Designation: E 455 – 98

An American National Standard

Standard Test Method for Static Load Testing of Framed Floor or Roof Diaphragm Constructions for Buildings[1]

This standard is issued under the fixed designation E 455; 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 (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

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 *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 and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 5.

2. Terminology

2.1 *Symbols*:

E	=	modulus of elasticity of flange or web material, depending upon which material is held constant in a transformed section analysis, psi (or MPa)
G	=	shear modulus of the web material, psi (or MPa)
G'	=	shear stiffness of the diaphragm obtained from test (includes shear deformation factor for the connection system), lbf/in. (or N/mm)
I	=	moment of inertia of the transformed section of the diaphragm based on webs or flanges, in.^{4} (or mm^4)
L	=	total span of a simply supported diaphragm, in. (or mm)
P	=	concentrated load, lbf (or N)
R_u	=	maximum diaphragm reaction, lbf (or N)
S_u	=	ultimate shear strength of the diaphragm, lbf/ft (or N/m)
a	=	span length of cantilever diaphragm, in. (or mm)
b	=	depth of diaphragm, in. (or mm)
t	=	thickness of web material, in. (or mm)
w	=	uniform load, lbf/in. (or N/mm)
Δ_b	=	bending deflection of diaphragm, in. (or mm)
Δ_k	=	empirical expression for that portion of the diaphragm deflection contributed by the shear deformation of the connection system, in. (or mm)
Δ_s	=	pure shear deformation of diaphragm, in. (or mm)
Δ_s'	=	apparent total shear deformation of the diaphragm based on test (see section 8.1.2.2), in. (or mm). This factor includes both the pure shear deformation and that contributed by distortion of the connection system.
Δ_t	=	total deflection of diaphragm, in. (or mm)
$\Delta_{1,2,\_\ \_\ \_}$	=	deformation measured at Point 1, 2, _ _ _, in. (or mm)

3. Summary of Method

3.1 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

[1] This method is under the jurisdiction of ASTM Committee E-6 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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setup details are provided, along with loading procedures, instrumentation, and evaluation methods.

3.2 *Construction*:

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

3.2.2 *Connections*—The performance of the diaphragm is influenced by the type and spacing of the panel attachments and perimeter anchorage. 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 structure.

3.3 *Deformations*—The in-plane diaphragm deformation(s) shall be recorded. The total in-plane deformation of a diaphragm consists of bending and shear deformation plus any additional deformation caused by distortion of the connection system. Table 1 contains some useful deflection equations.

4. Significance and Use

4.1 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.

5. Apparatus

5.1 *Test Assembly*:

5.1.1 *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.

5.1.2 *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-deformation 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.

5.1.2.1 *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 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.

5.1.2.2 *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

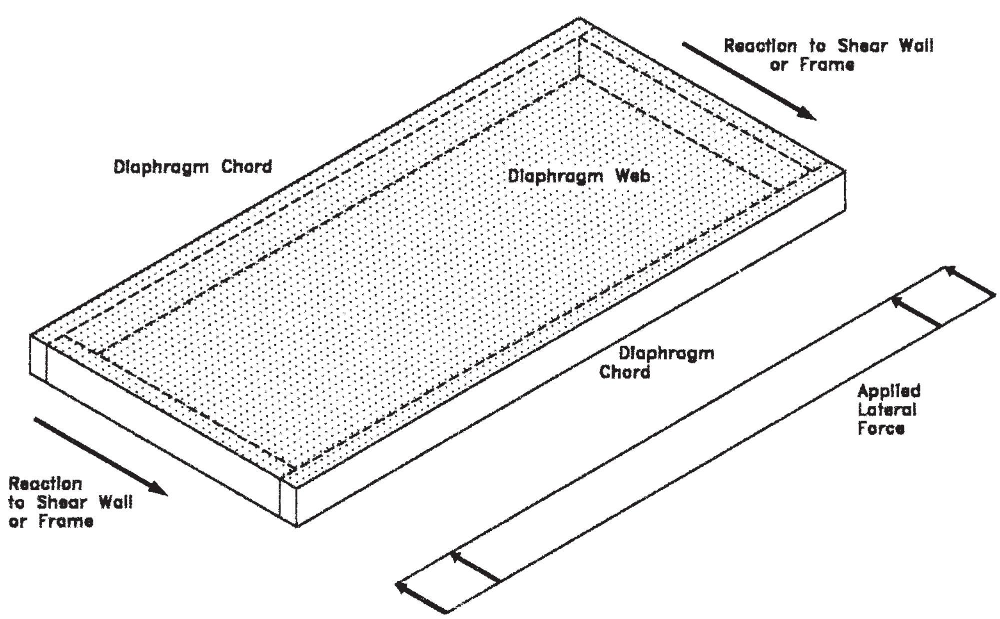


FIG. 1 Schematic of Simple Span Diaphragm

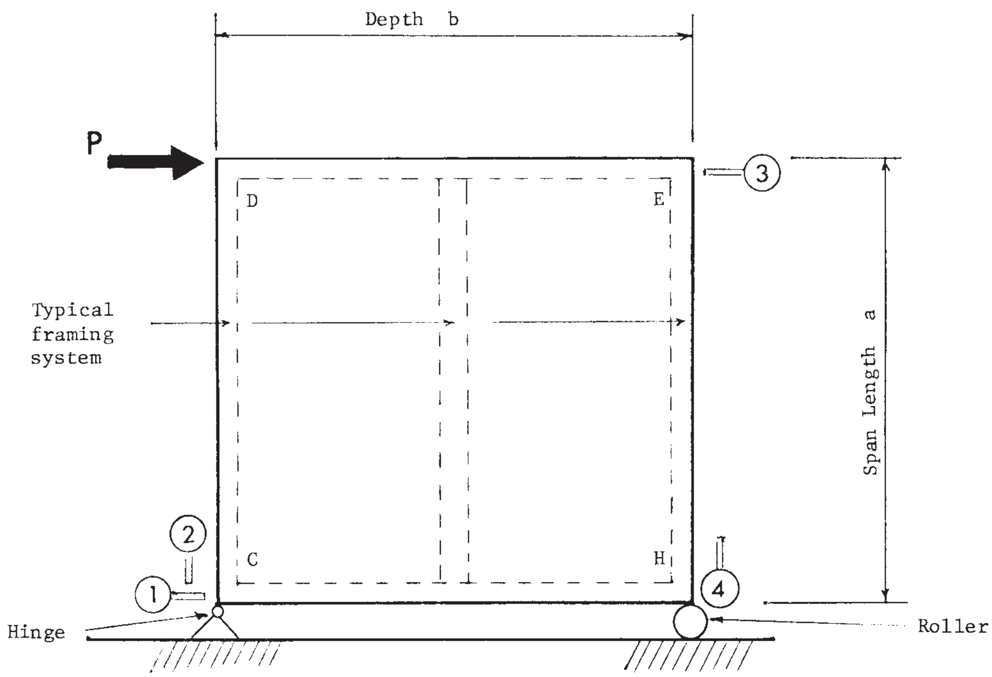
TABLE 1 Useful Deflection Equations

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

Type of Beam	Loading Condition	Maximum Deflections[A]		
		Δ_b	Δ_s	Δ_s'
Simple beam	uniform load	$5wL^4/384EI$	$wL^2/8Gbt$	$wL^2/8G'b$
Simple beam	third-point load[B]	$23PL^3/648EI$	$PL/3Gbt$	$PL/3G'b$
Cantilever beam	uniform load	$wa^4/8EI$	$wa^2/2Gbt$	$wa^2/2G'b$
Cantilever beam	concentrated load at free end	$Pa^3/3EI$	Pa/Gbt	$Pa/G'b$

[A] At midspan of simple beam and free end of cantilever beam. Make appropriate adjustment in units as required for compatibility when SI units are used.
[B] For bending deflection at the load points under a third-point load, use the following equation:

$$\Delta_{b\,(at\ L/3)} = (5PL^3/162EI)$$



NOTE 1—|sr○ Dial gage or other deflection 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

supported by tension reactions at points (*C*) and (*D*) instead of reactions shown at points (*E*) and (*H*) in Fig. 3.

5.1.3 *Diaphragm Size*:

5.1.3.1 *Cantilever Diaphragm*—The diaphragm shall be tested on a span length *a*, 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 length or width; nor shall it contain less 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.

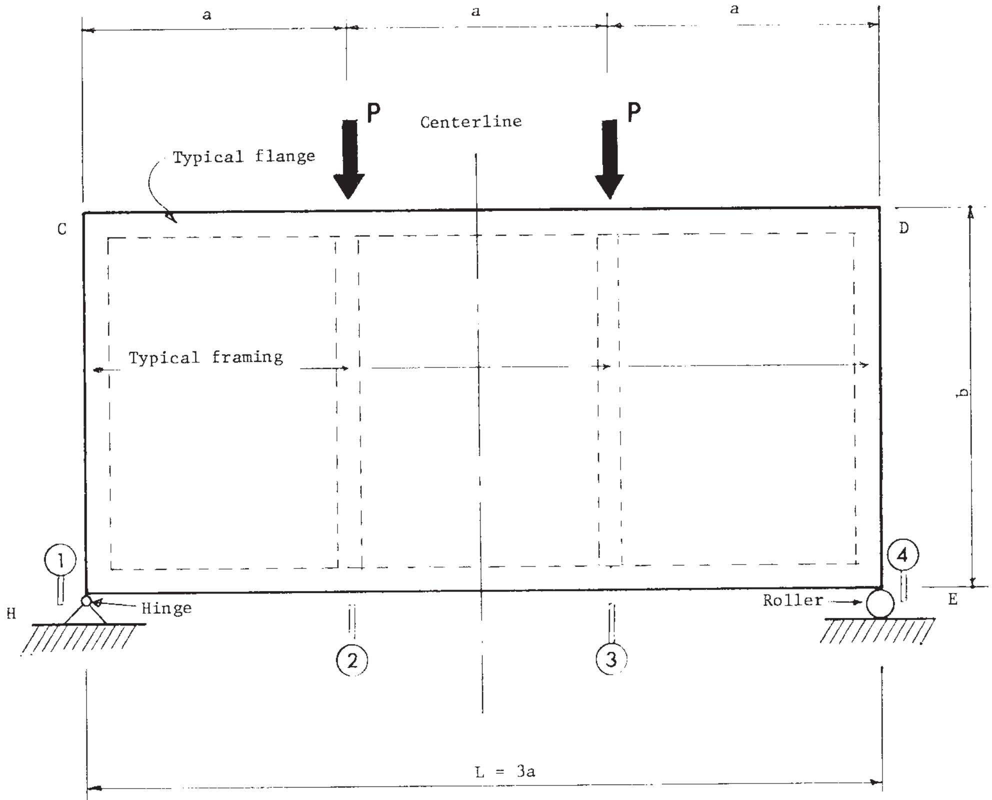
5.1.3.2 *Simple Beam Diaphragm*—The diaphragm length and depth shall be as shown in Fig. 3, where the dimensions *a* and *b* have the same connotation as above with a minimum dimension in either case of 8 ft (2.4 m). The diaphragm shall contain typical end and side joints for the elements.

6. Safety Precautions

6.1 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.

7. Number of Tests

7.1 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



$$\Delta_t \text{ (Vertical Under Load Point)} = \frac{(\Delta_2 + \Delta_3 - \Delta_1 - \Delta_4)}{2}$$

NOTE 1—|sr○ Dial gage or other deflection measuring device.

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

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

the specimen orientation reversed with respect to the load application used on the first specimen. If the tests 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.

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

8. Procedure

8.1 *Determination of Frame Stiffness*—Determine the frame stiffness prior to 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.

8.2 *Loading Procedure for Complete Diaphragm*—Apply the loads to the diaphragm parallel to and as close as practical to the place of contact between the diaphragm web and frame, in a manner duplicating, as far as practical, the in-service loading conditions. Choose the rate of load such that the anticipated full design load level will be reached in not less than 10 min. Take at least ten sets of uniformly spaced deflection readings prior to failure to establish the load-deformation curve. The rate of load application shall permit load and deformation 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 deformations with dial gages or other suitable devices to establish an adequate load-deformation curve. Measure deflections to the nearest 0.01 in. (0.2 mm). Load-measuring devices shall be accurate to within ±2 %. At loadlevels 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.

9. Calculation

9.1 Base evaluation on the mean values resulting from tests of identical specimens or on the results of single tests if only one specimen is involved, in accordance with the provisions of Section 6. The following information is obtained from these tests:

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

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

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

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.

9.1.2 *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 Δ_b is determined using the appropriate equations from Table 1.

9.1.2.1 For use in determining the apparent shear stiffness, calculate the total deflection at any load level, Δ_t, taking account of the support movements, as follows:

$$\text{Cantilever beam test: } \Delta_t = \Delta_3 - \left[\Delta_1 + \frac{a}{b}(\Delta_2 + \Delta_4)\right] \quad (3)$$

$$\text{Simple beam test: } \Delta_t = \frac{(\Delta_2 + \Delta_3 - \Delta_1 - \Delta_4)}{2} \quad (4)$$

where Δ_1, Δ_2, Δ_3, and Δ_4 are measured deformations with appropriate signs at locations indicated in Figs. 2 and 3, and a/b is the ratio of the diaphragm assembly dimensions. The load-deformation curve can then be plotted on the basis of the test results.

9.1.2.2 Calculate the real (Δ_s) and apparent (Δ_s') shear deformations at any load level as follows:

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

$$\Delta_s' = \Delta_t - \Delta_b \quad (6)$$

For the concentrated load conditions shown in Figs. 2 and 3, calculate the apparent shear stiffness, G', of the diaphragm as follows:

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

The test setups and loading pattern used in Figs. 2 and 3 may be used to determine the apparent shear stiffness of the construction.

NOTE 2—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 nontested 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.

10. Report

10.1 The report shall include the following information:

10.1.1 Date of test and of report.

10.1.2 Identification of the specimen (manufacturer, source of supply, dimensions, model, type, materials, other pertinent information, test sponsors, test agency, and their locations).

10.1.3 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.

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

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

10.1.4.2 Details of attachment of specimens in test fixture.

10.1.4.3 Location of load points, strain gages, deflection points, and other items for test as applicable.

10.1.4.4 General ambient conditions at:

(a) (*a*) Date of construction.

(b) (*b*) During curing (time from construction to test).

(c) (*c*) Date and time of test.

10.1.4.5 Details of materials of construction (that is, yield point, tensile strength, compressive strength, density, etc., as appropriate for materials used).

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

10.1.6 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.

10.1.7 *Summary of Results*:

10.1.7.1 Load-deformation graphs visually depicting diaphragm stiffness.

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

10.1.7.3 Other required data in tabular and graphical form.

10.1.7.4 Total time under load at various load levels.

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

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

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

11. Precision and Bias

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

12. Keywords

12.1 connections; framed floor; roof diaphragm; static shear