



AMERICAN NATIONAL STANDARDS INSTITUTE/ STEEL DECK INSTITUTE

ANSI/SDI AISI S907-2017 (R2024)

**Test Standard for Determining the Strength and
Stiffness of Cold-Formed Steel Diaphragms by the
Cantilever Test Method**



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PREFACE

(This Preface is not part of the ANSI/SDI AISI S907-2017 (R2024), *Test Standard for Determining the Strength and Stiffness of Cold-Formed Steel Diaphragms by the Cantilever Test Method*, but is included for informational purposes only.)

This Standard is a reaffirmation of ANSI/ AISI S907-2017.

This Standard has been developed as a consensus document for the design of cold-formed steel members and structures. The intention is to provide criteria for routine use and not to provide specific criteria for infrequently encountered problems, which occur in the full range of structural design. The Symbols and Appendices to this Standard are an integral part of the Standard. A non-mandatory Commentary has been prepared to provide background for the Standard provisions and the user is encouraged to consult it. Additionally, non-mandatory User Notes may be interspersed throughout the Standard to provide concise and practical guidance in the application of the provisions. The user is cautioned that professional judgment must be exercised when data or recommendations in the Standard are applied, as described more fully in the disclaimer notice preceding this Preface.



AISI S907-17



AISI STANDARD

Test Standard for Determining the Strength and Stiffness of Cold-Formed Steel Diaphragms by the Cantilever Test Method

2017 EDITION

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.

The materials set forth herein are for general information only. They are not a substitute for competent professional advice. Application of this information to a specific project should be reviewed by a registered professional engineer. Indeed, in most jurisdictions, such review is required by law. Anyone making use of the information set forth herein does so at their own risk and assumes any and all resulting liability arising therefrom.

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PREFACE

The American Iron and Steel Institute Committee on Specifications has developed this Standard to provide requirements for static and cyclic testing of floor, roof and wall *diaphragm* assemblies. This standard applies to framed cold-formed *steel panel* floor, roof and wall *diaphragm* construction.

The Committee acknowledges and is grateful for the contributions of the numerous engineers, researchers, producers and others who have contributed to the body of knowledge on the 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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AISI S907-17
TEST STANDARD FOR DETERMINING THE STRENGTH AND
STIFFNESS OF COLD-FORMED STEEL DIAPHRAGMS
BY THE CANTILEVER TEST METHOD

1. Scope

This Standard applies to framed cold-formed *steel panel* floor, roof and wall *diaphragm* construction and provides requirements for static and cyclic testing of floor, roof and wall *diaphragm* assemblies.

1.1 *Static Testing*. Static testing to develop *in-plane* nominal shear strength and shear stiffness for floor, roof and wall *diaphragm* assemblies with *steel panels* shall be performed in accordance with Section 9.1 and with the following conditions and requirements:

1.1.1 Tests shall be conducted using the cantilever test frame.

User Note:

An alternative test method using a simple span test frame is given in ASTM E455-16.

1.1.2 Framing members supporting the cold-formed *steel panels* are permitted to be steel, concrete, wood, or a combination of materials representative of the intended end use.

1.1.3 Fills such as *structural concrete*, cellular concrete, or *insulating concrete* are permitted to be placed over the steel deck panels. Insulation is permitted to be placed between the *steel panels* and the support framing or over the top of *steel panels*.

1.1.4 Tests are permitted to be run in the horizontal or vertical orientation.

1.1.5 Tests are permitted as follows:

- (1) To determine *in-plane diaphragm* shear strength and shear stiffness or flexibility values for a *single diaphragm system* in a specific condition; and
- (2) To develop, modify or verify the application of an analytical model for *in-plane diaphragm* shear strength and shear stiffness or flexibility.

1.2 *Cyclic Testing*. Cyclic testing to develop load-displacement data and hysteresis loops for floor, roof and wall *diaphragm* assemblies with *steel panels* shall be performed in accordance with Section 9.2.

1.3 This Standard consists of Sections 1 through 13 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:

AISI S100-16, *North American Specification for the Design of Cold-Formed Steel Structural Members*

AISI S310-16, *North American Standard for the Design of Profiled Steel Diaphragm Panels*

b. ASTM International (ASTM), West Conshohocken, PA:

ASTM A370-14, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM C31/C31M-10, *Standard Test Practice for Making and Curing Concrete Test Specimens in the Field*

ASTM C33/33M-16e1, *Standard Specification for Concrete Aggregates*

ASTM C39/C39M-12, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*

ASTM C330/330M-14, *Standard Specification for Lightweight Aggregates for Structural Concrete*

ASTM C332-09, *Standard Specification for Lightweight Aggregates for Insulating Concrete*

ASTM C495/C495M-12, *Standard Test Method for Compressive Strength of Lightweight Insulating Concrete*

ASTM C869/C869M-11(2016), *Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete*

ASTM E6-15, *Standard Terminology Relating to Methods of Mechanical Testing*

IEEE/ASTM SI10-10, *American National Standard for Metric Practice*

c. American Welding Society (AWS), Miami, FL:

AWS D1.1/D1.1M-2015, *Structural Welding Code - Steel*

AWS D1.3/D1.3M-2008, *Structural Welding Code - Sheet Steel*

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, ASTM A370 or ASTM E6 shall have the ordinary accepted meaning for the context for which they are intended.

Aspect Ratio. Ratio of length to depth (a/b) of *test assembly*.

Base Steel Thickness. The thickness of bare steel exclusive of all coatings.

Bare Frame. Steel, wood, concrete, or a combination of materials support members assembled to form the test frame of the *diaphragm* without *steel panels* installed onto the frame.

Cellular Deck. Composite or partially composite built-up deck formed by fastening either a flat steel sheet or a *fluted panel* beneath and to another *fluted panel*.

Composite Deck. Fluted or *cellular deck* that combines with *structural concrete* fill to form a slab with the steel deck as reinforcement. The fluted deck has embossments, interlocking profile geometry, or other horizontal shear connection devices to develop a mechanical bond between the deck and concrete so the slab compositely resists vertical and *diaphragm* shear loads.

Configuration. A specific arrangement of panel geometry, thickness, mechanical properties, span(s), and attachments that is unique to a *test assembly*.

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

Fluted Panel. Product formed from steel coils into profiles having single or a repeating pattern such that top and bottom flanges are connected by webs.

Form Deck. Fluted or cellular deck that chemically bonds with structural concrete or insulating concrete fill to form a slab that resists diaphragm shear loads. The deck resists the concrete dead load prior to development of compressive strength. Reinforcement is required in structural concrete to resist slab flexure.

In-Plane. Orientation of loads that are applied in line with the plane in which the steel panels are installed.

Insulating Concrete. A mixture of Portland cement, cellular or expanded mineral concrete aggregate, and water that forms a relatively lightweight concrete.

Out-of-Plane. Orientation of loads applied normal to the surface of the plane in which the steel panels are installed.

Power-Actuated Fastener (PAF). Hardened steel fastener driven through deck or panels into supports using either powder cartridges or compressed gas as the driving energy source.

Sidelap Connection. Connections that attach adjacent panels to each other along the panel edges between the support members.

Single Diaphragm System. A diaphragm system having a specific configuration with one set of profile, thickness, mechanical properties, span, support fastener and sidelap connection types and patterns, support type and thickness, fill type and thickness when applicable, and edge detail.

Standing Rib 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 legs back-to-back.

Steel Panel. A sheet of steel cold-formed into fluted panel or cellular deck with specified width and variable length.

Structural Concrete. A mixture of Portland or other hydraulic cement, fine aggregate, coarse aggregate and water.

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

Test Assembly. Steel panels installed and connected to a bare frame to form the diaphragm test assembly.

Top Arc Seam Sidelap Weld. Arc seam weld applied at the top of a standing rib sidelap connection.

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 = Length of diaphragm test frame (See Figures 1 through 3)
- b = Depth of diaphragm test frame and dimension parallel with load P (See Figures 1 through 3)
- d_c = Average concrete cover depth over top of the deck measured at supports
- F = Shear flexibility of diaphragm web as determined from test measurements (flexibility factor)

F_u	= Tensile strength of steel
G'	= Shear stiffness of the <i>diaphragm</i> web as determined from test measurements
L_v	= Span of <i>steel panels</i> between supports with fasteners
P	= Applied load to test frame
P_d	= Load of P at which the <i>diaphragm</i> stiffness is determined = $0.4P_{max}$
P_{fd}	= Load of P from testing of the <i>bare frame</i> at the deflection equal to the deflection for load of $P_d = 0.4P_{max}$ for stiffness
P_{fn}	= Load of P from testing of the <i>bare frame</i> at the deflection equal to the deflection for load P_{max} for strength
P_{max}	= Maximum applied load of P to test frame
P_n	= Load of P for determining nominal shear strength [resistance], S_n
S_n	= Nominal shear strength [resistance] of the <i>diaphragm</i> per unit length
t	= <i>Base steel thickness</i> of steel deck element of <i>diaphragm</i> web
Δ	= Reference displacement
Δ_d	= Net shear deflection of <i>diaphragm</i> at load $P_d = 0.4P_{max}$
Δ_i	= Net shear deflection of <i>diaphragm</i> at any load level
Δ_u	= Displacement corresponding to ultimate load of average of a minimum of two static tests of <i>test assembly</i> run in accordance with Section 9.1
$\Delta_{1,2}$	= Diagonal displacement measured at points 1 or 2 (See Figure 2)
$\Delta_{1,2,3,4}$	= Orthogonal displacement measured at points 1, 2, 3 or 4 (See Figure 3)

5. Units of Symbols and Terms

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

6. Measurement Precision

Precision in measurements shall be in accordance with this section.

6.1 The accuracy of the recorded loads shall be within ± 1 percent of 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 Displacements shall be recorded to a precision of 0.01 in. (0.25 mm).

7. Test Assembly

The *test assembly* shall consist of a rectangular test frame upon which the *steel panels* are placed and fastened using connections spaced as intended for end use. The *test assembly* is

permitted to have intermediate framing members to support the *steel panels*. All *steel panels* of the *test assembly* shall be full-width, except for parallel edge sheets which are permitted to be partial-width sheets, and shall use the same grade of steel, thickness, details, methods of construction, and connections as intended for end use. It is permitted to fasten partial-width panels to develop the strength of full-width panels.

7.1 Components of Test Assembly. The components of the test assembly shall meet the requirements of this section:

7.1.1 Steel Panels. The *steel panels* shall be installed perpendicular to the load beam(s) as shown in Figures 1 through 3 or parallel to the load beam(s). All of the panels in a *test assembly* shall be produced from the same coil of steel. The end lap splice, as illustrated in Figure 1, is optional, but shall be included in the test program if end lap performance is a test program parameter.

User Note:

It is permitted to apply test results for butted or continuous sheets to lapped construction.

It is permitted to connect the *steel panel's* parallel edges to the support framing members, as required, to ensure the failure mechanism of the test occurs in the field of the *diaphragm*. To test an edge detail parallel with the *steel panel* span or an end detail perpendicular to the *steel panel* span, it is permitted to provide enough connections elsewhere to ensure the failures occur at the desired locations. The same *configuration* shall be tested without the end detail to isolate the contribution of the end detail, unless the end detail contribution can be determined analytically.

7.1.2 Test Frame Support Members. The test frame members that support the *steel panels* are permitted to be steel, concrete, wood, or a combination of materials representative of intended end use. The intermediate support beams shall be installed consistent with the intended construction.

User Notes:

- a. The failure mechanism and flexibility of *steel panel* connections to the test frame support members should be representative of the intended end use.
- b. The test frame member sizes need not be the same size as those for the intended end use.

7.2 Cantilever Test Assembly. The cantilever test consists of the rectangular *test assembly* with load applied along one side of the test frame, and supports provided at the opposite side of the test frame. See Figures 1 through 3 for illustrations.

The *test assembly* size shall not be less than five (5) full-width *steel panels* and shall have an *aspect ratio* (see Figures 1 through 3) between 0.6 and 1.67. When the intended end use of the *diaphragm* is outside these limits, it is permitted for the *test assembly* size to be less than five (5) full-width *steel panels* and have an *aspect ratio* outside the 0.6 to 1.67 limits.

8. Number of Diaphragm Tests

8.1 Tests for Single Diaphragm System. To determine the strength and the stiffness of a single *diaphragm* assembly from testing, the minimum number of tests shall be in accordance with Section K2.1.1(a) of AISI S100.

User Note:

AISI S100 Section K2.1.1(a) requires a minimum of three (3) tests, with additional tests required based on the deviation from the average.

8.2 Analytical Model Tests. For analytical model tests, the number of tests shall be enough to cover the application range(s) of the parameter(s) being evaluated, but shall not be less than three (3). Individual tests are permitted to vary multiple parameters. Extrapolation beyond the limits of the parameters tested is not permitted.

User Note:

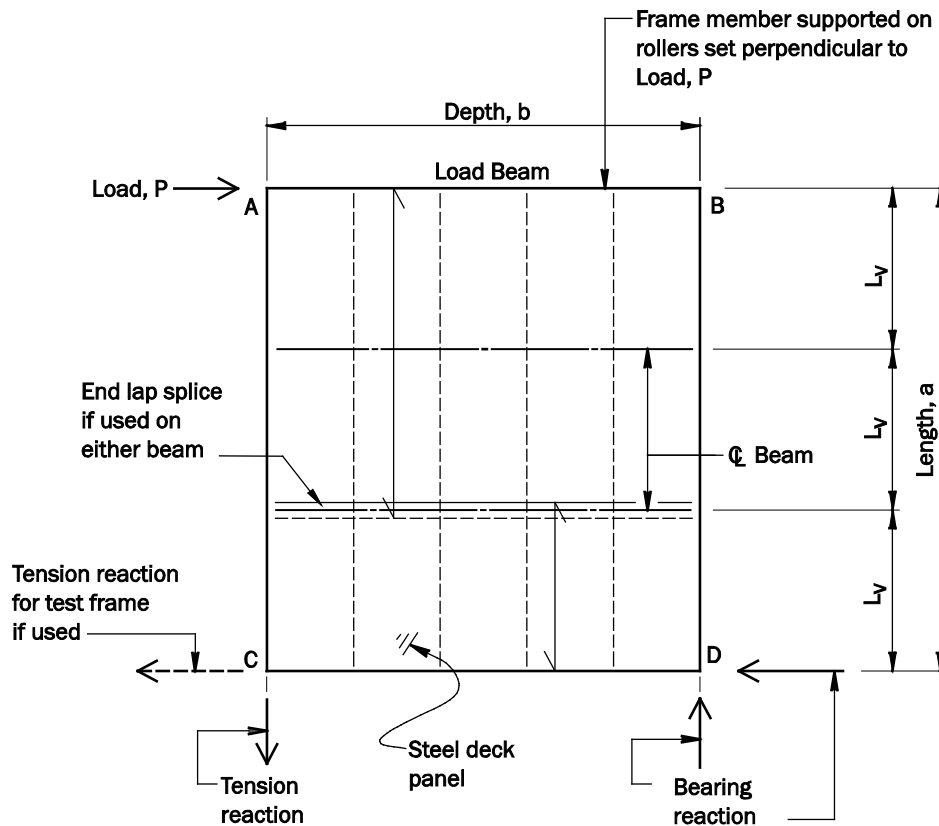
The number of tests required will vary based on the specific test objective. See Section E1.2 of AISI S310 for examples of test objectives.

8.2.1 Tests for the Development of an Analytical Equation. The tests for development of an analytical equation shall include the bounds and at least one intermediate point of each parameter being evaluated.

User Note:

A list of common parameters is included in the Commentary.

8.2.2 Tests Used to Modify or Verify Applications of an Analytical Model. For tests used to modify or verify the applications of an analytical model, a minimum of three (3) tests or three (3) times the number of essential parameters as provided in Table E1.2-1 of AISI S310 whichever is larger, shall be required.



Note: Reaction to axial load in member CD is permitted to be a tension reaction at point C.

Figure 1 – Cantilever Test Assembly

User Note:

To minimize the *out-of-plane* movement, the load should be applied to the load beam(s) as close as practical to the shear center of the *test assembly*. An *out-of-plane* load or a restraint device should be applied to the load beam(s) to offset or restrain the net *out-of-plane* uplift.

9. Test Procedure

9.1 Static Test

A static test shall follow the test procedure outline in this section.

9.1.1 Bare Frame. The strength and stiffness of the *bare frame* shall be determined using the *diaphragm* load test procedure outlined in Section 9.1.2. The load beam member shall support at least the dead load that will be on the member when testing the *test assembly*. The same displacement measurement method used during the *diaphragm* load test shall be used for the *bare frame* test. The load-deflection curve of the *bare frame* shall include deflection greater than that expected in the *test assembly*.

The means used to restrain the *out-of-plane* movement of the *test assembly* shall be in place during the *bare frame* test.

The measured *bare frame* contribution from a test frame arrangement with a greater number of interior beams is permitted to be applied to tests on the same size test frame, but with fewer interior beams installed.

9.1.2 Loading Procedure. It is optional to apply 5% of the estimated maximum load, $0.05P_{\max}$, as an initial load to the *test assembly*. At least 10 sets of load and displacement readings shall be provided prior to reaching maximum applied load, P_{\max} . The sets of readings shall be taken with approximately equal load increments. The rate of loading shall be such that P_{\max} is achieved in not less than 10 minutes. Loads shall be applied with a calibrated load system. Displacements shall be measured with dial gages or other devices. At load levels of approximately one-quarter and one-half of the estimated maximum load, the load shall be lowered to the initial load and the residual displacement of the *diaphragm* shall be recorded.

9.2 Cyclic Test

A cyclic test shall follow the test procedure outlined in this section.

9.2.1 Summary of Method. The cyclic shear strength and shear stiffness for *steel panels* shall be determined by subjecting the *test assembly* to full-reversal cyclic displacements, $\pm\Delta$. As the assembly is full-reverse cyclically loaded to specified displacement increments, the racking (shear) force and displacements shall be continuously measured.

9.2.2 Loading Procedure. Prior to the cyclic tests, at least two static tests shall be performed in accordance with Section 9.1. The full-reverse cyclic loading sequence shall follow the loading cycles in Table 1 for floor, roof, or wall *diaphragms*. The rate of loading shall not exceed 1.0 Hz. A minimum of 100 load displacement points shall be recorded for each load cycle. It is permitted to pause the test at the end of a load cycle and then continue with the subsequent load cycle to observe the condition of the *test assembly*. Alternate cyclic loading sequences are permitted.

Table 1
Basic Load Cycles

Cycle No.	% Δ_u	Cycle No.	% Δ_u	Cycle No.	% Δ_u	Cycle No.	% Δ_u
1	5.0	11	5.6	21	20	31	30
2	5.0	12	5.6	22	15	32	70
3	5.0	13	5.6	23	15	33	53
4	5.0	14	10.0	24	15	34	53
5	5.0	15	7.5	25	30	35	100
6	5.0	16	7.5	26	23	36	75
7	7.5	17	7.5	27	23	37	75
8	5.6	18	7.5	28	23	38	150
9	5.6	19	7.5	29	10	39	113
10	5.6	20	7.5	30	30	40	113

where

Δ_u = Displacement corresponding to ultimate load of average of a minimum of two static tests of the *test assembly* run in accordance with Section 9.1

10. Data Analysis

10.1 Nominal Diaphragm Web Shear Strength [Resistance]. The nominal *diaphragm* web shear strength [resistance], S_n , which is the shear load per unit length across the depth of the test frame, shall be determined in accordance with Eq. 10.1-1 as follows:

$$S_n = \frac{P_n}{b} \quad (\text{Eq. 10.1-1})$$

where

$$P_n = P_{\max} - P_{\max} \left(\frac{P_{fn}}{P_{\max}} - 0.02 \right) \quad \text{if } \frac{P_{fn}}{P_{\max}} > 0.02 \quad (\text{Eq. 10.1-2})$$

$$P_n = P_{\max} \quad \text{if } \frac{P_{fn}}{P_{\max}} \leq 0.02 \quad (\text{Eq. 10.1-3})$$

where

P_{\max} = Maximum applied load of P to test frame

P_{fn} = Load of P from testing of the *bare frame* at the deflection equal to the deflection for load of P_{\max} for strength

b = Depth of *diaphragm* test frame and dimension parallel to load, P

10.2 Diaphragm Web Shear Stiffness. To determine the *diaphragm* web shear stiffness, G' , for the full frame *test assembly*, the load-net deflection curve shall be plotted for the static test (See Figure 4) or the backbone curve of the cyclic test (See Figure 5). When the deflection curve from no load to the initial load as described in Section 9.1.2 is inconsistent with the deflection envelope from the initial load to load, P_d , it is permitted to project the envelope back to the no-load condition to establish the zero-load deflection. That deflection shall then be used as the zero point to determine G' .

When Deflection Device Scheme 1 with diagonal displacement measurements (illustrated in Figure 2) is used, the net shear deflection, Δ_i , shall be determined in accordance with Eq. 10.2-1 as follows:

$$\Delta_i = \frac{(|\Delta_1| + |\Delta_2|) \sqrt{a^2 + b^2}}{2b} \quad (\text{Eq. 10.2-1})$$

where

$\Delta_{1,2}$ = Diagonal displacement measured at points 1 or 2 (See Figure 2)

a = Length of *diaphragm* test frame

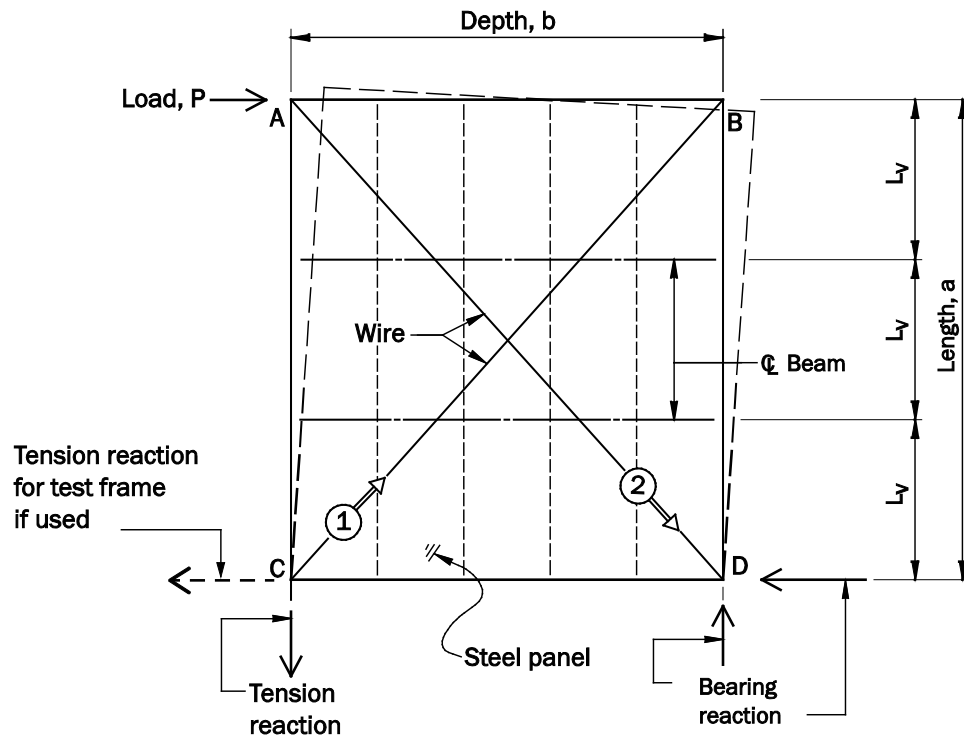
b = Depth of *diaphragm* test frame

When Deflection Device Scheme 2 with orthogonal displacement measurements (illustrated in Figure 3) is used, the net shear deflection, Δ_i , shall be determined in accordance with Eq. 10.2-2 as follows:

$$\Delta_i = \Delta_3 - [\Delta_1 + (\Delta_2 + \Delta_4)a/b] \quad (\text{Eq. 10.2-2})$$

where

$\Delta_{1,2,3,4}$ = Orthogonal displacement measured at points 1, 2, 3, or 4 (See Figure 3)



Legend:

○ ⇒ Displacement device mounted on top flange of test frame. Arrow indicates direction of positive reading.

Note: Reaction to axial load in member CD is permitted to be a tension reaction at point C.

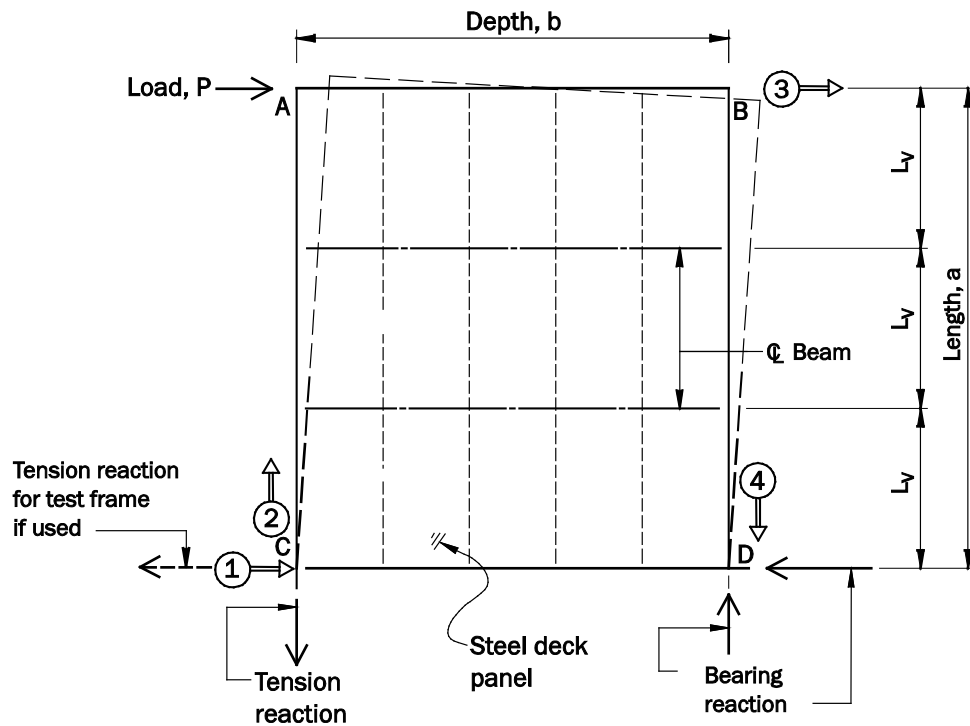
Figure 2—Cantilever Assembly - Deflection Device Scheme 1

In lieu of Eq. 10.2-1, it is permitted to use Eq. 10.2-3 to determine the *bare frame* deflection, Δ_i , with only displacement device 1 if Deflection Device Scheme 1 (illustrated in Figure 2) is used:

$$\Delta_i = (\Delta_1) \frac{\sqrt{a^2 + b^2}}{b} \quad (\text{Eq. 10.2-3})$$

In lieu of Eq. 10.2-2, it is permitted to use Eq. 10.2-4 to determine the *bare frame* deflection, Δ_i , with only displacement device 3 if Deflection Device Scheme 2 (illustrated in Figure 3) is used:

$$\Delta_i = \Delta_3 \quad (\text{Eq. 10.2-4})$$



Legend:

○⇒ Displacement device mounted on the ground at frame corners measuring movement of the test frame.
 Arrow indicates direction of positive reading.

Note: Reaction to axial load in member CD is permitted to be a tension reaction at point C.

Figure 3—Cantilever Assembly - Deflection Device Scheme 2

The *diaphragm* web shear stiffness, G' , shall be determined in accordance with Eq. 10.2-5, where P_d shall be determined in accordance with Eq. 10.2-6 or 10.2-7, and Δ_d is the corresponding net deflection as illustrated in the load-net deflection curve for static tests (See Figure 4) or the backbone curve for the cyclic tests (See Figure 5):

$$G' = \left(\frac{P_d a}{\Delta_d b} \right) \quad (Eq. 10.2-5)$$

where

$$P_d = 0.4P_{\max} - 0.4P_{\max} \left(\frac{P_{fd}}{0.4P_{\max}} - 0.02 \right) \quad \text{if } \frac{P_{fd}}{0.4P_{\max}} > 0.02 \quad (Eq. 10.2-6)$$

$$P_d = 0.4P_{\max} \quad \text{if } \frac{P_{fd}}{0.4P_{\max}} \leq 0.02 \quad (Eq. 10.2-7)$$

where

P_d = Load of P at which the *diaphragm* stiffness is determined

P_{fd} = Load of P from testing of bare test frame at the deflection equal to the net deflection for load of $P_d = 0.4P_{\max}$

Δ_d = Net shear deflection of *diaphragm* test at load $P_d = 0.4P_{\max}$

User Note:

When mixed component systems are tested to confirm theoretical stiffness equations, an assembly-specific theoretical stiffness equation should be developed for comparison with tested deflections. A test specimen with differing panel lengths is an example of a system with mixed components.

10.3 Flexibility Factor. The flexibility factor of the *diaphragm* web, F , shall be determined in accordance with Eq. 10.3-1 as follows:

$$F = 1/G' \quad (\text{Eq. 10.3-1})$$

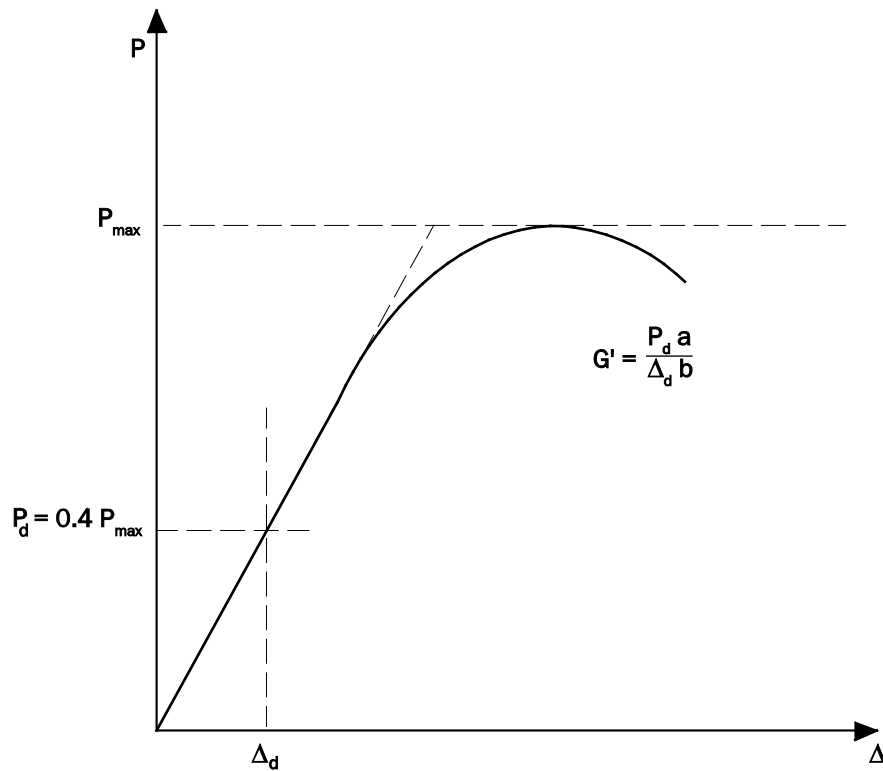


Figure 4 - Typical Load - Net-Deflection Curve

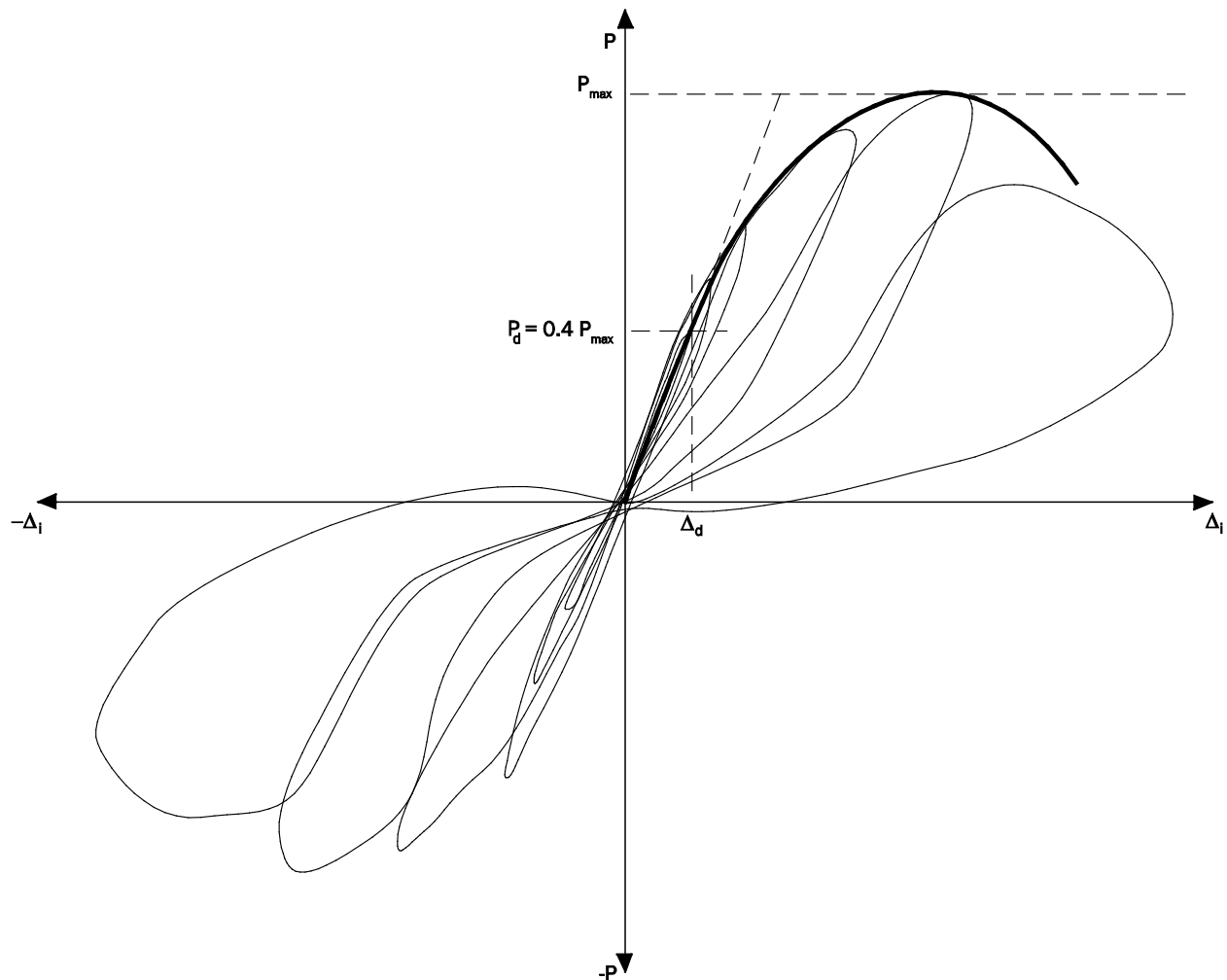


Figure 5 – Typical Backbone Curve

11. Conditions of Acceptance

11.1 Existing Test Data. Existing test data and criteria used for the development, modification, or verification of an analytical model from test programs conducted in accordance with test methods that predate this Standard are permitted to be combined with the test data obtained from these provisions.

11.2 Analytical Model Tests. Analytical model test results for developing, verifying or modifying an analytical model for *diaphragm* web shear strength [resistance] shall achieve a correlation coefficient (C_C) as specified in Section K2.1.1(c) of AISI S100. Calibration of safety and resistance factors shall be in accordance with E1.2.2(c) of AISI S310.

11.3 Elimination of Test Results. No test result shall be eliminated unless a rationale for its exclusion is provided.

11.4 Load Displacement Hysteresis Loops. Sections 11.1 and 11.2 shall not be required if the results of the test program are only used to generate load-displacement hysteresis loops.

12. Test Specimen Materials and Connectors

12.1 Steel. *Steel panels* used in *diaphragm* tests shall be evaluated by mechanical property tests to determine the tensile strength, yield stress, and percent elongation in accordance with ASTM A370. In addition, the *base steel thickness* shall be determined. Test results shall be based on the evaluation of at least three samples in each thickness. The samples shall be selected from different *steel panels* of the *test assembly*.

12.2 Structural Concrete. *Structural concrete* cylinders shall be field-cured in accordance with ASTM C31/C31M. Test cylinders shall be cured close to and in a manner similar to the *diaphragm* construction. If test cylinders indicate that f'_c is near the design value, the curing time is permitted to be less than 28 days, but shall not be less than seven days. Two tests with two cylinders in each test shall be performed in accordance with ASTM C39/C39M and the average compressive strength shall be reported during a 48-hour period immediately preceding and following any *diaphragm* test series. The average of two tests, or four cylinders total, shall be used to establish the compressive strength of the *structural concrete*.

Normal-weight aggregates in the *structural concrete* shall comply with ASTM C33/C33M. An aggregate description shall include the rock and mineral components, shape, hardness, maximum size and grading specification.

Lightweight aggregate shall be in accordance with the requirements of ASTM C330/C330M. Lightweight aggregate shall be identified by the generic or trade name, shape, size, maximum size, and grading specification.

Average *structural concrete* cover depth over top of the deck at the supports, d_c , shall be recorded from at least two locations per support for each test assembly.

User Note:

Accessibility of interior beams may limit measurement of d_c to near the ends of the beams.

12.3 Insulating Concrete. The *insulating concrete* cylinders shall be field-cured close to and in a manner similar to the *diaphragm* construction. The compressive strength and density of the *insulating concrete* used in the *diaphragm* tests shall be determined in accordance with ASTM C495/C495M. Two tests with two cylinders in each test shall be performed, and the average compressive strengths shall be reported during a 48-hour period immediately preceding and following any *diaphragm* test series. The average of two tests, or four cylinders total, shall be used to establish the compressive strength of the *insulating concrete*.

For *insulating concrete* with aggregates, the aggregates shall conform to ASTM C332.

For insulating cellular concrete, the foaming agents shall conform to ASTM C869/C869M. Insulating-cellular concrete shall be applied to the *steel panels* in accordance with the instructions of the manufacturer of the foaming agents.

Average *insulating concrete* cover depth over top of the deck at the supports, d_c , shall be recorded from two locations per support for each test assembly.

User Note:

Accessibility of interior beams may limit measurement of d_c to near the ends of the beams.

12.4 Welding. Fillet welds, arc-spot welds, arc-seam welds, *top arc seam sidelap welds*, arc-plug welds, and flare-groove welds used in the *diaphragm* tests shall be in accordance with AWS D1.3/D1.3M. Steel-headed stud anchors shall be welded in conformance with AWS D1.1/D1.1M.

12.5 Mechanical Fasteners to Framing. Mechanical fasteners used in the *diaphragm* tests shall be installed in accordance with the fastener manufacturer's recommendations. A detailed description of the fasteners shall be provided, including length, diameter, thread pitch, head diameter, head shape and penetration distance into or through the substrate material (steel, wood, concrete, etc.).

12.6 Steel Panel Side Seam Mechanical Connectors. Detailed descriptions of the connections between adjacent *steel panels* used in the *diaphragm* tests, such as screws, button punch or clinch connections, shall be provided, including the method of installation and the edge dimension of fasteners.

12.7 Added Elements at Steel Panel Supports. Added elements used in the *diaphragm* test at the test frame support reactions to transfer shears or to stiffen the panel shall be described in detail, including the connections used to connect the elements to the *steel panel* and framing members.

13. Test Report

13.1 Test Scope. A test scope, a description of each test *configuration*, shall include a drawing that details all pertinent dimensions, including *base steel thickness*, t , and thickness of fill, d_c . The description shall define size, type, strength and source, where applicable, of fasteners, and shall define the fastener installation procedures, including equipment, applicable settings and times.

13.2 Steel Specimen. The measured mechanical properties of the tested steel specimen shall be included.

13.3 Individual Materials. Results of tests on individual materials shall be included.

13.4 Details Related to Connections. Details related to connections shall be included in accordance with Sections 13.4.1 and 13.4.2:

13.4.1 Weld Connections. The report shall include weld procedure(s), filler metal, visible weld size (visible diameter of arc spot welds, visible width and length of arc seam welds, visible length of top arc seam and fillet welds), description of weld washers (if applicable), location and any weld defects such as cracks shall be reported. Any welds considered to be critical to the failure of the *test assembly* shall be reported.

13.4.1.1 Welds transverse and perpendicular to structural supports shall be measured at sidelaps and at the adjacent interior flutes if applicable. It is permitted to measure all transverse support welds.

13.4.1.2 Welds at panel sidelaps between supports shall be measured.

13.4.2 Mechanically Fastened Connections. For mechanical fasteners, the report shall include a record of the installation tools utilized, tool settings specific to the *test assembly*, and a record of trial connections used to establish the tool settings. Any connection considered to be critical to the failure of the *test assembly* shall be reported.

User Note

Calibration of analytical equations and *single diaphragm systems* should conform to S310 Sections

E1.2.2 and E2.2, respectively. Sections E1.2.1 and E2.1.1 provide instruction on the number and location of welded connection measurements plus acceptable scatter on weld sizes in each test assembly.

13.5 Loading. The report shall provide a detailed drawing of the test setup, depicting location and direction of load application, location of displacement instrumentation and their point of reference, and a description of the test method and loading procedure used, rate of loading, and time to maximum load. Equipment calibration certificates shall be provided.

13.6 Ambient Conditions. Ambient conditions at the date of construction, curing period, and date and time of tests shall be reported where relevant to the performance of the tested assembly. The ambient conditions at the test site include relative humidity, temperature and, if outside testing is performed, wind speed.

13.7 Test Results. The test results shall be included in accordance with Sections 13.7.1 and 13.7.2.

13.7.1 The test report shall include individual and average, if applicable, maximum test load values observed; a description of the nature, type and location of failure exhibited by each specimen tested; and a description of the general behavior of the test fixture during load application. Failure modes shall be recorded. Any connection or panel buckling failures shall be identified and recorded. Any failure that occurs prior to the *steel panel* buckling failure, or connection failures between *steel panels* or *steel panels* to the support members, shall be noted. Additionally, photographs shall supplement the description of the failure mode(s).

User Note:

Failures of test frame beams or failures of connections between the test frame members should be noted as test frame beam failures if such failures occur prior to the panel buckling or connection failures between *steel panels* or *steel panels* to the support members.

13.7.2 Tested shear strength [resistance] and stiffness and load-versus-deformation curves, as plotted directly or as reprinted from data acquisition systems for each test, shall be included in the report.

13.8 The cellular concrete mix design and placement instruction shall be included in the test report.

13.9 The report shall include certification that the assembly and testing were performed under the direction of an engineer in charge of testing.

AISI S907-17-C
COMMENTARY ON TEST STANDARD FOR DETERMINING THE
STRENGTH AND STIFFNESS OF COLD-FORMED STEEL
DIAPHRAGMS BY THE CANTILEVER TEST METHOD

1. Scope

Shear *diaphragms* perform the same function of maintaining the shape in a building roof, floor or wall as do plate girder webs in maintaining shape between their stiffeners and flanges. However, the *diaphragm* stiffness, G' , usually is an order of magnitude lower than that for thin web girders.

The response of a *diaphragm* assembled from typical *steel panels* is dependent on the panel type and thickness, panel spans, and especially on the number, type and size of connections used. The *diaphragm* involves a “web” (panels), “stiffeners” (joists or purlins), and “flanges” (perimeter members). While its response may be thought of in terms of a short and deep beam, its behavior is much more related to that of truss panels having flexible diagonals.

The design *diaphragm* web shear strength and stiffness per unit length have been developed and are available in the SDI *Diaphragm Design Manual* (2004, 2006, and 2015), in the MCA *A Primer on Diaphragm Design* (2004), and in TM 5-809-10 (U.S. Departments of Army, Navy and Air Force, 1982) within the limits given in the documents.

Testing may be conducted to: (1) determine the strength and stiffness of a specific condition; and (2) to develop, modify, or verify the application of analytical models to new connections, *steel panel* profiles or system characteristics. Tests may be conducted using either a cantilever test frame or a simple span test frame. Procedures related to the simple span test method can be found in ASTM E455 (2016).

In practice, *steel panels* may be attached to structural supports other than steel, such as wood, concrete, or a combination of materials. *Diaphragms* of *steel panels* may include fills such as *structural* or *insulating concrete*. Insulation may be interposed between the deck panels and structural supports or over the top of *steel panels*. The standard does not preclude the use of alternative support materials or combinations of materials not explicitly listed.

Monotonic testing of roof and floor *diaphragms*, particularly using cantilever frames is commonly performed by manufacturers, test laboratories and university researchers. The use of cyclic testing is not common practice for roof and floor *diaphragms*. The test requirements necessary to perform cyclic testing of large-scale roof and floor *diaphragm* assemblies are different from those for monotonic tests, but research has been conducted in this area by universities and manufacturers. The work by Essa, Tremblay and Rogers (2002) is an example of this type of testing. Cyclic testing is recognized as an optional test method, primarily for the purposes of developing load displacement data or hysteresis loops, while monotonic testing remains the standard method of determining *diaphragm* web shear strength and stiffness for design.

In 2013, *wall diaphragm* was added to the test standard since walls (vertical *diaphragms*) often are part of the lateral force resisting system. However, *wall diaphragms* may be subject to additional requirements by the applicable building code, particularly when resisting and dissipating seismic loads.

7. Test Assembly

The majority of *diaphragm* tests have been conducted on a guided cantilever or simple span *test assembly*. These methods are both described generally in *AISI Design of Light Gage Steel Diaphragms* (First Edition, 1967) and in ASTM E455. ASTM E455 was adopted by the International Conference of Building Officials (ICBO) in early versions of ICC-ES AC43, as described in the Historical Overview in Section 8 of this Commentary. Testing conducted in accordance with AISI, ASTM E455, or other methods that predate AISI S907 should be considered acceptable provided the testing protocol, specimen assemblies and results are documented and meet the intent of this Standard.

The *test assembly* may have perimeter members formed using various steel shapes, including wide-flange beams, C-sections, Z-sections, HSS sections, or open web steel joists. The perimeter members may also be formed from wood, concrete, or a combination of material construction, as necessary to reflect the intended end use. The study of support connections on the edges parallel to the flutes of the *diaphragm* assembly usually is not part of a test program.

The *test assembly* should model typical construction, including perimeter transfer elements. In certain assemblies involving open web steel joists, the lower surfaces of the *diaphragm* may be above the perimeter member joist supports, thus limiting perimeter attachment for the *diaphragm*. An edge support angle can be welded to the joist ends to facilitate frequently used edge connections. Such angles should be attached to the joist ends and the joists then secured to the frame to permit proper shear transfer on the perimeter. Other block-like devices may be attached to the frame, between joists, to receive edge connections directly.

Since the ability to transfer forces across the edges of a *diaphragm* parallel to the deck flutes may be assessed directly through evaluation of individual connections used, it is possible to avoid those individual failures by providing sufficient strength. For example, the shear strengths, Q_s , of steel-headed stud anchors in concrete-filled cold-formed steel deck *diaphragms* can be predetermined, and studs may be placed sufficiently close so that perimeter shear failures are virtually eliminated.

7.1.1 Steel Panels. End laps should be included when they are part of the design *configuration* when shear strength at end laps is a test program parameter. A test without an end lap may help an engineer to isolate particular design parameters or to confirm analytical methods since multiple layers of sheets at the end lap connection may impact support connection shear strength and the connection installation quality, particularly in welded connections. End laps often require mixing of span conditions and make the determination of stiffness based on test results for a particular system difficult.

7.1.2 Test Frame Support Members. It is not intended that this Standard preclude the use of alternative support member materials other than those listed, such as aluminum. The test frame support members should be constructed such that the connections perform in a manner consistent with the intended construction. It is always acceptable for the test frame support members and connections between test frame members to be strong enough to carry the full load of the test without failing.

7.2 Cantilever Test Assembly. The *test assembly* size is based on the most common practices that have been historically used for testing *diaphragms* with cold-formed *steel panels*. Testing by the SDI, MCA, and industry under ICC-ES AC43 or ASTM E455 generally was conducted with assemblies that were at least five panels wide. The *aspect ratio* of the length to the width

was generally close to square for cantilever frames. The five-panel width reduces the influence of the side panels that have an edge attached to the sides of the support frames. This leaves three interior panels that are not influenced by the parallel edge attachment to represent the majority of the panels in a *diaphragm* system, using the *steel panels* as the shear resisting stressed skin of the system. Partial-width panels should not be used to complete a *test assembly* unless the partial-width panel is fastened to supports and stitched to the full-width panel so that the full-width interior panel strength can be fully developed. The assembly size is limited to a ratio of 1.67 to 0.6 to limit the effects of *in-plane* bending stress and deflection relative to the shear and shear deflection of the assembly for general use.

It should be noted that *test assemblies* outside the range of the specified size or *aspect ratio* may be used to investigate conditions in which the specified assembly size may not be representative of the actual usage in a structure. This could include *diaphragms* with large or small *aspect ratios* or fewer than five panels in the width of the assembly. Some of the MCA, SDI, and industry testing performed in accordance with ICC-ES AC43 or ASTM E455 fall into this category and have been demonstrated to provide acceptable results. *Test assembly* sizes outside the range of the *aspect ratio* specified in AISI S907 should only be used to reflect such actual *diaphragm* conditions.

8. Number of Diaphragm Tests

The development of a large-scale test program is dependent on its objective, such as to expand the limits of or to confirm an analytical method. The number of tests required will vary depending on the parameters involved in the theory being investigated. A literature review of the historic practices, theory, and tests should be considered when developing a test program. The differences in historical practices are not necessarily reasons for discarding existing test data.

Historical Overview

There has been significant testing of *steel panel diaphragms* and *diaphragm* components or connections in the United States since the late 1940s. Much of that work can be generally grouped based on the two commonly used analytic design methodologies; the Steel Deck Institute *Diaphragm Design Manual* (DDM) and the U.S. Government Department of the Army, Navy, and Air Force TM-5-809-10 (1982) *Seismic Design for Buildings* (Tri-Services Manual, or TSM). The Canadian Sheet Steel Building Institute (CSSBI) recognizes both the SDI DDM method and the TSM method in its *Design of Steel Deck Diaphragms* (CSSBI, 2006).

The TSM was derived from the analysis of product manufacturer's proprietary (non-public) large-scale *diaphragm* testing made available to the authors of the initial TSM chapter on *diaphragms*, S.B. Barnes and C.W. Pinkham of S.B. Barnes and Associates, in 1966. This data is reported to have been comprised of tests covering profiles ranging in depth from 1.5 in. (38.1 mm) to 8 in. (203 mm), nominal thicknesses from 0.0295 in. (0.749 mm) to 0.0598 in. (1.519 mm), end lapped, non-end lapped, fluted, cellular, deep deck, and with and without concrete fill. The deck-to-structural support attachments were all welded. Sidelap attachments included button punches and various types of welds based on deck side joint *configuration* including top arc seam welds, side seam welds (as shown in Figures 2.12 (A) and 7 (B) of AWS D1.3/D1.3M), fillet welds, and flare groove welds. Most of the testing used to develop this method was based on single and double span deck panels used in

combination (single/single, double/double, or single/double). Tests included either lapped or butted end conditions.

Significant additional testing has been conducted in the years since the initial publication of the TSM, typically by individual manufacturers for purposes of recognition or listing by product evaluation agencies such as ICC-ES (formerly ICBO-ES). The recognition of product and test data is commonly based upon evaluation standards published by the particular recognition agency. The most commonly cited evaluation standard is AC43, *Acceptance Criteria for Steel Deck Roof and Floor Systems*, as published by ICC-ES. AC43 was first published in 1996, and reflected the general practices in use at the time of its initial adoption. The tests have often been analyzed based on the general principles presented in either the TSM or DDM, or elements of both. Through the evaluation report process, the TSM and DDM methods have both been readily accepted as a basis to describe the *diaphragm* web shear strength and shear stiffness of proprietary fastening systems including *power-actuated fasteners* (PAF), screw fasteners, and side seam clinch systems based on testing. The published evaluation reports have been historically accepted and approved by building officials and structural engineers for these products on projects in the U.S. and internationally.

The Steel Deck Institute (SDI) published a method for the design of profiled steel deck *diaphragms* in the *Diaphragm Design Manual*, First Edition (DDM01) (SDI, 1981). The basis for confirmation of the theoretical formulas given in the DDM01 was a series of approximately 110 welded and 50 mechanically attached with screw or PAF to large-scale *diaphragm* tests performed at West Virginia University (Luttrell and Ellifritt, 1970). In addition, 53 welded and 75 mechanically fastened sheet-to-sheet and sheet-to-structure connection tests were performed, which resulted in the development of fastener strength and flexibility equations published in DDM01 (1981). The DDM01 (1981) did not specify the range of panels that could be calculated, but the confirmatory testing was based on panels ranging from 1.0 inch to 1.5 inch deep, nominal thickness from 0.018 in. (0.457 mm) to 0.0587 in. (1.49 mm), non-end lapped, fluted, without concrete fill. This testing program involved WR (Type B), IR (Type F), and NR (Type A) deck profiles. A few tests were conducted using 1.0 in. (25.4 mm) form deck and 1-3/8 in. (34.9 mm) V-Beam panels. Most of the testing was based on multiple span deck panels and end laps were not investigated. The majority of the test program involved 18-gage (0.0474 in. (1.20 mm)) and thinner sheets with shorter span lengths (6 ft-8 in. (2032 mm) and under). The majority of the large-scale *diaphragm* tests did not include any sheet-to-sheet (sidelap) connections. The *Diaphragm Design Manual*, Third Edition (DDM03) (SDI, 2004) established application limits not addressed in DDM01. DDM01 primarily discussed 1-1/2 in. (38.1 mm) decks since those were the generic decks at the time.

To conduct tests for developing, modifying or verifying an analytical model, it is beneficial for researchers to study the test scope used to confirm the analytical model given in SDI DDM01 (1981), and the test programs described in the previous research (MCA, 2004; VT, 2008).

8.1 Tests for Single Diaphragm System. Tests of *single diaphragm systems* are intended to establish the strength and stiffness of a unique assembly based solely on the interpretation of the test results. For this reason, a minimum of three tests is required in accordance with Section K2.1.1(a) of AISI S100.

8.2 Analytical Model Tests. Analytical model testing is conducted to develop, modify or verify an analytical model. This includes verifying or modifying a model based on connections, profiles, or other conditions not previously addressed by the model. Testing a new connection which demonstrates strength and stiffness within the bounds of the connections currently addressed in an analytical model is an example of verifying the application of an analytical model. Testing a new profile with dimensions outside the profile limitations previously included is an example of modifying an analytical model.

Large-scale tests in accordance with this Standard are commonly conducted in conjunction with small element connection tests in accordance with AISI S905 (2017). Chapter E of AISI S310 provides guidance regarding whether small element tests, large-scale tests, or both are required. Large-scale testing is not mandatory in all cases, although the researcher is not discouraged from running large-scale tests to better understand or verify the system effect of the new fastener, profile, or characteristic.

All existing diaphragm analytical methods count on a system effect, which includes the contribution and interaction of panel, support connections and *sidelap connections* while developing shear strength and stiffness per unit length. To verify that the method's system effect can be developed, the contribution of each parameter must be significant in some test *configurations*. The contribution of sidelap strength to the calculated nominal *diaphragm* strength in large-scale tests conducted to verify the system effect for *diaphragm* systems is varied based on the support fastener or sidelap fastener type being evaluated. For large-scale tests to verify the system effect of new support fastener strength, guidelines for percentage of sidelap connector strength contribution should be between 10% and 25%. For large-scale tests to verify the system effect of new sidelap fastener strength, guidelines for percentage of sidelap connector strength contribution should be between 25% and 67%.

(a) *Parameters*

Section 8.2 (b) provides a list of commonly considered parameters in a *diaphragm* system to assist engineers selecting parameters applicable to a particular test program. The test program scope should include tests across the expected application ranges of the parameters. Parameters that can be determined by analytical methods can be excluded from the test program. When behavior differs across a given parameter's range, tests to explore the transitions in behavior should be considered. The minimum suggested increments are 0.005 in. (0.127 mm) for thickness and 20 ksi (138 MPa) for tensile strength based on material availability.

(b) *Summary of Diaphragm System Parameters*

1. Span
2. Single-span and multiple-span applications
3. Deck or panel profile
4. Deck or panel uncoated thickness
5. Deck or panel tensile strength
6. Deck or panel cover width
7. Deck or panel sidelap type
8. Deck or panel end lap detail
9. Support fastener type
10. Support fastener size
11. Support fastener location within the panel

12. *Sidelap connection type*
13. *Sidelap connection size*
14. Number of *side-lap connections* per span
15. Stiffening or reinforcing accessories
16. Edge detail parallel with the panel span
17. Limits for out-of-plane buckling
18. Support thickness
19. Support tensile strength
20. Concrete fill type and thickness
21. Concrete fill mechanical properties (density and strength)

Some parameters are naturally included in each test assembly, such as span, profile, thickness, and mechanical properties. The contributions of these essential parameters are considered in tests that are constructed to evaluate other variables. Multiple parameters may be varied in an individual test. The contribution of parameters being purposely evaluated must be significant in the test or the result might be trivial. Table C-E1.2-1 of AISI S310 summarizes the parameters whose contributions are defined in the SDI, MCA, and TSM analytical equations for their rational models.

Profile geometry can affect the number, type and size of acceptable fasteners; the ability to end lap; buckling resistance; and the response to warping shear. Fastener dimensions and mechanical properties may include but are not limited to shank dimensions, head or washer dimensions, hardness, and tensile strength. The number of required tests will depend on the *diaphragm* system analytical model.

It is acceptable to set a singular, minimum or maximum, value for the contribution of a parameter through testing. Examples are:

- (i) Constant sidelap shear strength, P_{ns} , for all values of t and F_u , as used in Section D1.2.6 of AISI S310 for a non-piercing button punch, and
- (ii) The benefit of increasing F_u for a particular fastener is determined to be negligible after some value of F_u .

(c) *Failure Modes*

Diaphragm failure modes are typically connection-related or limited by *out-of-plane* buckling of the *diaphragms*. Common failure modes can be summarized as follows (with applicable fastener types or materials enclosed in the parentheses):

- End-shearing failure (PAF, screw or weld)
- Bearing, tearing, slotting and piling up (PAF, screw or weld)
- Tension failure in net section of fastener (PAF, screw or weld)
- Shearing of fastener (PAF, screw or weld)
- Tilting/Bearing, pull-over, and pull-out of fastener (PAF or screw)
- Deck *out-of-plane* stability (*buckling*) failure (deck)

If, in a given test program, any one of the above-mentioned failure modes does not occur (e.g. deck buckling failure), additional tests are not required to develop a particular failure mode. Companion small element lap-joint shear connection tests may be conducted in accordance with AISI S905 for all combinations of sheet steel and base steel that are within the fastening system or welding application limits. It should be noted that historically, *diaphragm* values have been derived based on large-scale testing only, and thus programs without small element tests are permissible. These companion small element lap-joint shear

connection tests “fill in the gaps” in any large-scale *diaphragm* system test program and serve to isolate the behavioral contributions of both frame support connections and *side-lap connections*. Some conservative simplification can be made to the companion small element lap-joint shear test scope, such as selecting minimum *base steel thickness* or minimum sheet steel tensile strength. Other simplifications may also be possible.

8.2.2 Based on the complexity present in most analytical models for cold-formed steel *diaphragms*, this Standard requires a minimum of three tests to modify, extend or verify an analytical model. Tests are not restricted to only one parameter change at a time. For large complex models, this may not be practical. However, it may be necessary to develop portions of the theory by having single-parameter control to understand the effect of a particular parameter. Researchers should apply the rules rationally to specific conditions; for example, a parameter with limited range may not require tests at intermediate points. The following examples illustrate a recommended minimum number of tests to modify, extend or verify the application of an analytical model for various scenarios.

(1) Fastener type outside the scope of an analytical model, while all other parameters in the design application are within the acceptable limits of the analytical model:

The purpose of the test is to verify that the analytical model used to compute the *diaphragm* strength can predict an acceptable strength for the assembly with the proposed fastener type. Acceptability includes use of the model’s existing safety and resistance factors. The test program will be limited to one size and type of the proposed fastener. The test fixture will be based on the minimum acceptable support thickness.

AISI S310 Table E1.2-1 sets the essential parameters. The essential parameters that define connection strength and flexibility and that should vary in the test program are the deck thickness, t_{deck} , and the grade of steel of the deck, F_u deck. Therefore, the minimum number of tests is six, i.e. 3 (number of tests per essential parameter) \times 2 (number of essential parameters). The test program must include the full design range of each essential variable. Other assembly parameters may be included in the test program but must be within the analytical model’s acceptable limits. Supplemental small-scale tests of the proposed fastener type could precede the large-scale tests and could determine a starting point strength and flexibility to use in the theory.

(2) New panel profile outside the scope of an analytical model, while all other parameters in design applications are within the acceptable limits of the analytical model:

The purpose of the test program is to verify that *diaphragm* strength and stiffness can be predicted using the new profile in the analytical model. Acceptability includes use of the model’s existing safety and resistance factors. The test program will include the range of variables:

- (a) Only one panel depth, pitch and width,
- (b) Several panel thicknesses, t_{deck} and
- (c) One specified tensile strength, i.e. grade of steel sheet, F_u deck.

Every effort should be made to maintain F_u deck relatively constant and near the specified value at each deck thickness. However, this is difficult in practice and the

actual tested $F_{u, \text{deck}}$ and deck thickness values must be used to confirm that the theory reasonably predicts the tests.

AISI S310 Table E1.2-1 sets the essential parameters. If more than one cover width is needed, it is acceptable to test the smallest width. The essential parameter that defines strength and stiffness and that should be varied is the deck thickness, t_{deck} . The minimum number of tests is three, i.e. 3 (number of tests per essential parameter) \times 1 (number of essential parameters). It is rational to select connections that have better repeatability to help isolate the panel profile's contribution. Other assembly parameters may be considered in the test program, but must be within the analytical model's acceptable limits. For example, a test program may vary the span range and support connection spacing over the manufacturer's stated design limits.

(3) End restraint device across panels is outside the scope of an analytical model while all other parameters in design applications are within the acceptable limits of the analytical model:

The purpose of the test is to verify the *diaphragm* strength and stiffness using the stiffening device, which will enable one to calculate the benefit relative to the unstiffened system. The test program will include the proposed end device in one thickness, depth, cover width, and tensile strength and will be attached to the panels with #12 screws. If more than one device configuration is possible, it is acceptable to test the least combination of width, thickness, and tensile strength for each stiffening device depth and to use that restraint in design. Small-scale tests (and rational design) have shown that the minimum-specified stiffening device support connections would not control the device's contribution to strength and stiffness. Also, a minimum support thickness of 0.125 in. (3.2 mm) is required to achieve satisfactory performance and will be used in the tests. The stiffening device is attached to the panel where the strength contribution of the screw connection can be calculated using AISI S100. The test assembly will replicate design, which requires that each panel corrugation be attached to supports at the ends.

AISI S310 Table E1.2-1 does not explicitly set the essential parameters, but this stiffening accessory is a hybrid between a new panel profile and a new support fastener. There is one essential parameter that defines strength and stiffness. That parameter is the stiffening device strength contribution, which per AISI S100 depends on the combination of panel thickness and tensile strength, so the contribution of each essential parameter has been previously established. The minimum number of tests is three, i.e., 3 (number of tests per essential parameter) \times 1 (number of essential parameters). It is rational to aim at panel thickness and tensile strength combinations that hit the probable high, low and mid-range expected in design. Other assembly parameters may be considered in the test program, but must be within the model's acceptable limits. It is rational to select panel span to thickness combinations that investigate the strength limits of the unstiffened system. If the intent were to allow variance in panel to support connection other than every corrugation, additional tests would be required.

(4) Small-scale tests have been performed in accordance with AISI S905, and analytical strength and flexibility equations have been established and calibrated for one new support fastener type and one new sidelap fastener type.

The purpose of a large-scale *diaphragm* test is to verify that *diaphragm* strength and stiffness can be predicted using the new fasteners in the analytical model. Acceptability includes use of the model's existing safety and resistance factors. These fasteners will be used over a range of support and panel profiles where the thickness and tensile strength of support or panel can vary. The established limits of the new connection strength equations conform to the limits of the system model.

AISI S310 Table E1.2-1 sets the essential parameters, but these were used in the small-scale tests to establish maximum nominal strength and application limits. Each fastener strength and flexibility equation may depend on deck thickness, t_{deck} , and the grade of steel of the deck, $F_{u \text{ deck}}$, so the independent essential parameters are two and the same in each fastener strength and flexibility equation. As long as all other parameters are within the acceptable limits, S310 Chapter D, with certain restrictions, does not require large-scale tests. However, large-scale confirmatory tests are generally supportive and encouraged, but may not be absolutely necessary depending on the intent of the test program. The essential parameters for the large-scale tests are two: (1) the support fastener strength and flexibility equation, and (2) the sidelap fastener strength and flexibility equation. The strength and flexibility equations for either a support or *sidelap connection* are dependent on the same properties (fastener, support and panel) and should be simultaneously evaluated at each connection during a test. The minimum number of tests is six, i.e. 3 (number of tests per essential parameter) \times 2 (number of essential parameters). A discussion of the interrelationship between support and sidelap fasteners is in the Commentary of AISI S310 Section E1.2. Other configuration parameters may be considered in the test program, but must be within the model's acceptable limits. The contribution of each fastener must be significant in each test. The range limits of Standard Section 8.2.1 can be based on the product of thickness and tensile strength.

9. Test Procedure

9.1 Static Test

9.1.1 Bare Frame. Testing the *bare frame* assembly is required to determine if the *bare frame* carries a significant amount of the shear in relation to the shear being carried by the *diaphragm* web. If $P_{fn}/P_{\text{max}} > 0.02$, the maximum applied load needs to be corrected per Eq. 10.1-2 for *diaphragm* strength analysis; if $P_{fd}/(0.4P_{\text{max}}) > 0.02$, the load at which the stiffness is calculated needs to be corrected as well per Eq. 10.2-6.

The weight equivalent to the weight carried by *bare frame* in the full-frame assembly should be added on the load beam of the *bare frame test assembly* so that any effect of roller friction can be assessed.

9.1.2 Loading Procedure. The loading system used to apply loads to the full-frame assembly should be calibrated conforming to the requirements of ASTM E4 (2016).

The test sequence should be long enough to allow adequate data collection and to allow potential time-dependent relaxations in the system. Particularly when using manual data collection, the time required to conduct a test usually exceeds the minimum-specified time.

The stiffness and resistance of the *bare frame* will not be available in a field construction, and are removed by the formulas indicated. In evaluation, it should be noted that the *diaphragm* as a “beam” is in the “short-deep beam” category. Therefore, the “plane section” assumptions for longer beams do not apply.

The measured stiffness, G' , reflects the performance of the *diaphragm* field as it resists shear forces. The frame itself usually has little resistance to movement prior to attaching the *diaphragm*.

The shear strength and stiffness values for *diaphragms* may vary in a nonlinear manner with respect to panel length. However, reasonably conservative intermediate design values may be found by interpolation of results from similar systems of differing lengths. Extrapolation of data may lead to erroneous results.

10. Data Analysis

These sections provide a clarification in the analysis of test data to produce values of nominal shear strength [resistance] and stiffness for use in design.

10.1 Determination of Nominal Diaphragm Web Shear Strength [Resistance]. The *test assembly* members parallel to the hydraulic actuator load will have a maximum load of P_{\max} and an average maximum unit shear to the *diaphragm* web of P_{\max}/b . The frame members perpendicular to the load P will have a maximum load of P_{\max} (a/b) and an average maximum unit shear to the *diaphragm* web of P_{\max} (a/b) / $a = P_{\max}/b$. Thus, the average maximum unit shear to the four perimeter framing beams is constant P_{\max}/b .

10.2 Determination of Diaphragm Web Shear Stiffness. The net deflection at which stiffness or flexibility is to be determined is set at $P_d = 0.4P_{\max}$. The load, P_d , used to calculate the stiffness or flexibility of the *diaphragm* web is reduced if the load on the *bare frame* test, P_{fd} , exceeds 2% at that net deflection.

The zero deflection adjustment removes frame and/or deflection gage slack that is not part of the *diaphragm* stiffness. However, if the initial load deflection is due to either movement at *diaphragm* to panel support or *sidelap connections* or panel distortion, the zero point adjustment should not be made and the full displacement at $P_d = 0.4P_{\max}$ should be used to determine G' .

When a preload is applied to the test assembly, the point of zero deflection is considered as the origin of the load-net deflection curve as shown in Figure C-1. Determining G' when a preload is applied as follows:

$$G' = \frac{(P_d - P_{\text{preload}})a}{\Delta_d b} \quad (\text{Eq. C-1})$$

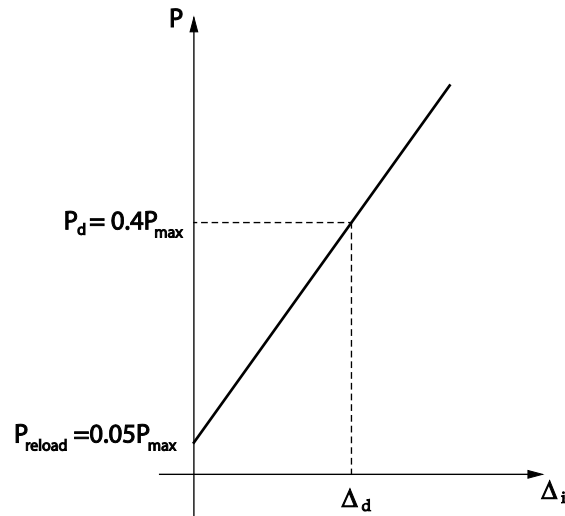


Figure C-1 – Load-Displacement Curve With Preload Condition

Test assemblies utilizing panels with mixed numbers of spans and continuity combinations, such as would be found in a test with both double span and single span sheets, have been used for years. This is required to confirm that end laps can be made or to test the impact of end laps on strength. Theoretical stiffness equations often need to consider the effects of span continuity and the number of spans. The theoretical test frame deflection must be calculated based on the particular configuration used in the test so this deflection can be compared with the tested deflection.

11. Conditions of Acceptance

11.1 Existing Test Data. Earlier editions of S907 required a correlation coefficient (C_C) of greater than or equal to 0.95 between test results and analytical model values for *diaphragm* web shear strength and C_C greater than or equal to 0.95 for *diaphragm* web stiffness. Existing recognition from various evaluation services (Building Departments, ICC-ES, etc.) were based on this requirement. There was a consensus decision in the committee to align AISI S310 with the requirements of AISI S100 Section K2.1.1(c) such that the correlation coefficient (C_C) be greater than or equal to 0.80. It should be noted that the lower correlation coefficient limit ($C_C \geq 0.80$) is justified only because AISI S100 Section K2.1.1 requires a reliability calibration to be performed to determine the resistance factor or safety factor, and includes both the mean bias factor, P_{mv} and the coefficient of variation, V_P , in the evaluation. In the case of *diaphragms*, the required calibration procedure is given in AISI S310 Section E1.2.2. Without such calibration procedures, a correlation coefficient of 0.8 would be inadequate. The historical measure of (C_C) of greater than or equal to 0.95 remains a rational benchmark for the comparison of new data historical results. More information on calibration and correlation coefficient C_C can be found in AISI S100 Commentary Section K2.1.1.

11.2 Analytical Model Tests. When extending the limits of an existing model or confirming that a model is within its limits, it is necessary to make sure the new data fits the scatter of the existing data and will not alter the calibration leading to the system's factors. AISI S310 Sections E1.2.2 and E2.2 and the corresponding Commentary give guidance in this area.

11.4 Load Displacement Hysteresis Loops. Testing performed in accordance with AISI S907 may be used to determine other characteristics of the *steel panel* or *steel panel* assembly. The use of FEMA P695/ATC-63 or FEMA P-795/ATC 63-1 may be used to develop seismic system coefficients for test assemblies using *steel panels* tested in accordance with this standard.

Cyclic behavior usually results in backbone curves that are lower and different in shape than the monotonic load-displacement curves. The differences between cyclic tests and monotonic tests are in the post-elastic range and not in the elastic zone. How close the cyclic backbone curve follows the reference monotonic load-displacement curve is an indicator of steel deck diaphragm ductility.

12. Test Specimen Materials and Connectors

This section describes the materials and connectors that have been used to date. It is not the intent to limit either materials or connectors to those described. However, testing to obtain enough data to have a reasonable assurance of repeatability should be performed.

12.2 Structural Concrete. To obtain desired concrete compressive strengths, the mix of the concrete used in the *diaphragm* tests should follow the requirements in ACI 211.1 or ACI 211.2, as applicable. Test cylinders of concrete used in *diaphragm* tests should be prepared in accordance with ASTM C31/C31M and tested in accordance with ASTM C39/C39M.

12.4 Welding. Resistance welding should conform to the requirements of AWS C1.1M/C1.1 (2015).

13. Test Report

Information related to the material used and installation of the *test assembly* should be provided in the test report. The behavior and failure modes observed during testing should be reported.

References

- American Concrete Institute (Reapproved 2002), ACI 211.1-09 *Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete*, 2009.
- American Concrete Institute (Reapproved 2004), ACI 211.2-98, *Standard Practice for Selecting Proportions for Structural Lightweight Concrete*, 2004.
- American Iron and Steel Institute (2013), S905-17, *Test Standard for Determining the Strength and Deformation Characteristics of Cold-Formed Steel Connections*, 2017.
- American Welding Society (AWS) (2012), AWS C1.1M/C1.1-2015, *Recommended Practices for Resistance Welding*, 2015.
- ASTM International (ASTM) (2016), ASTM E4-16, *Standard Practice for Force Verification of Testing Machines*, 2016.
- ASTM International (ASTM) (2016), ASTM E455-16, *Standard Method for Static Load Testing of Framed Floor or Roof Diaphragm Constructions for Buildings*, 2016.
- Canadian Sheet Steel Building Institute (CSSBI) (2006), *Design of Steel Deck Diaphragms*, Third Edition, 2006.
- Departments of Army, Navy and Air Force (1982), TM 5-809-10, *Seismic Design for Buildings*

- Essa, H., R. Tremblay and C. Rogers (2002), "Behavior of Roof Deck Diaphragms under Quasi-Static Cyclic Loading," Ecole Polytechnique and McGill University, Montreal, Canada, 1982.
- Federal Emergency Management Agency (FEMA), FEMA P-695/ATC-63 (2009), *Qualification of Building Seismic Performance*, 2009.
- Federal Emergency Management Agency (FEMA), FEMA P-795/ATC-63-1 (2011), *Qualification of Building Seismic Performance Factors: Component Equivalency Methodology*, 2011.
- ICC Evaluation Service (ICC-ES) (2010), AC43-10, *Acceptance Criteria for Steel Deck Roof and Floor Systems*, 2010.
- Metal Construction Association (MCA) (2004), *A Primer on Diaphragm Design*, First Edition, IL, 2004.
- Nunna, R. (2011), S. B. Barnes Associates, Report No. 11-03, "Buckling of Profiled Steel Diaphragms," July 18, 2011, Revised October 21, 2011.
- Steel Deck Institute (SDI) (1981), *SDI Diaphragm Design Manual*, First Edition, 1981.
- Steel Deck Institute (SDI) (2004), *SDI Diaphragm Design Manual*, Third Edition, 2004.
- Steel Deck Institute (SDI) (2006), *SDI Diaphragm Design Manual*, Appendix VI, 2006.
- Steel Deck Institute (SDI) (2015), *SDI Diaphragm Design Manual*, Fourth Edition, 2015.
- Virginia Polytechnic Institute and State University (VT) (2008), Report CEE/VPI-ST-08/03, "Deep Deck and Cellular Deck Diaphragm Strength and Stiffness Evaluation," 2008.



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