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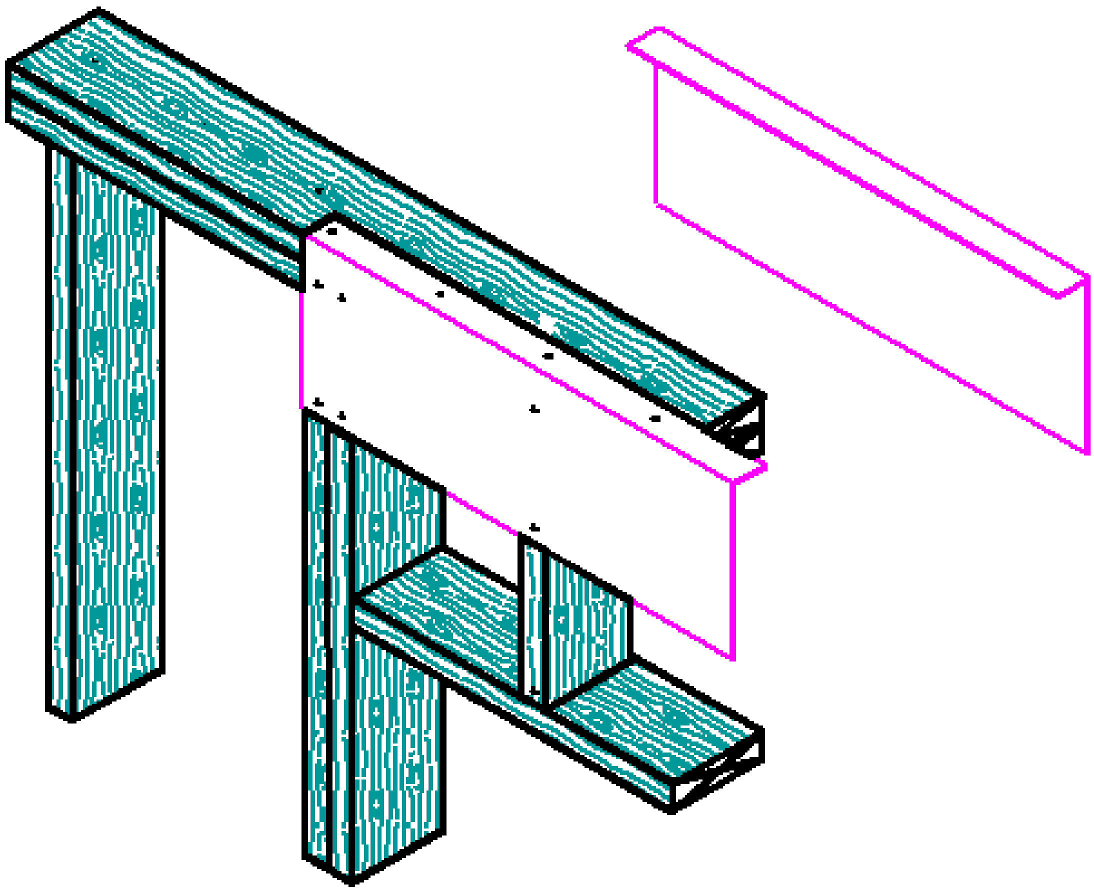
Testing of steel I-headers on wood walls

NAHB Research Center

Testing of Steel L-Headers on Wood Walls



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Testing of Steel L-Headers on Wood Walls

Prepared for

Steel Framing Alliance
Washington, DC

And

The U.S. Department of Housing and
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Office of Policy Development and
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by

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Kirk Grundahl	Wood Truss Council

CONTENTS

INTRODUCTION

Cold-formed steel framing has seen some market growth in the housing market most probably due to its similarity to wood stick framing. However, in different regions of the U.S., the installed cost of steel framing may not be less than that of wood. Houses however, do not have to be framed entirely from one material. As more builders "mix and match" due to local material and labor availability and cost, the need of connecting different materials becomes more urgent.

Although, the use of steel L-headers in residential cold-formed steel framing is relatively new to the U.S. homebuilding industry, L-headers have gained popularity among steel framers because of their simplicity and ease of construction (see Figure 1). A steel L-header consists of steel angle(s) placed over the top track of a steel wall and fastened to the king, jack and cripple studs. The Steel Framing Alliance recently published an L-Header Guide [1] for builders that contains span tables and construction details. The Guide, however, does not address L-headers used over wood walls.

The purpose of this report is to investigate the feasibility of using double steel L-headers placed over wood walls. The investigation was limited to testing of headers used for small openings (i.e., window and door openings) that are common in single-family dwellings.

Figure 1 – Typical Steel L-Header

LITERATURE REVIEW

Review of Existing Test Data and Design Procedures

Currently, there is no test data or literature on steel L-headers used for wood walls. All testing to date has been done on steel L-headers over steel walls.

There is no single design criteria that can be used to design steel L-headers for use in wood walls.

EXPERIMENTAL APPROACH

Test Specimens

The L-header test specimens were assembled using construction materials and methods appropriate for residential construction of wood and cold-formed steel framing. All steel materials used in the tests conform to the dimensional and material requirements of Tables 1 and 2. Tensile and yield strength were verified by tensile tests in accordance with ASTM A370 [2]. Base steel thicknesses were also established and measured in accordance with ASTM A90 [3]. Mechanical properties were based on coupons cut from the center of the web of a sample of the test specimens.

Each L-header assembly consisted of two cold-formed steel angles with the short leg of each angle lapping over the top 2x4 plate and the long leg of each angle extending down the side of the wall above openings. Each angle was fastened to the top plate above an opening with nails spaced 12-inches on center (305 mm). A detail of the built-up L-header assembly is shown in Figure 2.

A total of 6 L-header assemblies were constructed and tested, three for each assembly identified in Table 1.

Table 1 - L-Header Dimensions

Member Designation	Web Depth (in.)	Flange Width (in.)	Thickness (in.)
600L150-33	6.0	1.50	0.033
600L150-43	6.0	1.50	0.043

For SI: 1 inch = 25.4 mm

Table 2 – Material Properties

<table>
<tr><th>Material Property</th><th colspan="2">Value[1] (psi)</th></tr>
<tr><td>Steel Yield Strength</td><td colspan="2">33,000</td></tr>
<tr><td rowspan="4">2x4 SPF Wood Members, S-Dry</td><td>Bending, F_b</td><td>675</td></tr>
<tr><td>Shear Parallel to Grain, F_v</td><td>70</td></tr>
<tr><td>Tension Parallel to Grain, F_t</td><td>350</td></tr>
<tr><td>Modulus of Elasticity, E</td><td>1,200,000</td></tr>
<tr><td>Nails</td><td colspan="2">0.120 inches x 3 inches full round head pneumatic nail</td></tr>
</table>

For SI: 1 psi = 0.0703 kg/cm^2.

[1] Wood properties are taken from 1997 NDS Supplement [4].

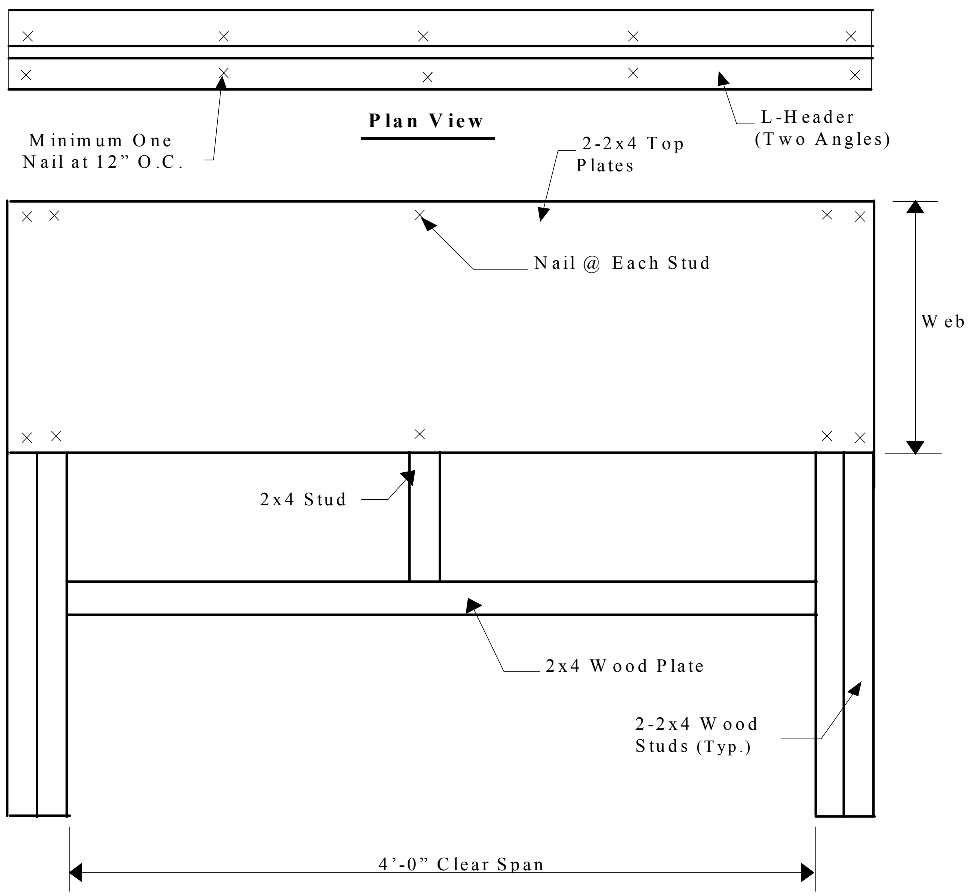


Figure 2 - Detail of a Built-up L-Header Assembly

Test Apparatus

The header assemblies were tested using a 200,000 lb universal testing machine (UTM, Southwark-Emery Model 78075), a Satek Epsilon Series 2 inch deflectometer, and a Newvision II Data Acquisition System. The 2-2x4 wood studs were fastened to each end of the L-header and to the bottom beam of the UTM. The test set-up is illustrated in Figure 3. The load is applied at a load rate of 1/20 inch per minute until each header failed. Failure constitutes failure of the header material (buckling, bearing or crippling), failure of the nails (shear or pull out), or failure of the wood plate. Deflections at the midpoint of the opening were recorded during the full range of loads using linear variable differential transformers (LVDTs). The assembly was laterally restrained against weak axis rotation and lateral movement. Rotation of the header and wall framing assembly was allowed in the plane of bending. Rollers were not needed at the reactions because rotation was provided by the configuration of the wood studs.

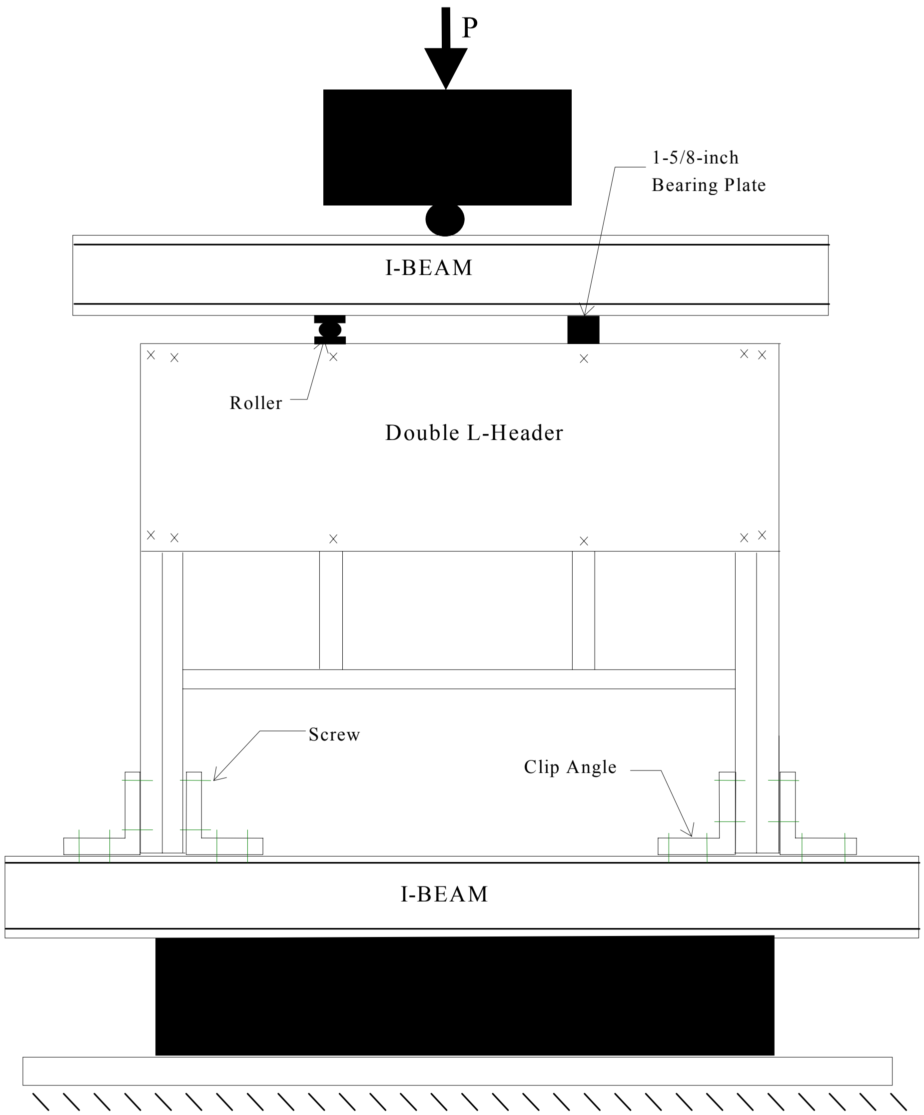


Figure 3 - L-Header Test Apparatus

RESULTS

The results of the tests are shown in Table 3. The actual steel physical properties are summarized in Table 4.

Table 3 - L-Header Test Results

Double L-Header Designation	Web Depth (in.)	Flange Width (in.)	Wood Top Plate	Header Clear Span (ft)	Ultimate Load[1] (lb)	Deflection at Ultimate Load (in.)
600L150-33	6.0	1.5	2-2x4	4.0	5,134	0.9478
600L150-33	6.0	1.5	2-2x4	4.0	5,576	1.1016
600L150-33	6.0	1.5	2-2x4	4.0	5,933	1.1124
Average					5,548	1.0539
Standard Deviation					400.25	0.09207
COV					0.072148	0.08376
600L150-43	6.0	1.5	2-2x4	4.0	6,899	1.1911
600L150-43	6.0	1.5	2-2x4	4.0	7,818	1.4207
600L150-43	6.0	1.5	2-2x4	4.0	7,211	1.3812
Average					7,309	1.3310
Standard Deviation					467.3	0.12276
COV					0.063935	0.09223

For SI: 1 inch = 25.4 mm, 1 foot = 305 mm, 1 lb. = 4.448 N.

[1] Load measured by the load cell.

Table 4 – Physical and Mechanical Properties of Steel Angles

Steel Angle Designation	Yield Point[1] (psi)	Tensile Strength[1] (psi)	Uncoated Thickness[2] (in.)	Elongation[3] (percent)
600L150-33	34,900	45,100	0.0339	21.2
600L150-33	36,740	44,250	0.0341	22.3
600L150-33	35,670	47,630	0.0337	20.9
Average	35,770	45,660	0.0339	21.5
Standard Deviation	924	1758	0.0002	0.7371
COV	0.0258	0.0385	0.0059	0.0343
600L150-43	36,500	46,300	0.0459	21.5
600L150-43	37,550	45,700	0.0451	20.5
600L150-43	38,220	48,140	0.0462	22.7
Average	37,423	46,713	0.0457	21.6
Standard Deviation	867	1271	0.0006	1.1015
COV	0.0231	0.0272	0.0124	0.0511

For SI: 1 inch = 25.4 mm, 1 psi = 0.0703 kg/cm^2

[1] Yield point and tensile strength are actual yield point and tensile strength from coupons cut from the web of the angle specimen and tested per ASTM A370 [2].

[2] Uncoated thickness is the bare steel thickness of the steel angle as tested per ASTM A90 [3].

[3] Tested in accordance with ASTM A370 [2] for a two-inch gauge length.

FAILURE MODE

All tested samples ultimately failed at connection of the 2-2x4 wood studs and the head plate (wood plate below steel header). The head plate was end-nailed through the jack studs (2-2x4) with two nails (0.120 inch x 3 inch). The steel angles in all tested specimens were severely buckled and deformed at ultimate loads. Each steel angle started to show signs of local buckling at load bearing points at approximately 50 percent of the ultimate load. The angles continued to deform and bulge at locations of load bearing points as the load was increased. The deformation spread to the web of the angle between the load points at loads higher than 50 percent of the ultimate load. Refer to Figures 4 through 9 for illustrations of failure modes.

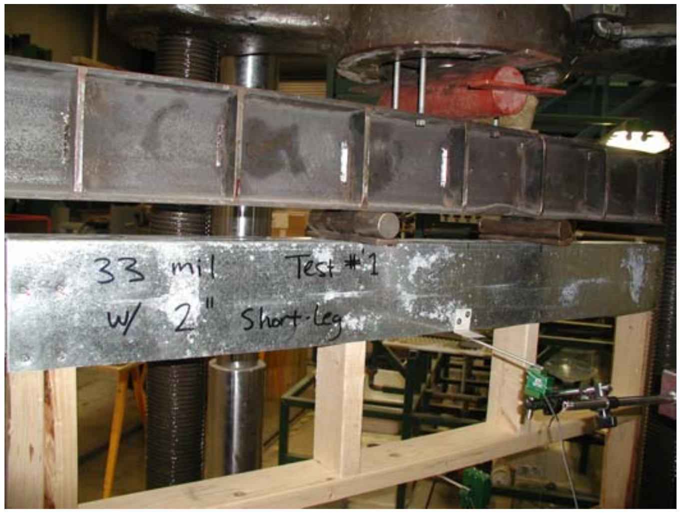


Figure 4 – 33 mil L-Header Test

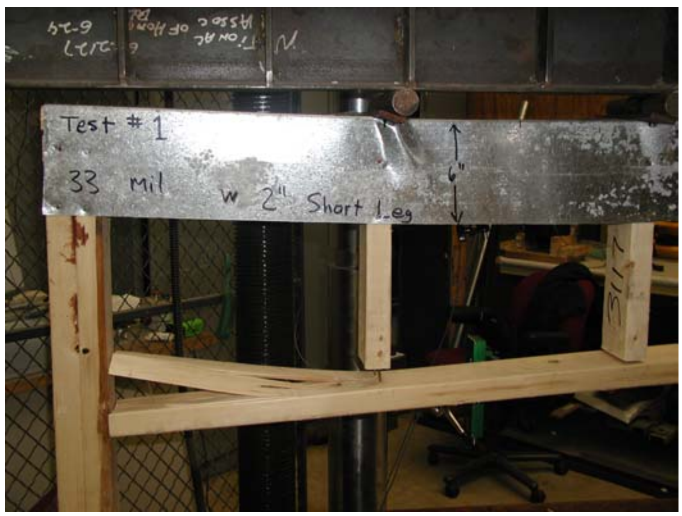


Figure 5 – Failure of 33 mil L-Header Assembly

Figure 6 – Failure of Wood Plate at Stud

Figure 7 – 43 mil L-Header Test

Figure 8 – 43 mil L-Header Assembly at Failure Load

Figure 9 – Top Plate at Ultimate Load

DISCUSSION

A factor can be applied to the average ultimate capacity for each header assembly shown in Table 3 to estimate the factored (design) capacity. The factor is calculated in accordance with the AISI Design Specification [5] as follows:

The strength of the tested assemblies shall satisfy the following equation:

$$\sum \gamma_i Q_i \leq \phi R_n$$

Where: R_n = Average value of the test results.
ϕ = Resistance factor
$\gamma_i Q_i$ Required strength based on the most critical load combination.

ϕ = Resistance factor = $1.5(M_m F_m P_m)e^{-\beta_0\sqrt{V^2{}_M + V^2{}_F + C_P V_P{}^2 + V^2{}_Q}}$

M_m = Mean value of the material factor = 1.10 (bending or compression)
F_m = Mean value of the fabrication factor = 1.00
P_m = Mean value of the professional factor for the tested component = 1.0
β_0 = Target reliability index = 2.5
V_M = Coefficient of variation of the material factor = 0.10 (bending or compression)
V_F = Coefficient of variation of the fabrication factor = 0.05
C_P = Correction factor = 5.7
V_P = Coefficient of variation of the test results = 7.21% and 6.39%
V_P = 7.21% (for V_p < 6.5%, use 6.5%)
m = Degree of freedom = 1
V_Q = Coefficient of variation of the load effect = 0.21

$\phi = 1.5(1.10x1.00x1.00)e^{-2.5\sqrt{0.10^2+0.05^2+5.7x0.0721^2+0.21^2}}$ = 0.7199

ϕ = 0.7199 (for 600L200-33)
ϕ = 0.7400 (for 600L200-43)

Therefore, the factored capacity for each header is shown in Table 5 for use with LRFD design provisions and factored LRFD load combinations. The Factored Capacity is computed using the Ultimate Load (as measured by the load cell) from Table 3 with the appropriate phi (ϕ) factor shown above.

Table 5 – Factored Capacity

L-Header Designation	Factored Capacity (lb)	Factored Moment (in-lb)
600L150-33	3,994	23,964
600L150-43	5,409	64,908

For SI: 1 inch = 25.4 mm, 1 lb. = 4.448 N.

To investigate the feasibility of using the L-header assemblies (tested in this report) in single-family dwellings, a simple example is provided as follows:

Using the applicability limits of the *Prescriptive Method for Residential Cold-Formed Steel Framing* (Prescriptive Method) [6], determine the loads acting on a header supporting one roof and ceiling only for a 28-foot (8534 mm) wide building (with 2-foot overhang) with a 30-psf (1.4364 Mpa) ground snow load. All other loads will be in accordance with the Prescriptive Method.

Load Combinations:

1. 1.4D
2. 1.2D + 1.6(L_r or S) + 0.5L
3. 1.2D + 0.5(L_r or S) + 1.6L

Loads

Dead Loads:

Ceiling Dead Load =	5(28/2) =	70 plf
Roof Dead Load =	7(32/2) =	112 plf
Total Dead Load	=	182 plf

Live Loads:

Roof Live Load =	16(28 + 4)/2=	256 plf
Roof Snow Load =	0.7(30)(32/2)=	336 plf ← controls

Design load acting on header = P

1. 1.4(182) = 255 plf
2. 1.2(182) + 1.6(336)= 756 plf ⇐ Controls
3. 1.2(182) + 0.5(336)= 386 plf

Assuming a 4-foot header, the moment due to a 756 plf distributed load is 22,128 in-lb
This moment is less than the factored moment shown in Table 5 (23,964). Therefore a double 600L200-33 header is adequate.

Tables 6 and 7 were developed to be used with the Prescriptive Method applicability limits. The values in Tables 6 and 7 were derived similar to the example above.

Table 6 – Minimum Thickness (Mils) of 600L150 Double L-Headers for Openings Not Greater Than 4-Feet (Headers Supporting Roof and Ceiling Only)

Building Width (Feet)	Ground Snow Load (psf)			
	20	**30**	**50**	**70**
24	33	33	33	43
28	33	33	33	43
32	33	33	43	43
36	33	33	43	43
40	33	43	43	43

For SI: 1 mil = 1/1000 inch = 25.4 mm, 1 foot = 305 mm, 1 psf = 0.0479 kN/m^2.

Table 7 – Minimum Thickness (Mils) of 600L150 Double L-Headers for Openings Not Greater Than 4-Feet (Headers Supporting One Floor, Roof and Ceiling

Building Width (Feet)	Ground Snow Load (psf)			
	20	**30**	**50**	**70**
24	43	43	43	43
28	43	43	43	43
32	43	43	43	43
36	43	43	43	43
40	43	43	43	43

For SI: 1 mil = 1/1000 inch = 25.4 mm, 1 foot = 305 mm, 1 psf = 0.0479 kN/m^2.

CONCLUSION

The L-shaped header is a viable alternative to conventional wood headers for common window and door openings in lightly loaded (wood) residential applications. It is anticipated that possible applications will include headers supporting short or moderate roof spans and other light structures. Tables were developed for use with the Prescriptive Method.

REFERENCES

[1] *L-Shaped Header, Field Design Guide*. North American Steel Framing Alliance, Washington DC. December 1999.

[2] ASTM A370-02 *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, American Society for Testing and Materials (ASTM), West Conshohocken, PA. 2002.

[3] ASTM A90/A90M-01 *Standard Test Method of Weight [Mass] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings*. American Society for Testing and Materials (ASTM), West Conshohocken, PA. 2001.

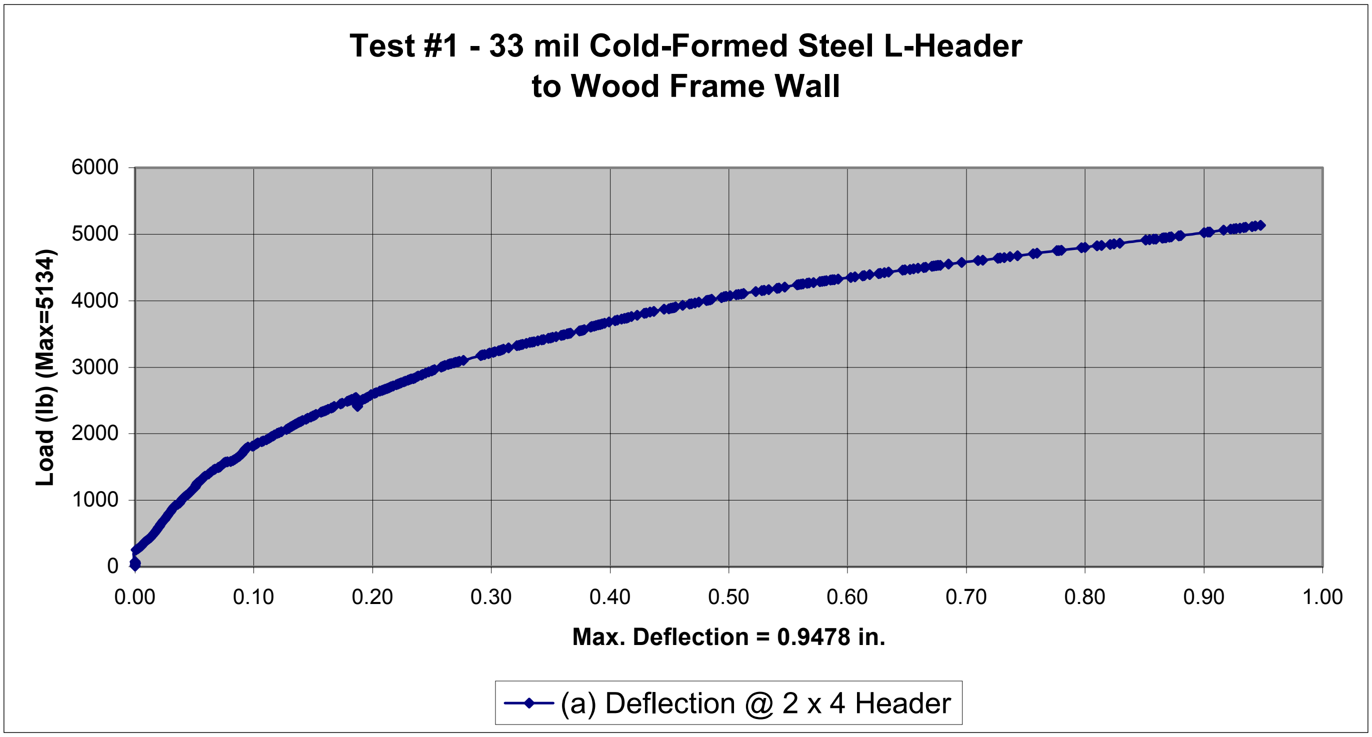
[4] *National Design Specification (NDS), Supplement,* 1997 Edition. American Forest & Paper Association, American Wood Council. Washington, DC. 1997.

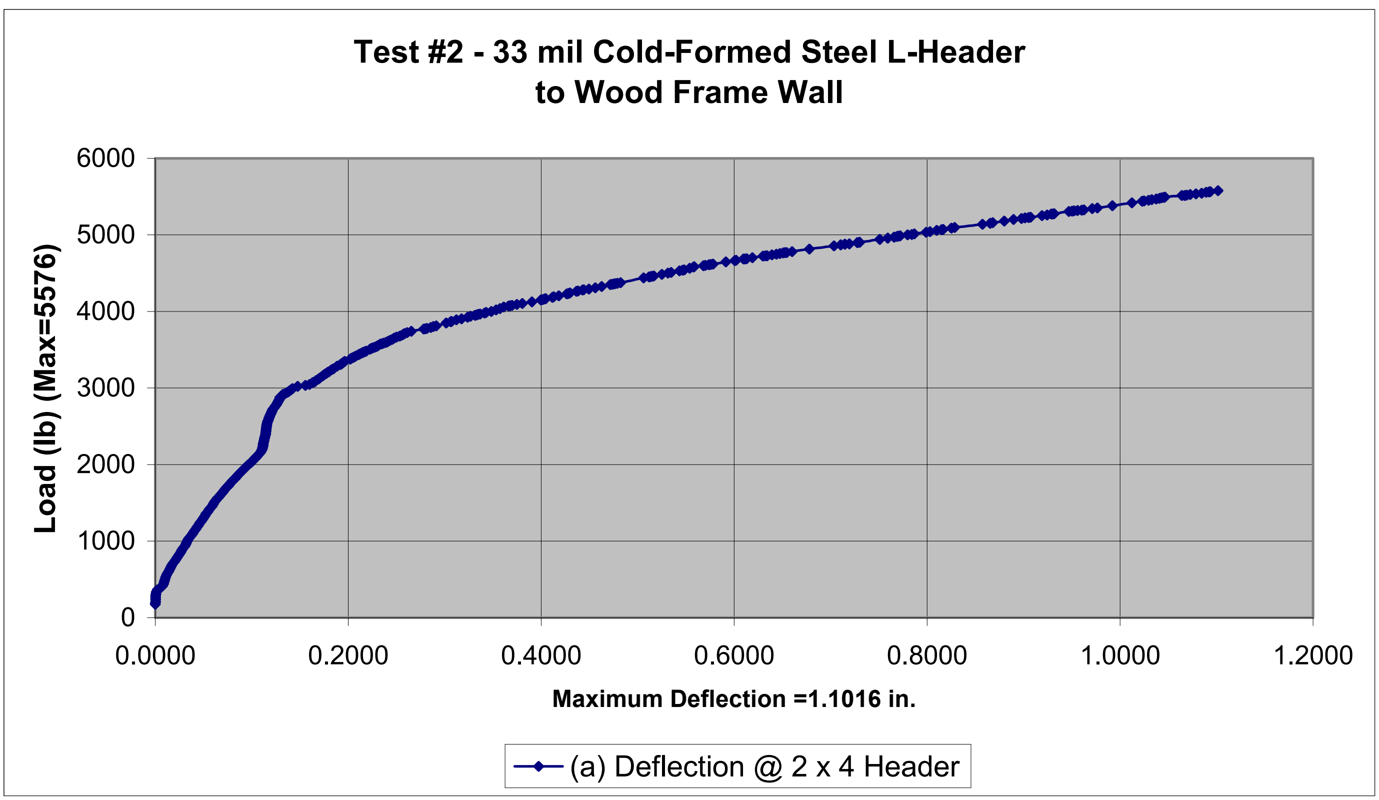
[5] *Specification for the Design of Cold-Formed Steel Structural Members*, 1996 Edition. American Iron and Steel Institute (AISI), Washington, DC. June 1997.

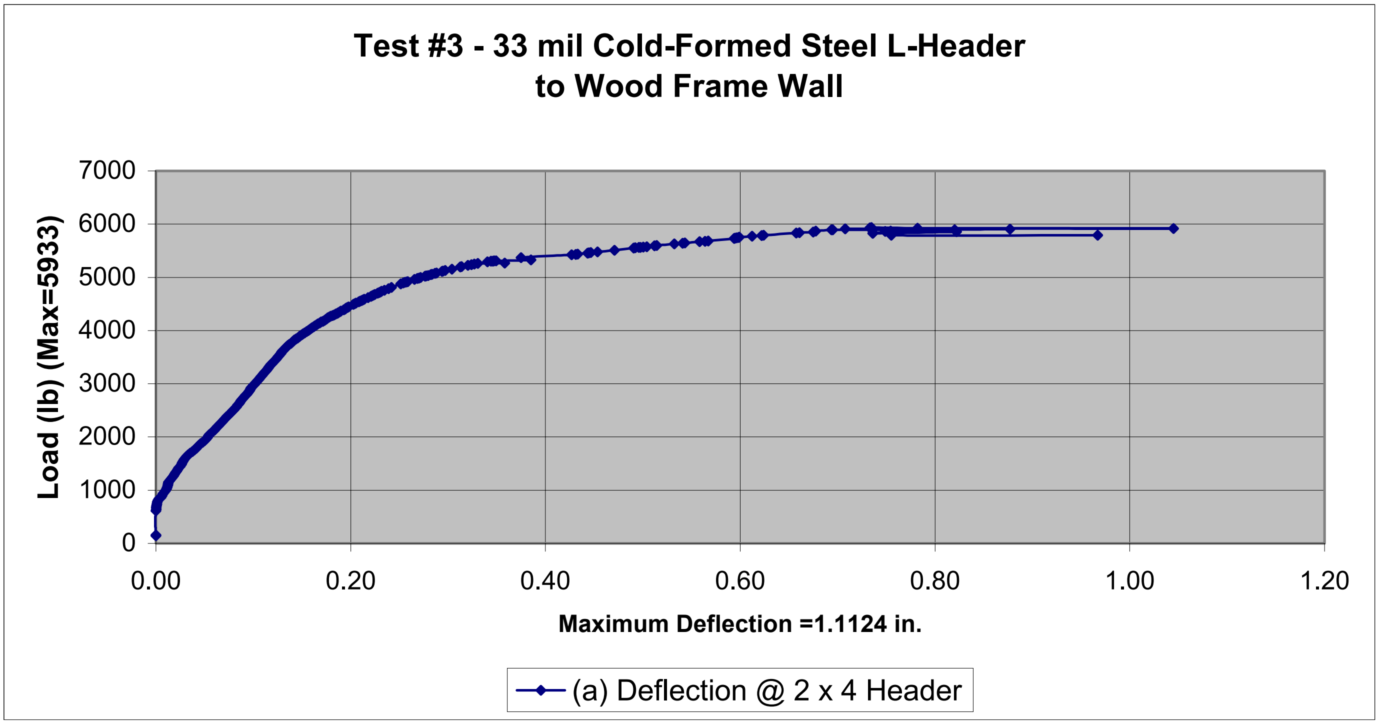
[6] *Prescriptive Method for Residential Cold-Formed Steel Framing,* 2000 Edition. Steel Framing Alliance, Washington, DC. 2000.

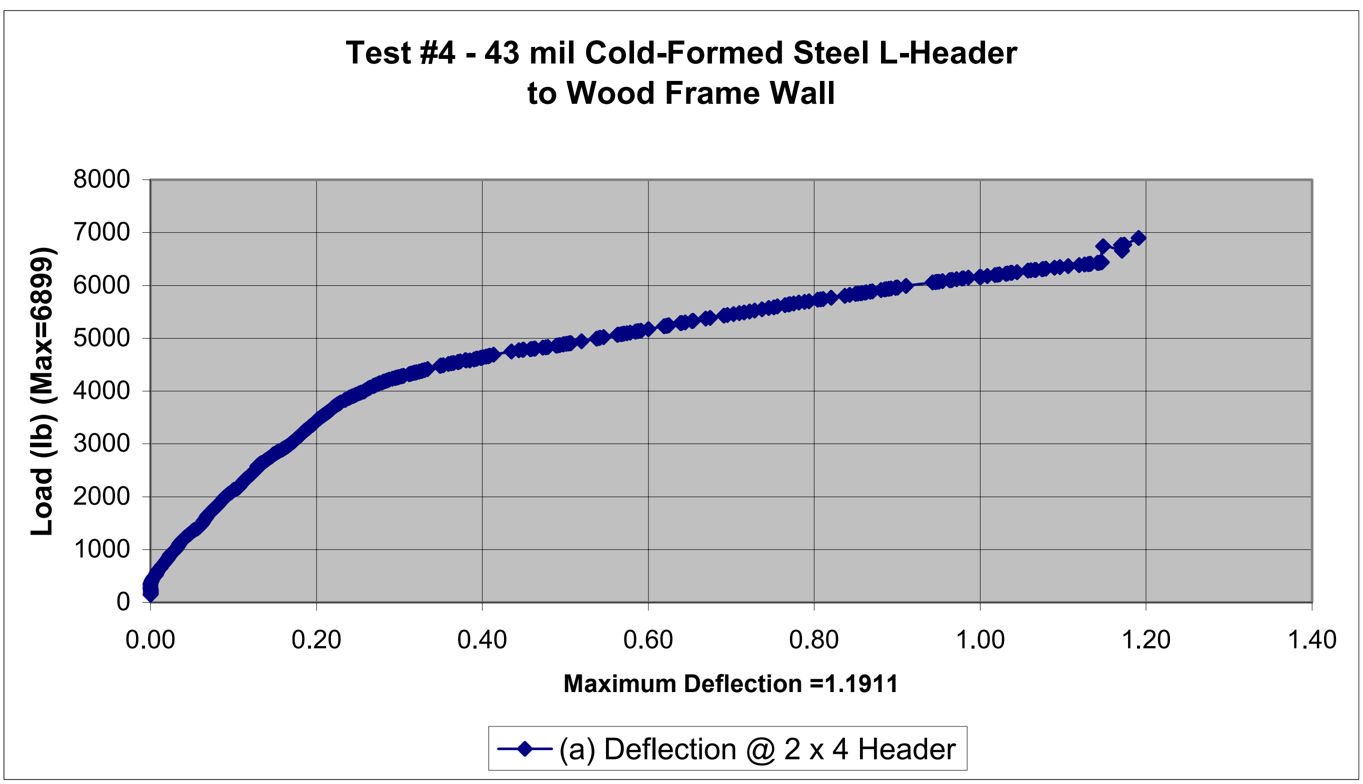
APPENDIX A

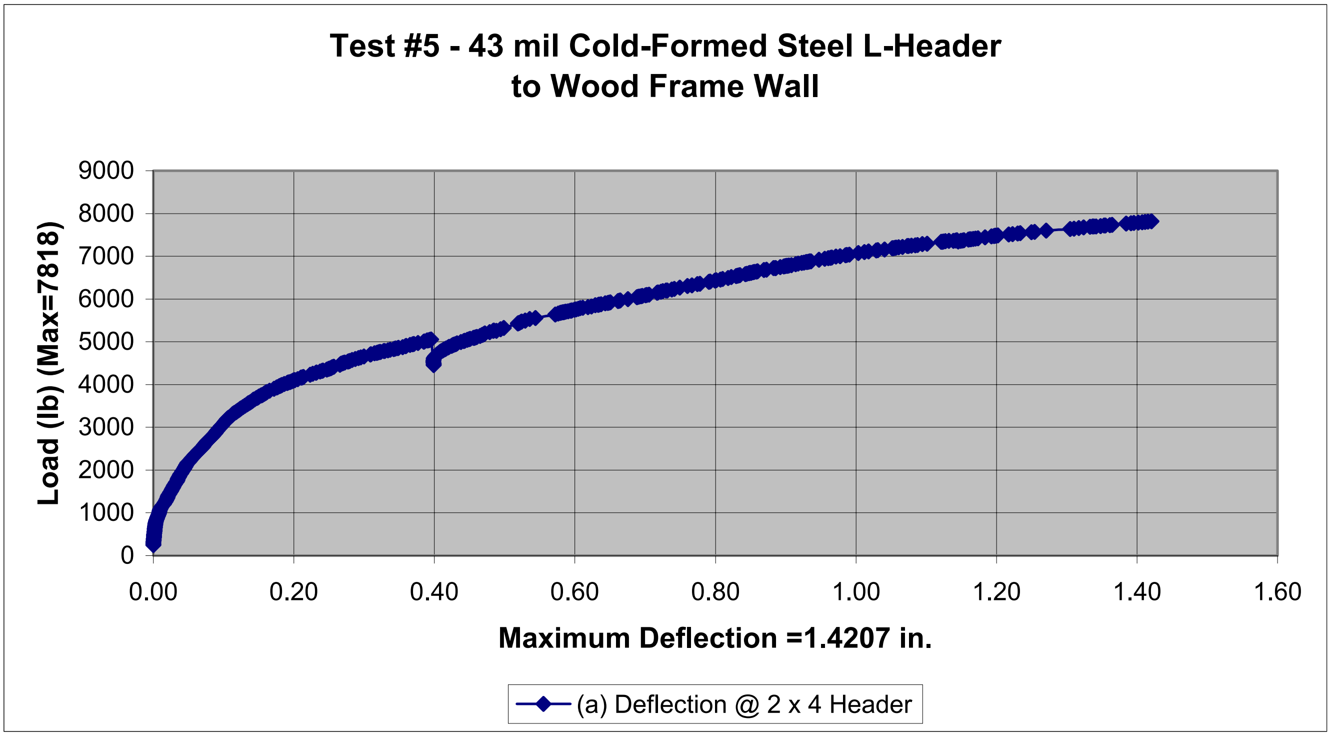
L-Header Assembly Test Plots

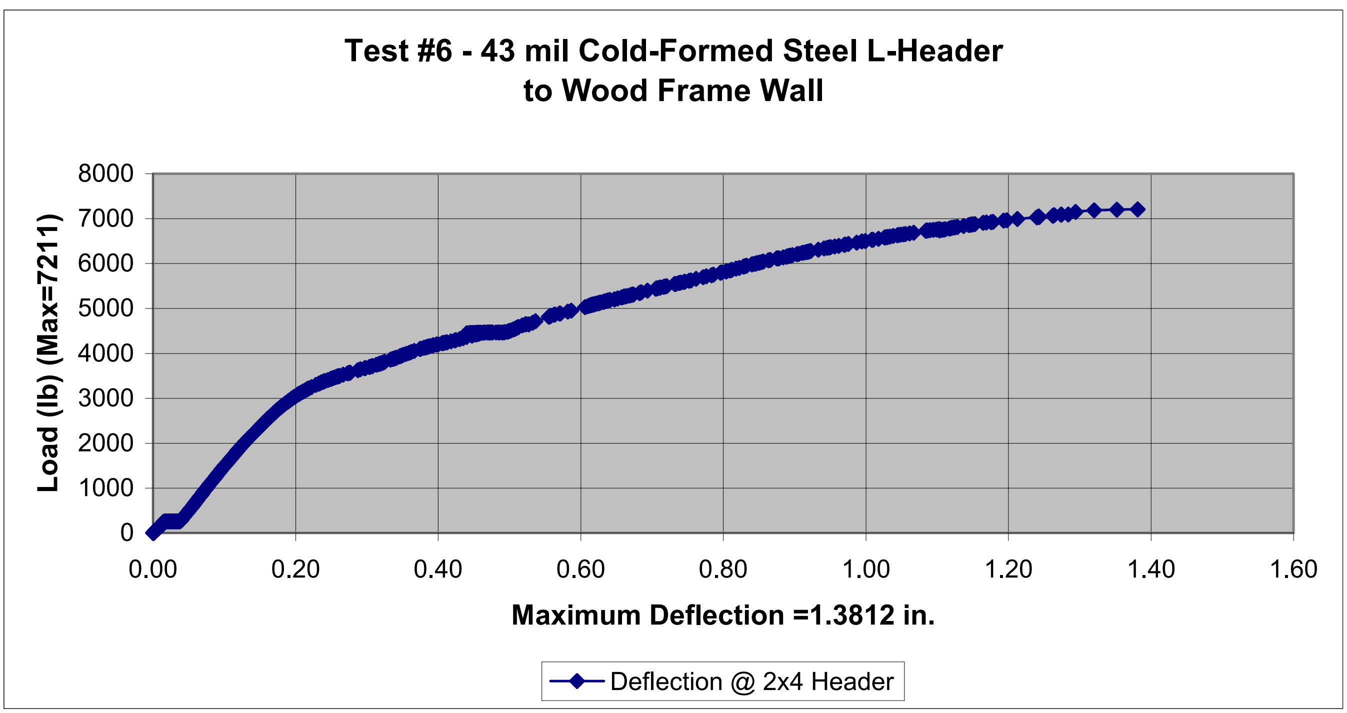

Test #1 - 33 mil Cold-Formed Steel L-Header
to Wood Frame Wall
Load (lb) (Max=5134)
6000
5000
4000
3000
2000
1000
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Max. Deflection = 0.9478 in.
(a) Deflection @ 2 x 4 Header


Test #2 - 33 mil Cold-Formed Steel L-Header
to Wood Frame Wall
Load (lb) (Max=5576)
6000
5000
4000
3000
2000
1000
0
0.0000
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
Maximum Deflection =1.1016 in.
(a) Deflection @ 2 x 4 Header


Test #3 - 33 mil Cold-Formed Steel L-Header
to Wood Frame Wall
Load (lb) (Max=5933)
7000
6000
5000
4000
3000
2000
1000
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Maximum Deflection =1.1124 in.
(a) Deflection @ 2 x 4 Header


Test #4 - 43 mil Cold-Formed Steel L-Header
to Wood Frame Wall
Load (lb) (Max=6899)
8000
7000
6000
5000
4000
3000
2000
1000
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Maximum Deflection =1.1911
(a) Deflection @ 2 x 4 Header


Test #5 - 43 mil Cold-Formed Steel L-Header
to Wood Frame Wall
Load (lb) (Max=7818)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Maximum Deflection =1.4207 in.
(a) Deflection @ 2 x 4 Header


Test #6 - 43 mil Cold-Formed Steel L-Header
to Wood Frame Wall
Load (lb) (Max=7211)
8000
7000
6000
5000
4000
3000
2000
1000
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Maximum Deflection =1.3812 in.
Deflection @ 2x4 Header