



AISI S905-17



AISI STANDARD

Test Standard for Determining the Strength and Deformation Characteristics of Cold-Formed Steel Connections

2017 Edition



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Approved by
the AISI Committee on Specifications for the Design of
Cold-Formed Steel Structural Members

The material contained herein has been developed by the American Iron and Steel Institute (AISI) Committee on Specifications for the Design of Cold-Formed Steel Structural Members. The organization and the Committee have made a diligent effort to present accurate, reliable, and useful information on testing of cold-formed steel members, components or structures. The Committee acknowledges and is grateful for the contributions of the numerous researchers, engineers, and others who have contributed to the body of knowledge on the subject. With anticipated improvements in understanding of the behavior of cold-formed steel and the continuing development of new technology, this material will become dated. It is anticipated that future editions of this test procedure will update this material as new information becomes available, but this cannot be guaranteed.

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1st Printing – April 2018

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PREFACE

The American Iron and Steel Institute Committee on Specifications developed this Standard to provide test methods for determining strength and deformation characteristics of mechanically fastened and welded connections for cold-formed steel building components.

The Committee acknowledges and is grateful for the contribution of the numerous engineers, researchers, producers and others who have contributed to the body of knowledge on this subject.

Commentary and User Notes are non-mandatory and copyrightable portions of this Standard.

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of Cold-Formed Steel Structural Members**

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Subcommittee 6 – Test-Based Design

L. R. Daudet, <i>Chairman</i>	Simpson Strong-Tie
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C. Moen	NBM Technologies, Inc.
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G. Ralph	ClarkDietrich Building Systems
V. E. Sagan	Metal Building Manufacturers Association
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R. Schuster	Consultant
F. Sesma	California Expanded Metal Products
M. Speicher	NIST Engineering Laboratory
T. Sputo	Steel Deck Institute
C. Yu	University of North Texas

AISI S905-17
TEST STANDARD FOR
DETERMINING THE STRENGTH AND DEFORMATION
CHARACTERISTICS OF COLD-FORMED STEEL CONNECTIONS

1. Scope

1.1 This Standard applies to test methods to determine the strength and deformation characteristics of mechanically fastened and welded *connections* for cold-formed steel building components. *Connections* that are stressed in shear (loads applied perpendicular to the shank or cross-section of the fastener, or in plane with the *connection* faying surfaces) and *connections* that are stressed in tension (loads applied parallel to the shank or cross-section of the *fastener*, or perpendicular to the *connection* faying surfaces) and the interaction effects on *connections* are included. The objective is to evaluate field *connections* using standard test specimens and fixtures as provided in Section 7.

1.2 For circumstances in which *connection* configurations exclude the use of the standard tests, alternate tests are permitted. Requirements for both standard tests and alternate tests are provided.

1.3 *Connections* of thin components (such as exterior building steel sheet) to relatively thick components (such as structural frame supports) are considered as well as *connections* between two or more thin components.

1.4 Mechanical *fasteners* include screw *fasteners*, power-actuated *fasteners*, bolts, rivets, clinch joining *connections*, mechanically formed *connections* and button punches.

1.5 Welded *connections* include groove welds in butt joints, arc spot welds, arc seam welds, top arc seam welds, fillet welds and flare groove welds as described in AISI S100 and AWS D1.3.

1.6 The subject test methods are also applicable in determining the strength and flexibility characteristics of *connections* for use in cold-formed steel *diaphragms*.

1.7 The test methods are suitable for hydraulic or screw-operated testing machines using force or displacement control.

User Note:

Fastener fracture can occur in tests, but other test standards are designed to determine these limits (e.g., screws are defined in AISI S904).

1.8 This test does not apply to hold-downs and joint hangers attached to cold-formed steel structural framing. Those devices shall be tested in accordance with AISI S913 and AISI S914, respectively.

1.9 This Standard does not preclude the use of other materials, assemblies, structures or designs if the other materials, assemblies, structures or designs demonstrate equivalent performance for the intended use to those specified in this Standard.

User Note:

This test Standard may also be used for alternate material supports such as concrete or wood.

1.10 This Standard is composed of Sections 1 through 11 inclusive.

2. Referenced Documents

The following documents or portions thereof are referenced within this Standard and shall be considered as part of the requirements of this document.

- a. American Iron and Steel Institute (AISI), Washington, DC:
 - S100-16, *North American Specification for the Design of Cold-Formed Steel Structural Members*
 - S310-16, *North American Standard for the Design of Profiled Steel Diaphragm Panels*
 - S913-17, *Test Standard for Determining the Strength and Deformation Behavior of Hold-Downs Attached to Cold-Formed Steel Structural Framing*
 - S914-17, *Test Standard for Determining the Strength and Deformation Behavior of Joist Connectors Attached to Cold-Formed Steel Structural Framing*
- b. American Welding Society (AWS), Miami, FL:
 - AWS D1.3/D1.3M: 2008, *Structural Welding Code—Sheet Steel*
- c. ASTM International (ASTM), West Conshohocken, PA:
 - A370-16, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*
 - E6-15, *Standard Terminology Relating to Methods of Mechanical Testing*
 - E1190-11, *Standard Test Methods for Strength of Power-Actuated Fasteners Installed in Structural Members*
 - IEEE/ASTM SI10-10, *American National Standard for Metric Practice*

3. Terminology

Where the following terms appear in this Standard, they shall have the meaning as defined herein. Terms not defined in Section 3 of this Standard, AISI S100, or ASTM E6 shall have the ordinary accepted meaning for the context for which they are intended.

Characteristic Connection Strength per Fastener. A statistically adjusted value for the mean maximum load per fastener measured for the test unit.

Connection. Combination of structural elements and joints used to transmit forces between two or more members.

Fastener. A mechanical device, weld, crimp or other similar method or device used to connect two or more elements.

Diaphragm. Roof, floor, or other horizontal or nearly horizontal membrane or bracing system that transfers in-plane forces to the lateral force resisting system.

Gross Distortion. A failure mode where a steel sheet or support member undergoes very large permanent deformation prior to fastener failure.

Load-Deformation Curve per Fastener. The load-deformation curve for the test *connection* with the load values divided by the number of *fasteners*.

Maximum Load per Connection. The maximum load recorded during a test.

Maximum Load per Fastener. The maximum *connection* load divided by the number of *fasteners* in the *connection*.

Pull-Over. A failure mode where a steel sheet is pulled over the *fastener* head (the *fastener* head is pulled through the sheet steel) or around the weld contour. Also referred to as pull-through.

Pull-Out. A failure mode where *fasteners* are pulled free from the support member.

Sidelap Connection. A connection formed by attaching adjacent panels to each other along the panel edges between the support members.

Standing Rib Sidelap Connection. A connection formed by a vertical sheet leg (edge stiffener of deck) inside an overlapping sheet hem, or by vertical sheet legs back-to-back.

Structural Fastener. A fastener attaching one or more steel sheets to a support member.

Top Arc Seam Sidelap Weld. Arc seam weld applied at the top *sidelap connection*.

Top Sidelap Connection. A connection formed by a vertical sheet leg (edge stiffener of deck) inside an overlapping sheet hem, or by vertical sheet legs back-to-back.

Top Overlapping Sidelap Connection. Welded, screwed, mechanically formed or crimped connection located at or near the top of an overlapping *sidelap*.

Wall Diaphragm. A wall, bearing or non-bearing, designed to resist forces acting in the plane of the wall (commonly referred to as a “vertical *diaphragm*” or “shear wall”).

4. Symbols

The following notations shall apply to this Standard:

- A = Elongation in tension test
- a = Width of end supports in alternate tension tests
- a_s = Shear deformation or slip
- a_t = Deformation in tension test
- b = Width of troughs or flats in profiled sheet
- C = Number of *fasteners* used in shear test setup
 - = 2 for test setups illustrated in Figures 1(a) and 1(b)
 - = 4 for test setup illustrated in Figure 1(c)
 - = 1 if one *fastener* is used in test setup in Figure 1(a) but with one *fastener*
- d = Nominal diameter of mechanical *fastener*
 - = Visible diameter of outer surface of arc spot weld or width of arc seam weld
- e₁ = End distance of *fastener* in standard test specimen
- e₂ = *Fastener* gage distance in standard test specimen
- e₃ = *Fastener* edge distance in standard test specimen
- e₄ = *Fastener* edge distance in alternate test specimen
- F_y = Yield stress of steel
- F_u = Tensile strength of steel
- F_{xx} = Tensile strength of electrode classification
- h_{st} = Height of stiffening ribs in profiled sheet
- L = Length of mechanically formed *connection*
- L_w = Length of groove weld in butt joint, length of arc-seam weld (not including circular ends), length of top arc-seam *sidelap* weld, length of fillet weld or length of flare groove weld
- L_s = Free strap length in standard shear test specimen
- L_a = Test span for alternate tension test specimen

- ℓ_g = Extensometer gage length in shear test
 M_n = Nominal moment resistance per flute determined using AISI S100 Section F3
 M_u = Maximum bending moment per stiffening rib
 n = Number of valid tests in test unit
 p = *Fastener* spacing or pitch
 P = Estimated maximum *connection* load per *fastener*
 P_K = *Characteristic connection strength per fastener*
 P_m = Mean *connection* strength per *fastener*
 P_{not} = Structural *fastener* nominal *pull-out* strength [resistance] from support member
 P_{nov} = Structural *fastener* nominal *pull-over* strength [resistance] for sheet to support member
 P_u = Maximum applied load
 Q_f = Structural *connection* strength for sheet to support member
 Q_s = *Stitch connection* strength for sheet to sheet steel
 S_f = Structural *connection* flexibility for sheet to support member
 S_s = *Stitch connection* flexibility for sheet to sheet steel
 t = Base metal sheet thickness
 = Thickness of support material (Table 3)
 u_s = Shear flexibility per *fastener*
 u_t = Tensile (uplift) flexibility per *fastener*
 w = Width of the shear test specimen
 w_1, w_2 = Leg of fillet weld
 α = Coefficient to convert the measured elongation, Δ_g , to individual elongation at *fastener*
 = 1 for setups illustrated in Figures 1(a) and (c) or for test setups with one *fastener*
 = 2 for setup illustrated in Figure 1(b)
 Δ_g = Total elongation of extensometer gage length, ℓ_g , at 40 percent of P_u in standard or alternate shear test
 σ = Standard deviation

5. Units of Symbols and Terms

Any compatible system of measurement units is permitted to be used with this Standard, except where explicitly stated otherwise. The unit systems considered for use with this Standard shall include U.S. customary units (force in kips and length in inches) and SI units (force in Newtons and length in millimeters) in accordance with IEEE/ASTM SI10. SI units are provided in parentheses.

6. Measurement Precision

6.1 The rate of loading shall be controlled, constant loads shall be maintained, and the applied load shall be measured accurately to within ± 1 percent of the full range of the measuring device.

User Note:

The capacity (range) of the load-measuring device should be appropriate to the expected maximum tested load. The use of a measuring device with a calibrated capacity greatly exceeding the anticipated load is inappropriate. A target ratio of the load-measuring device capacity to specimen strength of no greater than three is recommended.

The tests should be conducted on a testing machine that complies with the requirements of ASTM E4-16, *Standard Practices for Force Verification of Testing Machines*.

6.2 The test specimen support fixtures and testing machine grips shall have the capability of maintaining a constant loading direction throughout the test.

6.3 The devices used to measure deformation shall provide a precision of ± 0.001 in. (0.02 mm) for shear tests and ± 0.002 in. (0.05 mm) for tension tests.

6.4 The devices used to measure the dimensions of the test specimens shall be accurate to within ± 0.0005 in. (0.01 mm) for sheet base metal thickness, ± 0.05 in. (1 mm) for sheet profile dimensions, and ± 0.005 in. (0.1 mm) for *fastener* dimensions.

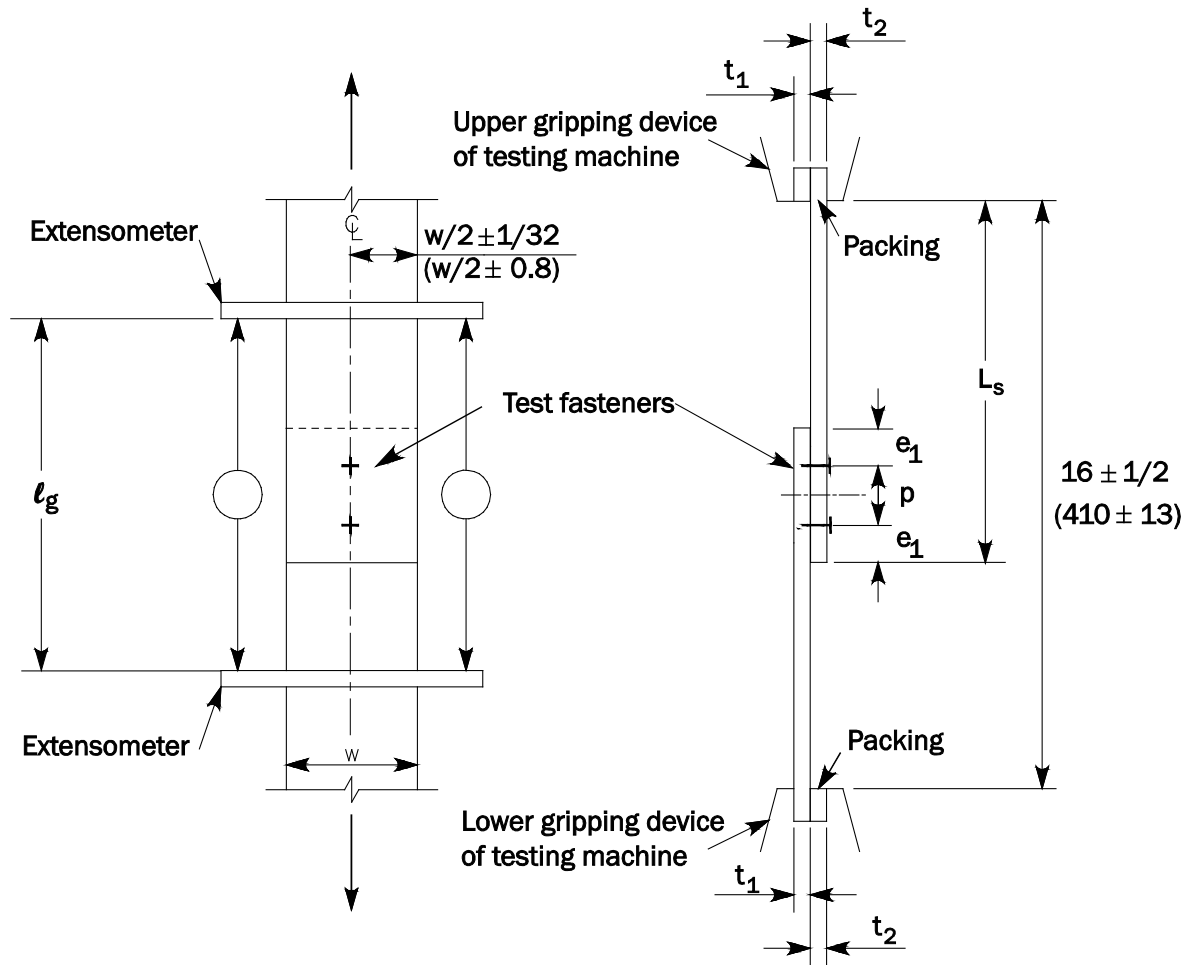
7. Test Fixtures

7.1 Test Fixtures – Lap-Joint Shear Tests

Standard and alternate shear test fixture diagrams are permitted to be used for the investigation of shear strength and stiffness of cold-formed steel *connections* described in Section 1.3. Shear test deformations shall be obtained from extensometer measurements across the lap-joint to the precision as specified in Section 6.3.

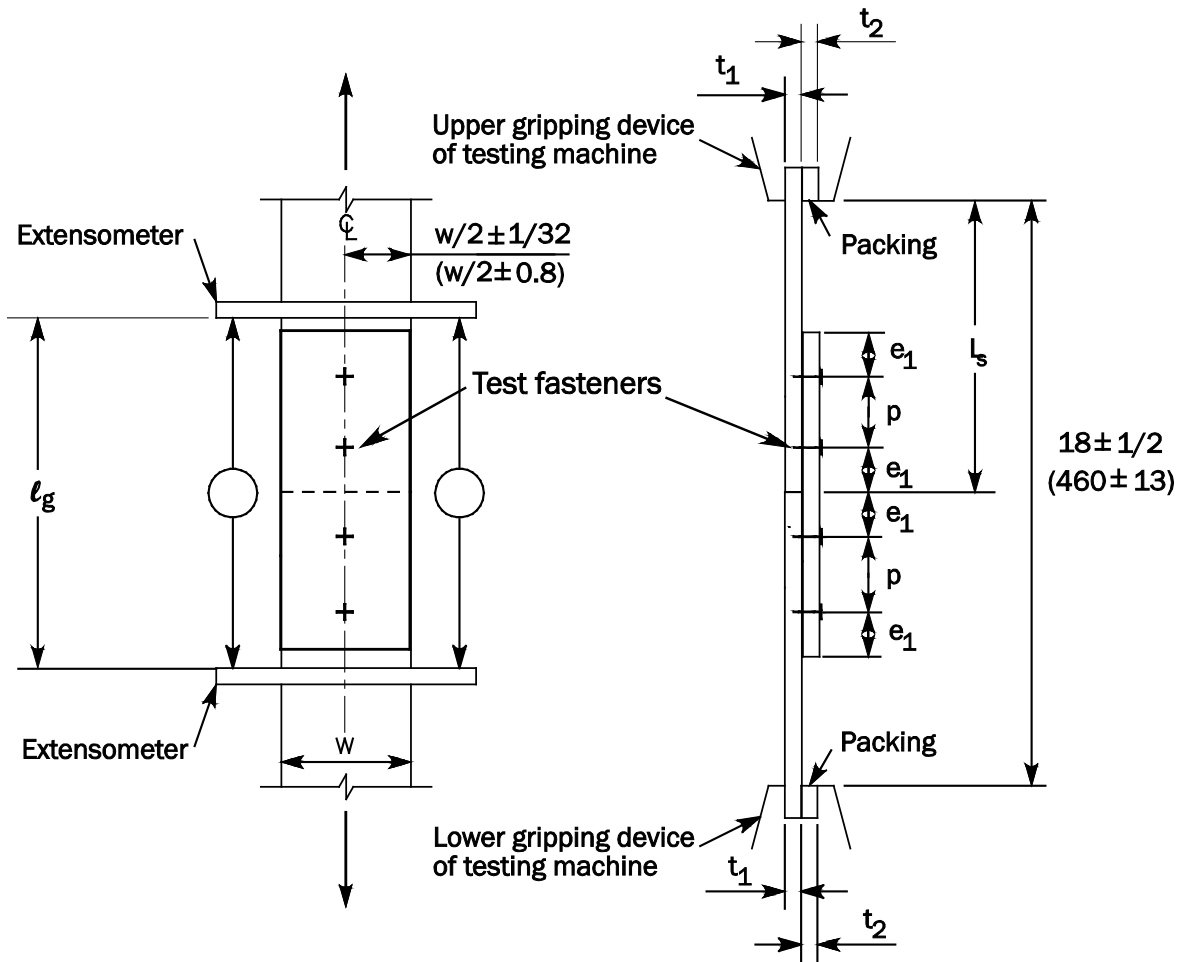
User Note:

Shear test deformations may be measured using crosshead movement of the testing machine if any gripping device slip, specimen elongation and any eccentricity are accounted for.



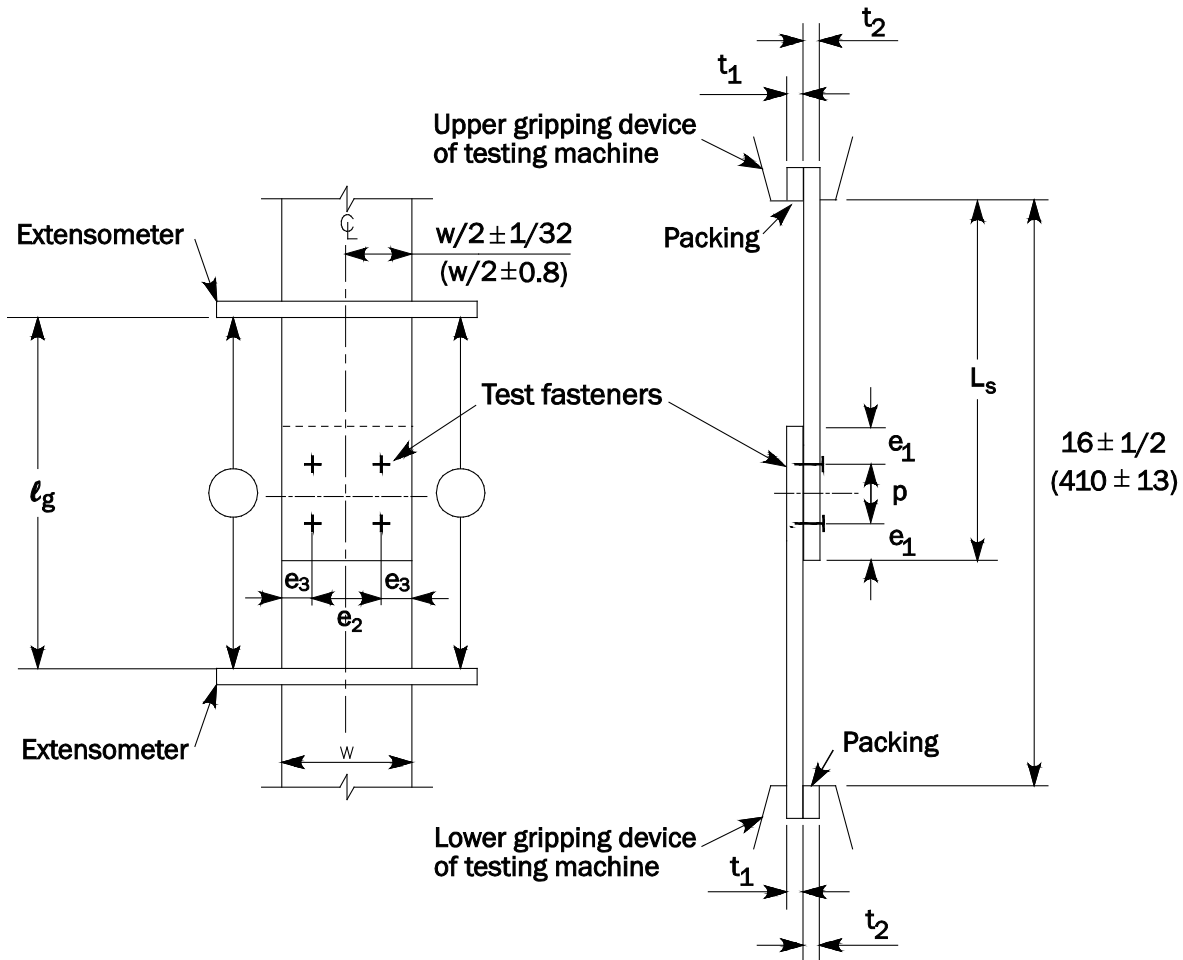
(a) Lap Shear Setup for Two Fasteners per Specimen

Figure 1 Standard Lap-Joint Shear Test, units - in. (mm)
(Continue)



(b) Lap Shear Setup for Four Fasteners per Specimen

Figure 1 Standard Lap-Joint Shear Test, units - in. (mm)
(Continue)



(c) Lap Shear Setup for Four Fasteners per Specimen

Figure 1 Standard Lap-Joint Shear Test, units - in. (mm)

User Note:

Pinned *connections* to the test machine may be used in lieu of mechanical gripping devices provided that bearing of the steel specimen against the pin does not adversely affect the results.

7.1.1 Standard Lap-Joint Shear Tests

Standard shear test specimens shall be a single-lap joint using two flat steel components connected with two *fasteners* (See Figure 1(a)). The test fixture setup shown in Figure 1(b) is permitted if one sheet steel component is connected to two *connection* plates or support members in a lap-joint *connection* with four *fasteners*. The test fixture setup shown in Figure 1(c) shall be used for edge distance investigations. Geometrical proportions of the shear test specimens shall be as given in Table 1, and edge dimension, e_3 , shall be greater than or equal to $1.5d$ and less than $2d$, except for tests investigating other special edge distance and spacing conditions where dimensions are permitted to be modified.

User Note:

Lap-joint shear tests are intended to develop the strength and stiffness of individual *fasteners* and not for group effects. There may be instances when it is rational to modify test setups in order to verify group effects or other influences on *fastener* strength and stiffness.

7.1.1.1 The test fixture for the standard shear test shall provide for central loading across the lap-joint (See Figures 1(a), 1(b) and 1(c)). When the machine grips are adjustable or when the thickness of either strap is less than 1/16 in. (approximately 2 mm), packing shims are not required for central loading.

7.1.1.2 Test setups as shown in Figures 1(a), 1(b) and 1(c) are permitted for the determination of strength and flexibility of structural and *sidelap connections*.

User Note:

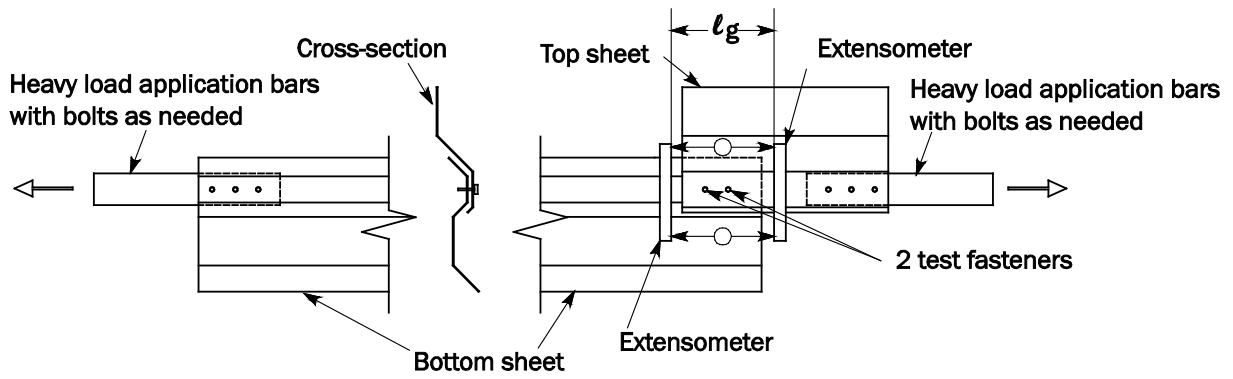
The extensometer gage length, ℓ_g , in Table 1 is deemed short enough to eliminate the influence of stretch in the specimen straps on the extensometer measurements.

Table 1
Geometrical Proportions for Standard Lap-Joint Connection Tests

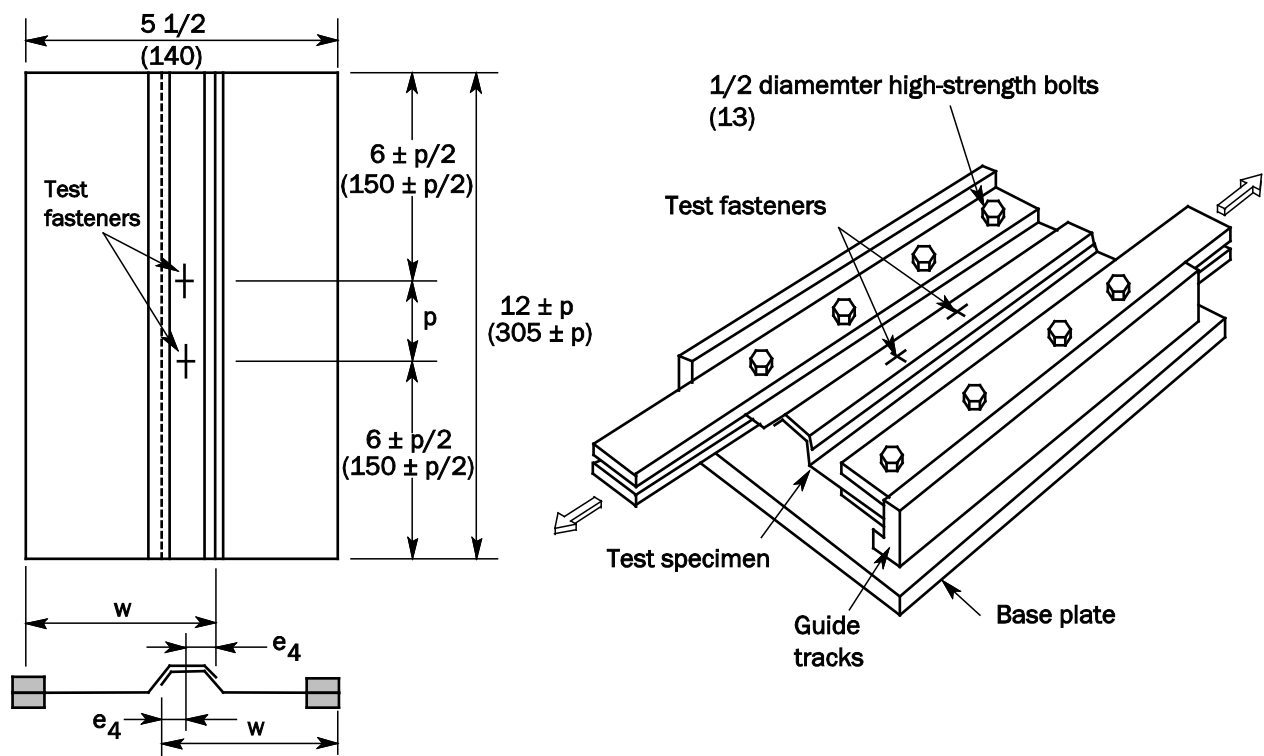
Fastener Critical Dimension, in. (mm)	Specimen Dimensions, in. (mm)					
	w	L_s	e_1	e_2	p	ℓ_g
$d \leq 1/4$ (6.4)	2-3/8 (60)	10-1/4 (260)	1-3/16 (30)	3/4 (19)	2-3/8 (60)	5-7/8 (150)
$d > 1/4$ (6.4)	10d (10d)	8+10d (200+10d)	5d (5d)	3d (3d)	10d (10d)	1-3/16+20d (30+20d)
Circular Weld Diameter $1/2 \leq d \leq 3/4$ (13 ≤ d ≤ 19)	≥ 3 (≥ 76)	12 (310)	> 1.5d (>1.5d)	≥ 3d (≥ 3d)	≥ 3d (≥ 3d)	<16 (410)
Longitudinal Weld Length $L_w \leq 3d$ or Mechanically Formed Connection Length L	≥ 3 (≥ 76)	12 (310)	≥ 3-1/2 (≥ 89)	≥ 3d (≥ 3d)	≥ 3-1/2 (≥ 89)	≥ 16 (410)
Tolerance	±1/16 (±1.6)	±3/16 (±4.8)	±1/32 (±0.8)	±(1/16) (±1.6)	±1/16 (±1.6)	±3/16 (±4.8)

User Note:

For welded *connection* tests, the visible diameter of the weld is used in Table 1 for geometrical proportions in the standard lap-joint shear *connection* tests. The dimension, e_3 , and thus w shown in Figure 1(c) may vary depending on the objectives of the investigation. Normal permissible values of e_3 are provided in Section 7.1.1.

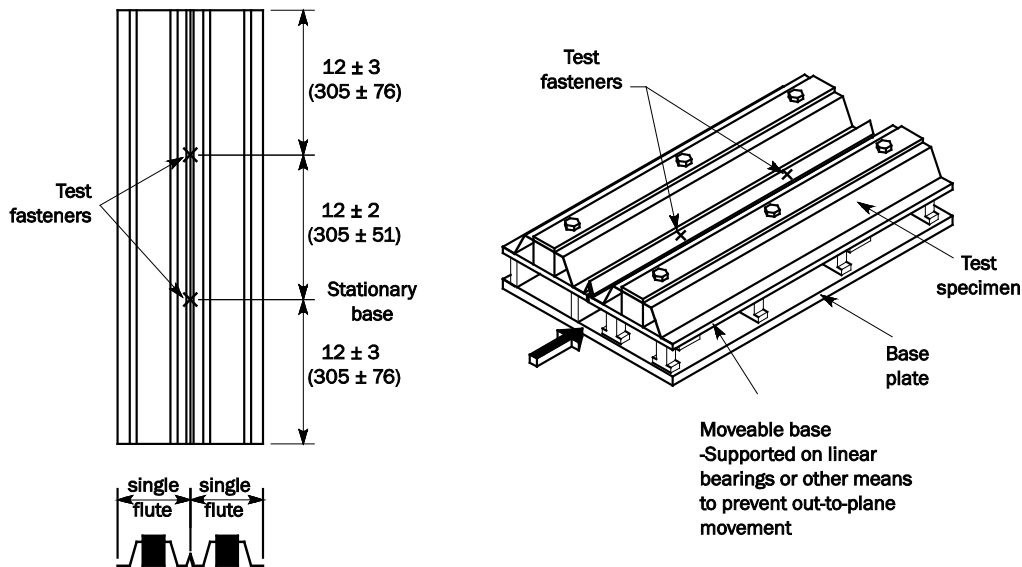


(a) Alternate Lap-Joint Shear Setup 1



(b) Alternate Lap-Joint Shear Setup 2

Figure 2 – Alternate Lap-Joint Shear Test, units - in. (mm)
(Continue)



(c) Alternate Lap-Joint Shear Setup 3

Figure 2 – Alternate Lap-Joint Shear Test, units - in. (mm)

User Note:

Extensometers have not been shown in Figure 2(b) Setup 2, and Figure 2(c) Setup 3, for the clarity of the presentation.

7.1.2 Alternate Lap-Joint Shear Tests

7.1.2.1 Simulated Diaphragm Action Fixtures. The alternate shear test fixture in Figure 2(a) Setup 1 is permitted to be used to simulate *diaphragm connection* with central loading applied in the plane in which the overlapping elements are joined by the *fasteners*. This test fixture is permitted to determine the strength and flexibility of *diaphragm connections* when standard shear test fixtures are unsuitable for evaluating the *connection* properties under consideration. Geometric proportions of the specimen shall be as given in Table 2, unless the proportions of a profile require otherwise.

The alternate shear test specimen in Figure 2(b) Setup 2 is permitted to be used to simulate *diaphragm connection* with central loading applied in a plane different from that in which the overlapping elements are joined by the *fasteners*. This test fixture is permitted to determine the strength and flexibility of the *diaphragm connection* specifically for crest-connected or sidelap up overlapping elements of *diaphragms*. Geometric proportions of the specimen shall be as given in Table 2, unless the proportions of a profile require otherwise.

The alternate shear test fixture in Figure 2(c) Setup 3 shall be used to determine the strength and flexibility of *diaphragm sidelap connections* including mechanically formed *connections*, button punches, mechanical *fasteners* and top arc seam welds. The moveable base shall be restrained by linear slide bearings or similar mechanisms, such that the base moves only in the direction of the load, parallel to and in plane with the stationary base. Guides shall be machined and polished. Sidelap *fastener* spacing tolerances shall be ± 2.0 in. (51 mm) provided the requirements of Table 2 are met. *Fastener* end spacing tolerance shall be ± 3.0 in. (76 mm).

One end of the extensometer shall be mounted on the top sheet and the other end mounted on the bottom sheet of the test specimen to be consistent with Setup 1, illustrated in Figure 2(a). Mounting shall not resist shear and slip at the *connection* faying surface. Dial indicators or linear variable differential transformers (LVDTs) are permitted to be used in lieu of extensometers.

7.1.2.2 The alternate test fixtures, as illustrated in Figures 2(b) and 2(c), shall be designed such that the base plate is securely attached to a level foundation beam (or slab) and loaded in a horizontal plane using a hydraulic ram or an equivalent system. Lubricating material shall be used to reduce the friction between guide and grips or between the guide and moveable base.

Table 2
Geometrical Proportions for Alternate Lap-Joint Shear Tests

Fastener or Weld Critical Dimension in. (mm)	Specimen Dimensions, in. (mm)			
	w	e ₄	p	l _g
Fastener Diameter d ≤ 1/4 (6.5)	3-5/8 (92)	3/8 (10)	2-3/8 (60)	5-7/8 (150)
Fastener Diameter d > 1/4 (6.5)	3-5/8 (92)	1.5d (1.5d)	10d (10d)	1-3/16 + 20d (30 + 20d)
Circular Welds Diameter 1/2 ≤ d ≤ 3/4 (13 ≤ d ≤ 20)	3-5/8 (92)	1.5d (1.5d)	> 3d (> 3d)	≥ 12 (≥ 310)
Longitudinal Weld Length L _w ≤ 3d or Mechanically Formed Connection Length L ≤ 3d	≥ 3-5/8 (≥ 92)	3d (3d)	7 + L (180 + L)	≥ 12 (≥ 310)
Tolerance	±1/16 (±1.6)	±1/32 (±0.8)	±1/32 (±0.8)	±3/16 (±4.8)

7.1.3 Connection Flexibilities

Structural and *sidelap connection* flexibilities shall be determined by measuring the displacement of the *connection* corresponding to 40% of the ultimate lap-joint shear capacity on the load-displacement curve (0.4P_U). For structural *connection* flexibilities, tests shall be conducted at the minimum base steel thickness of the supporting member in accordance with *fastener* application limits. If tilting, bearing, tearing and piling up or other distortion is observed in the support member, additional support thicknesses shall be tested. Tests shall be conducted with sheet steel and base steel thickness combinations for which the *fastener* is intended. In order to establish variation of *connection* flexibility, a minimum of three sheet thicknesses shall be tested if the sheet application range difference is greater than 0.02 in. (0.51 mm); otherwise, two sheet thicknesses near the application limits are permitted. Test specimen flexibility shall be determined in

accordance with Section 10.3.5.

7.2 Test Fixtures – Tension Tests

7.2.1 The following failure modes shall be identified when loading induces tension in the *fasteners* that connect steel to structural support members:

- a. *Pull-over*
- b. *Pull-out*
- c. *Fastener fracture*
- d. *Gross distortion*

User Note:

AISI S904 is used for determining screw *fastener* fracture strengths.

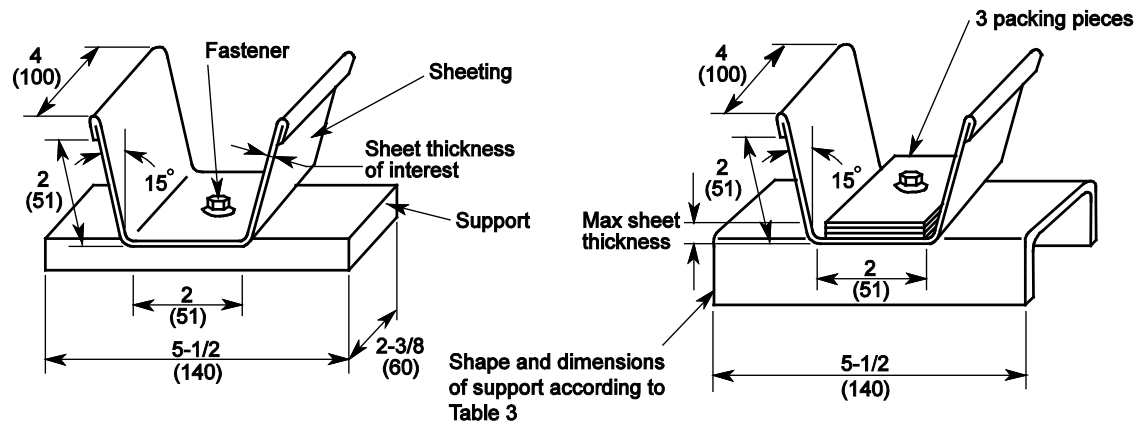
Reference:

S904-17, *Test Standard for Determining the Tensile and Shear Strength of Carbon Steel Screws*

7.2.2 The standard tension test specimens, such as those illustrated in Figures 3(a) and 3(b), for *pull-over* and *pull-out* strength shall be made from flat sheet stock used to produce the sheet steel product under consideration. The specimen geometry shall serve as a generic model for profiled sheet steel. The *connection* support member thickness for the *pull-over* test shall be at least 1/8 in. (3.2 mm) in order to resist *fastener pull-out* with a minimal amount of symmetrical deformation from the test loads. Support members for standard *pull-over* and *pull-out* tests shall be in accordance with Table 3. For *pull-out* or *pull-over* tests, the total sheet steel thickness connected to the support is permitted to be simulated by adding pieces of steel sheet, either two or four layers for end lap and corner lap *connections* respectively (See Figures 3(b) and 4).

Table 3
Standard Support Members for Tension Pull-Over and Pull-Out Tests

Thickness of Support Material, in. (mm)	$t \geq 1/4$ (6.4)	$t < 1/4$ (6.4)	
Type of Support to be Used in Practice	All Types	Hot-Rolled Sections	Cold-Formed Sections, Hollow Sections, and Sheet Steel
Dimension of Standard Support to be Used in the Tests, in. (mm)	Hot-Rolled Flat Steel: $2\text{-}3/8 \times t$ (60 × t)	Hot-Rolled Angle: $1\text{-}5/8 \times 1\text{-}5/8 \times t$ (41 × 41 × t)	Cold-Formed Channel: $2\text{-}3/4 \times 1\text{-}3/16 \times t$ (70 × 30 × t)



(a) Standard Pull-Over Test Specimen

(b) Standard Pull-Out Test Specimen

Figure 3 – Standard Tension Test Fixtures for One and Four Layer Connection Tests, units – in. (mm)

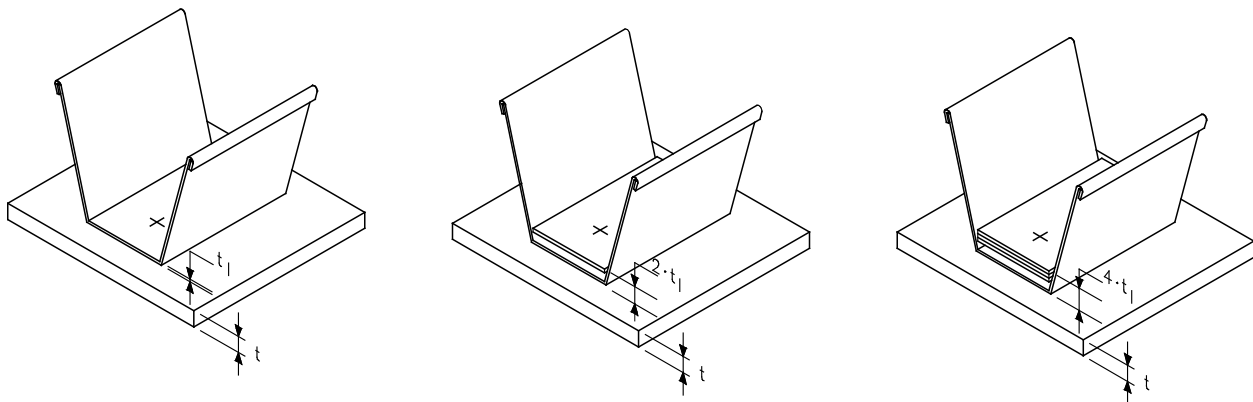


Figure 4 – Standard Tension Test Fixtures with One, Two and Four Layers of Steel Sheet

User Note:

Test specimens may be with or without folded lip.

7.2.2.1 The standard tension test fixture shall be designed for clamping of the test specimen and central loading along the axis of the *fastener* (See Figure 5).

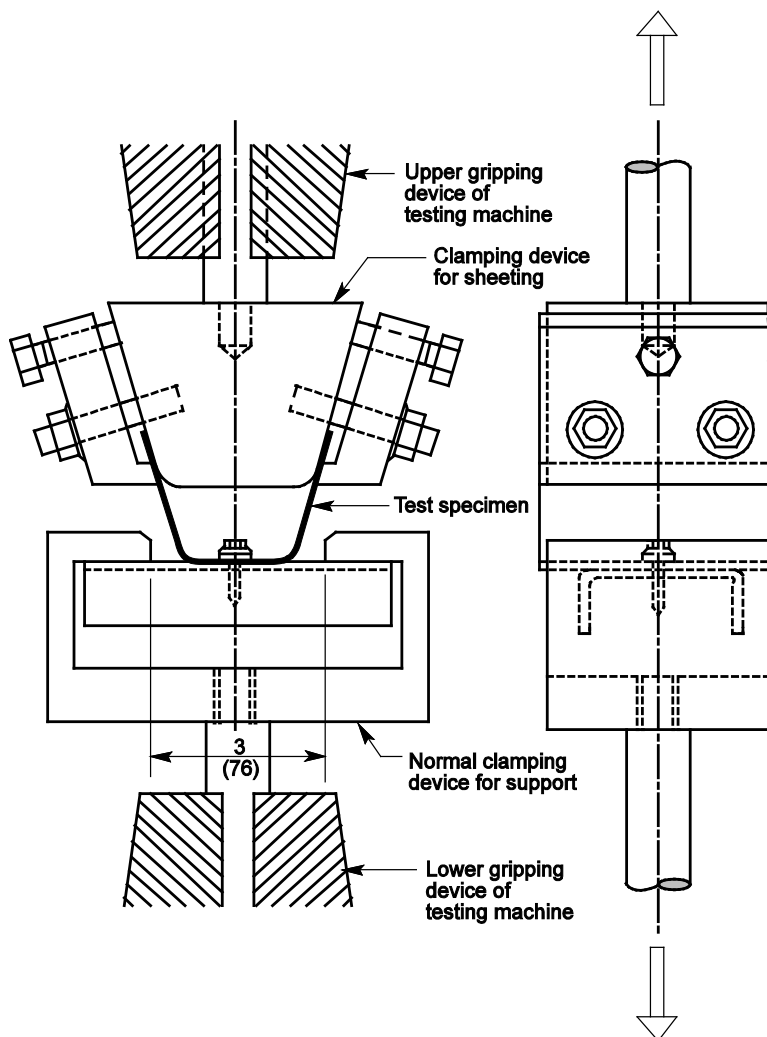


Figure 5 - Standard Tension Test Fixture, units - in. (mm)

User Note:

Pinned *connections* to the test machine may be used in lieu of mechanical gripping devices provided that bearing of the steel specimen against the pin does not adversely affect the results.

7.2.2.2 The alternate tension test fixture with a hook, vice grips or other gripping device is permitted for tension *pull-out* specimens. The test fixture dimension, *X*, for minimum test fixture bearing distance is shown in Figure 6 and Table 4. *X* is two times the minimum edge distance in ASTM E1190 Table 1.

Table 4
Alternate Tension Test Fixture Minimum Bearing Distance

Fastener Nominal Diameter, in. (mm)	Minimum Test Fixture Bearing Distance, X, in. (mm)
0.100 to 0.156 (2.5 to 4.0)	1.0 (25)
0.157 to 0.199 (4.1 to 5.0)	1.0 (25)
0.200 to 0.250 (5.1 to 6.5)	2.0 (50)

User Note:

Shank diameter is the same as the *fastener* nominal diameter, d.

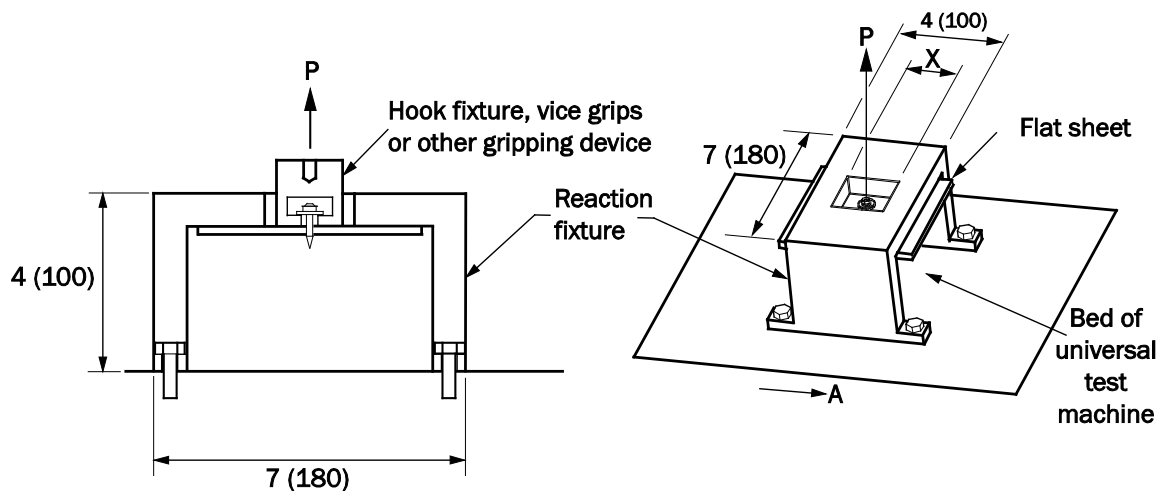


Figure 6 – Alternate Tension-Test Fixture With Hook, units – in. (mm)

User Note:

The test fixture may include a square opening as shown, or a round opening of diameter X.

7.2.2.3 The influence of asymmetrical deformation of the sheet steel support members on *pull-over* strength is permitted to be tested with the generic standard test specimen by using the alternate standard tension-test fixture (See Figure 7). Where the supporting member rotates, such as with C- or Z-shaped purlins or girts between lateral supports, the prying tension shall be considered.

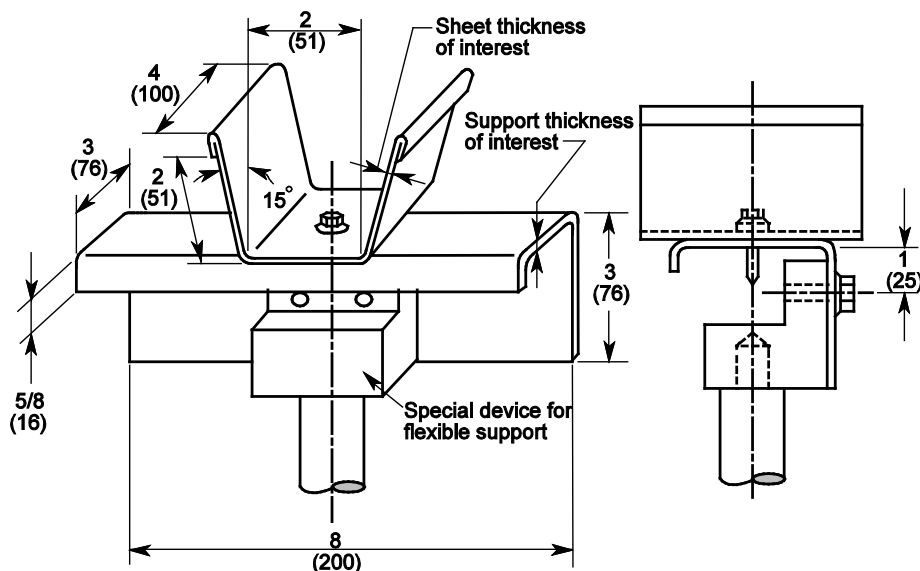


Figure 7 – Alternate Tension – Test Fixture for Influence of Flexible Support Members, units – in. (mm)

7.3 Test Fixtures – Tension Tests. Requirements for other tension test fixtures shall be in accordance with this section. Test fixtures shall comply with all dimensions listed.

7.3.1 A tension test specimen for *pull-over* strength of a profiled sheet, with length and width dimensions of 8 in. by 6 in. (200 mm by 150 mm) or one flute width, shall be cut from the steel sheet under consideration and drilled for four 1/2-in. (13 mm)-diameter bolts located 6 in. (150 mm) apart (See Figure 8). The specimen shall be cut and drilled so that the location of the test *fastener* on the sheet profile corresponds to the location where the prototype has flexural tensile stresses in the region of the *fastener*, which will augment the tensile stresses caused by the *fastener pull-over* test.

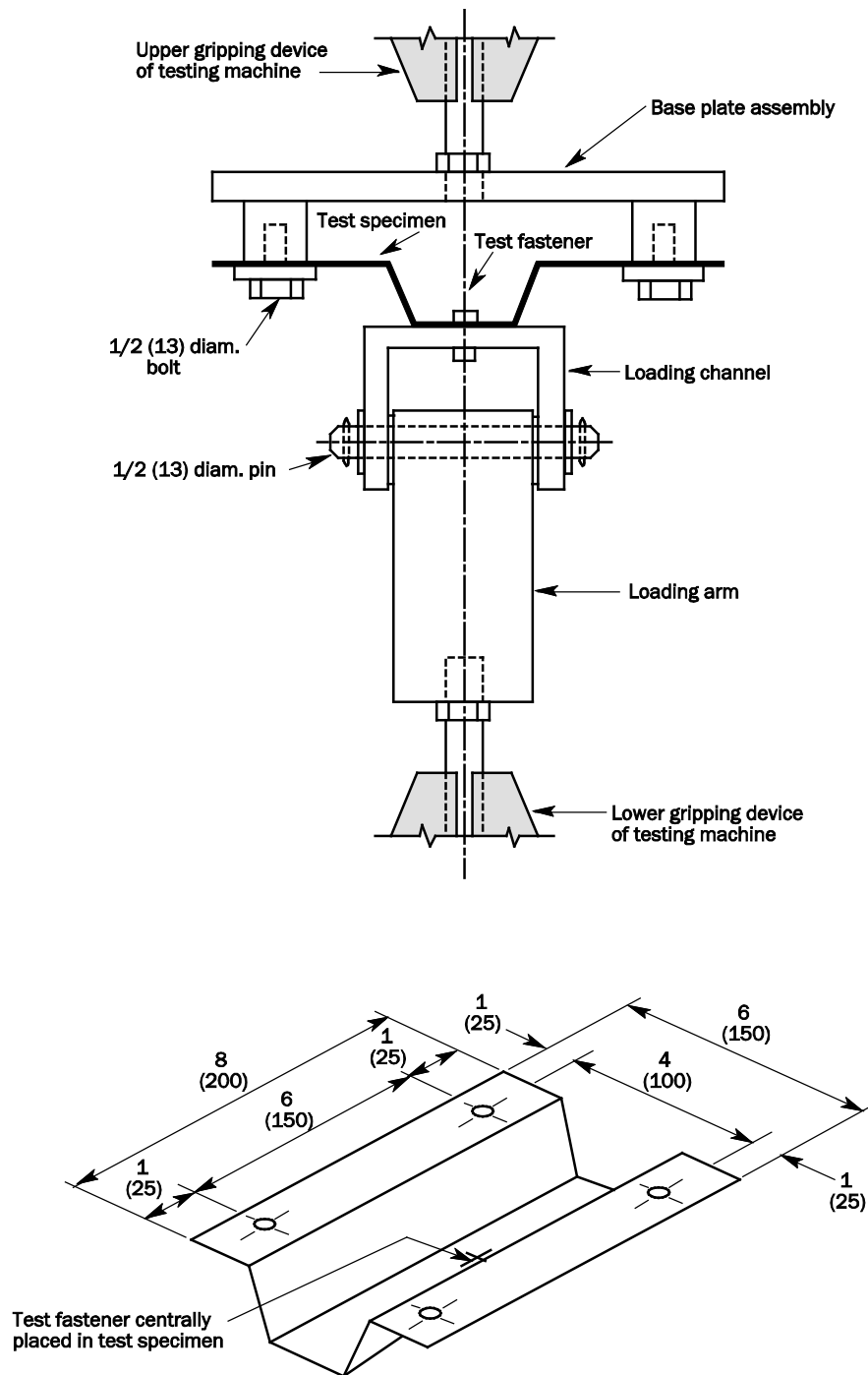


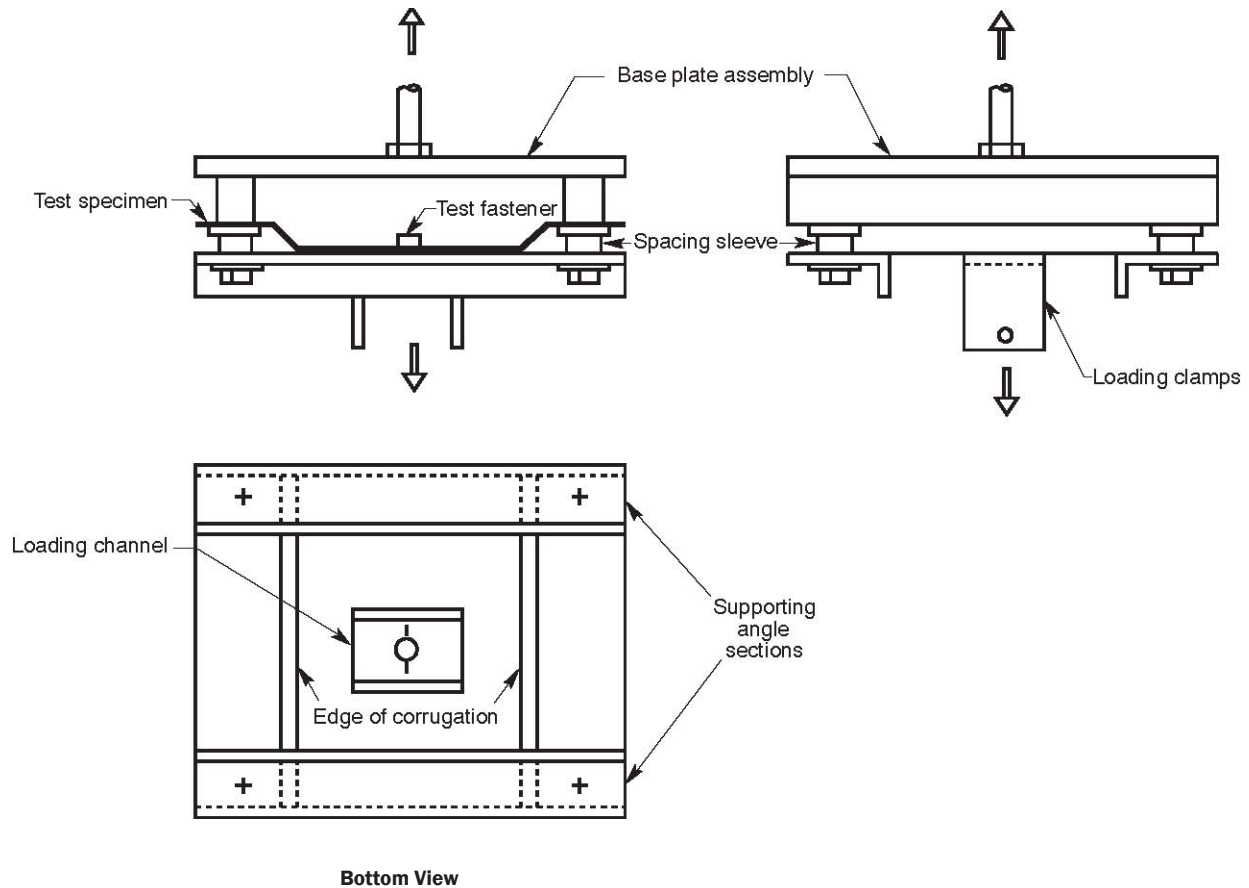
Figure 8 – Tension Test Fixture and Specimen, units – in. (mm)

User Note:

Pinned *connections* to the test machine may be used in lieu of mechanical gripping devices provided that bearing of the steel specimen against the pin does not adversely affect the results.

The test fixture for this tension test shall consist of a stiff base plate assembly with

four tapped holes located to match the holes in the test specimen (See Figure 8). The test specimen shall be clamped to the base with four 1/2-in. (13 mm)-diameter bolts with 1-1/8-in. (29 mm)-diameter by 3/32-in. (2.4 mm)-thick washers under the bolt heads. Central loading shall be provided by a loading arm that is pin connected to the symmetric loading channel to which the sheet steel is fastened. The loading channel is permitted to be fabricated from the member used in the field *connection* or specially fabricated in accordance with the test objectives. Alternatively, the tension test fixture in Figure 9 is permitted if the behavior of the thin flexible sheet is not altered.



**Figure 9 – Tension Test Fixture and Specimen
With Location of Support Angles for Flexible Sheet Steel**

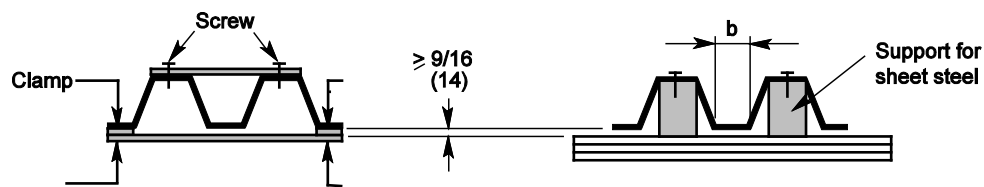
7.3.2 The tension test fixture and specimen with a trapezoidal cross-section is permitted to be utilized whenever detailed information about the sheet steel deformation is required, or where the prototype has flexural tension at the *fastener* (See Figures 10(a) and 10(b)). The fixture and specimen shall consist of a segment of the test sheet steel with a centrally located test *fastener* that connects to a loading channel similar to that used for the standard tension test. The length of the specimen, L , shall be such that the flexural tension is at design value, and L is at least 12 times the flat-width of the corrugations, b .

The width of the specimen shall be two (2) corrugations for trough fastening and three (3) corrugations for crest fastening. Transverse stiffening straps approximately 3/4-in.

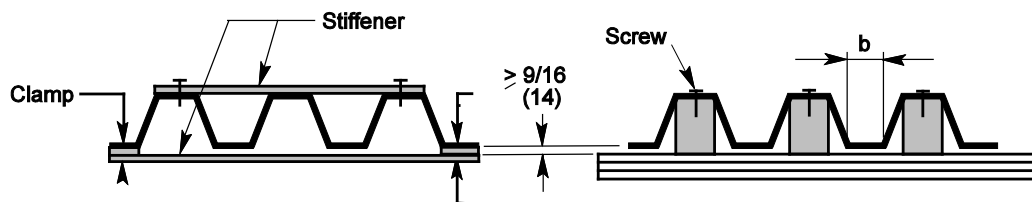
(19 mm)-wide by 1/16-in. (1.6 mm)-thick shall be fastened across the specimen width to ensure that the sheet profile is maintained during loading. The straps shall be located at $L_a/4$ from the mid-length of the specimen. The test fixture shall provide for simple end supports of the test specimen. For tensile loading of a single *fastener* at mid-span, a loading channel shall be used (See Figure 10(c)). The test specimen and the test fixture shall provide the following proportions:

- 1) Span L_a equal to or greater than $6b$, and less than $3M_u/P$, to prevent premature bending failure of the test sheet,
- 2) Specimen sheet steel support width, a , less than $L_a/6$, and
- 3) Transverse stiffening straps located at a distance $L_a/4$ from the mid-span.

7.3.3 Where sheet steel is fastened to the support by a clip, as shown in Figure 10(d), or by a *fastener* near the edge of the underneath sheet so as to hide a *fastener* head, as shown in Figure 10(e), the test specimen shall be such that the panel lap is at the center of the width. All other specimen dimensions and test fixture requirements at stiffeners and sheet steel supports shall meet the requirements of Section 7.3.2.

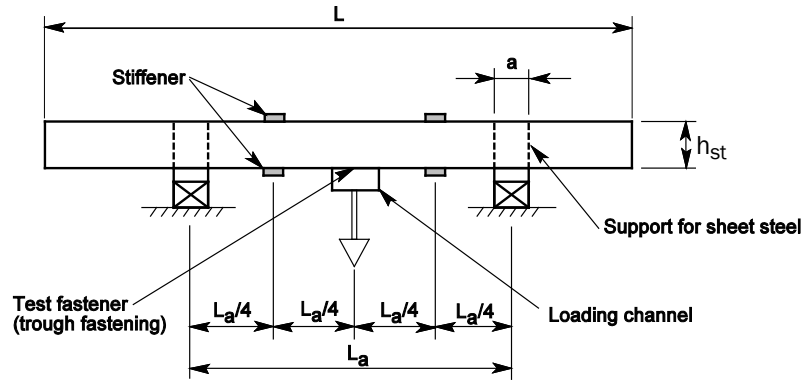


(a) Cross-Section (Trough Fastening) at Stiffeners at Support, units – in. (mm)

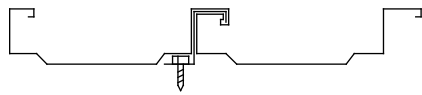


(b) Cross-Section (Crest Fastening) at Stiffeners at Support, units – in. (mm)

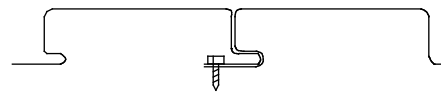
Figure 10 – Tension Test Fixtures and Specimens
(Continue)



(c) Test Fixture (Elevation)



(d) Clip Fastening



(e) Hidden Fastener

Figure 10 – Tension Test Fixtures and Specimens

7.3.4 A large-scale tension test capable of full-scale prototype testing of sheet steel *connections* is permitted (See Figure 11). The test panel shall contain two beams (purlins or girts, or similar). The test panel shall be uniformly loaded over its surface by regulating the air pressure inside the chamber below the panel.

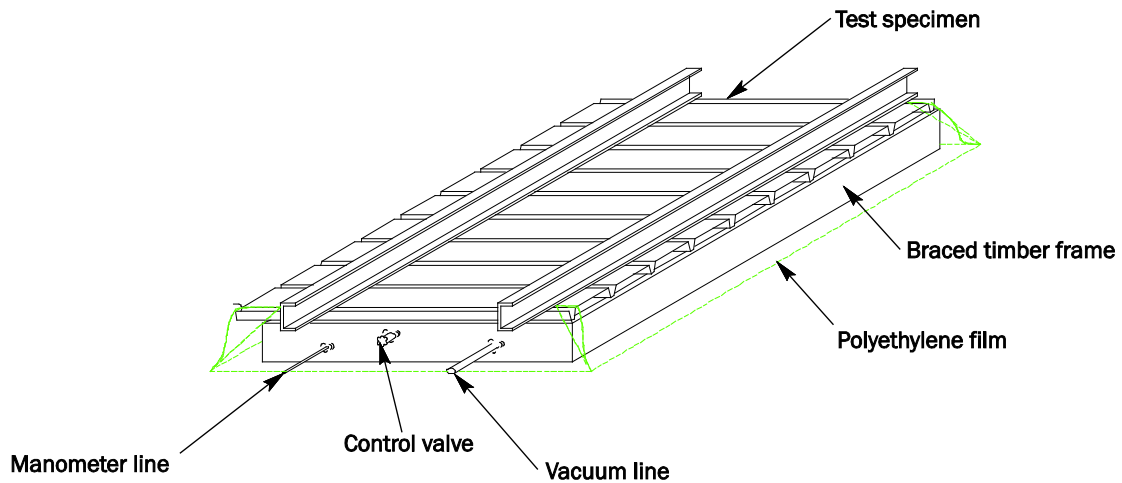


Figure 11 – Large-Scale Tension Test Fixture

8. Test Specimens

8.1 Test Specimens – General

8.1.1 The number of specimens tested shall comply with the requirements of Section K2.1.1(a) or K2.1.1(b) of AISI S100 as applicable.

User Note:

Standard shear and tension tests should be used whenever possible. Alternate shear and tension tests are permitted when the standard tests are unsuitable for evaluating the *connection* properties under consideration. When such tests are conducted to study the influence of a specific *connection* parameter, the dimensions given in Tables 1 and 2 are permitted to be changed as required.

8.1.2 Mechanical *fasteners* and welded *connections* shall be installed in accordance with the manufacturer's recommendations or the established welding procedures. Special note shall be taken of the following, as applicable:

- (1) Diameter of pre-drilled holes,
- (2) Calibrated torque and depth control for threaded *fasteners*,
- (3) Installation tools, cartridge or gas canister types and power or air pressure settings used for power-actuated *fasteners*, and
- (4) Nominal specified tensile strength of electrode, F_{xx} type of electrode, welding machine type and current setting, weld time and the AWS welding procedure.

Weld sizes reported in the welding procedure and visible weld diameters shall be reported.

8.1.3 The differences necessary to define distinct nominal values for sheet thickness and tensile strength shall be at least 0.005 in. (0.13 mm) and approximately 20 ksi (140 MPa), respectively.

8.2 *Test Specimens – Steel Materials.* Two (2) sheet-type tension test coupons shall be tested for each thickness and strength of steel sheet used in the fabrication of the test specimens. The tension test coupon shall be taken from a flat undamaged area of the sheet component. When the sheet component is corrugated or profiled, the tension test coupon shall be oriented parallel to the corrugations or ribs. The sheet tension tests shall be conducted in accordance with ASTM A370 and the yield stress, tensile strength, and percent elongation at fracture shall be measured. The average of the two (2) respective test values shall be considered as the yield stress, tensile strength, and elongation.

9. Test Procedure

9.1 General

9.1.1 The speed of static testing shall not be greater than that at which the relative displacement readings can be accurately taken. End grips of the testing machine shall be in alignment with the axis of the specimen test fixtures during loading.

9.1.2 When manual controlled tests are performed without computerized crosshead rate control and without a computer-based data acquisition system, loading shall be applied in load increments of approximately one-fifth of the estimated maximum load. When the maximum estimated load is approached, smaller increments shall be used. Each load increment shall be maintained for at least one minute (or until it has stabilized)

before proceeding with the next increment. Loading shall continue until the load cannot be maintained, or until one or more *fasteners* have failed.

9.1.3 When a computerized test system is used with crosshead rate control capacity and data acquisition capability, the speed of testing as determined by the rate of separation of the testing-machine heads shall be 0.10 in. (approximately 3 mm) per minute or the rate caused by a loading rate of 500 pounds (approximately 2 kN) per minute.

9.2 Static Shear Tests

9.2.1 The speed of testing shall conform to Section 9.1.2 or 9.1.3, depending on the type of test system in use. For structural and stitch *sidelap connections*, once the ultimate lap shear capacity of the test specimen has been reached, the deformation or slip measurements corresponding to 40 percent of the ultimate lap shear capacity shall be determined from the load-displacement curve.

User Note:

Tension coupon tests should be conducted prior to these tests.

9.2.2 When deformation measurements are necessary, they shall be recorded at each loading increment and at the maximum load if damage to the test equipment will not occur. Sufficient readings shall be taken to establish the load-displacement curve. If permanent set measurements are necessary, a small preload (approximately 10 percent of the anticipated maximum load) shall be used. After maximum load is attained, the load shall be reduced to the preload and the permanent set shall be recorded. Alternatively, it is permitted to unload at 40 percent of the estimated ultimate lap shear capacity and measure any permanent set.

9.2.3 Failure Mode Identification. Failure mode(s) shall be identified and recorded in accordance with the following classifications:

Type I - End shearing failure, or longitudinal shearing of the sheet along two approximately parallel lines (Figure 12(a)).

Type II - Bearing, tearing, or piling up of the thinner, or of both (equal thickness), sheet material in front of the *fastener* or weld contour (Figure 12(b)).

Type III - Tension failure of one sheet in the net section (Figure 12(c)).

Type IV - Shearing of the *fastener* or weld (Figure 12(d)).

Type V - Tilting and *pull-out* of *fastener* including sheet *pull-over* (Figure 12(e)).

User Note:

Figure 12 shows only one *fastener* for illustration purpose of failure modes. It should not prevent using two or more *fasteners* for similar applications. In fact, two or more *fasteners* are more commonly used to prevent lift-off of the top sheet.

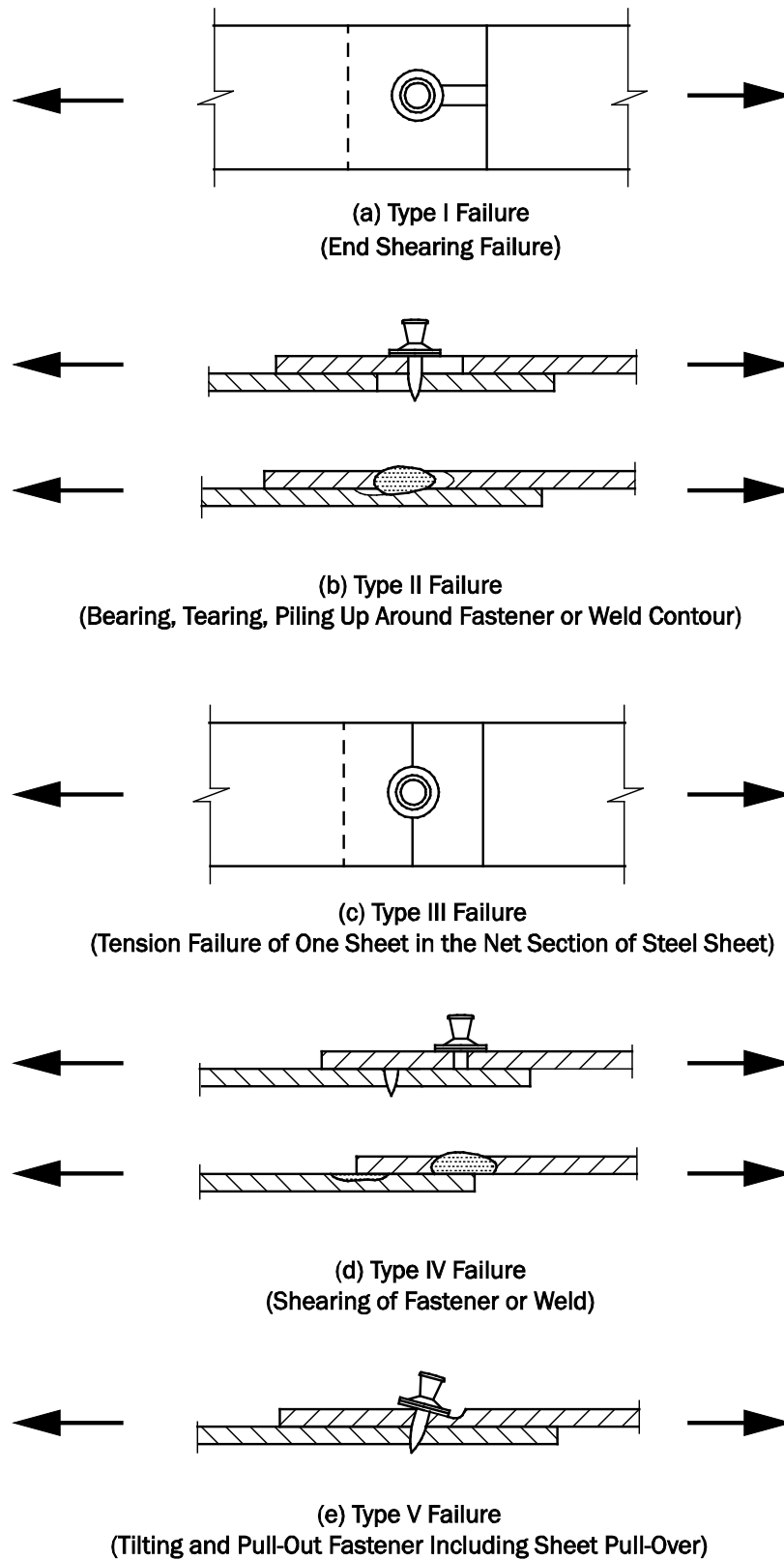


Figure 12 - Lap-Joint Shear Failure Mode Identification

9.3 Static Tension Tests

9.3.1 The speed of testing shall conform to Section 9.1.2 or 9.1.3, depending on the type of test system in use.

9.3.2 When deformation measurements are necessary, they shall be recorded at each loading increment and at the maximum load. If permanent-set measurements are necessary, a small preload (approximately 10 percent of the anticipated maximum load) shall be used. After maximum load is attained, the load shall be reduced to the preload and the permanent set shall be recorded.

9.3.3 Failure Mode Identification. Failure mode(s) shall be identified and recorded in accordance with the following classifications:

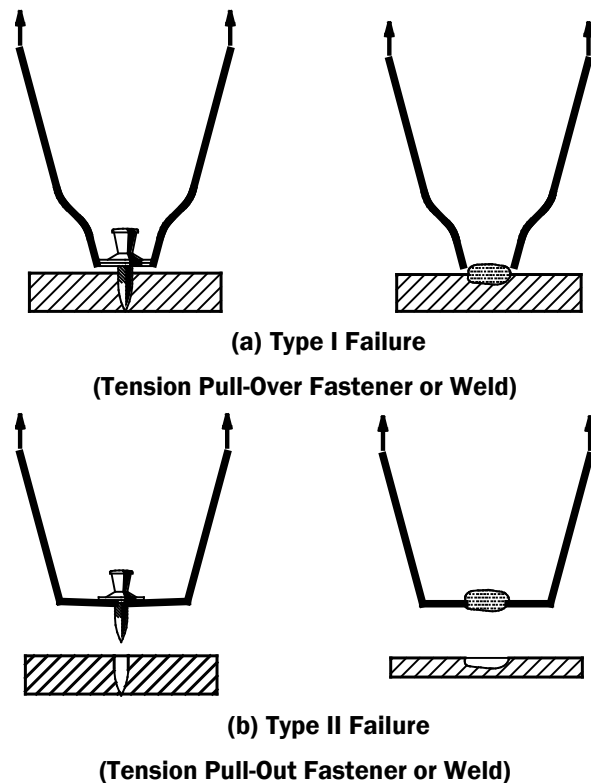
Type I - Tension *pull-over* of *fastener* head, *fastener* washer or around weld contour (Figure 13 (a)).

Type II - Tension *pull-out* of *fastener* or weld/separation of *fastener* from support member (Figure 13 (b)).

Type III - Tension failure of *fastener* or weld (Figure 13 (c)).

User Note:

Depending on the application and objectives of the tension tests, *gross distortion* of the steel sheet or support member can be a potential tension failure mode (Type IV, as illustrated in the Commentary).



**Figure 13 - Tension Failure Mode Identification
(Continue)**

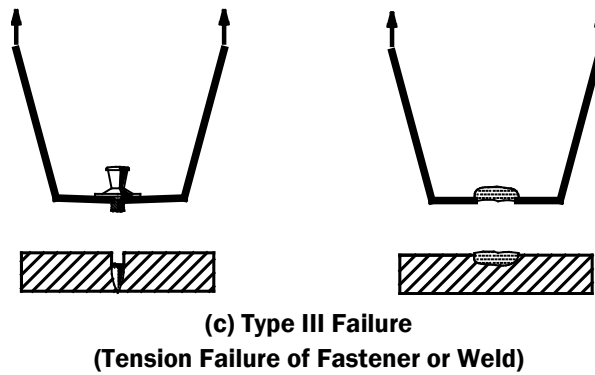


Figure 13 – Tension Failure Mode Identification

9.4 Combined Shear and Tension Tests. Static interaction tests are permitted if the *connection* will be subjected to combined shear and tension loading, such as structural *connections* for cold-formed steel *diaphragms*. Test *fasteners* shall connect the panel sample to a steel angle or channel representative of the field *connection*. Test specimens shall be attached to the test fixture by bolts such that bearing does not control at the test fixture *connection*. Test fixtures are permitted to consist of welded T-sections at fixed angles, or a rotating arm that moves independently of the test specimen to establish the desired test angle. The rotating arm shall allow the test specimen to be loaded directly through the vertical line of action of the *fastener*, such that no out-of-plane bending forces are applied to the test specimen. See Figure 14 for a depiction of an interaction load test using a rotating arm. The specimens shall be tested at angles not to exceed 30 degrees (0.524 radians) with four (4) tests per essential variable combination in order to establish the relationship. Tests are permitted to include 0 and 90 degrees (1.57 radians) as determined in Sections 7.2 and

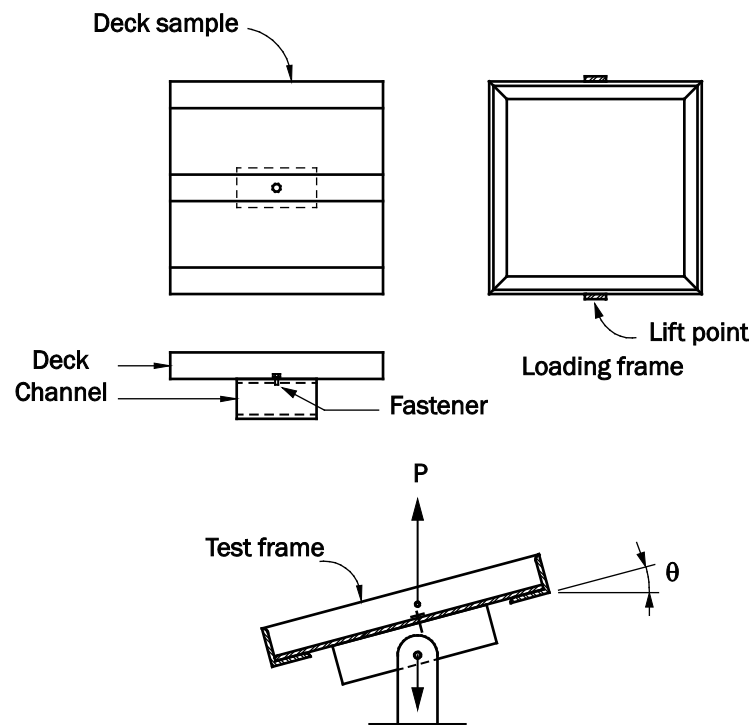


Figure 14 – Interaction Load Test With Rotating Arm

7.1 respectively to establish the end points where no interaction occurs.

9.5 Cyclic Tests. Reverse cyclic load tests are permitted to determine inelastic shear and tension performance of cold-formed steel *connections*.

9.5.1 Summary of Method. The cyclic shear or tension strength and shear stiffness for cold-formed steel *connections* in general and *diaphragm* applications are permitted to be determined by subjecting the test specimens to full-reverse cyclic loads, $\pm P$. The test assembly is permitted to be the standard or alternate test setup as shown in Figures 1 through 8. Shear test specimens are permitted to have stiffened edges or guides to avoid unintended damage to the application bars during compression loading. Tension test specimens shall include a folded lip in the coupon as shown in Figures 3 and 4. As the assembly is full-reverse cyclically loaded to specified displacement increments, the shear or tension forces and displacements shall be continuously measured and cumulative damage recorded.

User Note:

Reverse cyclic load tests in tension may create thrust in webs with only secondary forces imparted to the *fastener*. The tension test setup depends on the objectives of the test program, but this condition may be representative of actual construction conditions.

9.5.2 Loading Procedure. The reverse cyclic loading sequence shall follow the approved loading cycles. The load cycles are permitted to follow various protocols or seismic load histories depending on the objectives of the test program.

10. Data Evaluation

10.1 Evaluation of the test results and the determination of the available strength (allowable strength and/or design strength [factored resistance]) shall be made in accordance with the procedures described in Section K2.1 of AISI S100.

When lap-joint shear *connection* tests are conducted in accordance with this Standard for use in *diaphragm* applications, the entire test data set across varying panel thicknesses and strengths shall be used in the determination of ϕ and Ω .

10.2 No test result shall be eliminated unless a rationale for its exclusion can be provided that is acceptable to the reviewing authority. Such rationale shall be included in the laboratory testing report.

10.3 For cold-formed steel *diaphragm connection* design, the strength and the stiffness/flexibility shall be calculated in accordance with Sections 10.3.1 to 10.3.5, as applicable to the case listed in Section 7.1.

10.3.1 Structural *connection* shear strength, Q_f , and stitch *sidelap connection* shear strength, Q_s , shall be determined in accordance with K2.1.1(a) of AISI S100 and this Standard. Structural *connection pull-over* strength, P_{nov} , *pull-out* strength, P_{not} , or other failure limits shall be determined in accordance with Section K2.1.1(a) of AISI S100.

10.3.2 When tests include a range of variables, it is permitted to calibrate an equation for calculating the strengths of Q_f , Q_s , P_{nov} , P_{not} or other failure limits. Calibration shall be in accordance with AISI S310 Section E1.2.2.

10.3.3 When tests include a range of variables, it is permitted to calibrate an equation for calculating the structural *connection* flexibility, S_f , and *sidelap connection* flexibility, S_s . Calibration of the equation for the characteristic flexibility per *fastener* is permitted.

10.3.4 Using standard shear test (Figure 1), test specimen strength shall be determined as:

$$Q_f \text{ (or } Q_s) = P_u / C \quad (1)$$

where

Q_f, Q_s = Structural or *sidelap connection* strength for steel sheet to support member or steel sheet to sheet, respectively

P_u = Maximum applied load in test

C = Number of *fasteners*

User Note:

$C = 2$ for test setups illustrated in Figures 1(a) and 1(b); $C = 4$ for test setup illustrated in Figure 1(c); $C = 1$ for test setup illustrated in Figure 1(a) but with one *fastener*.

10.3.5 Using standard shear test (Figure 1), test specimen flexibility shall be determined as:

$$S_f = \frac{\Delta_g}{(\alpha)(0.4Q_f)} \quad (2a)$$

$$S_s = \frac{\Delta_g}{(\alpha)(0.4Q_s)} \quad (2b)$$

where

S_f = Structural *connection* flexibility for sheet to support member

S_s = *Sidelap connection* flexibility for sheet to sheet steel

Δ_g = Total elongation of extensometer gage length, ℓ_g , at 40% of P_u

α = Coefficient to convert the measured elongation Δ_g to individual elongation at *fastener*

User Note:

$\alpha = 1$ for setups illustrated in Figures 1(a) and (c) or for test setup illustrated in Figure 1(a) but with one *fastener*; $\alpha = 2$ for setup illustrated in Figure 1(b).

Q_f = Structural *connection* strength for sheet to support member

Q_s = *Sidelap connection* strength for sheet to sheet steel

11 Test Report

11.1 The test report shall include a description of the tested specimens, including a drawing that details all pertinent dimensions.

11.2 The test report shall include a detailed drawing of the test setup depicting location and direction of load application, location of displacement instrumentation and their point of reference, and details of any deviations from the test requirements stipulated in Sections 7, 8 and 9. Additionally, photographs shall supplement the detailed drawings of the test fixture and specimen.

11.3 The test report shall include load-versus-deformation values and the maximum load and load-displacement curves, as plotted directly or as reprinted from data acquisition systems. Load-versus-deformation values are not required when *connection* deformation is not a design criterion.

11.4 The test report shall include a description of the nature, mode and location of failure exhibited by each specimen tested, and a description of the general behavior of the test specimen during load application. Additionally, photographs shall supplement the description of the failure mode(s).

11.5 The test report shall include a description of the test method, loading procedure used, rate of loading or rate of motion of the crosshead movement, and load increments.

11.6 The test report shall include calibration data or identifying information that corresponds with calibration data in the test laboratory quality documentation demonstrating compliance with Section 6 for each loading device and measuring instrument.

11.7 The objectives of the test series shall be stated at the outset of the test report so that the necessary test results, such as the *maximum load per fastener*, the flexibility of the *connection*, and the failure mode, are identified.

11.8 The types of tests, the testing organization, and the dates on which the tests were conducted shall be included in the documentation.

11.9 The test series shall be fully documented, including:

(1) Identification data for the *fasteners* and accessories such as washers. *Fastener* data shall include the name of the manufacturer, designation or type, dimensions, number of threads, threads per inch (mm), including unthreaded length or imperfect threads below head, and the major and minor diameters in the threaded region.

(2) The details of *fastener* application including pre-drilling, tightening torque, and any unique installation tools used in the operation including: (a) the diameter of predrilled holes, (b) the calibrated torque and depth control for threaded *fasteners*, (c) the installation tools, cartridge or gas canister types and power or air pressure settings used for power-actuated *fasteners*, and (d) nominal specified tensile strength of electrode, F_{xx} , electrode type, welding machine type and current setting, weld times and the AWS welding procedure. Weld sizes reported in the welding procedure and the visible diameters in the test specimens shall be reported.

(3) The results of the sheet-type tension tests including yield stress, tensile strength and elongation to failure. The location and orientation of sheet-tension coupons shall also be given.

(4) For *pull-out* tests, additional data shall indicate the drill-point diameter and screw size if self-drilling screws are used. Otherwise, the diameter of the pilot drill shall be stated.

(5) For *pull-over* tests, additional data shall indicate *fastener* washers or washer head data including diameter, thickness, configuration and material. Welding washer data including diameter, thickness, configuration and material shall also be reported if used in weld *connection pull-over* or shear tests. Sealing washer data shall additionally define the type, material, and dimensions of sealant.

11.10 The test setup shall be fully described including the testing machine, the specimen end grips or supports and the devices used to measure deformation.

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AISI S905-17-C

COMMENTARY ON TEST STANDARD FOR DETERMINING THE STRENGTH AND DEFORMATION CHARACTERISTICS OF COLD-FORMED STEEL CONNECTIONS

1. Scope

The continued introduction of new and different mechanical *fasteners* and welding techniques confirms the need for standardized tests for cold-formed steel *connections*. Standard test specimens, fixtures, and procedures facilitate the exchange of information vital to understanding the behavior of a variety of *fasteners* with diverse properties by providing a basis for comparing strength and deformation measurements. This test Standard provides shear, tension and interaction performance test procedures for determining the strength and deformation of mechanically fastened and welded *connections* of cold-formed steel members, including *diaphragm* applications. *Connections* involving gypsum wallboard, wood and Oriented Strand Board (OSB) are outside the scope of this test method, but the test protocols in the Standard may be adapted for other materials at the discretion of the engineer. These test methods provide the requirements for evaluating mechanically fastened and welded *connections* for cold-formed steel members in buildings designed according to AISI S100 (AISI, 2016) and related building codes. These performance test procedures are based extensively on test methods used successfully in the past (ECCS, 1978; Fraczek, 1974 and 1976). While *fastener* failure can occur in *connection* tests, other standards may be used to isolate *fastener* strength and behavior including AISI S904 (2017) for screw *fasteners*.

3. Terminology

In 2013, *fasteners* were defined as the interconnecting element of a cold-formed steel *connection*. This may include mechanical *fasteners* (screws, power-actuated *fasteners*, bolts, rivets, clinch joining, mechanical crimps and punches) and welds (butt joints, arc spot welds, arc seam welds, fillet welds or flare groove welds) as described in AISI S100 (2016) and AWS D1.3. Sidelap *fasteners* for *diaphragms* include welds, screws, mechanically formed *connections* or button punches. Structural *fasteners* for *diaphragms* include screw *fasteners*, power-actuated *fasteners*, welds, and less commonly, bolts or rivets. Additional terminology addressing welded *connections* is also included in the Standard. Power-actuated *fasteners* (PAFs) are hardened steel *fasteners* with or without pre-mounted washers, that are driven through deck or panels into supports using either powder cartridges or compressed gas as the driving energy source. Terminology in this Standard is consistent with AISI S100 (2016) and other test standards.

4. Symbols

In 2013, additional symbols were added to the Standard that address welded *connections*. The number of *fasteners* used in the *fastener* shear strength calculation, C , may also equal 1, if shear tests are conducted with only one *fastener*.

7. Test Fixtures

In general, test fixtures should be constructed to be representative for the end use of the *connection*. Test fixtures may be constructed with one or multiple *fasteners* or welds to best

represent the end use of the *connection*. The test fixture should be configured to ensure that when the intent is to test for shear, that the fixture does not introduce eccentricity that subjects the *connection* to combined shear and tension forces beyond that of the intended end use condition. When the intent is to test for tension, the fixture should not introduce eccentricity that subjects the *connection* to combined tension and shear forces beyond that of the intended end use condition. Test fixtures for combined shear and tension should be configured to apply the load at a predictable ratio of shear and tension or in a manner that the angle of load to the *connection* can be measured during the test to determine the ratio of shear and tension forces. It is permissible to construct tests in which edge distance is not contributory or is contributory to the mode of failure to determine the strength of the *connection* without or with edge distance influence, respectively.

The standard tension-test fixture described in Standard Section 7.2.2.1 is designed for the convenience of clamping the test specimen and centering the load along the axis of the *fastener*.

The dimensions of the asymmetrical support member as shown in Figure 7 of the Standard simulate mechanical fastenings to cold-formed C-sections, Z-sections and angles. Researchers (LaBoube, 1983; Haussler, 1988) provide information on how prying tension is considered.

For the large-scale tension test fixture shown in Figure 11, failure can occur in the panel *connections* to the beams. Only the nominal tension forces, which do not include the prying forces caused by the rotations of the C- and Z-shaped purlins or girts, can be computed from the known value of the load acting on the panel surface at failure. A description of prying forces is given by Haussler (1988). The arrangement illustrated in Figure 10 is fully described in the studies by Fraczek (1976), LaBoube (1983 and 1988), and Pekoz (1982). The beam span and the purlin spacing should match those of the prototype given by Haussler (1988) within $\pm 20\%$ in order to properly simulate the effects of prying action.

The determination of the individual *fastener* lap-joint shear strength is independent of which test setup is used. The test setups in Figures 1(a) and 1(b) with two and four *fasteners* are essentially the same. The two-*fastener* setup (shown in Figure 1 (a)) has one base steel component and one sheet steel component. The four-*fastener* setup (shown in Figure 1 (b)) uses two base steel components with one sheet steel component bridging across both base steel components. These two different test setups are the same from a load distribution standpoint, with the four-*fastener* test specimen offering some fabrication and test specimen efficiency. The individual *fastener* lap-joint shear strength is the total *connection* strength divided by two in either case. The test setup in Figure 1(c) was added to cover the geometric condition of an application having a small edge dimension. This test setup permits the edge dimension, e_3 , to be less than $2d$, but the total width of the specimen is still required to satisfy the dimension given in Table 1, so $w \geq e_2 + 2e_3$. A range of edge dimension between $1.5d$ to $2d$ is provided in the Standard for conditions with a typical edge dimension when test setup (c) in Figure 1 is to be used. Standard Section 7.1.1 and Table 1 include minimum edge dimensions for typical application nominal strength tests so the minimum edge dimension requirements of AISI S100 are met. Test setup (c) allows deviations to investigate special cases. Test setup (c) in Figure 1 should not be used for determining the design strength of interior *fasteners*. The determination of the individual *fastener* lap-joint shear flexibility, however, is dependent on which test setup is used. In 2013, Section 8.1 was

revised to be consistent with AISI S100 Section K2.1.1 (a) or Section K2.1.1 (b) with respect to the required number of test specimens.

In 2013, the Standard was reformatted and reorganized with specific shear and tension test fixture assignments for structural and *sidelap connections* in cold-formed steel *diaphragms*. Figure 4 was added to more accurately depict standard tension test fixtures for single, double and four-layer sheet *connections* to the support member. These fixtures may be used to determine tension *pull-over* and *pull-out* strengths for specific combinations of sheet steel and support members, along with the test fixtures shown in Figures 5 and 7. In 2013, Section 8.1 was revised to be consistent with AISI S100 Section K2.1.1 (a) or K2.1.1 (b) with respect to the required number of test specimens. The required application of the respective sections is discussed in Commentary Section 8.

8. Test Specimens

For *diaphragms*, essential variables to determine the necessary test combinations are defined in AISI S310 Table E1.2-1, Essential Test Parameters. Two cases are addressed:

Case 1 - Single Test for Confirmation of a Specific Project Application – Users are directed to AISI S100 Section K2.1.1(a).

Case 2 – Tests to Develop or Confirm Test-Based Analytical Equations – Users are directed to AISI S100 Section K2.1.1(b). For extending application of an existing equation, tests are required only at the extended application limits or boundary conditions.

Repeatability, linearity or non-linearity and applicability should be established over the applicable range.

In 2013, welded *connections* were added to the Standard as these are frequently used in cold-formed steel *diaphragm* research and design. Research by Snow and Easterling (2008) and Guenfoud, Tremblay and Rogers (2010) followed the TS5-02 and S905-08 test procedures and are consistent with this approach, using either one or two arc spot welds in the standard lap-shear *connection* fixtures. If only one arc spot weld is used in the standard lap-shear *connection* test, then $C = 1$ in Equation 1 of the Standard (See Figure C-1). Inclusion of guidance for weld test fixtures and specimens allows for verification of welding techniques and provides a consistent method for evaluation of different types of cold-formed steel *connections*.

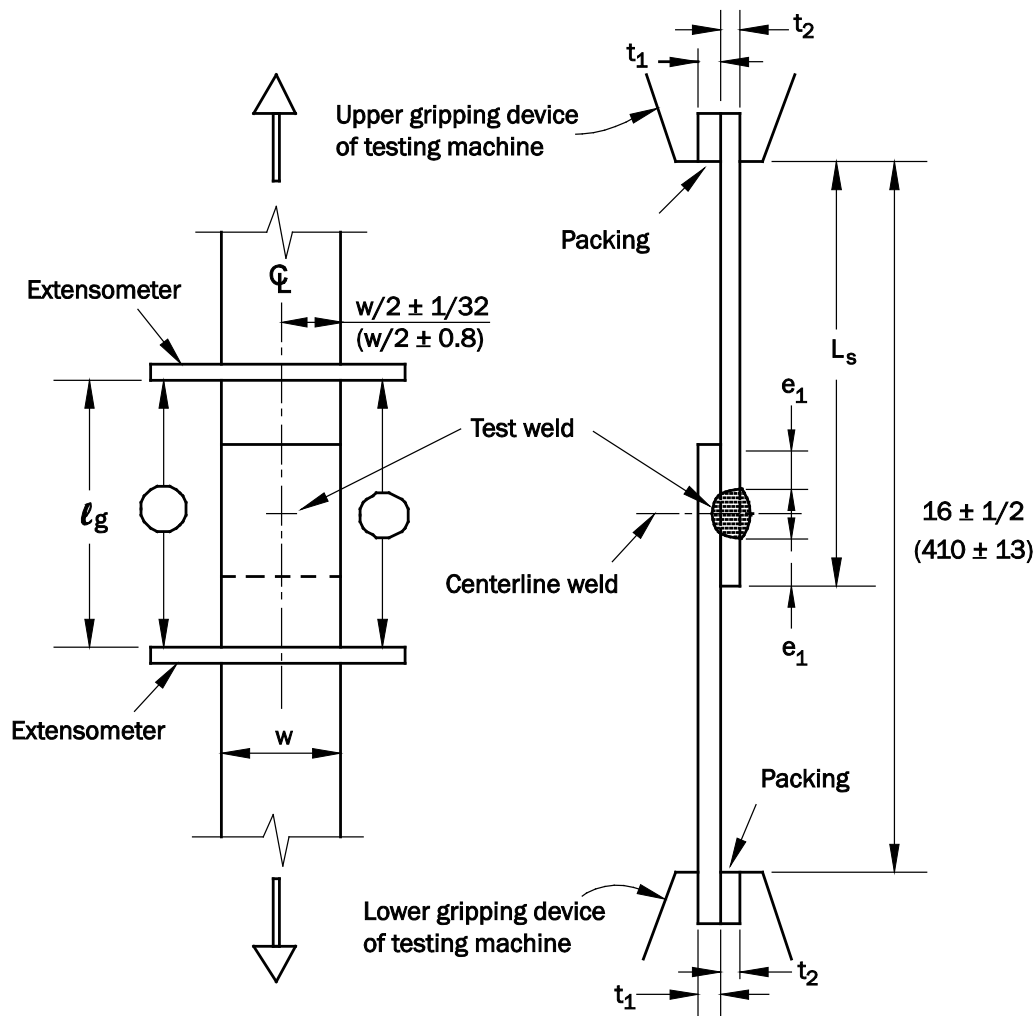


Figure C-1 Lap Shear Setup with One Weld per Specimen, units – in. (mm)

Diaphragm connection test scope may be configured in a logical manner considering the influence of sheet steel thickness and tensile strength on the *connection* performance. AISI S310 Table E1.2-1 provides essential parameters to be considered for *diaphragm connection* tests. The critical support member thickness and minimum tensile strength may be conservatively fixed in order to reduce the test scope of structural and *sidelap connections* for *diaphragms*. In this case, a thicker support member might provide a higher strength and additional testing may be conducted, but that benefit is neglected. Similarly, testing with a higher tensile strength might provide a higher strength and additional testing may be conducted, but that benefit is neglected. In order to develop a relationship between *connection* shear strength and stiffness and sheet steel tensile strength, testing across varying sheet steel tensile strengths is permitted in the lap-joint shear *connection*.

9. Test Procedure

In 2013, specific guidance was included on cold-formed steel *diaphragm connection* test setups with specific test fixture assignments for structural and *sidelap connections*. Standard test setups are the preferred test methods, but the alternate test setups are permitted when profile geometry or the required information indicates that an alternate method is more

effective. Additional test fixtures are also included in this Commentary for the standard lap-joint shear *connection* tests involving multiple layers of sheet steel. It is common in cold-formed steel *diaphragms* for *connections* of single, double and four layers of sheet steel to occur in the *diaphragm* field, at end laps of steel panel sheets and at corner laps of nestable panel sheets, respectively. For instance, multi-layer lap-shear *connection* tests with two (2) or four (4) layers of sheet steel may be configured using the standard lap-shear and tension test fixtures except for the additional packing pieces of steel sheet (See Figure C-2). Multi-layer steel sheet tests for *diaphragm* structural *connections* may be conducted to verify suitability of *connection* types for end-lap and corner lap conditions. These tests can be used to establish application limits for the *connection* over the intended range.

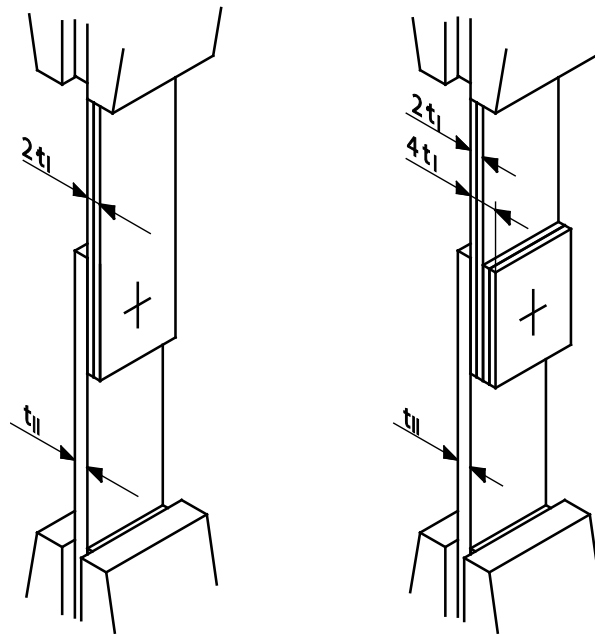


Figure C-2 Multi-Layer Lap-Joint Shear Connection Tests for Diaphragm Connections

These additional test setups allow investigation of the effects on the small element *connection* shear strength and stiffness behavior of *diaphragm connections* when large scale *diaphragm* system tests are not performed. *Fastener* application limits and maximum fastened thickness of cold-formed steel should be established. Load and deformation limits for the various conditions allow for performance comparisons in single and multi-layer sheet *connections* (See Figure C-3).

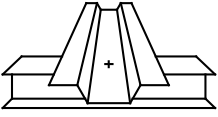
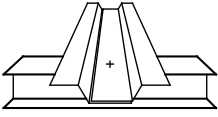
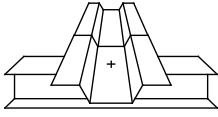
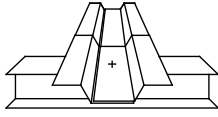
Types of Connections			
Type a	Type b	Type c	Type d
			
Single connection	Sidelap connection	End overlap connection	Sidelap + end connection

Figure C-3 Diaphragm Connection Types

In 2013, a new section was added to the Standard to address reverse cyclic loading of cold-formed steel *diaphragm connections*. The procedure follows studies conducted by researchers (Pekoz and Hall, 1988; Pekoz and Soroushian, 1982; Peuler, et al, 2002; Rogers and Tremblay, 2003 and 2003a) that found differences in the performance of cold-formed steel *connections* under reverse cyclic loading depending on the sheet steel thickness and other parameters. Various loading protocols exist and can be selected depending on the objectives of the test program. An example protocol is ATC-24 (1992).

Gross distortion of the support member or sheet steel can be a potential tension failure mode (Type IV), but often a cosmetic or serviceability concern at the available strength point. Depending on the specific cold-formed steel product application being investigated, *gross distortion* may control the tension behavior of the *connection* (See Figure C-4).

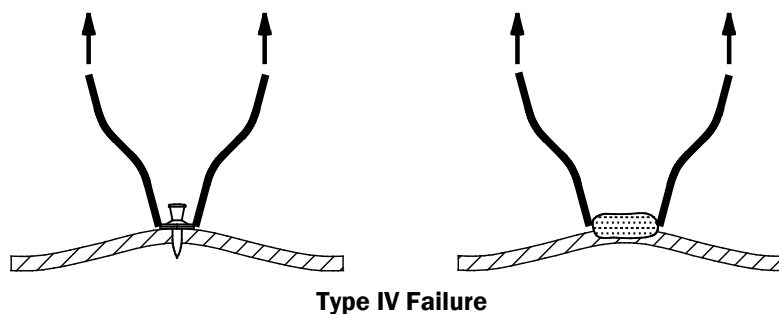


Figure C-4 – Gross Distortion of Support Member and Sheet Steel

A new section was also added to the Standard to address interaction load tests of cold-formed steel *connections*. The procedures follow research (Luttrell, 1999; Stirneman and LaBoube, 2008; and Francka and LaBoube, 2010) and allow for the use of fixed angle or rotating arm type fixtures. Tests listed in Standard Section 7 may be used to establish the end points when determining the interaction effects.

10. Data Evaluation

The test result evaluation described in Section K2.1 of AISI S100 is based on procedures provided by Pekoz (1988) and AISI S100 Commentary Section B3.2.2. Standard Equations

(2a) and (2b) for determining the test specimen flexibility are developed based on the SDI *Diaphragm Design Manual* (SDI, 2006).

When calculating safety and resistance factors for theoretical resistance equations applicable to *diaphragm* structural and *sidelap connections*, AISI S310 Section E1.2.2 or E2.2, as applicable, should be used. Individual combinations of sheet steel and support member are not used in the determination of ϕ unless the combination is unique and an application range is not intended to be developed. An example would be for a *diaphragm fastener* that is evaluated for attachment of sheet design thicknesses of 0.030 in. (0.76 mm), 0.036 in. (0.91 mm), 0.048 in. (1.2 mm) and 0.060 in. (1.5 mm) to one minimum support member thickness, with three (or six) tests per combination. Each individual sheet steel gauge thickness combination would not be evaluated separately, but rather all 12 (or 24) tests would be combined in the test data evaluation across the intended application range of the *fastener*.

12. Test Report

Identification of shear and tension failure modes for cold-formed steel *connections* are included in the Standard. It is critical to properly identify the failure modes during the tests. Practically, certain failure modes may prohibit the use of a *connection* type regardless of its strength.

Standard and alternate test setups of fixtures and specimens are provided in Standard Section 7 for lap-joint shear and tension tests. Test procedures and data recording are generally not affected by the modified fixtures and specimens used for alternate tests, but these alternate tests represent the state-of-the-art with respect to mechanical *fastener* and weld *connection* testing.

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25 Massachusetts Avenue NW
Suite 800
Washington, DC 20001
www.steel.org





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