



Designation: E455 – 19

# Standard Test Method for Static Load Testing of Framed Floor or Roof Diaphragm Constructions for Buildings<sup>1</sup>

This standard is issued under the fixed designation E455; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers procedures designed (1) to evaluate the static shear capacity of a typical segment of a framed diaphragm under simulated loading conditions, and (2) to provide a determination of the stiffness of the construction and its connections. A diaphragm construction is an assembly of materials designed to transmit shear forces in the plane of the construction.

1.2 No effort has been made to specify the test apparatus, as there are a number that can be used as long as the needs of the testing agency are met. If round-robin testing is to be conducted, test apparatus and testing procedures shall be mutually agreed upon in advance by the participants.

1.3 The text of this standard contains notes and footnotes that provide explanatory information and are not requirements of the standard. Notes and footnotes in tables and figures are requirements of this standard.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 6.

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

**E575 Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies**

**E631 Terminology of Building Constructions**

### 2.2 Other Documents:

**AISI S310 North American Standard for the Design of Profiled Steel Diaphragm Panels<sup>3</sup>**

**ANSI/AWC SDPWS Special Design Provisions for Wind and Seismic<sup>4</sup>**

## 3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology **E631**.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *deflection*—in-plane deformation (distortion) of a diaphragm due to bending and shear excluding translational displacement due to movement of supports.

3.2.2 *diaphragm*—horizontal or sloped system acting to transmit lateral forces to the vertical resisting elements.

3.2.2.1 *Discussion*—A diaphragm is analogous to a horizontal deep beam with interconnected membrane elements such as panels, sheathing, or cladding acting as the deep beam web, intermediate elements such as joists acting as web stiffeners, and perimeter boundary elements such as girders acting as deep beam chords.

3.2.3 *displacement*—the distance between the initial and the final position of a point on the diaphragm in a given direction.

### 3.3 Symbols Specific to This Standard:

$E$  = modulus of elasticity of flange or web material, depending upon which material is held constant in a transformed section analysis, psi (or MPa).

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.11 on Horizontal and Vertical Structures/Structural Performance of Completed Structures.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> Available from American Iron and Steel Institute (AISI), 25 Massachusetts Ave., NW, Suite 800, Washington, DC 20001, <http://www.steel.org>.

<sup>4</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.



$G$	= shear modulus of the web material, psi (or MPa).
$G'$	= apparent shear stiffness of the diaphragm, which is derived from the apparent shear deflection of the diaphragm, lbf/in. (or N/mm).
$I$	= moment of inertia of the transformed section of the diaphragm based on webs or flanges, in. <sup>4</sup> (or mm <sup>4</sup> ).
$L$	= total span of diaphragm, in. (or mm).
$P$	= concentrated load, lbf (or N).
$P_{max}$	= maximum jack load applied to test frame, lbf (or N).
$R_u$	= maximum diaphragm reaction, lbf (or N).
$S_u$	= ultimate shear strength of the diaphragm, lbf/ft (or N/m).
$b$	= depth of diaphragm parallel to applied loads, in. (or mm).
$t$	= thickness of web material, in. (or mm).
$w$	= uniform load, lbf/in. (or N/mm).
$\Delta_b$	= portion of the diaphragm deflection attributed to bending, in. (or mm).
$\Delta_k$	= portion of the diaphragm deflection attributed to deformation of the diaphragm fasteners and connections, in. (or mm).
$\Delta_s$	= portion of the diaphragm deflection attributed to shear deflection of the diaphragm web, in. (or mm).
$\Delta_s'$	= apparent shear deflection of the diaphragm (see 10.1.2.2), which includes the deflection due to shear deflection of the diaphragm web and deformation of the diaphragm fasteners and connections, in. (or mm).
$\Delta_t$	= total deflection of diaphragm, in. (or mm).
$\Delta_{i, \dots}$	= displacement measured at Point $i$ ( $i = 1, 2, \dots$ ), in. (or mm).

#### 4. Summary of Test Method

4.1 The general purpose of this test method is to evaluate the shear forces that can be carried by the web of a framed floor

or roof diaphragm assembly by testing a simulation of the construction. The test method outlines basic procedures for the static load testing of these constructions using simple beam or cantilever-type test specimens. Suggested specimen and test setup details are provided, along with loading procedures, instrumentation, and evaluation methods.

#### 4.2 Construction:

4.2.1 *Diaphragm Performance Assumptions*—These diaphragm assemblies, assumed to act as deep beams, span between shear walls, moment frame bents, or other constructions that furnish the end or intermediate reactions to the system. The chord members of the assembly perpendicular to the line of applied load act as the flanges of the deep beam, and the plate or panel elements act as the web of the deep beam, and the framing members act as web stiffeners. A schematic drawing of a simple span diaphragm is shown in Fig. 1.

4.2.2 *Connections*—The performance of the diaphragm is influenced by the type and spacing of the plate or panel element attachments, framing connections, and perimeter anchorage at intermediate and perimeter supports. It is necessary to ensure that the type of connection system used and its application as nearly as possible duplicate the system intended for use in the prototype construction.

4.3 *Displacements*—To calculate deflections, the in-plane diaphragm displacement(s) shall be recorded. The total deflection of a diaphragm consists of bending deflection, shear deflection of the diaphragm web, and any additional deflection attributed to deformation of the diaphragm fasteners and connections. Table 1 contains some useful deflection equations.

#### 5. Significance and Use

5.1 Framed floor and roof systems are tested by this test method for static shear capacity. This test method will help determine structural diaphragm properties needed for design purposes.

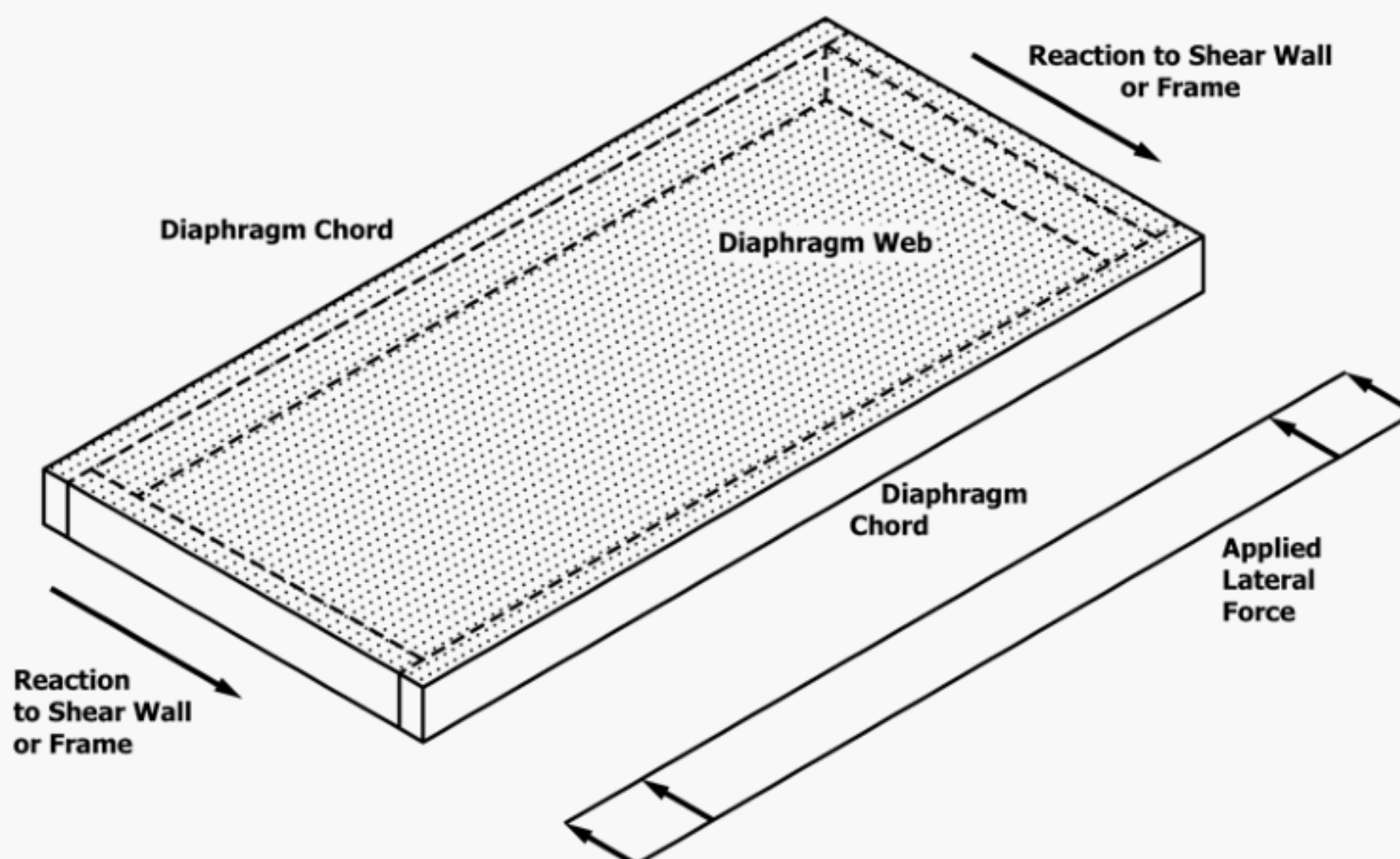


FIG. 1 Schematic of Simple Span Diaphragm



**TABLE 1 Useful Deflection Equations**

NOTE 1—Other equations may be applicable depending on the number of load points used.

Type of Beam	Loading Condition	Maximum Deflections <sup>A</sup>		
		$\Delta_b$	$\Delta_s$	$\Delta_s'$
Simple beam	uniform load	$5wL^4/(384EI)$	$wL^2/(8Gbt)$	$wL^2/(8G'b)$
Simple beam	third-point load <sup>B</sup>	$23PL^3/(648EI)$	$PL/(3Gbt)$	$PL/(3G'b)$
Cantilever beam	uniform load	$wL^4/(8EI)$	$wL^2/(2Gbt)$	$wL^2/(2G'b)$
Cantilever beam	concentrated load at free end	$PL^3/(3EI)$	$PL/(Gbt)$	$PL/(G'b)$

<sup>A</sup> At midspan of simple beam and free end of cantilever beam.

<sup>B</sup> For bending deflection at the load points under a third-point load, use the following equation:

$$\Delta_b(\text{at } L/3) = 5 PL^3 / (162 EI)$$

## 6. Apparatus

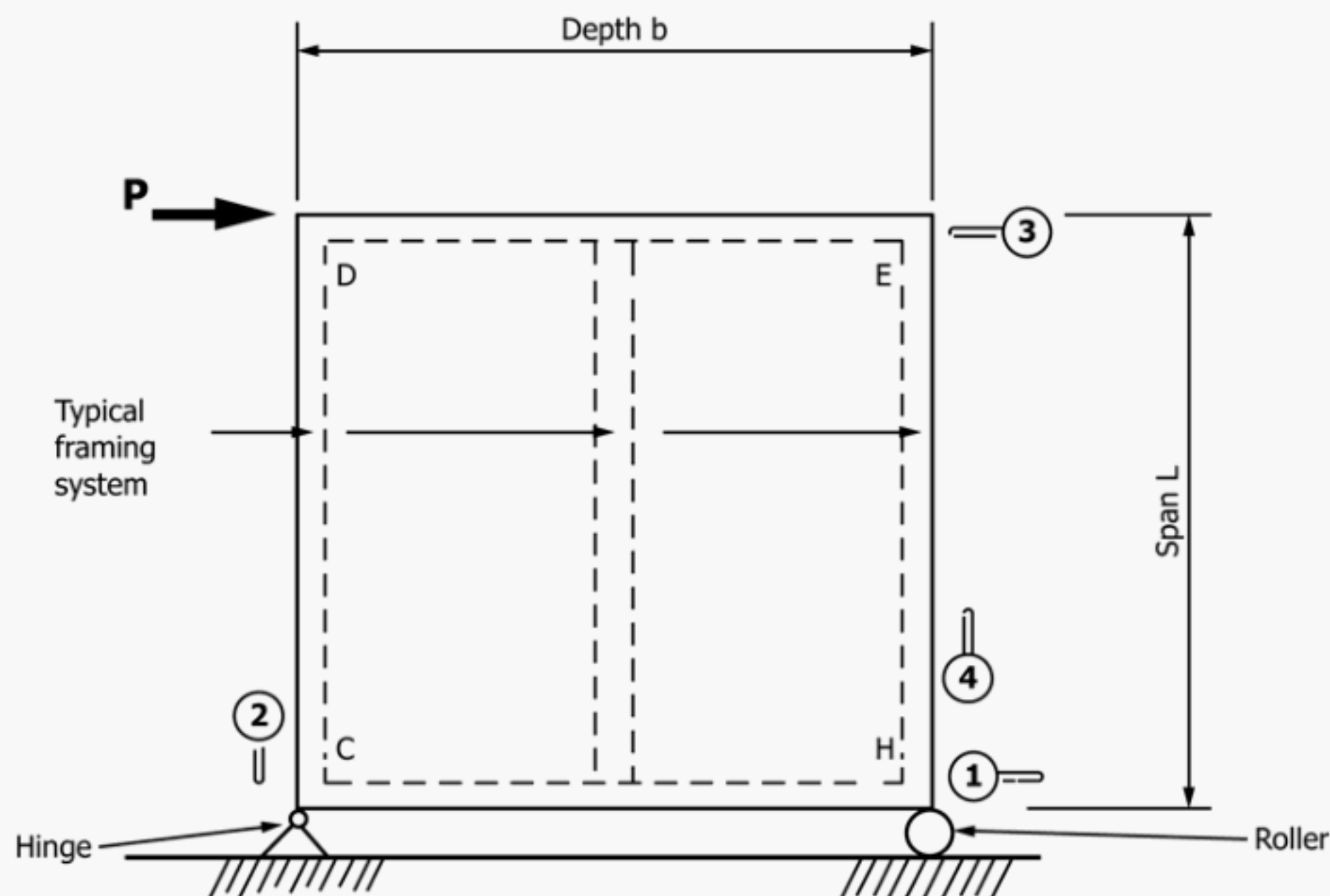
### 6.1 Test Assembly:

6.1.1 *General*—The diaphragm test assembly consists of a frame or framing system on which the elements comprising the web of the diaphragm are placed. The elements are fastened to the frame in a manner equivalent to their attachment in the field. The assembly may be tested horizontally or vertically. Either a cantilever or a simple span diaphragm assembly may be used, with concentrated or distributed loading.

6.1.2 *Frame Requirements*—The frame is a part of the test assembly and shall consist of members of the same or similar materials as those intended for use in the prototype construction. The test frame members shall be of equal or less strength than those intended for use in the prototype construction. If the

test objective is to force failure to occur elsewhere in the assembly, make the test frame members stronger and note the modification in the test report. The frame shall be calibrated to establish its load-deflection characteristics before attaching the diaphragm elements. If the frame has a stiffness equal to or less than 2 % of the total diaphragm assembly, no adjustment of test results for frame resistance need be made. However, if the frame stiffness is greater than 2 % of the total assembly, the test results shall be adjusted to compensate for frame resistance.

6.1.2.1 *Cantilever Frame* (see Fig. 2)—A pinned frame reaction at corner (C) shall be provided to transfer the horizontal force (P) through the diaphragm into the support system. The pin shall be located as close as possible to the diaphragm-to-frame contact plane to minimize warping of the



NOTE 1—

Dial gage or other displacement measuring device.

NOTE 2—Lateral restraint devices are not shown, and should not restrict movement in the plane of the diaphragm.

**FIG. 2 Plan of a Cantilever Beam Diaphragm Test with a Concentrated Load**



diaphragm surface. A vertical reaction roller or rollers shall be provided in the diaphragm plane at corner (*H*). The frame shall be laterally supported at adjacent corners (*D*) and (*E*) on rollers and at other locations as necessary to prevent displacement of the diaphragm from the plane of testing, but not to restrict in-plane displacements.

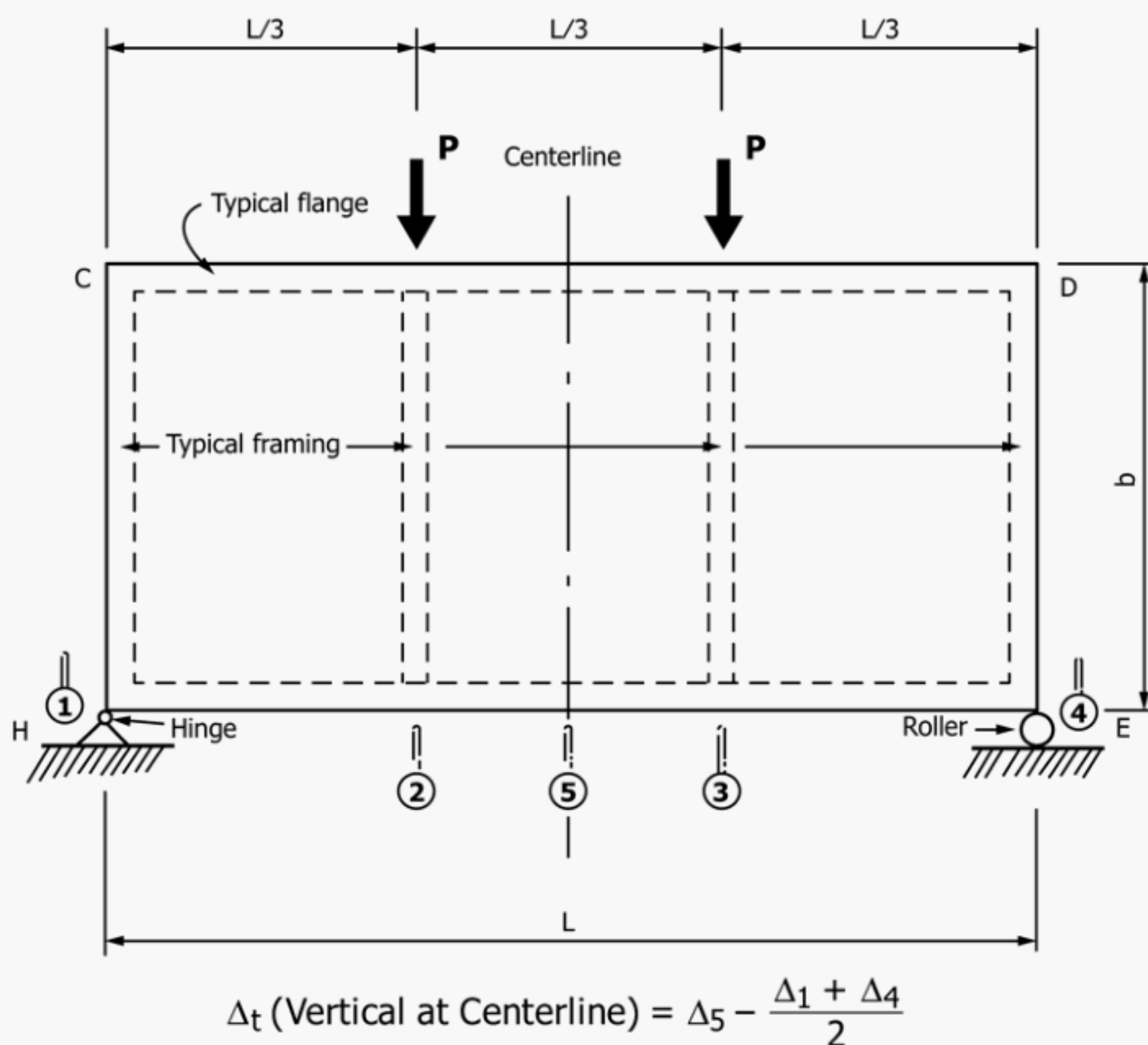
6.1.2.2 *Simple Span Frame* (see Fig. 3)—In-plane reactions shall be provided at points (*E*) and (*H*) as shown to resist the applied test load or loads. The frame shall be supported with rollers at points (*C*), (*D*), (*E*), and (*H*), and under each loading point. Hold-downs with rollers shall be provided to prevent displacement of the specimen from the plane of testing but not to restrict in-plane displacements. The diaphragm can also be supported by tension reactions at points (*C*) and (*D*) instead of reactions shown at points (*E*) and (*H*) in Fig. 3.

### 6.1.3 Diaphragm Size:

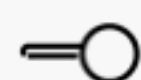
6.1.3.1 *Cantilever Diaphragm*—The diaphragm shall be tested on a span *L*, as shown in Fig. 2, equal to or greater than the typical support spacing likely to be used in the building. The test assembly shall not be less than 8 ft (2.4 m) in either span *L* or depth *b*; nor shall it contain fewer than four elements if the diaphragm consists of individual elements. The diaphragm shall contain typical end and side joints for the elements.

NOTE 1—When the web of the diaphragm is made of individual elements, they might not be equally effective for the same span length if laid perpendicular or parallel to the load direction.

6.1.3.2 *Simple Beam Diaphragm*—The diaphragm span *L* and depth *b* shall be as shown in Fig. 3, where the dimensions *L* and *b* have similar meaning as used in 6.1.3.1 with a



NOTE 1—



Dial gage or other displacement measuring device.

NOTE 2—Lateral restraint devices are not shown, and should not restrict movement in the plane of the diaphragm.

NOTE 3—The centerline (midspan) displacement,  $\Delta_5$ , is measured. The total deflection of the diaphragm,  $\Delta_t$ , is calculated relative to a straight line through the displaced locations of support points 1 and 4.

NOTE 4—Displacement measurements at points 2 and 3 are not used in this test method to calculate mid-span deflections of the diaphragm and are permitted to be omitted. The displacement measurements at points 2 and 3, though, may be used to verify the degree of the diaphragm's symmetrical response to the loadings. In addition, the user may calculate deflection due to bending at third-points and then determine apparent shear deflection at points 2 and 3 as supplemental data.

FIG. 3 Plan of a Simple Beam Diaphragm Test with Third-Point Loading



minimum dimension in either case of 8 ft (2.4 m). The diaphragm shall contain typical end and side joints for the elements.

## 7. Safety Precautions

7.1 Tests of this type can be dangerous. Equipment and facilities must be designed with ample safety factors to ensure that it is the specimen that fails and not the test apparatus or facilities. Observers and sensitive instrumentation must be kept away from diaphragms when loading to failure or in a load range where performance is unknown.

## 8. Number of Tests

8.1 A minimum of two specimens shall be tested to determine the value of a given construction. If the plan of the diaphragm is unsymmetrical, the second test shall be run with the specimen orientation reversed with respect to the load application used on the first specimen. If the tested strengths,  $S_u$ , do not agree within 10 % of the lower value, a third specimen shall be tested with this specimen oriented in the same manner as the weaker of the two previous tests. A mean value is computed from the lowest two values of the three tests.

8.2 Duplicate tests may be waived when a series of tests are being made to simulate a range of variables.

## 9. Procedure

9.1 *Determination of Frame Stiffness*—Determine the frame stiffness without the application of the web elements. Load the frame in a manner similar to that intended for the completed diaphragm. If the frame is a “standard” frame, determine the stiffness of the frame. If calculations show that the frame stiffness is less than 2 % of the total diaphragm assembly, a separate frame test is not required.

9.2 *Loading Procedure for Complete Diaphragm*—Apply the loads to the diaphragm in a manner duplicating, as far as practical, the in-service loading conditions.

NOTE 2—Out-of-plane movement of the test shall be minimized. Any suitable means that do not restrict in-plane movement of the diaphragm are acceptable. Possible ways are to apply the load as close as practical to the shear center of the test assembly; along the loaded framing member, apply a vertical load to the end of the framing member at the opposite end from the load application, or apply a restraining device (such as wheel or roller) to the frame. Any means used to restrain the vertical movement shall also be used when testing the bare frame.

Choose the rate of load such that  $P_{max}$  or  $R_u$  will be reached in not less than 10 min. Take at least ten sets of uniformly spaced displacement readings prior to failure to establish the load-deflection curve. The rate of load application shall permit load and displacement readings to be recorded. Apply loads by hydraulic jacks that have been previously calibrated, or by other suitable types of loading apparatus. Take account of the weight of the specimen and loading apparatus if it is anticipated that the weights will affect the results. Measure displacements with dial gages or other suitable devices to establish an adequate load-deflection curve. Measure displacements to the nearest 0.01 in. (0.2 mm). Load-measuring devices shall be accurate to within  $\pm 2$  %. At load levels such as approximately one-third and two-thirds of the estimated ultimate load, the

load may be removed and the recovery of the diaphragm recorded after 5 min. Maintain a record of the total length of time the diaphragm is under load.

## 10. Calculation

10.1 Base evaluation on the mean values resulting from tests of identical specimens in accordance with the provisions of Section 6. The following information is obtained from these tests:

10.1.1 *Ultimate Shear Strength*—Calculate the ultimate shear strength,  $S_u$ , as follows:

$$S_u, \text{ lbf/ft} = \frac{12 R_u}{b} \text{ or} \quad (1)$$

$$S_u, \text{ N/m} = \frac{1000 R_u}{b} \quad (2)$$

where  $R_u$  is the maximum reaction at failure in a simple beam test, or the maximum reaction acting parallel to the applied load in a cantilever beam test, and  $b$  is the diaphragm depth, as indicated in Figs. 2 and 3.

10.1.2 *Apparent Shear Stiffness*—An apparent shear stiffness  $G'$  may be determined for the entire assembly on the basis of an applied load at a reference load level below the proportional limit for use in deflection calculations. In the following formulas  $\Delta_b$  is determined using the appropriate equations from Table 1.

10.1.2.1 For use in determining the apparent shear stiffness, calculate the total deflection at a reference load level below the proportional limit, taking account of the support displacements, as follows:

Cantilever beam test, measured at free end:

$$\Delta_t = \Delta_3 - \left[ \Delta_1 + \frac{L}{b} (\Delta_2 + \Delta_4) \right] \quad (3)$$

Simple beam test, measured at the center of the span  $L$ :

$$\Delta_t = \Delta_5 - \frac{\Delta_1 + \Delta_4}{2} \quad (4)$$

where  $\Delta_1$ ,  $\Delta_2$ ,  $\Delta_3$ ,  $\Delta_4$ , and  $\Delta_5$  are measured displacements with appropriate signs at locations indicated in Figs. 2 and 3, and  $L/b$  is the ratio of the diaphragm assembly dimensions. The load-deflection curve ( $P$ – $\Delta_t$ ) can then be plotted using the deflections calculated from the test results.

10.1.2.2 Calculate  $\Delta_s'$  shear deflection at any load level as follows:

$$\Delta_s' = \Delta_t - \Delta_b \quad (5)$$

NOTE 3—The sources contributing to the apparent shear deflection,  $\Delta_s'$ , include deflection of the diaphragm web,  $\Delta_s$ , and deformation of the fasteners and connections,  $\Delta_k$ . Where the shear modulus,  $G$ , for the web material is known,  $\Delta_s$  may be estimated by the equations in Table 1. The values of  $\Delta_k$  for connections of certain fasteners and diaphragm materials may be estimated based on references such as ANSI/AWC SDPWS and AISI S310. The relationship may be taken as follows:

$$\Delta_t = \Delta_b + \Delta_s + \Delta_k \quad (6)$$

10.1.2.3 The test setups and loading pattern used in Figs. 2 and 3 may be used to determine the apparent shear stiffness,  $G'$ , of the construction, which is the slope of the test assembly's



load-deflection curve for the region between the support location and the nearest location of third-point concentrated load.

10.1.2.4 For a cantilever beam diaphragm under concentrated load at the free end, as shown in Fig. 2, measured between end support and free end:

$$G' = \frac{P}{\Delta_s'} - \left( \frac{L}{b} \right) \quad (7)$$

10.1.2.5 For a simple beam diaphragm under equal third-point concentrated loads, as shown in Fig. 3, measured between end supports and center of span  $L$ :

$$G' = \frac{P}{\Delta_s'} - \left( \frac{L}{3b} \right) \quad (8)$$

NOTE 4—The apparent shear stiffness,  $G'$ , varies with the length of the panel span. Unless multiple tests are to be made for various lengths, the following method may be used for determining the apparent shear stiffness based on the results of limited tests:

Perform tests for the longest and shortest reasonable diaphragm lengths. Determine  $G'$  as above; for any non-tested panel length,  $G'$  may be obtained by interpolation.

Another factor that may be determined from these tests is the reciprocal of the apparent shear stiffness multiplied by  $10^6$  to obtain a “flexibility” factor expressed in microinches of deflection per foot of diaphragm span stressed with a shear of 1 lb/ft.

## 11. Report

11.1 The report shall include details described in Practice E575 and the following information:

11.1.1 Date of test and of report.

11.1.2 Identification of the specimens (manufacturers, sources of supply, dimensions, models, types, materials, other pertinent information, test sponsors, test agencies, and their locations).

11.1.3 Detailed drawings of the specimen which provide a description of the physical characteristics, including dimensioned section profiles and any other pertinent construction details. Any modifications made on the specimen to obtain the reported values shall be noted on the drawings. Describe any noted defects existing in the diaphragm construction prior to test.

11.1.4 *Description of Test Specimen, Assembly, and Conditions:*

11.1.4.1 Details of structural design of the test specimen and test assembly.

11.1.4.2 Details of attachment of specimens in test fixture.

11.1.4.3 Location of load points, strain gages, displacement points, and other items for test as applicable.

11.1.4.4 General ambient conditions at:

(1) Date of construction.

(2) During curing (time from construction to test).

(3) Date and time of test.

11.1.4.5 Details of materials of construction (that is, yield point, tensile strength, compressive strength, density, and so forth, as appropriate for materials used).

11.1.5 *Description of Test*—Include a statement that the test was conducted in accordance with this method or with certain deviations, which shall be described.

11.1.6 An official statement indicating whether or not the construction of the test diaphragm represents actual or intended construction. If the construction does not represent typical field construction, deviations shall be noted.

11.1.7 *Summary of Results:*

11.1.7.1 Load-deflection graphs visually depicting diaphragm stiffness.

11.1.7.2 Record of maximum load applied to test specimens and description of mode of failure.

11.1.7.3 Other required data in tabular and graphical form.

11.1.7.4 Total time under load at various load levels.

11.1.7.5 Photographs of the tested specimens to show what cannot be described easily or clearly by writing.

11.1.8 List of official observers, with signatures of responsible persons.

11.1.9 Appendix that includes all data not specifically required by test standards but useful for a better understanding of the test results. Special observations for building code approvals should be included here.

## 12. Precision and Bias

12.1 No statement is made either on the precision or on the bias of this test method due to the variety of materials involved.

## 13. Keywords

13.1 connections; framed floor; roof diaphragm; static shear

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