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Testing of steel single l-headers

NAHB Research Center

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

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February 2003

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Testing Of Steel Single L-Headers

Prepared for

Steel Framing Alliance
Washington, DC

And

The U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Washington, DC

by

NAHB Research Center, Inc.
400 Prince George's Boulevard
Upper Marlboro, MD 20774-8731

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Disclaimer

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Project Manager	Nader Elhajj, P.E.
Technical Reviewer	Jay Jones, P.E.
Lab Technician	Stuart Denniston
	Ayman Al-Hajj
Administrative Support	Lynda Marchman

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Preface

The NAHB Research Center, U.S. Department of Housing and Urban Development (HUD) and the Steel Framing Alliance have worked cooperatively to introduce cold-formed steel framing into the residential construction market and to provide objective builders and homeowners with a cost-effective alternative construction material. This report investigates the structural adequacy of single steel L-headers for short openings in steel-framed residential buildings. Double L-headers have been previously investigated and proved to be a cost-effective alternative to conventional back-to-back and box-beam headers.

HUD and the Steel Framing Alliance commissioned the NAHB Research Center to test single L-headers for short door and window openings used in conventional steel-framed residential buildings (openings up to 4-feet wide). This report provides test results as well as span tables that can be used by builders.

Executive Summary

The purpose of this test report is to substantiate a more cost-competitive alternative to "box beam" and "back-to-back" headers by expanding upon the L-header testing program that was previously conducted at the NAHB Research Center, Inc. Previous testing of double L-shaped headers indicated that these headers could be a viable alternative to the existing box-beam or back-to-back headers in lightly loaded applications. The higher capacity of the previously tested L-headers was mainly due to the fact that there is an added benefit from the top track that may be neglected in the design process. However, the application of these previous tests were limited to double L-headers.

Single L-headers for short openings were tested in this report and span tables were developed for residential building that comply with the applicability limits of the *Prescriptive Method for One and Two Family Dwellings*.

This report starts by providing a literature review of existing tests and/ or design procedures for single L-headers. A list of single L-headers that were tested in this report is then tabulated. Test configuration and test procedures are described. Test results are tabulated and a prescriptive table is developed.

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INTRODUCTION

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 light-gauge 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 containing span tables and construction details. The Guide, however, is limited to double angles (double L-headers). No span tables or details were published for single angles (single L-headers).

The purpose of this report is to investigate the feasibility of using single steel L-headers placed over steel-framed walls. The investigation is limited to testing of single L-headers used for 4-foot (1.2 m) openings (i.e., window and door openings), which are common in residential buildings.

Figure 1 – Typical Steel L-Header

LITERATURE REVIEW

Review of Existing Test Data

A literature review of similar work was performed prior to testing. Little information pertaining to the benefits of single L-shaped headers was found in the literature. Tests of single L-shaped headers conducted at the NAHB Research Center, Inc. [2] using 6-inch and 8-inch angles with 33 mil and 43 mil thicknesses showed a noticeable increase in tested ultimate capacity over calculated ultimate capacity as shown in Table 1. The results show that a 6-inch, 33 mil L-header, with single angle does not provide adequate strength for wide openings in residential construction, but may be acceptable for smaller openings, especially for lightly loaded buildings. Tests also showed a significant increase in the single L-header's capacity as the thickness of the angle increases or the depth of the angle increases.

TABLE 1
SUMMARY DATA OF TESTED SINGLE L-HEADERS[1]

L-Shape Header Specimen	Angle Size (inches)	Header Clear Span (feet)	Angle Thickness (mils)	Tested Ultimate Load (lb.)	Calculated Ultimate Load (lb.)	Load Ratio (Tested / Calculated)
L-Header #1	6"	4.0	33	1,446	949	1.52
L-Header #2	6"	4.0	33	1,306	971	1.34
L-Header #6	8"	4.0	43	2,662	1,806	1.47
L-Header #7	8"	4.0	43	2,693	1,788	1.51
L-Header #12	6"	4.0	33	1,354	952	1.42
L-Header #13	6"	4.0	33	1,384	953	1.45

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

[1]Reproduced from reference 2. For angle size, thickness, loading configuration, span length, material properties, number of tests, and other pertinent information, refer to reference 2.

Review of Design Procedures

The design of an L-header may be performed in accordance with the *North American Specification for the Design of Cold-Formed Steel Structural Members* [3]. The *AISI Standard for Cold-Formed Steel Framing - Header Design* [4] contains design equations that are limited to double L-headers.

EXPERIMENTAL APPROACH

Test Specimens

The L-header test specimens were assembled using construction materials and methods appropriate for residential construction of cold-formed steel framing. All steel materials used in the tests conform to the dimensional and material requirements of the *Standard for Cold-Formed Steel Framing - General Provisions* [5] and Table 2. Tensile and yield strength were verified by tensile tests in accordance with ASTM A370 [6]. Base steel thicknesses were also established and measured in accordance with ASTM A90 [7]. Mechanical properties were based on coupons cut from the center of the web of a sample of the test specimens.

Each single L-header assembly consisted of one cold-formed steel angle with one short leg lapping over the top track (350T125-33) and one long leg extending down the side of the wall above openings. Each angle was fastened to the top plate above an opening with No. 8 screws spaced 12-inches (305 mm) on center. All screws used were No. 8 self-drilling tapping screws with low profile heads. All screws protruded through steel a minimum of three exposed threads. Details of the built-up single L-header assembly are shown in Figures 2 and 3.

A total of 18 single L-header assemblies were constructed and tested, three for each L-header designation identified in Table 2.

TABLE 2
MEMBER DIMENSIONS

Member Designation	Measured Long Angle Size (or Web Depth) (in.)	Measured Short Angle Size (or Flange Width) (in.)	Nominal Thickness (in.)
L-Headers			
600L150-33	6.0	1.50	0.033
600L150-43	6.0	1.50	0.043
600L150-54	6.0	1.50	0.054
800L150-33	8.0	1.50	0.033
800L150-43	8.0	1.50	0.043
800L150-54	8.0	1.50	0.054
Tracks			
350T125-33	3.50	1.25	0.033
Cripple Studs			
350S162-33	3.50	1.625	0.033
End Studs			
350S162-43	3.50	1.625	0.043

For SI: 1 inch = 25.4 mm

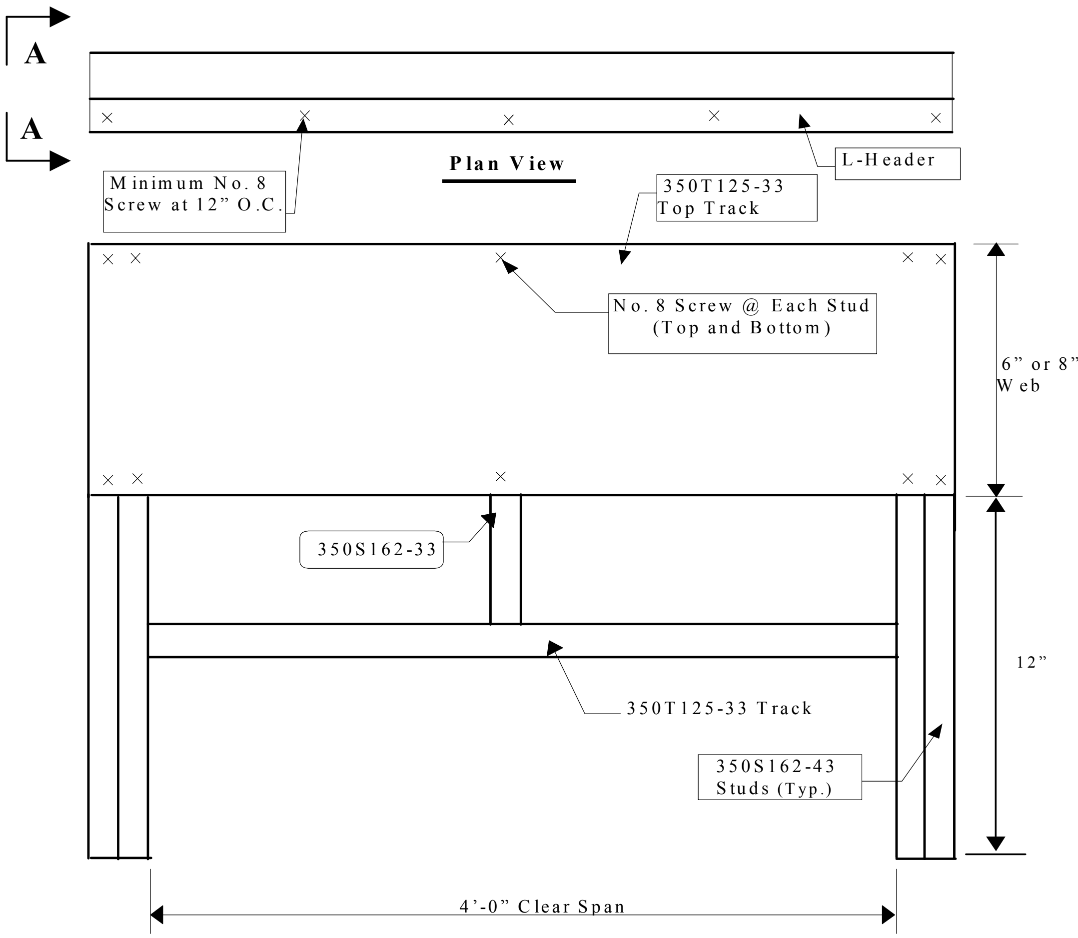

Figure 2 - Detail of a Built-up Single L-Header Assembly

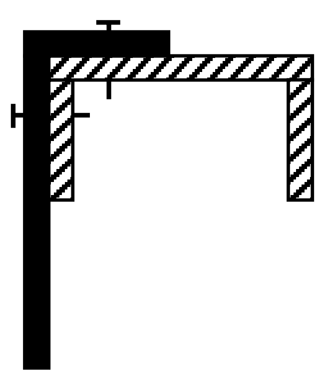

Figure 3 – Section A-A (Single L-Header)

Test Apparatus

The header assemblies were tested using a 200,000 lb (900 kN) universal testing machine (UTM, Southwark-Emery Model 78075), a Satek Epsilon Series 2 inch deflectometer, and a Newvision II Data Acquisition System. The two 350S162-43 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 4. 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 screws (shear or pull out), or failure of the head track. Deflections at the midpoint of the opening were recorded during the full range of loads using the 2-inch (51 mm) deflectometer. 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 used at the stud bearing points because rotation was provided by the configuration of the studs.

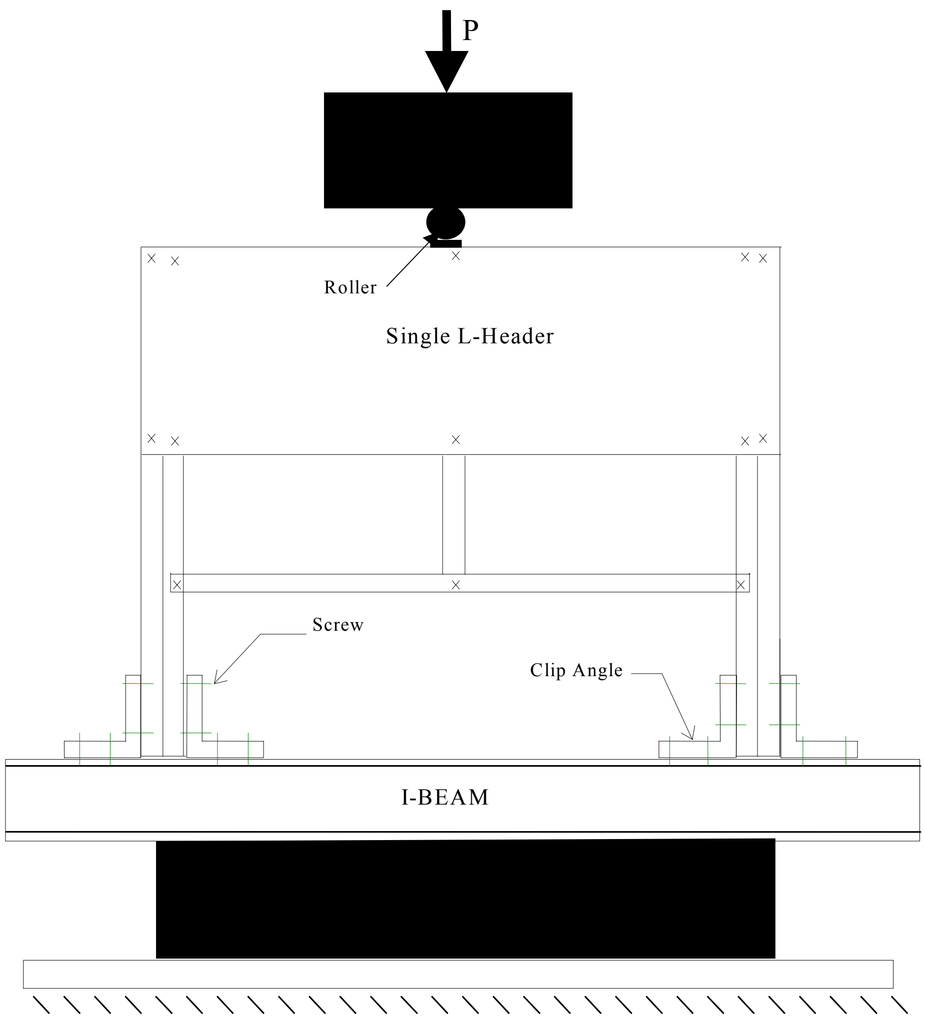

Figure 4 - L-Header Test Apparatus

RESULTS

The average steel physical properties are summarized in Table 3 (Table A1 of Appendix A contains all tested physical properties). The results of the single L-header tests are also shown in Appendix A (Test Plots). Summary of the single L-header test results is shown in Table 4. The ultimate loads shown in Table 4 are the loads measured by the load cell.

FAILURE MODE

All tested samples ultimately failed by buckling under the point load. The web of the angle bulged outwards under the point load that ultimately caused the screws, for some of the assemblies, at the point load location to fail (combination of pullout and shear failure). 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 60 percent of the ultimate load. The angles continued to deform and bulge as the load was increased. The deformation spread to the web of the angle between the load point and the end studs at loads close to the ultimate load. All screws that sheared off did so at ultimate loads. Refer to Figure 5 for illustrations of failure modes.

TABLE 3
AVERAGE PHYSICAL AND MECHANICAL PROPERTIES OF STEEL ANGLES

L-Header Designation	Average Yield Point[1] (psi)	Average Tensile Strength[1] (psi)	Average Uncoated Thickness[2] (in.)	Average Elongation[3] (percent)
600L150-33	37,500	46,633	0.0339	18.9
600L150-43	40,500	54,433	0.0448	20.3
600L150-54	53,533	65,867	0.0551	20.2
800L150-33	37,067	46,900	0.0337	22.1
800L150-43	39,533	56,967	0.0440	21.4
800L150-54	55,067	68,333	0.0541	21.2

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 [6].

[2] Uncoated thickness is the bare steel thickness of the steel angle as tested per ASTM A90 [7].

[3] Tested in accordance with ASTM A370 [6] for a two-inch gauge length.

TABLE 4
SINGLE L-HEADER TEST RESULTS

Single L-Header Designation	Web Depth (in.)	Flange Width (in.)	Top Track	Header Clear Span (ft)	Ultimate Load (lb)	Deflection at Ultimate Load (in.)
600L150-33	6.0	1.5	350S125-33	4.0	1,870	0.165
600L150-33	6.0	1.5	350S125-33	4.0	1,889	0.230
600L150-33	6.0	1.5	350S125-33	4.0	1,701	0.294
Average					**1,820**	**0.230**
Standard Deviation					**103**	**0.064**
COV					**0.057**	**0.281**
600L150-43	6.0	1.5	350S125-33	4.0	2,018	0.181
600L150-43	6.0	1.5	350S125-33	4.0	2,180	0.142
600L150-43	6.0	1.5	350S125-33	4.0	2,343	0.157
Average					**2,180**	**0.160**
Standard Deviation					**163**	**0.0200**
COV					**0.074**	**0.123**
600L150-54	6.0	1.5	350S125-33	4.0	2,812	0.237
600L150-54	6.0	1.5	350S125-33	4.0	2,907	0.248
600L150-54	6.0	1.5	350S125-33	4.0	2,809	0.226
Average					**2,843**	**0.237**
Standard Deviation					**56**	**0.011**
COV					**0.0200**	**0.046**
800L150-33	8.0	1.5	350S125-33	4.0	2,190	0.172
800L150-33	8.0	1.5	350S125-33	4.0	2,202	0.168
800L150-33	8.0	1.5	350S125-33	4.0	2,264	0.221
Average					**2,219**	**0.187**
Standard Deviation					**40**	**0.029**
COV					**0.018**	**0.158**
800L150-43	8.0	1.5	350S125-33	4.0	2,810	0.142
800L150-43	8.0	1.5	350S125-33	4.0	2,768	0.166
800L150-43	8.0	1.5	350S125-33	4.0	2,933	0.133
Average					**2,837**	**0.147**
Standard Deviation					**86**	**0.017**
COV					**0.030**	**0.116**
800L150-54	8.0	1.5	350S125-33	4.0	3,188	0.155
800L150-54	8.0	1.5	350S125-33	4.0	3,133	0.157
800L150-54	8.0	1.5	350S125-33	4.0	3,336	0.172
Average					**3,219**	**0.161**
Standard Deviation					**105**	**0.009**
COV					**0.033**	**0.058**

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

Figure 5 – Failure of Single L-Headers Tested Assemblies

DISCUSSION

The nominal L-header design value (R) can be determined by applying an appropriate factor of safety to average ultimate test values. The factor of safety is calculated in accordance with the AISI Specification [3] as follows:

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

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 = $C_\phi (M_m F_m P_m) e^{-\beta_0 \sqrt{V_M^2 + V^2{}_F + C_P V_P{}^2 + V^2{}_Q}}$

$C_ø$ = Calibration coefficient = 1.52
M_m = Mean value of the material factor = 1.10 (bending)
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 (for n = 3)
n = Number of tests
V_P = Coefficient of variation of the test results, ≥ 6.5% (for V_p < 6.5%, use 6.5%)
V_P = 6.5% for all single L-headers except 600L150-43
= 7.4% for single L-header 600L150-43
V_Q = Coefficient of variation of the load effect = 0.21

$\phi = 1.52(1.10x1.00x1.00)e^{-2.5\sqrt{0.10^2 + 0.05^2 + 5.7x0.065^2 + 0.21^2}}$

ϕ = 0.747 for all single L-headers except 600L150-43
ϕ = 0.723 for single L-header 600L150-43

The appropriate ϕ factor computed above can be applied to the average ultimate capacity for each single header assembly shown in Table 4 to estimate the factored (design) capacity.

Therefore, the factored capacity (as measured by the load cell) for each single header is shown in Table 5 for use with LRFD design provisions and factored LRFD load combinations.

TABLE 5
SINGLE L-HEADER FACTORED CAPACITY

Single L-Header Designation	Average Ultimate Load (lb)	Factored Capacity (lb)	Factored Moment[1] (in-lb)
600L150-33	1,820	1,360	16,320
600L150-43	2,180	1,576	18,912
600L150-54	2,843	2,124	25,488
800L150-33	2,219	1,658	19,896
800L150-43	2,837	2,119	25,428
800L150-54	3,219	2,405	28,860

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

[1] Moment is calculated assuming simply supported beam.

DESIGN METHOD

The design equations contained in the AISI *Header Design Standard* [4] for the double L-headers will be used to investigate their applicability to the single L-headers tested in this report.

The AISI *Header Design Standard* provides the following design equation for double L-header beam having vertical leg dimension of 8 inches (203 mm) or less:

$$M_{ng} = S_{ec}F_y$$

Where: F_y = yield strength used for design
S_{ec} = elastic section modulus of the effective section calculated at $f=F_y$ in the extreme compression fibers.

Design Moment Capacity, $M_a = M_{ng}/\Omega$ For ASD ($\Omega = 1.67$)
$M_a = \phi M_{ng}$ For LRFD ($\phi = 0.90$)

The nominal flexural strength (M_{ng}) for each of the tested assemblies is calculated using the above equations and tabulated in Table 6. The ratio of the tested-to-computed moments (M_{Test}/M_{ng}) is shown in Table 6 (un-factored moments). A ratio equals to 1.0 means that the double L-header design equations are applicable to single L-headers. A ratio greater than 1.0 indicates that the design equations are conservative while a ratio of less than 1.0 indicated that the design equations are unconservative for single L-headers.

TABLE 6
SINGLE L-HEADER MOMENT COMPARISON[1]

Single L-Header Designation	Test Moment (M_{Test}) (in-lb)	S_{ec} (in^3)	Design Moment (M_{ng}) (in-lb)	Ratio (M_{Test})/ (M_{ng})
600L150-33	21,840	0.28809	10,803	2.02
600L150-43	26,260	0.40585	16,437	1.60
600L150-54	34,116	0.50797	27,193	1.25
800L150-33	26,628	0.41002	15,198	1.75
800L150-43	34,044	0.64456	25,481	1.34
800L150-54	38,628	0.79878	42,888	0.90

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

1 The section modulus is computed based on the measured properties as shown in Tables 1 and 3.

It is concluded from the above table that the design equations for double L-headers can be conservatively used for the single L-headers tested in this report with the exception of the 800L150-54.

A trend in the ratios, **(M_{Test})/ (M_{ng}),** can also be concluded from Table 6. It appears that as the thickness of the L-header increases the ratio decreases. The decrease in the ratio indicates that the other elements of the assembly do not contribute as much to enhancing the strength of the L-header. That is, the thinner headers gain more from the help given by the top track and other elements than the thicker headers. Also, the decrease in the ratio for the longer leg angles is consistent with the trend observed for the double L-header.

DEFLECTION CHECK

Table 4 shows the deflection for each tested assembly at ultimate load. The average deflection varies from 0.147 to 0.237 inches (3.73 to 6.02 mm). The average (tested) deflections at design loads (factored loads) can be estimated from the charts in Appendix A. These deflections range from 0.05 to 0.1 inches (1.27 to 2.54 mm).

The deflection criterion that is typically used for headers is L/360. This deflection limit is also specified in the *Prescriptive Method* [8]. Using this L/360 limit, the allowable deflection for each assembly would be: 48/360 = 0.133 inches (3.38 mm). The tested deflection is well below the deflection limit of L/360, and therefore, deflection need not be checked for such assemblies.

PRESCRIPTIVE TABLES

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

> Using the applicability limits of the *Standard for Cold-Formed Steel Framing - Prescriptive Method for One and Two Family Dwellings* (Prescriptive Method) [8], determine the loads acting on a 4-foot (1220 mm) wide header supporting one roof and ceiling only for a 28-foot (8534 mm) wide building (with 24 inch, 610 mm, overhang) with a 30-psf (1.4364 MPa) ground snow load.

All other loads are in accordance with the Prescriptive Method. Select an appropriate single L-header for the 4-foot (1220 mm) opening. Refer to Appendix B for SI units.

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	Roof dead load	= 7 psf	[8]	
	Ceiling dead load	= 5 psf	[8]	
	Roof live load=	= 16 psf	[8]	
Dead Loads:				
	Ceiling Dead Load =	5 psf(28/2)	=	70 plf
	Roof Dead Load =	7 psf(32/2)	=	112 plf
	Total Dead Load		=	182 plf
Live Loads:				
	Roof Live Load =	16 psf(28 + 4)/2=		256 plf
	Roof Snow Load =	0.7(30 psf)(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

The moment due to a 756 plf distributed load is 18,144 in-lb. Using Table 5, the appropriate single L-header to use is 600L150-43 or 800L150-33 (with factored moment capacities of 18912 and 19896 respectively).

Table 7 was developed using the *Prescriptive Method* applicability limits and the design equations from the AISI *Header Design Standard*. The values in Table7 were derived in a similar manner to the example shown in the previous section. The moment capacity used for the 800L150-54 was normalized for the minimum thickness, 0.054” (1.37 mm) and the yield strength, 50 ksi (345 MPa). The factored moment capacity for the 800L150-54 is 26,156 in-lb (2956 N-m).

TABLE 7
MINIMUM THICKNESS (MILS) OF SINGLE L-HEADERS
FOR OPENINGS NOT GREATER THAN 4-FEET
(HEADERS SUPPORTING ROOF AND CEILING ONLY)

Building Width [1] (Feet)	L-Header Designation	Ground Snow Load (psf) [2]			
		20	30	50	70
24	600L150-	43	54	54	-
	800L150-	33	43	54	-
28	600L150-	54	54	-	-
	800L150-	43	43	-	-
32	600L150-	54	54	-	-
	800L150-	43	43	-	-
36	600L150-	54	54	-	-
	800L150-	43	43	-	-
40	600L150-	54	-	-	-
	800L150-	43	54	-	-

For SI: 1 mil = 1/1000 inch = 25.4 mm, 1 foot = 305 mm, 1 psf = 0.0479 kN/m^2.
[1] Building width is measured in the direction of horizontal framing members supported by the header.
[2] Design Assumptions:
Roof and ceiling dead load = 12 psf (0.58 kN/m^2)
2 foot (0.61 m) roof overhang

CONCLUSION

Single L-shaped header is a viable alternative to conventional back-to-back and box-beam headers for common window and door openings in lightly loaded buildings. It is anticipated that possible applications will include headers supporting short or moderate roof spans and other light structures. Tables were developed for single L-headers with a maximum span of 4-feet (1220 mm).

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APPENDIX A

Coupon Test Results and L-Header Assembly Test Results

TABLE A1
PHYSICAL AND MECHANICAL PROPERTIES OF STEEL ANGLES

L-Header (Angle) Designation	Yield Point[1] (psi)	Tensile Strength[1] (psi)	Uncoated Thickness[2] (inch)	Elongation[3] (percent)
600L150-33	36,800	46,100	0.0337	18.5
600L150-33	38,200	45,200	0.0341	18.7
600L150-33	37,500	48,600	0.0340	19.4
600L150-43	41,100	55,300	0.0444	19.6
600L150-43	39,900	54,600	0.0451	21.2
600L150-43	40,500	53,400	0.0448	20.0
600L150-54	53,700	64,600	0.0551	19.5
600L150-54	52,800	67,800	0.0555	19.9
600L150-54	54,100	65,200	0.0546	21.3
800L150-33	36900	48600	0.0339	23.2
800L150-33	37200	45900	0.0335	22.1
800L150-33	37100	46200	0.0336	20.9
800L150-43	39800	56900	0.0439	22.9
800L150-43	38700	58200	0.0441	21.6
800L150-43	40100	55800	0.0440	19.8
800L150-54	56500	69200	0.0540	21.6
800L150-54	54900	67500	0.0541	19.8
800L150-54	53800	68300	0.0541	22.3

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

[1] Yield point and tensile strength shown are based on coupons cut from each sample and tested per ASTM A370 [6].

[2] Uncoated thickness shown is based on uncoated thickness taken from each sample per ASTM A90 [7].

[3] Tested in accordance with ASTM A370 [6] for a two-inch gauge length.

TABLE A2
PHYSICAL AND MECHANICAL PROPERTIES OF STEEL MEMBERS

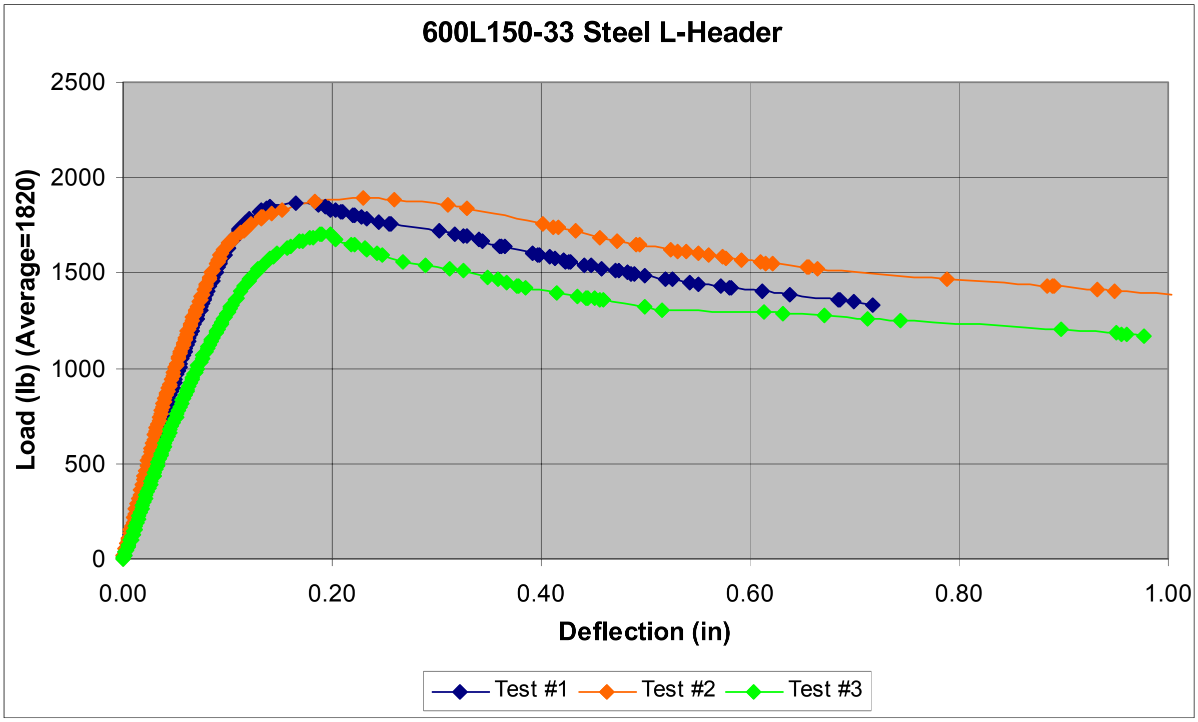
Member Designation	Yield Point[1] (psi)	Tensile Strength[1] (psi)	Uncoated Thickness[2] (inch)	Elongation[3] (percent)
350S162-33	37,850	48,620	0.0336	21.6
350S162-33	36,690	47,740	0.0334	23.4
350S162-33	36,230	47,020	0.0334	22.1
350T125-33	33,420	42,130	0.0332	21.9
350T125-33	34,050	41,010	0.0332	22.3
350T125-33	34,190	40,670	0.0331	22.6

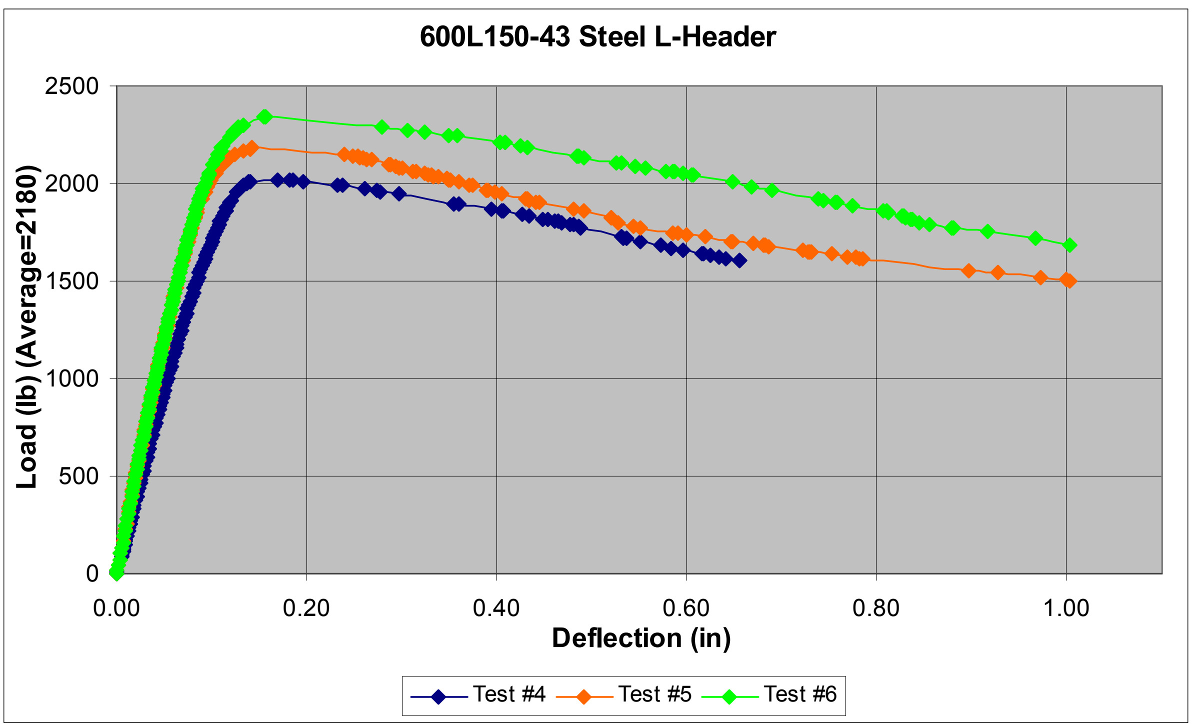
For SI: 1 inch = 25.4 mm, 1 psi = 0.0703 kg/cm^2

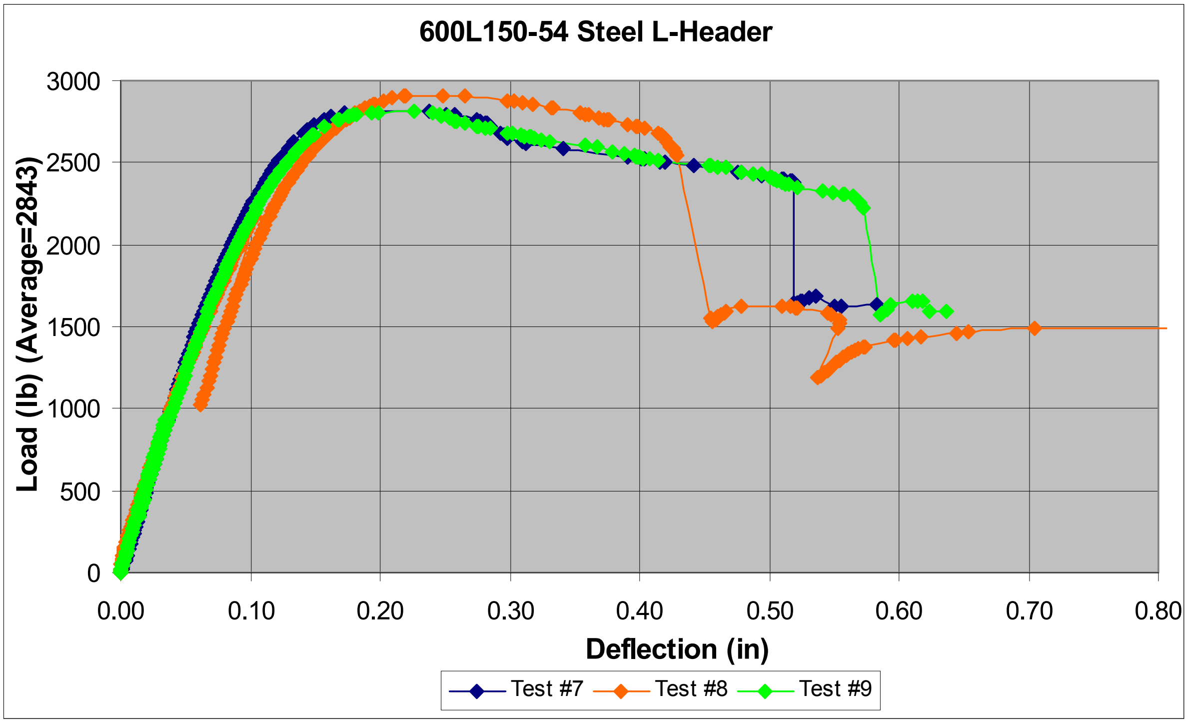
[1] Yield point and tensile strength shown are based on coupons cut from each sample and tested per ASTM A370 [6].

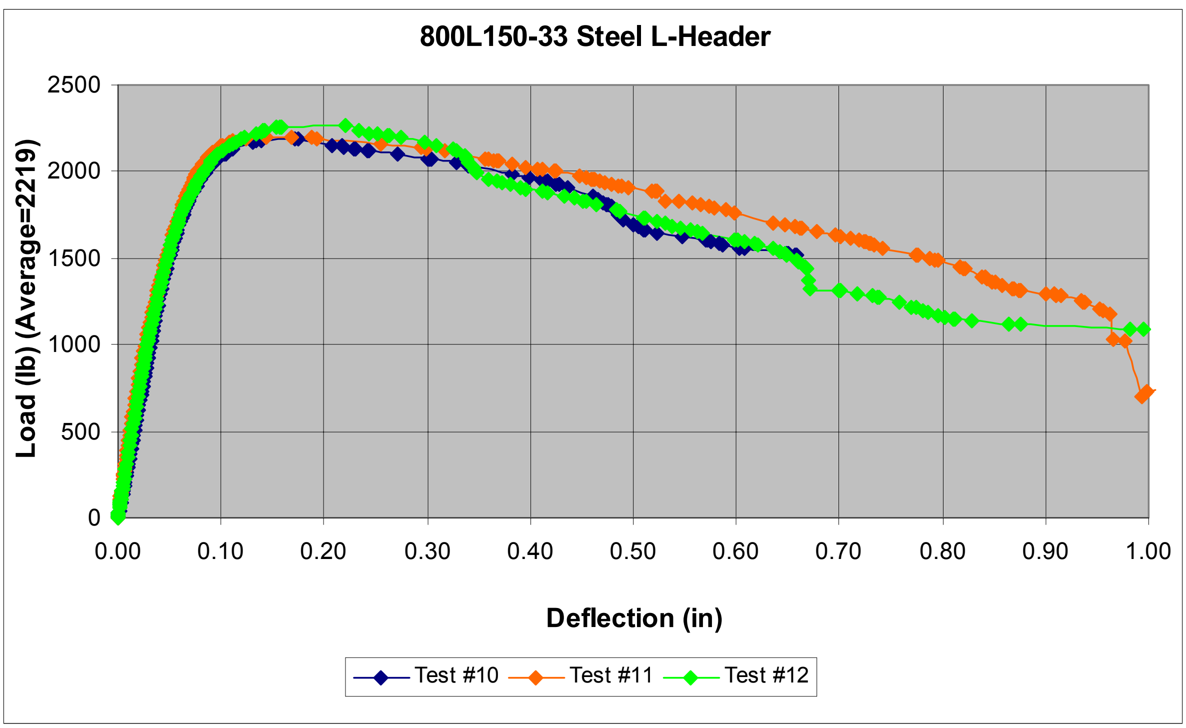
[2] Uncoated thickness shown is based on uncoated thickness taken from each sample per ASTM A90 [7].

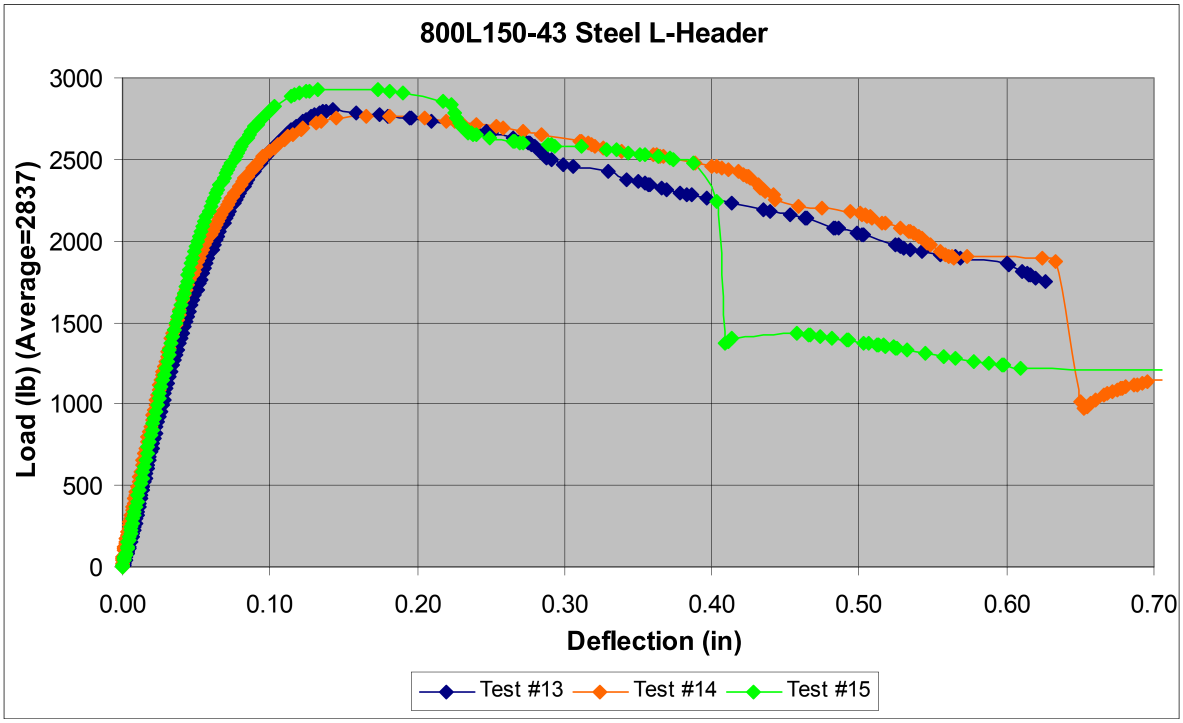
[3] Tested in accordance with ASTM A370 [6] for a two-inch gauge length.

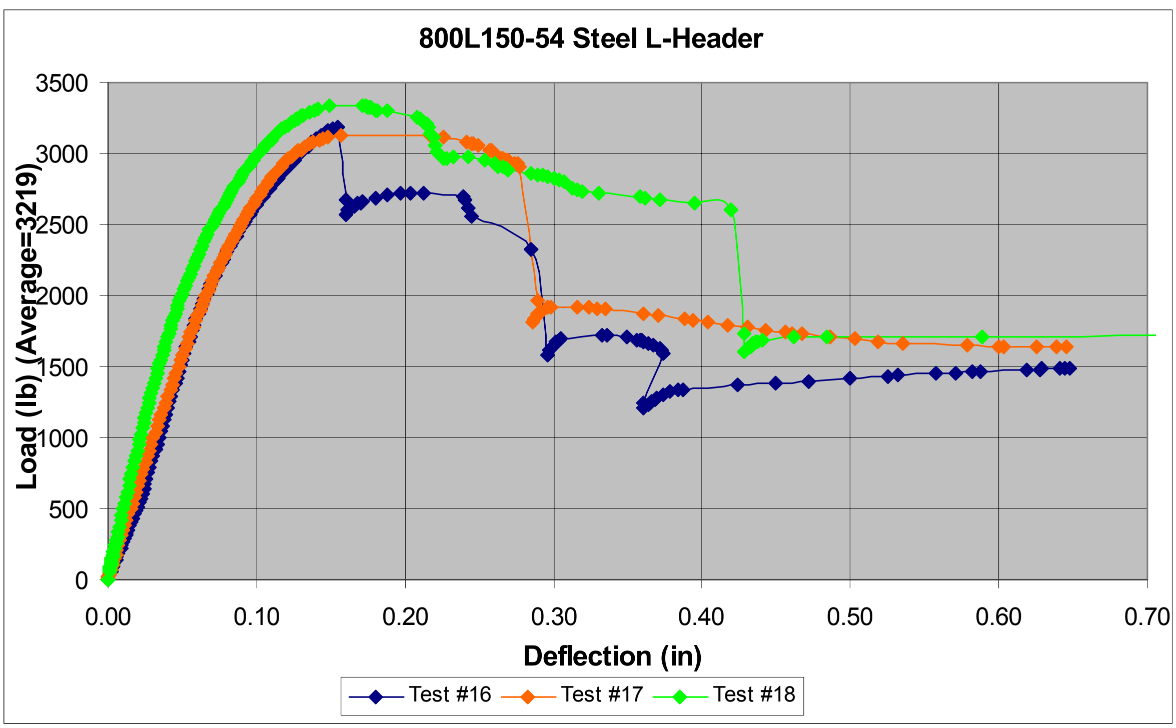

600L150-33 Steel L-Header
Load (lb) (Average=1820)
2500
2000
1500
1000
500
0
0.00
0.20
0.40
0.60
0.80
1.00
Deflection (in)
Test #1
Test #2
Test #3


600L150-43 Steel L-Header
Load (lb) (Average=2180)
2500
2000
1500
1000
500
0
0.00
0.20
0.40
0.60
0.80
1.00
Deflection (in)
Test #4
Test #5
Test #6


600L150-54 Steel L-Header
Load (lb) (Average=2843)
3000
2500
2000
1500
1000
500
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Deflection (in)
Test #7
Test #8
Test #9


800L150-33 Steel L-Header
Load (lb) (Average=2219)
2500
2000
1500
1000
500
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Deflection (in)
Test #10
Test #11
Test #12


800L150-43 Steel L-Header
Load (lb) (Average=2837)
3000
2500
2000
1500
1000
500
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Deflection (in)
Test #13
Test #14
Test #15


800L150-54 Steel L-Header
Load (lb) (Average=3219)
3500
3000
2500
2000
1500
1000
500
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Deflection (in)
Test #16
Test #17
Test #18

APPENDIX B

Metric Conversion

The following list provides the conversion relationship between U.S. customary units and the International System (SI) units. A complete guide to the SI system and its use can be found in ASTM E 380, Metric Practice.

To convert from	To	Multiply by
Length		
Inch (in.)	Micrometer (µm)	25,400
Inch (in.)	Millimeter (mm)	25.4
Inch (in.)	Centimeter (cm)	2.54
Inch (in.)	Meter (m)	0.0254
Foot (ft)	Meter (m)	0.3048
Yard (yd)	Meter (m)	0.9144
Mile (mi)	Kilometer (km)	1.6
Area		
Square foot (sq. ft)	Square meter (sq. m)	0.0929
Square inch (sq. in)	Square centimeter (sq. cm)	6.452
Square inch (sq. in.)	Square meter (sq. m)	0.00064516
Square yard (sq. yd)	Square meter (sq. m)	0.8391
Square mile (sq. mi)	Square kilometer (sq. km)	2.6
Volume		
Cubic inch (cu in.)	Cubic centimeter (cu cm)	16.387064
Cubic inch (cu in.)	Cubic meter (cu m)	0.00001639
Cubic foot (cu ft)	Cubic meter (cu m)	0.02831685
Cubic yard (cu yd)	Cubic meter (cu m)	0.7645549
Gallon (gal) Can. liquid	Liter	4.546
Gallon (gal) Can. liquid	Cubic meter (cu m)	0.004546
Gallon (gal) U.S. liquid*	Liter	3.7854118
Gallon (gal) U.S. liquid	Cubic meter (cu m)	0.00378541
Fluid ounce (fl oz)	Milliliters (ml)	29.57353
Fluid ounce (fl oz)	Cubic meter (cu m)	0.00002957
Force		
Kip (1000 lb.)	Kilogram (kg)	453.6
Kip (1000 lb.)	Newton (N)	4,448.222
Pound (lb.)	Kilogram (kg)	0.4535924
Pound (lb.)	Newton (N)	4.448222
Stress or pressure		
Kip/sq. inch (ksi)	Mega Pascal (Mpa)	6.894757
Kip/sq. inch (ksi)	Kilogram/square centimeter (kg/sq. cm)	70.31
Pound/sq. inch (psi)	Kilogram/square centimeter (kg/sq. cm)	0.07031
Pound/sq. inch (psi)	Pascal (Pa) **	6,894.757
Pound/sq. inch (psi)	Mega Pascal (Mpa)	0.00689476

To convert from	To	Multiply by
Stress or pressure		
Pound/sq. foot (psf)	Kilogram/square meter (kg/sq. m)	4.8824
Pound/sq. foot (psf)	Pascal (Pa)	47.88
Mass (weight)		
Pound (lb.)	Kilogram (kg)	0.4535924
Ton, 2000 lb	Kilogram (kg)	907.1848
Grain	Kilogram (kg)	0.0000648
Mass (weight) per length)		
Kip per linear foot (klf)	Kilogram per meter (kg/m)	0.001488
Pound per linear foot (plf)	Kilogram per meter (kg/m)	1.488
Moment		
1 foot-pound (ft-lb.)	Newton-meter (N-m)	1.356
Mass per volume (density)		
Pound per cubic foot (pcf)	Kilogram per cubic meter (kg/cu m)	16.01846
Pound per cubic yard (lb/cu yd)	Kilogram per cubic meter (kg/cu m)	0.5933
Velocity		
Mile per hour (mph)	Kilometer per hour (km/hr)	1.60934
Mile per hour (mph)	Kilometer per second (km/sec)	0.44704
Temperature		
Degree Fahrenheit (°F)	Degree Celsius (°C)	$t_C = (t_F - 32)/1.8$
Degree Fahrenheit (°F)	Degree Kelvin (°K)	$t_K = (t_F + 59.7)/1.8$
Degree Kelvin (°K)	Degree Celsius (°C)	$t_C = (t_K - 273.15)$
Degree Celsius (°C)	Degree Fahrenheit (°F)	$t_F = 1.8t_C + 32$

* One U.S. gallon equals 0.8327 Canadian gallon

** A Pascal equals 1000 Newton per square meter.

The prefixes and symbols below are commonly used to form names and symbols of the decimal multiples and submultiples of the SI units

Multiplication Factor	Prefix	Symbol
$1,000,000,000 = 10^9$	Giga	G
$1,000,000 = 10^6$	Mega	M
$1,000 = 10^3$	Kilo	k
$0.01 = 10^{-2}$	Centi	c
$0.001 = 10^{-3}$	Milli	m
$0.000001 = 10^{-6}$	Micro	µ
$0.000000001 = 10^{-9}$	Nano	n