	2-1000L150-54[3]	6"	54	6'-0"	2 point	7,812	7,090
66	2-800L150-54[3]	8"	54	6'-0"	2 point	6,940	5,712
67	2-800L150-43[3]	8"	43	3'-0"	1 point	4,351	4,100
68	2-800L150-54[4]	8"	54	6'-0"	2 point	7,418	6,200
69	2-600L150-43[4]	6"	43	3'-0"	1 point	3,586	3,000
70	2-800L150-54[4]	8"	54	3'-0"	1 point	5,146	-
71	2-800L150-54[5]	8"	54	3'-0"	1 point	8,305	-

Notes to Table 4:
[1]Ultimate load is the total vertical load applied to the header.
[2]Ends of header near supports buckled prematurely. Tested values varied by more than 15 percent. Specimens were unstable and hence additional tests were not performed.
[3]Screw size was changed to investigate the impact of screw size on header's capacity.
[4]Tested with 33 mil (20 gauge) end studs.
[5]Tested with no cripple stud at load point.
[4]Tested with 6" wide bearing plate at load point.

TABLE 5 TESTED RESULTS - UPLIFT LOADS

Test No.	L-Header Designation	Header Clear Span	Angle Size (inches)	Angle Thickness (mils)	Loading Configuration	Ultimate Load (lb.)
1	2-L600150-43	3'-0"	6"	43	1 point	1,375
2	2-L600150-43	3'-0"	6"	43	1 point	1,260
3	2-L600150-54	3'-0"	6"	54	1 point	1,800
4	2-L600150-54	3'-0"	6"	54	1 point	1,701
5	2-L600150-54	6'-0"	6"	54	2 point	1,188
6	2-L600150-54	6'-0"	6"	54	2 point	1,256
7	2-L800150-43	3'-0"	8"	43	1 point	1,305
8	2-L800150-43	3'-0"	8"	43	1 point	1,280
9	2-L800150-43	6'-0"	8"	43	2 point	1,004
10	2-L800150-43	6'-0"	8"	43	2 point	936
11	2-L800150-43	8'-0"	8"	43	2 point	623
12	2-L800150-43	8'-0"	8"	43	2 point	697
17	2-L800150-54	3'-0"	8"	54	1 point	2,530
18	2-L800150-54	3'-0"	8"	54	1 point	2,608
19	2-L800150-54	6'-0"	8"	54	2 point	1,697
20	2-L800150-54	6'-0"	8"	54	2 point	1,876
21	2-L800150-54	8'-0"	8"	54	2 point	1,500
22	2-L800150-54	8'-0"	8"	54	2 point	1,436
23	2-L800150-54	12'-0"	8"	54	2 point	1,138
24	2-L800150-54	12'-0"	8"	54	2 point	1,202
25	2-L1000150-43	3'-0"	10"	43	1 point	2,066
26	2-L1000150-43	3'-0"	10"	43	1 point	2,134
27	2-L1000150-43	6'-0"	10"	43	2 point	1,681
28	2-L1000150-43	6'-0"	10"	43	2 point	1,791
29	2-L1000150-43	8'-0"	10"	43	2 point	987
30	2-L1000150-43	8'-0"	10"	43	2 point	934
31	2-L1000150-54	3'-0"	10"	54	1 point	2,935
32	2-L1000150-54	3'-0"	10"	54	1 point	2,830

TABLE 5 TESTED RESULTS - UPLIFT LOADS (continued)

Test No.	L-Header Size	Header Clear Span	Angle Size (inches)	Angle Thickness (mils)	Loading Configuration	Ultimate Load (lb.)
33	2-L1000150-54	6'-0"	10"	54	2 point	1,801
34	2-L1000150-54	6'-0"	10"	54	2 point	1,831
35	2-L1000150-54	8'-0"	10"	54	2 point	1,167
36	2-L1000150-54	8'-0"	10"	54	2 point	1,180
37	2-L1000150-54	12'-0"	10"	54	2 point	788
38	2-L1000150-54	12'-0"	10"	54	2 point	832

TABLE 6 DOUBLE L-ANGLE TEST RESULTS

Test No.	Leg in.	Thickness in.	L in.	Leg / t	L / Leg	P kips	M_t kip-in.	M_n kip-in.	M_t / M_n
1	6	0.0459	36.000	129.719	6.000	3.194	28.746	31.040	0.926
2	6	0.0459	36.000	129.719	6.000	3.282	29.538	31.040	0.952
3	6	0.0575	36.000	103.348	6.000	5.586	50.274	55.600	0.904
6	6	0.0575	72.000	103.348	12.000	5.652	67.824	55.600	1.220
7	6	0.0575	72.000	103.348	12.000	6.120	73.440	55.600	1.321
8	6	0.0575	72.000	103.348	12.000	7.112	85.344	55.600	1.535
9	6	0.0575	72.000	103.348	12.000	6.201	74.412	55.600	1.338
10	8	0.0342	36.000	232.918	4.500	4.302	38.718	34.260	1.130
11	8	0.0342	36.000	232.918	4.500	4.634	41.706	34.260	1.217
12	8	0.0465	36.000	171.043	4.500	5.962	53.658	52.070	1.030
13	8	0.0465	36.000	171.043	4.500	5.516	49.644	52.070	0.953
14	8	0.0465	72.000	171.043	9.000	5.200	62.400	52.070	1.198
15	8	0.0465	72.000	171.043	9.000	5.150	61.800	52.070	1.187
16	8	0.0465	96.000	171.043	12.000	5.136	82.176	52.070	1.578
17	8	0.0465	96.000	171.043	12.000	5.452	87.232	52.070	1.675
24	8	0.055	72.000	144.455	9.000	7.154	85.848	93.150	0.922
25	8	0.055	72.000	144.455	9.000	7.230	86.760	93.150	0.931
26	8	0.055	96.000	144.455	12.000	7.244	115.904	93.150	1.244
27	8	0.055	96.000	144.455	12.000	7.252	116.032	93.150	1.246
28	8	0.055	138.000	144.455	17.250	4.200	96.600	93.150	1.037
29	8	0.055	138.000	144.455	17.250	4.200	96.600	93.150	1.037
32	10	0.0475	72.000	209.526	7.200	6.986	83.832	82.950	1.011
33	10	0.0475	72.000	209.526	7.200	7.344	88.128	82.950	1.062
34	10	0.0475	96.000	209.526	9.600	4.130	66.080	82.950	0.797
35	10	0.0475	96.000	209.526	9.600	4.138	66.208	82.950	0.798
36	10	0.0341	36.000	292.255	3.600	4.494	40.446	40.960	0.987
37	10	0.0341	36.000	292.255	3.600	4.232	38.088	40.960	0.930
38	10	0.0341	72.000	292.255	7.200	4.742	56.904	40.960	1.389
39	10	0.0341	72.000	292.255	7.200	3.822	45.864	40.960	1.120
40	6	0.0339	36.000	175.991	6.000	2.238	20.142	20.300	0.992
41	6	0.0339	36.000	175.991	6.000	2.314	20.826	20.300	1.026
44	10	0.0575	72.000	172.913	7.200	8.616	103.392	131.780	0.785
45	10	0.0575	72.000	172.913	7.200	7.722	92.664	131.780	0.703
46	10	0.0575	96.000	172.913	9.600	6.646	106.336	131.780	0.807
47	10	0.0575	96.000	172.913	9.600	6.400	102.400	131.780	0.777
48	10	0.0575	96.000	172.913	9.600	6.706	107.296	131.780	0.814
49	8	0.055	192.000	144.455	24.000	3.248	103.936	93.150	1.116
50	8	0.055	192.000	144.455	24.000	3.136	100.352	93.150	1.077
51	8	0.0719	144.000	110.266	18.000	7.711	185.064	121.830	1.519
52	8	0.0719	144.000	110.266	18.000	6.721	161.304	121.830	1.324
53	8	0.0719	192.000	110.266	24.000	5.578	178.496	121.830	1.465
54	8	0.0719	192.000	110.266	24.000	5.850	187.200	121.830	1.537
55	10	0.0575	144.000	172.913	14.400	6.458	154.992	131.780	1.176
56	10	0.0575	144.000	172.913	14.400	6.542	157.008	131.780	1.191
57	10	0.0575	192.000	172.913	19.200	5.428	173.696	131.780	1.318
58	10	0.0575	192.000	172.913	19.200	5.449	174.368	131.780	1.323
59	10	0.0719	144.000	138.082	14.400	9.043	217.032	177.270	1.224
60	10	0.0719	144.000	138.082	14.400	8.890	213.360	177.270	1.204
61	10	0.0719	192.000	138.082	19.200	7.232	231.424	177.270	1.305
62	10	0.0719	192.000	138.082	19.200	6.857	219.424	177.270	1.238
64	6	0.0459	36.000	129.719	6.000	3.190	28.710	31.040	0.925
65	10	0.0575	72.000	172.913	7.200	7.812	93.744	131.780	0.711
66	8	0.055	72.000	144.455	9.000	6.940	83.280	93.150	0.894
68	8	0.055	72.000	144.455	9.000	7.418	89.016	93.150	0.956
69	6	0.0459	36.000	129.719	6.000	3.586	32.274	31.040	1.040
								Mean	1.111
								Std. Dev.	0.233
								COV	0.210

TABLE 7 10" DOUBLE L-ANGLE RESULTS

Test No.	Leg in.	Thickness in.	L in.	Leg/t	L/Leg	P kips	M_t kip-in.	M_c kip-in.	M_t/M_c
32	10	0.0475	72.000	209.526	7.200	6.986	83.832	82.950	1.011
33	10	0.0475	72.000	209.526	7.200	7.344	88.128	82.950	1.062
34	10	0.0475	96.000	209.526	9.600	4.130	66.080	82.950	0.797
35	10	0.0475	96.000	209.526	9.600	4.138	66.208	82.950	0.798
36	10	0.0341	36.000	292.255	3.600	4.494	40.446	40.960	0.987
37	10	0.0341	36.000	292.255	3.600	4.232	38.088	40.960	0.930
38	10	0.0341	72.000	292.255	7.200	4.742	56.904	40.960	1.389
39	10	0.0341	72.000	292.255	7.200	3.822	45.864	40.960	1.120
44	10	0.0575	72.000	172.913	7.200	8.616	103.392	131.780	0.785
45	10	0.0575	72.000	172.913	7.200	7.722	92.664	131.780	0.703
46	10	0.0575	96.000	172.913	9.600	6.646	106.336	131.780	0.807
47	10	0.0575	96.000	172.913	9.600	6.400	102.400	131.780	0.777
48	10	0.0575	96.000	172.913	9.600	6.706	107.296	131.780	0.814
55	10	0.0575	144.000	172.913	14.400	6.458	154.992	131.780	1.176
56	10	0.0575	144.000	172.913	14.400	6.542	157.008	131.780	1.191
57	10	0.0575	192.000	172.913	19.200	5.428	173.696	131.780	1.318
58	10	0.0575	192.000	172.913	19.200	5.449	174.368	131.780	1.323
59	10	0.0719	144.000	138.082	14.400	9.043	217.032	177.270	1.224
60	10	0.0719	144.000	138.082	14.400	8.890	213.360	177.270	1.204
61	10	0.0719	192.000	138.082	19.200	7.232	231.424	177.270	1.305
62	10	0.0719	192.000	138.082	19.200	6.857	219.424	177.270	1.238
65	10	0.0575	72.000	172.913	7.200	7.812	93.744	131.780	0.711
								Mean	1.013
								Std. Dev.	0.313
								COV	0.309

TABLE 8 10" DOUBLE L-ANGLE WITH L/LEG < 10"

Test No.	Leg in.	Thickness	Leg/t	L/Leg	P kips	L in.	M_t kip-in.	M_c kip-in.	M_t/M_c	$M_t/(0.8M_c)$
34	10	0.0475	209.526	9.600	4.130	96.000	66.080	82.950	0.797	0.996
35	10	0.0475	209.526	9.600	4.138	96.000	66.208	82.950	0.798	0.998
45	10	0.0575	172.913	7.200	7.722	72.000	92.664	131.780	0.703	0.879
46	10	0.0575	172.913	9.600	6.646	96.000	106.336	131.780	0.807	1.009
47	10	0.0575	172.913	9.600	6.400	96.000	102.400	131.780	0.777	0.971
48	10	0.0575	172.913	9.600	6.706	96.000	107.296	131.780	0.814	1.018
65	10	0.0575	172.913	7.200	7.812	72.000	93.744	131.780	0.711	0.889
								Mean	0.773	0.966
								Std. Dev.	0.347	0.323
								COV	0.449	0.335

TABLE 9 DOUBLE L-ANGLE RESULTS – UPLIFT LOADS

Test No.	Leg in.	Thickness in.	P kips	L in.	M_t kip-in.	M_n kip-in.	M_t/M_n	M_t/RM_n
5	6	0.0575	1.188	72	14.256	55.5	0.257	1.027
6	6	0.0575	1.256	72	15.072	55.5	0.272	1.086
9	8	0.0465	1.004	72	12.048	52.06	0.231	1.157
10	8	0.0465	0.936	72	11.232	52.06	0.215	1.079
11	8	0.0465	0.623	96	9.968	52.06	0.191	0.957
12	8	0.0465	0.697	96	11.152	52.06	0.214	1.071
19	8	0.055	1.697	72	20.364	93.15	0.219	0.874
20	8	0.055	1.876	72	22.512	93.15	0.242	0.967
21	8	0.055	1.5	96	24	93.15	0.258	1.031
22	8	0.055	1.436	96	22.976	93.15	0.247	0.987
23	8	0.055	1.138	144	27.312	93.15	0.293	1.173
24	8	0.055	1.202	144	28.848	93.15	0.310	1.239
27	10	0.0475	1.681	72	20.172	82.95	0.243	1.216
28	10	0.0475	1.791	72	21.492	82.95	0.260	1.295
29	10	0.0475	0.987	96	15.792	82.95	0.190	0.952
30	10	0.0475	0.934	96	14.944	82.95	0.180	0.901
33	10	0.0575	1.801	72	21.612	131.78	0.164	0.820
34	10	0.0575	1.831	72	21.972	131.78	0.167	0.834
35	10	0.0575	1.167	96	18.672	131.78	0.142	0.945
36	10	0.0575	1.18	96	18.88	131.78	0.143	0.955
37	10	0.0575	0.788	144	18.912	131.78	0.144	0.957
38	10	0.0575	0.832	144	19.968	131.78	0.152	1.010
						Mean	0.215	1.024
						Std. Dev.	0.049	0.126
						COV	0.229	0.123

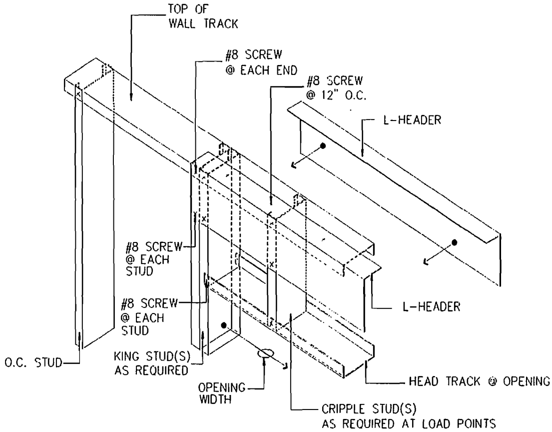


Figure 1- L-Header Configuration

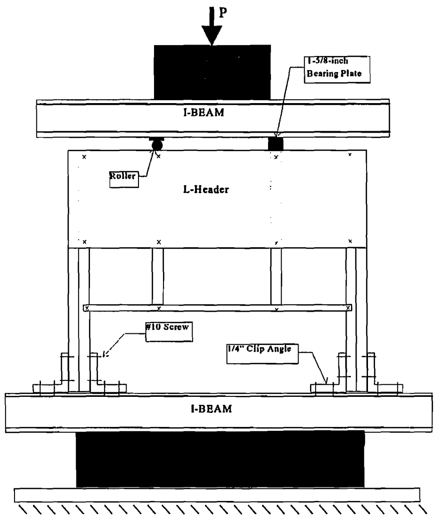
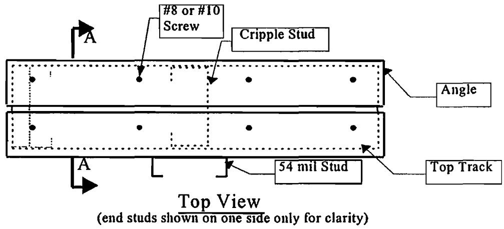
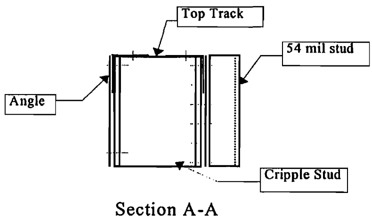


Figure 2 - L-Header Test Apparatus – Gravity Load Test





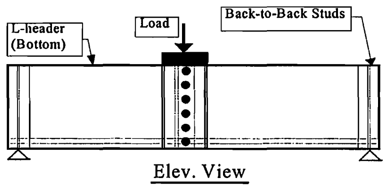


Figure 3 - L-Header Test Apparatus - Uplift Load Test I

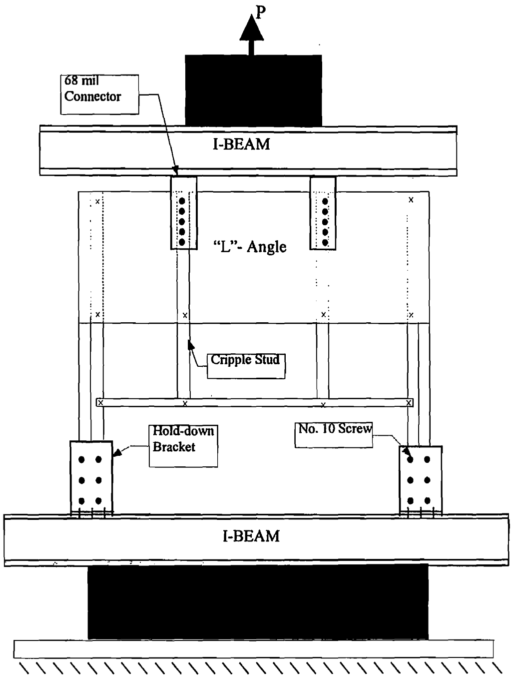


Figure 4 - L-Header Test Apparatus - Uplift Load Test II