# Standard Test Methods for
# Fire Tests of Building Construction and Materials[1]

This standard is issued under the fixed designation E119; 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.*

## INTRODUCTION

The performance of walls, columns, floors, and other building members under fire-exposure conditions is an item of major importance in securing constructions that are safe, and that are not a menace to neighboring structures or to the public. Recognition of this is registered in the codes of many authorities, municipal and other. It is important to secure balance of the many units in a single building, and of buildings of like character and use in a community; and also to promote uniformity in requirements of various authorities throughout the country. To do this it is necessary that the fire-resistive properties of materials and assemblies be measured and specified according to a common standard expressed in terms that are applicable alike to a wide variety of materials, situations, and conditions of exposure.

Such a standard is found in the test methods that follow. They prescribe a standard exposing fire of controlled extent and severity. Performance is defined as the period of resistance to standard exposure elapsing before the first critical point in behavior is observed. Results are reported in units in which field exposures can be judged and expressed.

The test methods may be cited as the "Standard Fire Tests," and the performance or exposure shall be expressed as "2-h," "6-h," "½-h," etc.

When a factor of safety exceeding that inherent in the test conditions is desired, a proportional increase should be made in the specified time-classification period.

## 1. Scope

1.1 The test methods described in this fire-test-response standard are applicable to assemblies of masonry units and to composite assemblies of structural materials for buildings, including loadbearing and other walls and partitions, columns, girders, beams, slabs, and composite slab and beam assemblies for floors and roofs. They are also applicable to other assemblies and structural units that constitute permanent integral parts of a finished building.

1.2 It is the intent that classifications shall register comparative performance to specific fire-test conditions during the period of exposure and shall not be construed as having determined suitability under other conditions or for use after fire exposure.

1.3 *This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products or assemblies under actual fire conditions.*

1.4 These test methods prescribe a standard fire exposure for comparing the test results of building construction assemblies. The results of these tests are one factor in assessing predicted fire performance of building construction and assemblies. Application of these test results to predict the performance of actual building construction requires the evaluation of test conditions.

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1.5 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.

1.6 *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.*

1.7 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

C569 Test Method for Indentation Hardness of Preformed Thermal Insulations[3]

D6513 Practice for Calculating the Superimposed Load on Wood-frame Walls for Standard Fire-Resistance Tests

E176 Terminology of Fire Standards

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E814 Test Method for Fire Tests of Penetration Firestop Systems

E2226 Practice for Application of Hose Stream

## 3. Terminology

3.1 *Definitions*—For definitions of terms found in this test method, refer to Terminology E176.

## 4. Significance and Use

4.1 These test methods are intended to evaluate the duration for which the types of building elements noted in 1.1 contain a fire, retain their structural integrity, or exhibit both properties during a predetermined test exposure.

4.2 The test exposes a test specimen to a standard fire controlled to achieve specified temperatures throughout a specified time period. When required, the fire exposure is followed by the application of a specified standard fire hose stream applied in accordance with Practice E2226. The test provides a relative measure of the fire-test-response of comparable building elements under these fire exposure conditions. The exposure is not representative of all fire conditions because conditions vary with changes in the amount, nature and distribution of fire loading, ventilation, compartment size and configuration, and heat sink characteristics of the compartment. Variation from the test conditions or test specimen construction, such as size, materials, method of assembly, also affects the fire-test-response. For these reasons, evaluation of the variation is required for application to construction in the field.

4.3 The test standard provides for the following:

4.3.1 For walls, partitions, and floor or roof test specimens:

4.3.1.1 Measurement of the transmission of heat.

4.3.1.2 Measurement of the transmission of hot gases through the test specimen.

4.3.1.3 For loadbearing elements, measurement of the load carrying ability of the test specimen during the test exposure.

4.3.2 For individual loadbearing members such as beams and columns:

4.3.2.1 Measurement of the load carrying ability under the test exposure with consideration for the end support conditions (that is, restrained or not restrained).

4.4 The test standard does not provide the following:

4.4.1 Information as to performance of test specimens constructed with components or lengths other than those tested.

4.4.2 Evaluation of the degree by which the test specimen contributes to the fire hazard by generation of smoke, toxic gases, or other products of combustion.

4.4.3 Measurement of the degree of control or limitation of *the passage of* smoke or products of combustion through the test specimen.

4.4.4 Simulation of the fire behavior of joints between building elements such as floor-wall or wall-wall, etc., connections.

4.4.5 Measurement of flame spread over the surface of test specimens.

4.4.6 The effect on fire-resistance of conventional openings in the test specimen, that is, electrical receptacle outlets, plumbing pipe, etc., unless specifically provided for in the construction tested. Also see Test Method E814 for testing of fire stops.

## 5. Test Specimen

5.1 The test specimen shall be representative of the construction that the test is intended to assess, as to materials, workmanship, and details such as dimensions of parts, and shall be built under conditions representative of those applied in building construction and operation. The physical properties of the materials and ingredients used in the test specimen shall be determined and recorded.

5.2 The size and dimensions of the test specimen specified herein shall apply for classifying constructions of dimensions within the range employed in buildings. When the conditions of use limit the construction to smaller dimensions, the dimensions of the test specimen shall be reduced proportionately for a test qualifying them for such restricted use.

5.3 Test specimens designed with a built-up roof shall be tested with a roof covering of 3-ply, 15-lb (6.8-kg) type felt, with not more than 120 lb (54 kg) per square (100 ft$^2$ (9 m$^2$)) of hot mopping asphalt without gravel surfacing. Tests with this covering do not preclude the field use of other coverings with a larger number of plys of felt, with a greater amount of asphalt or with gravel surfacing.

5.4 Roofing systems designed for other than the use of built-up roof coverings shall be tested using materials and details of construction representative of field application.

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

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

## 6. Protection and Conditioning of Test Specimen

6.1 Protect the test specimen during and after fabrication to ensure its quality and condition at the time of test. The test specimen shall not be tested until its required strength has been attained, and, until an air-dry condition has been achieved in accordance with the requirements given in 6.2-6.4. Protect the testing equipment and test specimen undergoing the fire-resistance test from any condition of wind or weather that is capable of affecting results. The ambient air temperature at the beginning of the test shall be within the range of 50 to 90°F (10 to 32°C). The velocity of air across the unexposed surface of the test specimen, measured just before the test begins, shall not exceed 4.4 ft (1.3 m/s), as determined by an anemometer placed at right angles to the unexposed surface. When mechanical ventilation is employed during the test, an air stream shall not be directed across the surface of the test specimen.

6.2 Prior to the fire-resistance test, condition test specimens with the objective of providing moisture condition within the test specimen representative of that in similar construction in buildings. For purposes of standardization, this condition is established at equilibrium resulting from conditioning in an ambient atmosphere of 50 % relative humidity at 73°F (Note 1).

6.2.1 With some constructions it is difficult or impossible to achieve such uniformity. Where this is the case, test specimens are tested when the dampest portion of the test specimen, or the portion at 6-in. (152-mm) depth below the surface of massive constructions, has achieved a moisture content corresponding to conditioning to equilibrium with air in the range of 50 to 75 % relative humidity at 73 ± 5°F (23 ± 3°C).

6.2.2 When evidence is shown that test specimens conditioned in a heated building will fail to meet the requirements of 6.2 after a 12-month conditioning period, or in the event that the nature of the construction is such that it is evident that conditioning of the test specimen interior is prevented by hermetic sealing, the moisture condition requirements of 6.2 are permitted to be waived, and either 6.2.2.1 or 6.2.2.2 shall apply.

6.2.2.1 Alternative conditioning methods are permitted to be used to achieve test specimen equilibrium prescribed in 6.2 (Note 2), or

6.2.2.2 The specimen tested when its strength is at least equal to its design strength after a minimum 28 day conditioning period.

6.3 Avoid conditioning procedures that will alter the structural or fire-resistance characteristics of the test specimen from those produced as the result of conditiong in accordance with procedures given in 6.2.

6.4 Information on the actual moisture content and distribution within the test specimen shall be obtained within 72 h prior to the fire. Include this information in the test report (Note 3).

NOTE 1—A recommended method for determining the relative humidity within a hardened concrete test specimen with electric sensing elements is described in Appendix I of the paper by Menzel, C. A., "A Method for Determining the Moisture Condition of Hardened Concrete in Terms of Relative Humidity," *Proceedings*, ASTM, Vol 55, 1955, p. 1085. A similar procedure with electric sensing elements is permitted to be used

to determine the relative humidity within test specimens made with other materials.

With wood constructions, the moisture meter based on the electrical resistance method can be used, when appropriate, as an alternative to the relative humidity method to indicate when wood has attained the proper moisture content. Electrical methods are described on page 12-2 of the 1999 edition of the *Wood Handbook of the Forest Products Laboratory*, U.S. Department of Agriculture. The relationships between relative humidity and moisture content are given in Table 3-4 on p. 3-7. This indicates that wood has a moisture content of 13 % at a relative humidity of 70 % for a temperature of 70 to 80°F (21 to 27°C).

NOTE 2—An example where alternative conditioning may be employed is where concrete specimens are conditioned at elevated temperatures in a "heated building" to more rapidly obtain the conditions described in 6.2. In such cases, temperatures other than 73°F are used to reach a maximum 50 % relative humidity.

NOTE 3—If the moisture condition of the test specimen is likely to change drastically from the 72-h sampling time prior to test, the sampling should be made not later than 24 h prior to the test.

## 7. Control

7.1 *Fire-Resistance Test*:

7.1.1 *Time-Temperature Curve*:

7.1.1.1 The furnace temperatures shall be controlled to follow the standard time-temperature curve shown in Fig. 1. The points on the curve that determine its character are:

| | |
|---|---|
| 1000°F (538°C) | at 5 min |
| 1300°F (704°C) | at 10 min |
| 1550°F (843°C) | at 30 min |
| 1700°F (927°C) | at 1 h |
| 1850°F (1010°C) | at 2 h |
| 2000°F (1093°C) | at 4 h |
| 2300°F (1260°C) | at 8 h or over |

7.1.1.2 For a more detailed definition of the time-temperature curve, see Appendix X1.

NOTE 4—*Recommendations for Recording Fuel Flow to Furnace Burners*—The following provides guidance on the desired characteristics of instrumentation for recording the flow of fuel to the furnace burners. Fuel flow data may be useful for a furnace heat balance analysis, for
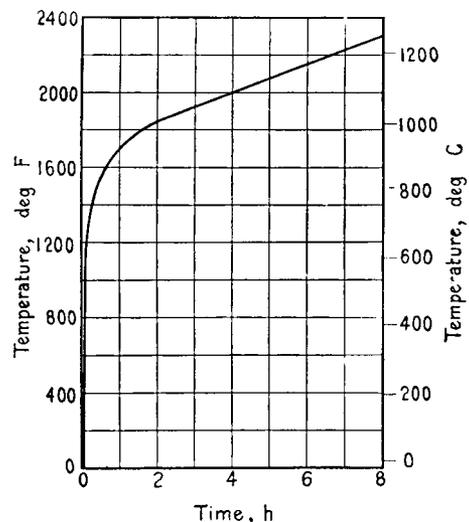


**FIG. 1 Time-Temperature Curve**

measuring the effect of furnace or control changes, and for comparing the performance of test specimens of different properties in the fire-resistance test.[4]

Record the integrated (cumulative) flow of gas (or other fuel) to the furnace burners at 10 min, 20 min, 30 min, and every 30 min thereafter or more frequently. Total gas consumed during the total test period is also to be determined. A recording flow meter has advantages over periodic readings on an instantaneous or totalizing flow meter. Select a measuring and recording system to provide flow rate readings accurate to within ±5 %.

Report the type of fuel, its higher (gross) heating value, and the fuel flow (corrected to standard conditions of 60°F (16°C) and 30.0 in. Hg) as a function of time.

7.2 *Furnace Temperatures*:

7.2.1 The temperature fixed by the curve shall be the average temperature from not fewer than nine thermocouples for a floor, roof, wall, or partition and not fewer than eight thermocouples for a column. Furnace thermocouples shall be symmetrically disposed and distributed to show the temperature near all parts of the test specimen, the thermocouples being enclosed in protection tubes of such materials and dimensions that the time constant of the protected thermocouple assembly lies within the range from 5.0 to 7.2 min (Note 5). The exposed length of the pyrometer tube and thermocouple in the furnace chamber shall be not less than 12 in. (305 mm). It is not prohibited to use other types of protecting tubes or pyrometers that, under test conditions, give the same indications as the above standard within the limit of accuracy that applies for furnace-temperature measurements.

7.2.1.1 For walls and partitions, the furnace thermocouples shall be placed 6 in. (152 mm) away from the exposed face of the test specimen at the beginning of the test. For all other test specimens, the furnace thermocouples shall be placed 12 in. (305 mm) from the exposed face of the test specimen at the beginning of the test. During the test, furnace thermocouples shall not touch the test specimen in the event of the test specimen's deflection.

Note 5—A typical thermocouple assembly meeting these time constant requirements may be fabricated by fusion-welding the twisted ends of No. 18 gage Chromel-Alumel wires, mounting the leads in porcelain insulators and inserting the assembly so the thermocouple bead is ½ in. (13 mm) from the sealed end of a standard weight nominal ½-in. iron, steel, or Inconel[5] pipe. The time constant is either measured or calculated from knowledge of its physical and thermal properties. The time constant for this and for several other thermocouple assemblies was measured in 1976.[6]

7.2.2 The furnace temperatures shall be read at intervals not exceeding 5 min during the first 2 h, and thereafter the intervals shall not exceed 10 min.

7.2.3 The accuracy of the furnace control shall be such that the area under the time-temperature curve, obtained by aver-

aging the results from the pyrometer readings, is within 10 % of the corresponding area under the standard time-temperature curve shown in Fig. 1 for fire-resistance tests of 1 h or less duration, within 7.5 % for those over 1 h and not more than 2 h, and within 5 % for tests exceeding 2 h in duration.

7.3 *Test Specimen Temperatures*:

7.3.1 *Temperatures Measurement of the Unexposed Surfaces of Floors, Roofs, Walls, and Partitions*:

7.3.1.1 Temperatures of unexposed test specimen surfaces shall be measured with thermocouples placed under dry, felted pads meeting the requirements listed in Annex A1. The wire leads of the thermocouple shall be positioned under the pad and be in contact with the unexposed test specimen surface for not less than 3½ in. (89 mm). The hot junction of the thermocouple shall be placed approximately under the center of the pad. The pad shall be held firmly against the surface, and shall cover the thermocouple. The wires for the thermocouple in the length covered by the pad shall be not heavier than No. 18 B&S gage (0.04 in.) (1.02 mm) and shall be electrically insulated with heat-resistant or moisture-resistant coatings, or both.

Note 6—For the purpose of testing roof assemblies, the unexposed surface shall be defined as the surface exposed to ambient air.

7.3.1.2 Temperatures shall be recorded at not fewer than nine points on the surface. Five of these shall be symmetrically disposed, one to be approximately at the center of the test specimen, and four at approximately the center of its quarter sections. The other four shall be located to obtain representative information on the performance of the test specimen. The thermocouples shall not be located closer to the edges of the test specimen than one and one-half times the thickness of the test specimen, or 12 in. (305 mm). Exception: those cases in which there is an element of the construction that is not otherwise represented in the remainder of the test specimen. The thermocouples shall not be located opposite or on top of beams, girders, pilasters, or other structural members if temperatures at such points will be lower than at more representative locations. The thermocouples shall not be located over fasteners such as screws, nails, or staples that will be higher or lower in temperature than at a more representative location if the aggregate area of any part of such fasteners on the unexposed surface is less than 1 % of the area within any 6-in. (152-mm) diameter circle, unless the fasteners extend through the assembly.

7.3.1.3 Temperatures shall be measured and recorded at intervals not greater than 30 s.

7.3.1.4 Where the conditions of acceptance place a limitation on the rise of temperature of the unexposed surface, the temperature end point of the fire-resistance period shall be determined by the average of the measurements taken at individual points; except that if a temperature rise 30 % in excess of the specified limit occurs at any one of these points, the remainder shall be ignored and the fire-resistance period judged as ended.

7.3.2 *Temperature Measurement of Non-loaded Structural Steel Columns (Alternative Test of Steel Columns)*:

7.3.2.1 Measure the temperature of the steel with not fewer than three thermocouples at each of four levels. The upper and lower levels shall be 2 ft (0.6 m) from the ends of the steel

[4] Harmathy, T. Z., "Design of Fire Test Furnaces," *Fire Technology*, Vol. 5, No. 2, May 1969, pp. 146–150; Seigel, L. G., "Effects of Furnace Design on Fire Endurance Test Results," *Fire Test Performance, ASTM STP 464*, ASTM, 1970, pp. 57–67; and Williamson, R. B., and Buchanan, A. H., "A Heat Balance Analysis of the Standard Fire Endurance Test."

[5] Inconel is a registered tradename of INCO Alloys, Inc., 3800 Riverside Dr., P. O. Box 1958, Huntingdon, WV 25720.

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E05-1001.

column, and the two intermediate levels shall be equally spaced. For situations in which the protection material thickness is not uniform along the test specimen length, at least one of the levels at which temperatures are measured shall include the point of minimum cover. Place the thermocouples at each level to measure temperatures of the component elements of the steel section.

7.3.3 *Temperature Measurement of the Components of Floors and Roofs*:

7.3.3.1 For steel floor or roof units, locate four thermocouples on each section (a section to comprise the width of one unit), one on the bottom plane of the unit at an edge joint, one on the bottom plane of the unit remote from the edge, one on a side wall of the unit, and one on the top plane of the unit, The thermocouples shall be applied, where practicable, to the surface of the units remote from fire and spaced across the width of the unit. No more than four or fewer than two sections need be so instrumented in each representative span. Locate the groups of four thermocouples in representative locations spaced across the width of the unit. Typical thermocouple locations for a unit section are shown in Fig. 2.

7.3.3.2 For test specimens employing structural members (beams, open-web steel joists, etc.) spaced at more than 4 ft (1.2 m) on centers, measure the temperature of the steel in these members with four thermocouples at each of three or more sections equally spaced along the length of the members. For situations in which the protection material thickness is not uniform along the test specimen length, at least one of the sections at which temperatures are measured shall include the point of minimum cover.

7.3.3.3 For test specimens employing structural members (beams, open-web steel joists, etc.) spaced at 4 ft (1.2 m) on center or less, measure the temperature of the steel in these members with four thermocouples placed on each member. No more than four members shall be so instrumented. Place the thermocouples at locations, such as at mid-span, over joints in the ceiling, and over light fixtures. It shall not be required that all four thermocouples be located at the same section.
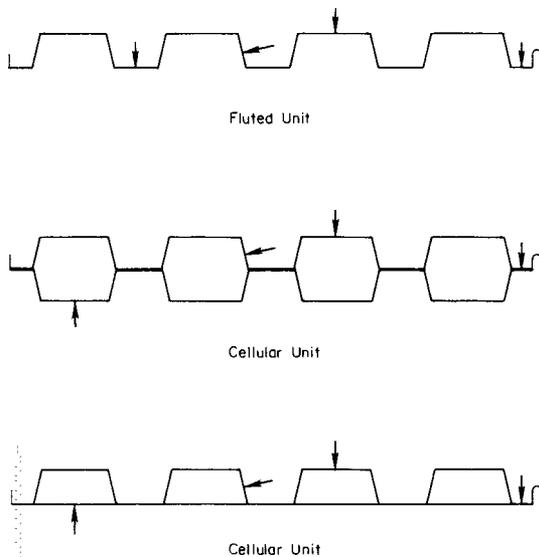
7.3.3.4 For steel structural members, locate thermocouples as shown in Fig. 3: two on the bottom of the bottom flange or chord, one on the web at the center, and one on the top flange or chord.

7.3.3.5 For reinforced or pre-stressed concrete structural members, locate thermocouples on each of the tension reinforcing elements, unless there are more than eight such elements, in which case place thermocouples on eight elements selected in such a manner as to obtain representative temperatures of all the elements.

7.3.4 *Temperature Measurement of Loaded Restrained Beams*:

7.3.4.1 Measure the temperature of the steel structural members with four thermocouples at each of three or more sections equally spaced along the length of the members. For situations in which the protection material thickness is not uniform along the test specimen length, at least one of the sections at which temperatures are measured shall include the point of minimum cover.

7.3.4.2 For steel structural members, locate the thermocouples as shown in Fig. 3: two on the bottom of the bottom flange or chord, one on the web at the center, and one on the bottom of the top flange or chord.

7.3.4.3 For reinforced or pre-stressed concrete structural members, locate thermocouples on each of the tension reinforcing elements unless there are more than eight such elements, in which case place thermocouples on eight elements selected in such a manner as to obtain representative temperatures of all the elements.

7.3.5 *Temperature Measurement of Non-loaded Structural Steel Beams and Girders*:

7.3.5.1 Measure the temperature of the steel with not fewer than four thermocouples at each of four sections equally spaced along the length of the member no nearer than 2 ft (0.6 m) from the inside face of the furnace. For situations in which the protection material thickness is not uniform along the test specimen length, at least one of the sections at which temperatures are measured shall include the point of minimum cover. Place the thermocouples at each section to measure temperatures of the component elements of the steel section.
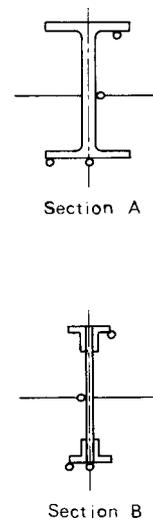


Fluted Unit

Cellular Unit

Cellular Unit

**FIG. 2 Typical Location of Thermocouples**



Section A

Section B

**FIG. 3 Typical Location of Thermocouple**

7.3.6 *Temperature Measurement of Protective Membranes*:

7.3.6.1 The temperature of protective membranes shall be measured with thermocouples, the measuring junctions of which are in intimate contact with the exposed surface of the elements being protected. The diameter of the wires used to form the thermo-junction shall not be greater than the thickness of sheet metal framing or panel members to which they are attached and in no case greater than No. 18 B&S gage (0.040 in.) (1.02 mm). The lead shall be electrically insulated with heat-resistant and moisture-resistant coatings.

7.3.6.2 For each class of elements being protected, temperature readings shall be taken at not fewer than five representative points. Thermocouples shall be located not less than 12 in. (305 mm) from the edges of the test specimen. An exception is made in those cases in which there is an element or feature of the construction that is not otherwise represented in the test specimen. None of the thermocouples shall be located opposite, on top of, or adjacent to fasteners such as screws, nails, or staples when such locations are excluded for thermocouple placement on the unexposed surface of the test specimen in 7.3.1.2.

7.3.6.3 Thermocouples shall be located to obtain information on the temperature at the interface between the exposed membrane and the substrate or element being protected.

7.3.6.4 Temperature readings shall be taken at intervals not exceeding 5 min.

7.4 *Loading*:

7.4.1 *Loading of Loadbearing Walls and Partitions*:

7.4.1.1 Throughout the fire-resistance and hose-stream tests, apply a superimposed load to the test specimen to simulate a maximum-load condition. This load shall be the maximum-load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load is applied (Note 7). A double wall assembly shall be loaded during the test to simulate field-use conditions, with either side loaded separately or both sides together (Note 8). The method used shall be reported.

NOTE 7—Examples of calculating the superimposed load for bearing lightweight wood-frame walls using the allowable stress design method and load and resistance factor design method are provided in X7.5. Also, an example for calculating the superimposed load for bearing lightweight cold-formed steel walls using the load and resistance factor design method is provided in X7.6.

NOTE 8—The choice depends on the intended use, and whether the load on the exposed side, after it has failed, will be transferred to the unexposed side. If, in the intended use, the load from the structure above is supported by both walls as a unit and would be or is transferred to the unexposed side in case of collapse of the exposed side, both walls should be loaded in the test by a single unit. If, in the intended use the load from the structure above each wall is supported by each wall separately, the walls should be loaded separately in the test by separate load sources. If the intended use of the construction system being tested involved situations of both loading conditions described above, the walls should be loaded separately in the test by separate load sources. In tests conducted with the walls loaded separately, the condition of acceptance requiring the walls to maintain the applied load shall be based on the time at which the first of either of the walls fails to sustain the load.

7.4.2 *Loading of Columns*:

7.4.2.1 Throughout the fire-resistance test, apply a superimposed load to the test specimen to simulate a maximum-load condition. This load shall be the maximum-load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load is applied (Note 9). Make provision for transmitting the load to the exposed portion of the column without increasing the effective column length.

NOTE 9—An example for calculating the superimposed load for concrete columns using the load and resistance factor design method is provided in X7.4.

7.4.2.2 As an optional procedure, subject the column to 1-¾ times its designed working load before undertaking the fire-resistance test. The fact that such a test has been made shall not be construed as having had a deleterious effect on the fire-resistance test performance.

7.4.3 *Loading of Floors and Roofs*:

7.4.3.1 Throughout the fire-resistance test, apply a superimposed load to the test specimen to simulate a maximum-load condition. This load shall be the maximum-load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load is applied (Note 10).

NOTE 10—Examples for calculating the superimposed load for lightweight wood-frame floors using the allowable stress design method and load and resistance factor design method are provided in X7.5. Also, an example for calculating the superimposed load for lightweight cold-formed steel floors using the load and resistance factor design method is provided in X7.6.

7.4.4 *Loading of Beams*:

7.4.4.1 Throughout the fire-resistance test, apply a superimposed load to the test specimen to simulate a maximum-load condition. This load shall be the maximum load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load is applied.

7.5 *Cotton Pad Test*:

7.5.1 Where required by the conditions of acceptance in other sections of this standard to determine that the test specimen has not allowed the passage of gases hot enough to ignite a cotton pad, the cotton pad test shall be conducted in accordance with 7.5.7 during the fire-resistance test whenever a crack, hole, opened joint, or other similar void or defect through which hot gases are capable of passing is observed in the unexposed surface of the test specimen.

7.5.2 The cotton pad test shall be conducted using a cotton pad as described in 7.5.3 and 7.5.4 in a wire frame provided with a handle as described in 7.5.5.

7.5.3 The cotton pad shall comply with the physical characteristics described in 7.5.3.1 through 7.5.3.3.

7.5.3.1 The cotton pad shall be nominally 4 by 4 in. (100 by 100 mm) by 0.75 in. (19 mm) thick.

7.5.3.2 The cotton pad shall consist of new, undyed, soft cotton fibers, without any admixture of artificial fibers.

7.5.3.3 The cotton pad shall weigh 0.12 ± 0.02 oz (3.5 ± 0.5 g).

7.5.4 The cotton pad shall be conditioned prior to the test by drying in an oven at 212 ± 9°F (100 ± 5°C) for a period of not less than 30 min. Immediately upon removal from the drying

oven, the cotton pad shall be stored in a desiccator for a period of not less than 24 h prior to the fire-resistance test.

7.5.5 The frame used to hold the cotton pad for the purpose of the cotton waste test shall be constructed using No. 16 AWG (0.05 in.) (1.3 mm) steel wire which has been fastened to a handle that has a length that reaches all points on the unexposed surface of the test specimen. See Fig. 4.

7.5.6 Ignition of the cotton pad shall be defined as glowing, flaming or smoldering of the cotton pad. Charring of the cotton pad shall not be an indication of ignition.

7.5.7 *Ingition Test Procedure*:

7.5.7.1 Conduct the cotton pad test using an unused cotton pad.

7.5.7.2 Position the cotton pad directly over the observed crack, hole, opened joint, or other similar void or defect in the unexposed surface of the test specimen, approximately 1 ± ⅛ in. (25 ± 3 mm) from the surface, for a period of 30 ± 1 s or utnil ignition of the cotton pad, whichever occurs first.

7.5.7.3 All test locations previously tested in accordance with 7.5.7.2 shall be retested as close as practical to the end of the desired fire-resistance period. An unused cotton pad shall be positioned over each previously tested location on the unexposed surface of the test specimen.

7.5.7.4 If ignition of the cotton pad occurs, record the time at which ignition occurs and report the description of the crack, hole, opened joint, or other similar void or defect and the location where it occurs.
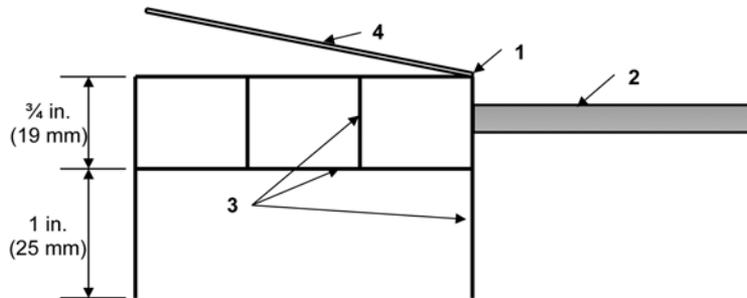
7.6 *Hose Stream*:

7.6.1 Where required by the conditions of acceptance, a test shall be conducted to subject the test specimen described in 7.6.2 or 7.6.3 to the impact, erosion, and cooling effects of a hose stream. The hose stream shall be applied in accordance with Practice E2226. The water pressure and duration of application shall be as prescribed in Table 1 of Practice E2226.

7.6.1.1 *Exemption*—The hose-stream test shall not be required in the case of test specimens having a resistance period, indicated in the fire-resistance test, of less than 1 h.

7.6.2 The hose stream test shall be conducted on a duplicate test specimen.
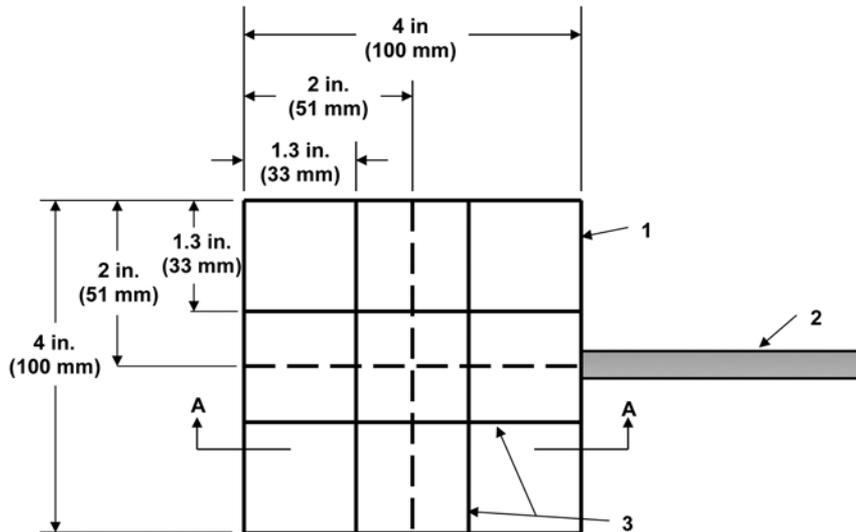


Note: All dimensions shall have a tolerance of ± 1/16 in. (1.6 mm)

Section A-A

1. Hinge
2. Handle
3. 16 AWG (0.05 in.)(1.3 mm) diameter steel framework
4. Hinged lid with latch

FIG. 4 Typical Cotton Waste Pad Holder

7.6.2.1 The duplicate test specimen shall be exposed to the effects of the hose stream immediately after being subjected to a fire-resistance test for a time period of one-half the fire-resistance classification period determined from the fire-resistance test on the initial test specimen.

7.6.2.2 The length of time that the duplicate test specimen is subjected to the fire- resistance test shall not exceed 1 h.

7.6.3 *Optional Program*—As an alternative procedure, conduct the hose stream test on the initially tested test specimen immediately following its fire-resistance test.

## 8. Procedure

8.1 *General*:

8.1.1 Continue the fire-resistance test on the test specimen with its applied load, if any, until failure occurs, or until the test specimen has withstood the test conditions for a period equal to that herein specified in the conditions of acceptance for the given type of building element.

8.1.2 Continue the test beyond the time fire-resistance classification is determined, when the purpose in doing so is to obtain additional information.

8.2 *Tests of Loadbearing Walls and Partitions*:

8.2.1 *Size of Test Specimen* —The area exposed to fire shall be not less than 100 ft$^2$ (9 m$^2$), with neither dimension less than 9 ft (2.7 m). The test specimen shall not be restrained on its vertical edges.

8.2.2 *Temperatures*—Determine temperatures in accordance with 7.3.1.

8.2.3 *Loading*—Load the test specimen in accordance with 7.4.1.

8.2.4 *Conditions of Acceptance*—Regard the test as successful if the following conditions are met:

8.2.4.1 The test specimen shall have sustained the applied load during the fire-resistance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

8.2.4.2 The test specimen shall have sustained the applied load during the fire and hose stream test as specified in 7.6, without passage of flame, of gases hot enough to ignite cotton waste, or with the passage of water of from the hose stream. The test specimen shall be considered to have failed the hose stream test if an opening develops that permits a projection of water from the stream beyond the unexposed surface during the time of the hose stream test.

8.2.4.3 Transmission of heat through the wall or partition during the fire-resistance test shall not raise the temperature on its unexposed surface more than 250°F (139°C) above its initial temperature.

8.3 *Tests of Non-Loadbearing Walls and Partitions*:

8.3.1 *Size of Test Specimen*—The area exposed to fire shall be not less than 100 ft$^2$ (9 m$^2$), with neither dimension less than 9 ft (2.7 m). Restrain the test specimen on all four edges.

8.3.2 *Temperatures*—Determine temperatures in accordance with 7.3.1.

8.3.3 *Loading*—There is no requirement for loading.

8.3.4 *Conditions of Acceptance*—Regard the test as successful if the following conditions are met:

8.3.4.1 The test specimen has withstood the fire-resistance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

8.3.4.2 The test specimen has withstood the fire and hose stream test as specified in 7.6, without passage of flame, of gases hot enough to ignite cotton waste, or of passage of water from the hose stream. The test specimen shall be considered to have failed the hose stream test if an opening develops that permits a projection of water from the stream beyond the unexposed surface during the time of the hose stream test.

8.3.4.3 Transmission of heat through the wall or partition during the fire-resistance test shall not raise the temperature on its unexposed surface more than 250°F (139°C) above its initial temperature.

8.4 *Tests of Loaded Columns*:

8.4.1 *Size of Test Specimen*—The length of the column exposed to fire shall be not less than 9 ft (2.7 m). Apply the contemplated details of connections and their protection, if any, according to the methods of field practice. The column shall be vertical during the fire exposure.

8.4.2 *Temperatures*—There is no requirement for temperature measurements.

8.4.3 *Loading*—Load the test specimen in accordance with 7.4.2.

8.4.4 *Condition of Acceptance*—Regard the test as successful if the column sustains the applied load during the fire-resistance test for a period equal to that for which classification is desired.

8.5 *Alternative Test of Non-loaded Steel Columns*:

8.5.1 *Application*—This alternative test procedure is used to evaluate the protection of steel columns without application of design load, provided that the protection material is not required by design to function structurally in resisting loads.

8.5.2 *Size and Characteristics of Test Specimen*:

8.5.2.1 The length of the protected column shall be at least 8 ft (2.4 m). The column shall be vertical during the fire exposure.

8.5.2.2 Restrain the applied protection material against longitudinal temperature expansion greater than that of the steel column with rigid steel plates or reinforced concrete attached to the ends of the steel column before the protection is applied. The size of the plates or amount of concrete shall provide direct bearing for the entire transverse area of the protection material.

8.5.2.3 Provide the ends of the test specimen, including the means for restraint, with thermal insulation to limit direct heat transfer from the furnace.

8.5.2.4 Throughout the fire-resistance test, expose the test specimen to fire on all sides for its full length.

8.5.3 *Temperatures*—Determine temperatures in accordance with 7.3.2.

8.5.4 *Loading*—There is no requirement for loading.

8.5.5 *Conditions of Acceptance*—Regard the test as successful if the transmission of heat through the protection during the period of fire exposure for which classification is desired does not raise the average (arithmetical) temperature of the steel at

any one of the four levels above 1000°F (538°C), or does not raise the temperature above 1200°F (649°C) at any one of the measured points.

8.6 *Tests of Floors and Roofs*:

8.6.1 *Application*—This procedure is applicable to floor and roof assemblies with or without attached, furred, or suspended ceilings and requires the application of the fire exposure to the underside of the test specimen.

8.6.1.1 Two fire-resistance classifications shall be determined for test specimens restrained against thermal expansion: a restrained assembly classification based upon the conditions of acceptance specified in 8.6.5 and an unrestrained assembly classification based upon the conditions of acceptance specified in 8.6.6.

NOTE 11—See Appendix X3, which is intended as a guide for assisting the user of this test method in determining the conditions of thermal restraint applicable to floor and roof constructions and individual beams in actual building construction.

8.6.1.2 An unrestrained assembly classification shall be determined for test specimens not restrained against thermal expansion based upon the conditions of acceptance specified in 8.6.6.1 and 8.6.6.2.

8.6.1.3 As an alternative classification procedure for loaded restrained beams specified in 8.7, an individual unrestrained beam classification shall be permitted for beams from restrained or unrestrained floor or roof specimens, based on the conditions of acceptance specified in 8.7.6. The unrestrained beam classification so derived shall be applicable to beams used with a floor or roof construction that has comparable or greater capacity for heat dissipation than that with which it was tested. The fire-resistance classification developed by this test method shall not be applicable to sizes of beams smaller than those tested.

8.6.2 *Size and Characteristics of Test Specimen*:

8.6.2.1 The area exposed to fire shall be not less than 180 ft$^2$ (16 m$^2$) with neither dimension less than 12 ft (3.7 m). Structural members, if a part of the test specimen, shall be positioned within the combustion chamber and have a side clearance of not less than 8 in. (203 mm) from the chamber walls.

8.6.2.2 Test specimens for which a restrained rating is desired shall be so restrained during the test exposure.

8.6.3 *Temperatures*—Determine temperatures in accordance with 7.3.1 and 7.3.3.

8.6.4 *Loading*—Load the test specimen in accordance with 7.4.3.

8.6.5 *Conditions of Acceptance—Restrained Assembly Classification*—In obtaining a restrained assembly classification, the following conditions shall be met:

8.6.5.1 The test specimen shall have sustained the applied load during its classification period without developing unexposed surface conditions which will ignite cotton waste.

8.6.5.2 Transmission of heat through the test specimen during its classification period shall not raise the average temperature on its unexposed surface more than 250°F (139°C) above its initial temperature.

8.6.5.3 For test specimens employing steel structural members (beams, open-web steel joists, etc.) spaced more than 4 ft

(1.2 m) on centers, the test specimen shall achieve a restrained assembly classification on the basis of the temperature of the steel structural members not having exceeded 1300°F (704°C) at any location and not having the average temperature recorded by four thermocouples at any section exceed 1100°F (593°C) during the first hour. For restrained assembly classifications greater than 1 h, these temperature criteria shall apply for a period of one half the classification period of the floor or roof construction or 1 h, whichever is the greater.

8.6.5.4 For test specimens employing steel structural members (beams, open-web steel joists, etc.) spaced 4 ft (1.2 m) or less on centers, the test specimen shall achieve a restrained assembly classification on the basis of the average temperature of the steel structural members, as recorded by all thermocouples, not having exceeded 1100°F (593°C) during the first hour. For restrained assembly classifications greater than 1 h, this temperature shall apply for a period of one half the classification period of the floor or roof construction or 1 h, whichever is the greater.

8.6.5.5 For test specimens employing conventionally designed concrete beams spaced more than 4 ft (1.2 m) on centers, the test specimen shall achieve a restrained assembly classification on the basis of the average temperature of the tension steel at any section of the concrete beam not having exceeded 800°F (427°C) for cold-drawn prestressing steel or 1100°F (593°C) for reinforcing steel during the first hour. For restrained assembly classifications greater than 1 h, these temperature criteria shall apply for a period of one half the classification period of the floor or roof construction or 1 h, whichever is the greater.

8.6.5.6 The fire resistance classification of a restrained assembly shall be reported as that developed by applying the conditions of acceptance specified in 8.6.5.1 and 8.6.5.2, and where applicable, to the conditions in 8.6.5.3 through 8.6.5.5.

8.6.6 *Conditions of Acceptance—Unrestrained Assembly Classification*—In obtaining an unrestrained assembly classification, the following conditions shall be met:

8.6.6.1 The test specimen shall have sustained the applied load during its classification period without developing unexposed surface conditions which will ignite cotton waste.

8.6.6.2 Transmission of heat through the test specimen during its classification period shall not raise the average temperature on its unexposed surface more than 250°F (139°C) above its initial temperature.

8.6.6.3 For test specimens employing steel structural members (beams, open-web steel joists, etc.), spaced more than 4 ft (1.2 m) on centers, the temperature of the steel structural members shall not have exceeded 1300°F (704°C) at any location during the classification period nor shall the average temperature recorded by four thermocouples at any section have exceeded 1100°F (593°C) during the classification period.

8.6.6.4 For test specimens employing steel structural members (beams, open-web steel joists, etc.), spaced 4 ft (1.2 m) or less on center, the average temperature recorded by all joist or beam thermocouples shall not have exceeded 1100°F (593°C) during the classification period.

8.6.6.5 For test specimens employing conventionally designed concrete structural members (excluding cast-in-place

concrete roof or floor slabs having spans equal to or less than those tested), the average temperature of the tension steel at any section shall not have exceeded 800°F (427°C) for cold-drawn prestressing steel or 1100°F (593°C) for reinforcing steel during the classification period.

8.6.6.6 For test specimens employing steel floor or roof units intended for use in spans greater than those tested, the average temperature recorded by all thermocouples located on any one span of the floor or roof units shall not have exceeded 1100°F (593°C) during the classification period.

8.6.6.7 The fire-resistance classification of an unrestrained assembly shall be reported as that developed by applying the conditions of acceptance specified in 8.6.6.1 and 8.6.6.2 and, where applicable, to the conditions in 8.6.6.3 through 8.6.6.6.

8.7 *Tests of Loaded Restrained Beams*:

8.7.1 *Application*:

8.7.1.1 An individual restrained beam classification shall be determined from tests by this procedure for loaded restrained beams based upon the conditions of acceptance specified in 8.7.5. The restrained beam classification so derived shall be applicable to beams used with a floor or roof construction that has comparable or greater capacity for heat dissipation than that with which it was tested. The fire-resistance classification developed by this method shall not be applicable to sizes of beams smaller than those tested.

8.7.1.2 As an alternative classification procedure for loaded restrained beams specified in 8.7.1.1, an individual unrestrained beam classification shall be determined from tests by this procedure for loaded restrained beams, based upon the conditions of acceptance specified in 8.7.6. The unrestrained beam classification so derived shall be applicable to beams used with a floor or roof construction that has comparable or greater capacity for heat dissipation than that with which it was tested. The fire-resistance classification developed by this test method shall not be applicable to sizes of beams smaller than those tested.

8.7.2 *Size and Characteristics of Test Specimen*:

8.7.2.1 The test specimen shall be tested in a horizontal position and its length exposed to the fire shall be not less than 12 ft (3.7 m).

8.7.2.2 For test specimens tested with a representative section of a floor or roof assembly, such sections shall not be wider than 7 ft (2.1 m) and shall be symmetrically located with reference to the beam.

8.7.2.3 Restrain the beam and those portions of the floor or roof assembly that are integral to the structural design of the beam, against the potential effects from thermally induced longitudinal expansion. The restraint shall replicate the restraint expected to occur in building construction. Do not support or restrain portions of the perimeter of the floor or roof assembly that are not integral to the structural beam design.

NOTE 12—Composite steel construction and concrete construction that incorporate beams as an integral part of the structural design are examples where portions of the floor or roof assembly that are attached to the beam should be restrained against thermal expansion. Restraining the portion of the concrete slab that is integral to the structural design of the beam serves the intent of providing restraint against thermal rotation of the test specimen. It is not permitted to restrain portions of the perimeter of the

test specimen other than that part that is integral to the structural design of the beam.

8.7.3 *Temperatures*—Determine temperatures in accordance with 7.3.4.

8.7.4 *Loading*—Load the test specimen in accordance with 7.4.4.

8.7.5 *Conditions of Acceptance—Restrained Beam Classification*—In obtaining a restrained beam classification, the following conditions shall be met:

8.7.5.1 The test specimen shall have sustained the applied load during its classification period.

8.7.5.2 For steel beams: during the first hour or during the first half of its classification period, whichever is the greater, the temperature of the steel shall not have exceeded 1300°F (704°C) at any location nor shall the average temperature recorded by four thermocouples at any section have exceeded 1100°F (593°C).

8.7.6 *Alternative Conditions of Acceptance—Unrestrained Beam Classification*—In obtaining an unrestrained beam classification, the following conditions shall be met:

8.7.6.1 The test specimen shall have sustained the applied load during its classification period.

8.7.6.2 For steel beams, the temperature of the steel shall not have exceeded 1300°F (704°C) at any location nor shall the average temperature recorded by four thermocouples at any section have exceeded 1100°F (593°C) during its classification period.

8.7.6.3 For conventionally designed concrete beams, the average temperature of the tension steel at any section shall not have exceeded 800°F (427°C) for cold-drawn prestressing steel or have exceeded 1100°F (593°C) for reinforcing steel during its classification period.

8.8 *Tests of Loaded Unrestrained Beams Supporting Floors and Roofs*:

8.8.1 *Application*:

8.8.1.1 An individual unrestrained beam fire resistance rating is obtained by this procedure for loaded unrestrained beams based upon the conditions of acceptance specified in 8.8.4. The fire resistance rating so derived shall be applicable to the beam when used with a floor or roof construction which has a comparable or greater capacity for heat dissipation from the beam than the floor or roof with which it was tested.

8.8.2 *Size and Characteristics of Specimen*:

8.8.2.1 The clear span ($L_c$) of beam exposed to the fire shall be not less than 12 ft (3.7 m) and the member shall be tested in a horizontal position.

8.8.2.2 For specimens tested with a representative section of a floor or roof assembly, such sections shall be not more than 7 ft (2.1 m) wide and symmetrically located with reference to the beam.

8.8.2.3 The beam and the representative section of the floor or roof assembly shall not be restrained prior to the start of the test or restrained against the potential effects from thermally induced longitudinal movement at any time during the test.

8.8.2.4 Provide bearing support for the beam and the ends of the representative section of the floor or roof assembly along its edges perpendicular to the beam. The representative section of

the floor or roof assembly shall not be supported along its edges parallel to the beam.

8.8.2.5 The total length of the specimen shall not exceed its clear span ($L_c$) and the total bearing length.

NOTE 13—It is recommended the test specimen include thermocouples placed at locations as described in the Section on Tests of Loaded Restrained Beams for future fire protection engineering applications.

8.8.3 *Loading*:

8.8.3.1 Throughout the fire resistance test, apply a superimposed load to the specimen to simulate a maximum load condition. This load shall be the maximum load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load is applied.

8.8.4 *Conditions of Acceptance*:

8.8.4.1 To obtain an unrestrained beam fire resistance rating the specimen shall have sustained the applied load during the rating period. The specimen shall be deemed as not sustaining the applied load when both of the following conditions are exceeded: A maximum total deflection of:

$$(L_c{}^2) / (400\,d)$$

and after the maximum total deflection has been exceeded, a maximum deflection rate per minute as determined over 1 min intervals of:

$$(L_c{}^2) / (9000\,d)$$

where:

$L_c$ = the clear span of the beam, and
$d$ = the distance between the extreme fiber of the beam in the compression zone and the extreme fiber of the beam in the tensile zone.

8.8.4.2 The deflection, $L_c$ and $d$ must be expressed in the same units such as inches or millimeters.

8.9 *Alternative Tests of Protection for Unloaded Solid Structural Steel Beams and Girders*:

8.9.1 *Application*—This alternative test procedure is used to evaluate the protection of solid steel beams and girders without the application of a design load, provided that the protection material is not required by design to function structurally in resisting applied loads. The classification so derived shall be applicable to solid steel structural members when used with a floor or roof construction that has a comparable or greater capacity for heat dissipation than that with which it was tested. The classification shall not be applicable to sizes of beams smaller than those tested.

8.9.2 *Size and Characteristics of Test Specimen*:

8.9.2.1 The test specimen shall be tested in a horizontal position and the length of the beam or girder exposed to the fire shall be not less than 12 ft (3.7 m). A section of a representative floor or roof construction not less than 5 ft (1.5 m) wide, shall be symmetrically located with reference to the beam or girder and extending the full length of the test specimen and shall be included in the test specimen.

8.9.2.2 Restrain the applied protection material against longitudinal temperature expansion greater than that of the steel beam or girder with rigid steel plates or reinforced concrete

attached to the ends of the steel beams before the protection material is applied. Provide the ends of the test specimen, including the means for restraint, with thermal insulation to limit direct heat transfer from the furnace.

8.9.3 *Temperatures*—Determine temperatures in accordance with 7.3.5.

8.9.4 *Loading*—There is no requirement for loading.

8.9.5 *Conditions of Acceptance*:

8.9.5.1 Regard the test as successful if the transmission of heat through the protection material during the period of fire exposure for which classification is desired does not raise the average (arithmetical) temperature of the steel at any one of the four sections above 1000°F (538°C), or does not raise the temperature above 1200°F (649°C) at any one of the measured points.

8.10 *Tests of Protective Membranes in Walls, Partition, Floor, or Roof Assemblies*:

8.10.1 *Application*—To determine the thermal protection afforded by membrane elements in wall, partition, floor, or roof assemblies, the nonstructural performance of protective membranes shall be obtained by the procedure given in 8.10. The performance of protective membranes is supplementary information only and is not a substitute for the fire-resistance classification determined elsewhere in this fire-test-response standard.

8.10.2 *Size of Test Specimen*—The size of the test specimen shall conform with 8.2.1 for loadbearing walls and partitions, with 8.3.1 for non-loadbearing walls and partitions, and with 8.6.2.1 for floors and roofs.

8.10.3 *Temperatures*—Determine temperatures in accordance with 7.3.6.

8.10.4 *Loading*—There is no requirement for loading.

8.10.5 *Conditions of Acceptance*—Unless otherwise specified, the performance of protective membranes shall be determined as the time at which the following conditions occur:

8.10.5.1 The average temperature rise of any set of thermocouples for each class of element being protected is more than 250°F (139°C) above the initial temperature, or

8.10.5.2 The temperature rise of any one thermocouple of the set for each class of element being protected is more than 325°F (181°C) above the initial temperature.

8.10.6 *Report of Results*:

8.10.6.1 The protective membrane performance, for each class of element being protected, shall be reported to the nearest integral minute.

8.10.6.2 The test report shall identify each class of elements being protected and shall show the location of each thermocouple.

8.10.6.3 The test report shall show the time-temperature data recorded for each thermocouple and the average temperature for the set of thermocouples on each element being protected.

## 9. Report of Results

9.1 Results shall be reported in accordance with the performance in the tests prescribed in these test methods. They shall be expressed in time periods of resistance, to the nearest integral minute. Reports shall include observations of details of the behavior of the material or construction during the test and

after the furnace fire is extinguished, including information on deformation, spalling, cracking, burning of the test specimen or its component parts, continuance of flaming, and production of smoke.

9.2 Reports of tests in which restraint is provided for the test specimen shall describe the method used to provide the restraint.

9.2.1 Describe the physical details of the restraint system and provide information to define the longitudinal and rotational resistance of the test specimen by the restraint system.

9.2.2 Describe the restraint conditions with regard to the free movement of the test specimen prior to encountering resistance to expansion, contraction or rotation.

9.3 Reports of tests in which other than maximum load conditions are imposed shall fully define the conditions of loading used in the test and shall be designated in the title of the report of the test as a restricted load condition.

9.4 When the indicated resistance period is ½ h or over, determined by the average or maximum temperature rise on the unexposed surface or within the test specimen, or by failure under load, a correction shall be applied for variation of the furnace exposure from that prescribed, where it will affect the classification, by multiplying the indicated period by two thirds of the difference in area between the curve of average furnace temperature and the standard curve for the first three fourths of the period and dividing the product by the area between the standard curve and a base line of 68°F (20°C) for the same part of the indicated period, the latter area increased by 54°F·h or 30°C·h (3240°F·min or 1800°C·min) to compensate for the thermal lag of the furnace thermocouples during the first part of the test. For fire exposure in the test higher than standard, the indicated resistance period shall be increased by the amount of the correction and be similarly decreased for fire exposure below standard.

Note 14—The correction can be expressed by the following equation:

$$C = 2I(A - A_s)/3(A_s + L)$$

where:
$C$ = correction in the same units as $I$,
$I$ = indicated fire-resistance period,
$A$ = area under the curve of indicated average furnace temperature for the first three fourths of the indicated period,
$A_s$ = area under the standard furnace curve for the same part of the indicated period, and
$L$ = lag correction in the same units as $A$ and $A_s$ (54°F·h or 30°C·h (3240°F·min or 1800°C·min)).

9.5 Unsymmetrical wall constructions are tested with either side exposed to the fire, and the report shall indicate the side so exposed. When test specimens have been tested with each side separately exposed to the fire, the report then shall indicate the fire-resistance classification determined as a result of each side having been exposed to the fire.

## 10. Precision and Bias [7]

10.1 The precision and bias statement for this test method is based on two interlaboratory studies of E119, Standard Test Methods for Fire Tests of Building Construction and Materials. Two different gypsum wall constructions were examined, one for each study. With the exception of one laboratory, the precision statements were determined through statistical examination of a single result from each of the participating laboratories.

10.1.1 The first interlaboratory study, ILS #591, was conducted during the period 1988 to 1991. The test assembly was a non-loadbearing gypsum partition with two layers of ½ in. (12.7 mm) gypsum board on each side of a steel stud frame. Eight laboratories participated in this study. Each laboratory reported a single fire resistance test result for the test assembly. Every "test result" reported represents an individual determination. Except for the testing of replicates, Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report RR:E05-1013.[8]

10.1.2 The second interlaboratory study, ILS #602, was conducted during the period 2006 to 2007. The test assembly was a non-loadbearing gypsum partition with one layer of ⅝ in. (15.9 mm) gypsum board on each side of a steel stud frame. Sixteen laboratories participated in this study. While 15 of the 16 laboratories reported a single fire resistance test result for the test assembly, one laboratory reported triplicate test results. Every "test result" reported represents an individual determination. Except for the minimal reporting of replicates, Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report RR:E05-1014.[9]

10.2 *Repeatability limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

10.2.1 Without replicate data, repeatability limits cannot be estimated for the ILS #591 interlaboratory study.

10.2.2 Single laboratory repeatability limits for the ILS #602 interlaboratory study are listed in Table 1.

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[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E05-1013.

[9] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E05-1014.

**TABLE 1 Fire Resistance Rating, (minutes)**

| | Average, $\bar{x}$ | Repeatability Standard Deviation[A] $S_r$ | Reproducibility Standard Deviation $S_R$ | Repeatability Limit[A] $r$ | Reproducibility Limit $R$ |
|---|---|---|---|---|---|
| Non-loadbearing steel stud gypsum wall, ILS #591 | 115.9 | NA | 11.1 | NA | 31.2 |
| Non-loadbearing steel stud gypsum wall, ILS #602 | 65.7 | 0.6 | 2.4 | 1.6 | 6.7 |

[A] Based on triplicate test results from a single laboratory.

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[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E05-1003.

10.3 *Reproducibility limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that material; "*R*" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

10.3.1 Reproducibility limits are listed in Table 1.

10.4 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

10.5 Any judgment in accordance with statements 10.2 and 10.3 would normally have an approximate 95 % probability of being correct, however the precision statistics obtained in these two interlaboratory studies must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of materials tested and laboratories reporting results guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. The

repeatability limit and the reproducibility limit should be considered as general guides, and the associated probability of 95 % as only a rough indicator of what can be expected.

10.6 *Bias*—There are no accepted reference materials suitable for determining the bias for this test method. Therefore, no statement on bias is being made.

10.7 The precision statement was determined through statistical examination of a total of twenty-six results: eight results as reported by eight laboratories on one type of gypsum wall construction (ILS #591); and eighteen results as reported by sixteen laboratories on a second type of gypsum wall construction (ILS #602).

## 11. Keywords

11.1 beams; building construction; building materials; ceiling assemblies; columns; fire; fire endurance; fire resistance; fire-resistance rating; fire-test-response standard; floor assembly; floors; restrained rating; restraint; roofs; roof assembly; truss; unrestrained rating; walls

## ANNEX

### (Mandatory Information)

### A1. REQUIREMENTS FOR THERMOCOUPLE PADS

A1.1 *Thermocouple Pads*—Thermocouple pads used in measurement of temperature of unexposed surfaces of test specimens shall be of a refractory fiber material placed with the softer surfaces in contact with the thermocouple. The pads shall not be used on surfaces subject to sharp distortions or discontinuities during the test unless the pads have been previously wetted, formed, and dried in accordance with A1.1.6. Properties of thermocouple pads shall be as follows:

A1.1.1 Length and width, $6 \pm \frac{1}{8}$ in. ($152 \pm 3$ mm).

A1.1.2 Thickness, $0.375 \pm 0.063$ in. ($9.5 \pm 1.6$ mm). The thickness measurement shall be made using a ½ in. (13-mm) diameter, anvil head micrometer, without compression of the pad.

A1.1.3 Dry weight, $0.147 \pm 0.053$ lb ($67 \pm 24$ g).

A1.1.4 Thermal conductivity (at 150°F (66°C)), $0.37 \pm 0.03$ Btu·in./h·ft$^2$·°F ($0.053 \pm 0.004$ W/m·K).

A1.1.5 Density, $18.7 \pm 0.2$ lb/ft$^3$ ($300 \pm 3.0$ kg/m$^3$).

A1.1.6 The pads shall be shaped by wetting, forming, and then drying to constant weight to provide complete contact on sharply contoured surfaces.

# APPENDIXES

## (Nonmandatory Information)

## X1. STANDARD TIME-TEMPERATURE CURVE FOR CONTROL OF FIRE-RESISTANCE TESTS

**TABLE X1.1 Standard Time-Temperature Curve for Control of Fire-Resistance Tests**

| Time | Temperature, °F | Area Above 68°F Base | | Temperature, °C | Area Above 20°C Base | |
|---|---|---|---|---|---|---|
| h:min | | °F-min | °F-h | | °C-min | °C-h |
| 0:00 | 68 | 00 | 0 | 20 | 00 | 0 |
| 0:05 | 1 000 | 2 330 | 39 | 538 | 1 290 | 22 |
| 0:10 | 1 300 | 7 740 | 129 | 704 | 4 300 | 72 |
| 0:15 | 1 399 | 14 150 | 236 | 760 | 7 860 | 131 |
| 0:20 | 1 462 | 20 970 | 350 | 795 | 11 650 | 194 |
| 0:25 | 1 510 | 28 050 | 468 | 821 | 15 590 | 260 |
| 0:30 | 1 550 | 35 360 | 589 | 843 | 19 650 | 328 |
| 0:35 | 1 584 | 42 860 | 714 | 862 | 23 810 | 397 |
| 0:40 | 1 613 | 50 510 | 842 | 878 | 28 060 | 468 |
| 0:45 | 1 638 | 58 300 | 971 | 892 | 32 390 | 540 |
| 0:50 | 1 661 | 66 200 | 1 103 | 905 | 36 780 | 613 |
| 0:55 | 1 681 | 74 220 | 1 237 | 916 | 41 230 | 687 |
| 1:00 | 1 700 | 82 330 | 1 372 | 927 | 45 740 | 762 |
| 1:05 | 1 718 | 90 540 | 1 509 | 937 | 50 300 | 838 |
| 1:10 | 1 735 | 98 830 | 1 647 | 946 | 54 910 | 915 |
| 1:15 | 1 750 | 107 200 | 1 787 | 955 | 59 560 | 993 |
| 1:20 | 1 765 | 115 650 | 1 928 | 963 | 64 250 | 1 071 |
| 1:25 | 1 779 | 124 180 | 2 070 | 971 | 68 990 | 1 150 |
| 1:30 | 1 792 | 132 760 | 2 213 | 978 | 73 760 | 1 229 |
| 1:35 | 1 804 | 141 420 | 2 357 | 985 | 78 560 | 1 309 |
| 1:40 | 1 815 | 150 120 | 2 502 | 991 | 83 400 | 1 390 |
| 1:45 | 1 826 | 158 890 | 2 648 | 996 | 88 280 | 1 471 |
| 1:50 | 1 835 | 167 700 | 2 795 | 1 001 | 93 170 | 1 553 |
| 1:55 | 1 843 | 176 550 | 2 942 | 1 006 | 98 080 | 1 635 |
| 2:00 | 1 850 | 185 440 | 3 091 | 1 010 | 103 020 | 1 717 |
| 2:10 | 1 862 | 203 330 | 3 389 | 1 017 | 112 960 | 1 882 |
| 2:20 | 1 875 | 221 330 | 3 689 | 1 024 | 122 960 | 2 049 |
| 2:30 | 1 888 | 239 470 | 3 991 | 1 031 | 133 040 | 2 217 |
| 2:40 | 1 900 | 257 720 | 4 295 | 1 038 | 143 180 | 2 386 |
| 2:50 | 1 912 | 276 110 | 4 602 | 1 045 | 153 390 | 2 556 |
| 3:00 | 1 925 | 294 610 | 4 910 | 1 052 | 163 670 | 2 728 |
| 3:10 | 1 938 | 313 250 | 5 221 | 1 059 | 174 030 | 2 900 |
| 3:20 | 1 950 | 332 000 | 5 533 | 1 066 | 184 450 | 3 074 |
| 3:30 | 1 962 | 350 890 | 5 848 | 1 072 | 194 940 | 3 249 |
| 3:40 | 1 975 | 369 890 | 6 165 | 1 079 | 205 500 | 3 425 |
| 3:50 | 1 988 | 389 030 | 6 484 | 1 086 | 216 130 | 3 602 |
| 4:00 | 2 000 | 408 280 | 6 805 | 1 093 | 226 820 | 3 780 |
| 4:10 | 2 012 | 427 670 | 7 128 | 1 100 | 237 590 | 3 960 |
| 4:20 | 2 025 | 447 180 | 7 453 | 1 107 | 248 430 | 4 140 |
| 4:30 | 2 038 | 466 810 | 7 780 | 1 114 | 259 340 | 4 322 |
| 4:40 | 2 050 | 486 560 | 8 110 | 1 121 | 270 310 | 4 505 |
| 4:50 | 2 062 | 506 450 | 8 441 | 1 128 | 281 360 | 4 689 |
| 5:00 | 2 075 | 526 450 | 8 774 | 1 135 | 292 470 | 4 874 |
| 5:10 | 2 088 | 546 580 | 9 110 | 1 142 | 303 660 | 5 061 |
| 5:20 | 2 100 | 566 840 | 9 447 | 1 149 | 314 910 | 5 248 |
| 5:30 | 2 112 | 587 220 | 79 787 | 1 156 | 326 240 | 5 437 |
| 5:40 | 2 125 | 607 730 | 10 129 | 1 163 | 337 630 | 5 627 |
| 5:50 | 2 138 | 628 360 | 10 473 | 1 170 | 349 909 | 5 818 |
| 6:00 | 2 150 | 649 120 | 10 819 | 1 177 | 360 620 | 6 010 |

**TABLE X1.1** *Continued*

| Time | Temperature, °F | Area Above 68°F Base | | Temperature, °C | Area Above 20°C Base | |
|---|---|---|---|---|---|---|
| h:min | | °F-min | °F-h | | °C-min | °C-h |
| 6:10 | 2 162 | 670 000 | 11 167 | 1 184 | 372 230 | 6 204 |
| 6:20 | 2 175 | 691 010 | 11 517 | 1 191 | 383 900 | 6 398 |
| 6:30 | 2 188 | 712 140 | 11 869 | 1 198 | 395 640 | 6 594 |
| 6:40 | 2 200 | 733 400 | 12 223 | 1 204 | 407 450 | 6 791 |
| 6:50 | 2 212 | 754 780 | 12 580 | 1 211 | 419 330 | 6 989 |
| 7:00 | 2 225 | 776 290 | 12 938 | 1 218 | 431 270 | 7 188 |
| 7:10 | 2 238 | 797 920 | 13 299 | 1 225 | 443 290 | 7 388 |
| 7:20 | 2 250 | 819 680 | 13 661 | 1 232 | 455 380 | 7 590 |
| 7:30 | 2 262 | 841 560 | 14 026 | 1 239 | 467 540 | 7 792 |
| 7:40 | 2 275 | 863 570 | 14 393 | 1 246 | 479 760 | 7 996 |
| 7:50 | 2 288 | 885 700 | 14 762 | 1 253 | 492 060 | 8 201 |
| 8:00 | 2 300 | 907 960 | 15 133 | 1 260 | 504 420 | 8 407 |

## X2. SUGGESTED REPORT FORM

ASTM E119

TITLE PAGE

(Preferably Cover)

Laboratory

Project Number

ASTM E119 (Year)

STANDARD FIRE-RESISTANCE TEST

Fire Resistance Time

Construction

Date Tested

Sponsor

Material

Maximum Load Conditions, or Restricted Load Conditions (as the conditions of the test dictate)

(Identify if test is part of a research program)

(Add—Table of Contents)

X2.1 *Description of Laboratory Test Facility*—Furnace, restraining frame, details of end conditions, including wedges, bearing, etc.

X2.1.1 If the test specimen is to be tested under load, indicate how the load is applied and controlled. (Give loading diagram.) Indicate whether the load is a maximum-load condition or a restricted-load condition and, for either condition, report the specific loads and the basis for limitation, such as bending stress, shear, etc. A restricted-load condition shall be reported as a percentage of the maximum-load condition.

X2.1.2 If the test specimen is to be tested as non-loadbearing, indicate whether frame is rigid or moves in test or whether test is of temperature rise only.

X2.2 *Description of all Materials*—Type, size, class, strength, densities, trade name, and any additional data necessary to define materials. The testing laboratory should indicate whether materials meet ASTM standards by markings, or by statement of sponsor, or by physical or chemical test by the testing laboratory.

X2.3 *Description of Test Specimen*:

X2.3.1 Give size of test specimen.

X2.3.2 Give details of structural design, including safety factors of all structural members.

X2.3.3 Include plan, elevation, principal cross section, plus other sections as needed for clarity.

X2.3.4 Give details of attachment of test specimen in frame.

X2.3.5 Location of thermocouples, deflection points, and other items for test.

X2.3.6 Describe general ambient conditions at:

X2.3.6.1 Time of construction,

X2.3.6.2 During curing (time from construction to test), and

X2.3.6.3 Time of test.

X2.4 *Description of Test*:

X2.4.1 Report temperature at beginning and every 5 min. If charts are included in report, clearly indicate time and temperature:

X2.4.1.1 In furnace space,

X2.4.1.2 On unexposed surface, and

X2.4.1.3 On protected framing members as stipulated in standard.

NOTE X2.1—It is recommended that temperature observations not required by the standard, but useful, be reported in the Appendix to the report. These include temperatures on the face of framing members in back of protection and others that may be required by various Building Codes.

X2.4.2 Report deflections every 5 min for the first 15 min of test and the last hour; in between, every 10 min.

X2.4.3 Report appearance of exposed face:

X2.4.3.1 Every 15 min,

X2.4.3.2 At any noticeable development, give details and time, that is, cracks, buckling, flaming, smoke, loss of material, etc., and

X2.4.3.3 At end of the test include the amount of drop out, condition of fasteners, sag, etc.

X2.4.4 Report appearance of unexposed face:

X2.4.4.1 Every 15 min,

X2.4.4.2 At any noticeable development including cracking, smoking, buckling, give details and time, and

X2.4.4.3 At the end of test.

X2.4.5 Report time of failure by:

X2.4.5.1 Temperature rise,

X2.4.5.2 Failure to carry load, and

X2.4.5.3 Passage of flame-heat-smoke.

X2.4.6 If a hose stream test is required repeat necessary parts of X2.1 and X2.3. If failure occurs in hose stream test—describe!

X2.5 *Official Comments on*:

X2.5.1 Included shall be a statement to the effect that the construction truly represents field construction. If the construc-

tion does not represent typical field construction, then the deviations shall be noted.

X2.5.2 If the test specimen is unsymmetrical (has different details on each face) be sure to indicate the face exposed to fire with comments on fire resistance from the opposite side.

X2.5.3 Fire-resistance test.

X2.6 *Summarize Results, include*:

X2.6.1 Fire Resistance time,

X2.6.2 Nature of failure, and

X2.6.3 Hose stream test results.

X2.7 *List Official Observers*—Signatures of responsible persons.

X2.8 *Appendix*—Include all data not specifically required by test standard, but useful to better understanding of test results. Special observations for Building Code approvals should be in appendix.

X2.9 *Pictures*—All taken to show what cannot be covered in the report or to clarify.

X2.9.1 Test specimen construction.

X2.9.2 Exposed face prior to fire-resistance test.

X2.9.3 Unexposed face at start of fire-resistance test; include recording equipment when possible.

X2.9.4 Unexposed face at end of fire-resistance test.

X2.9.5 Exposed face at end of fire-resistance test.

X2.9.6 Unexposed face at end of fire exposure before hose test.

X2.9.7 Exposed face at end of fire exposure before hose test.

X2.9.8 Exposed face after hose stream test.

X2.9.9 Unexposed face after hose stream test.

X2.10 It is essential to have the following:

X2.10.1 Detailed drawing of test specimen.

X2.10.2 Pictures (X2.9.1, X2.9.4, X2.9.8, and X2.9.9) for every test report.

## X3. GUIDE FOR DETERMINING CONDITIONS OF RESTRAINT FOR FLOOR AND ROOF ASSEMBLIES AND FOR INDIVIDUAL BEAMS

X3.1 The purpose of this appendix is to provide guidance in applying fire-resistance test results to floor and roof assemblies and individual beams of buildings.

X3.2 The revisions to Test Methods E119 adopted in 1970 introduced the concept of fire endurance classifications, now known as fire resistance ratings, for floor and roof assemblies and individual beams based on two conditions of restraint. As a result, such specimens can be fire tested in a restrained condition to develop two ratings (restrained and unrestrained). Alternatively, the standard allows some specimens to be tested in an unrestrained condition to develop a single rating (unrestrained).

X3.3 As used in Test Methods E119, a restrained condition is one in which expansion and rotation at the ends and supports

of a load carrying test specimen resulting from the effects of the fire are resisted by forces external to the test specimen exposed to fire. An unrestrained condition is one in which the load carrying test specimen exposed to fire is free to expand and rotate at its supports.

X3.4 This guide is based on knowledge currently available and recommends that all constructions be classified as either restrained or unrestrained. While it has been generally shown that certain conditions of restraint will improve fire resistance, methodologies for establishing the presence of sufficient restraint in actual constructions have not been standardized.

X3.5 For the purpose of this appendix, restraint in buildings is described as follows: "Floor and roof assemblies and individual beams in buildings are considered restrained when

the surrounding or supporting structure is capable of resisting substantial thermal expansion and rotation throughout the range of anticipated elevated temperatures caused by a fire. Constructions not complying with this description are assumed to be free to rotate and expand and therefore are considered as unrestrained."

X3.6  The description provided in X3.5 requires the exercise of engineering judgment to determine what constitutes restraint to "substantial thermal expansion and rotation."

X3.7  In actual building structures, restraint capable of improving fire resistance may be provided by the stiffness of the contiguous construction. In order to develop sufficient restraint, thermally-induced forces must be adequately transferred through connections or by direct bearing on contiguous structural members. The rigidity of connections and contiguous structural members should be considered in assessing the capability of the fire exposed construction to resist thermal expansion and rotation. Continuity, such as that occurring in beams acting continuously over more than two supports, will induce rotational restraint which will usually add to the fire resistance of structural members.

X3.8  For the purpose of providing guidance, common constructions and their restraint conditions are listed in Table X3.1. These examples and the information provided in X3.1 through X3.8 should provide the user with guidance for evaluating the application of restrained and unrestrained fire resistance ratings to specific building conditions.

X3.9  Test Methods E119 provide for two distinct tests of loaded floors and roofs, depending on the specimen's condition of restraint. In the restrained test, the floor or roof specimen (including any beams) is placed tightly against the test frame and vertically supported over the entire perimeter of the specimen. In addition to the restrained floor or roof assembly rating, and based on specific temperature criteria for concrete reinforcement, steel beams or steel deck, as specified in the standard, an unrestrained floor or roof assembly rating can also be determined from the same test. For restrained assembly ratings over 1 h, these temperature criteria are allowed to be exceeded for a limited duration of time (as specified in 8.6.5.3-8.6.5.5), provided the assembly maintains its ability to sustain the applied load without developing unexposed surface conditions, which will ignite cotton waste (as specified in 8.6.5.1), and maintains the average temperature of its unexposed surface within the prescribed limit (as specified in 8.6.5.2). In the unrestrained test, the floor or roof specimen (including any beams) is supported along its entire perimeter in such a way that a continuous horizontal gap is left between the test frame and the specimen to allow for the free (unrestrained) thermal expansion of the specimen during the fire test. The unrestrained floor and roof assembly ratings developed from unrestrained floor and roof tests are not subject to the temperature criteria for concrete reinforcement, steel beams or steel deck.

X3.10  Test Methods E119 provide for two distinct tests of loaded beams, depending on the specimen's condition of restraint. The test of loaded restraint beams is the older test method, while the test of loaded unrestrained beams was introduced to Test Methods E119 more recently in 2011. In the loaded restrained beam test, the two ends of the beam specimen (including the two ends of a slab integral to the beam) are placed tightly against the test frame that supports the beam specimen. In addition to the restrained beam rating, and based on specific temperature criteria for concrete reinforcement or steel beams, as specified in the standard, an alternative unrestrained beam rating can also be determined from the same test. For restrained steel beam ratings over 1 h, these temperature criteria are allowed to be exceeded for a limited duration of time (as specified in 8.7.5.2), provided the beam maintains its ability to sustain the applied load. For restrained concrete beam ratings, the temperature criteria do not apply. Alternative unrestrained beam ratings can also be determined, based on the same specific beam temperature criteria, from floor and roof tests described in X3.9. In the unrestrained loaded beam test, the two ends of the beam specimen (including the two ends of a slab tested with the beam) are supported in such a way that a continuous horizontal gap is left between the test frame and the specimen to allow for the free (unrestrained) thermal expansion of the specimen during the fire test. The unrestrained beam ratings developed from tests of loaded unrestrained beams are not subject to the temperature criteria for concrete reinforcement or steel beams.

X3.11  The beam, floor and roof restraint conditions described in X3.9 and X3.10 do not create the condition of rotational restraint, or rotational fixity, for beam ends or for floor and roof perimeters under normal room temperatures because the test frame offers vertical (gravity) support only. However, the described conditions generate horizontal reactions of the test frame in response to the thermal expansion of fire-exposed specimens. Because the resultants of these horizontal frame reactions do not necessarily coincide with the specimen sections' centroids (that is, frame reactions apply eccentrically to the specimen for extended periods during the test), rotational restraints are also generated. This partially replicates similar conditions found in building floors and roofs in terms of multi-directional resistance to expansion (restraint) that occurs under real fire conditions. However, this similarity is not complete as, for instance, the test frame does not replicate structural continuity, it does not offer anchorage to specimens sagging in the tensile membrane action mode (that is, the test frame does not resist the horizontal contraction of the specimen), and the stiffness of restraints in real construction does not necessarily match the test conditions.

X3.12  Thermal expansion of materials is three-dimensional. In beam specimens, and floor and roof assembly specimens, the thermal expansion usually manifests itself in terms of horizontal multi-directional elongations plus vertical deflections and rotations (around horizontal axes) generated by non-uniform temperature distributions (thermal gradients) along the vertical dimension of the specimens due to the one-sided (from below) fire exposure. Depending on the configuration of specimen components, thermal gradients, and the associated deflections and rotations (the so-called thermal

bowing) can occur in other directions as well. In addition, non-uniform thermal expansions within the specimen may cause internal mechanical stresses and strains, associated with the so-called phenomenon of self-restraint, where the cooler parts of the specimen resist the expansion of the hotter parts. Resistance to thermal expansion, whether generated internally within the specimen or externally by the testing frame, may have either positive or negative effects on the fire performance of construction assemblies – generally positive unless the restraint is large enough to cause compressive failure of the restrained components.

X3.13 Comparative testing of restrained versus unrestrained floor assembly specimens (34,35,41), and comparative testing of restrained versus unrestrained loaded beam specimens (42), have been too limited to be conclusive. The results of these comparisons should not be extrapolated without due consideration of all the relevant aspects involved. The available reports comparing the performance of restrained versus unrestrained concrete floor assembly specimens (34,35), and comparing the performance of restrained versus unrestrained steel framed floor assembly specimens (41), indicated that restrained floor tests were more conservative (specimens failed at earlier times) compared to unrestrained floor tests, because the restraint led to earlier compressive failure of concrete slabs

in the floor specimens. On the other hand, in comparative tests of a loaded unrestrained steel beam and two similar loaded restrained steel beams (42), the unrestrained beam test was found to be more conservative (beam failed at an earlier time) compared to the restrained steel beam tests (90 min versus 106 and 107 min, respectively). In this comparison, the failure of the beam specimens was based only on their ability to sustain the applied load, and no temperature criteria were used.

X3.14 Temperature-based unrestrained beam ratings and temperature-based unrestrained floor or roof assembly ratings, derived from restrained tests as described in X3.9 and X3.10, could be associated with reduced structural deflections when compared to similar restrained ratings. If the degree of structural deflection is of concern to the licensed design professional responsible for the design of the fire resistive protection, some experience suggests that the design professional may find an unrestrained rating to be of benefit to the structural performance.

X3.15 Thermal restraint by the test frame is believed to have no beneficial or detrimental effect for wood construction, because wood contracts at temperatures over 212°F (100°C). Wood-framed floor and roof specimens are usually tested in the unrestrained condition.

**TABLE X3.1 Guide for Determination of Restrained and Unrestrained Conditions of Construction**

| | |
|---|---|
| I. Wall bearing: | |
| Single span and simply supported end spans of multiple bays:[A] | |
| (1) Open-web steel joists or steel beams, supporting concrete slab, precast units, or metal decking | unrestrained |
| (2) Concrete slabs, precast units, or metal decking | unrestrained |
| Interior spans of multiple bays: | |
| (1) Open-web steel joists, steel beams or metal decking, supporting continuous concrete slab[B] | restrained |
| (2) Open-web steel joists or steel beams, supporting precast units or metal decking | unrestrained |
| (3) Cast-in-place concrete slab construction[B] | restrained |
| (4) Precast concrete construction[B,C] | restrained |
| II. Steel framing:[B] | |
| (1) Steel beams welded, riveted, or bolted to the framing members | restrained |
| (2) All types of cast-in-place floor and roof construction (such as beam-and-slabs, flat slabs, pan joists, and waffle slabs) where the floor or roof construction is secured to the framing members | restrained |
| (3) All types of prefabricated floor or roof construction where the structural members are secured to the framing members[C] | restrained |
| III. Concrete framing:[B] | |
| (1) Beams fastened to the framing members | restrained |
| (2) All types of concrete cast-in-place floor or roof construction (such as beam-and-slabs, flat slabs, pan joists, and waffle slabs) where the floor or roof construction is cast with the framing members | restrained |
| (3) Interior and exterior spans of precast construction with cast-in-place joints resulting in restraint equivalent to that which would exist in condition III (1) | restrained |
| (4) All types of prefabricated floor or roof construction where the structural members are secured to such construction[C] | restrained |
| IV. Wood construction: | |
| All types | unrestrained |

[A] Floor and roof construction may be considered restrained where they are tied (with or without tie beams) into walls designed and detailed to resist thermally induced forces from the floor or roof construction exposed to fire.

[B] To provide sufficient restraint, the framing members or contiguous floor or roof construction should be capable of resisting the potential thermal expansion resulting from a fire exposure as described in X3.5 and X3.6.

[C] Resistance to potential thermal expansion resulting from fire exposure may be achieved when one of the following is provided:
(1) Continuous structural concrete topping is used,
(2) The space between the ends of precast units or between the ends of units and the vertical face of supports is filled with concrete or mortar, or
(3) The space between the ends of precast units and the vertical faces of supports, or between the ends of solid or hollow core slab units does not exceed 0.25 % of the length for normal weight concrete members or 0.1 % of the length for structural lightweight concrete members.

## X4. METHOD OF CORRECTING FIRE RESISTANCE FOR CONCRETE SLABS DETERMINED BY UNEXPOSED SURFACE TEMPERATURE RISE FOR NONSTANDARD MOISTURE CONTENT

### X4.1 Scope

X4.1.1 The standard fire resistance is the time determined by unexposed surface temperature rise of a test specimen at a standard moisture level.

X4.1.2 This appendix gives a procedure to correct the fire resistance of unprotected vertical or horizontal slabs (solid or hollow), made from essentially inorganic building materials; and conditioned on both sides, when moisture content at the time of test is other than at a standard moisture level.

X4.1.3 From among the common inorganic building materials, only the hydrated portland cement products can hold (after due conditioning in accordance with Section 6) sufficient amount of moisture to affect noticeably the result of the fire-resistance test. Consequently, correcting the experimental fire resistance of constructions containing less than 5 volume % of portland cement paste is not necessary.

### X4.2 Symbols

X4.2.1 The symbols used in this Appendix are defined as follows:

$A$ = factor characterizing the drying conditions (see Table X4.1),
$b$ = factor characterizing the permeability of the specimen (see Table X4.2),
$FR$ = fire resistance of the test specimen, h,
$RH$ = relative humidity,
$m$ = moisture content, volume fraction $ft^3/ft^3$ or $cm^3/cm^3$,
$m_a$ = average moisture content of test specimen,
$m_c$ = average moisture content of cement paste,
$m_e$ = nominal equilibrium moisture content of cement paste for a given $RH$ (see Table X4.3).
$m_{es}$ = equilibrium moisture content of cement paste at the standard $RH$ level (see Table X4.3).
$m_s$ = average moisture content of a standard conditioned concrete test specimen of same concrete and cement paste volume as the test specimen, and
$v$ = volume fraction of cement paste, $ft^3/ft^3$ or $cm^3/cm^3$.

**TABLE X4.1 Equilibrium Moisture Content (Desorption) of Cement Paste at Given Relative Humidity**

| RH at mid-depth, % | $m_e$ |
|---|---|
| 90 | 0.30 |
| 85 | 0.275 |
| 80 | 0.255 |
| 75 | 0.24 |
| 70 | 0.225 |
| 65 | 0.21 |
| 60 | 0.195 |
| 55 | 0.185 |
| 50 | 0.175 |
| 45 | 0.16 |
| 40 | 0.15 |

**TABLE X4.2 Factor Characterizing Permeability of Test Specimen**

| Material | $b$ |
|---|---|
| Normal weight and gun-applied concrete (dry unit weight greater than 135 lb/ft³ (2162 kg/m³)) | 5.5 |
| Lightweight concrete (dry unit weight between 85 and 115 lb/ft³ (1361 and 1841 kg/m³)) | 8.0 |
| Lightweight insulating concrete (dry unit weight less than 50 lb/ft³ (801 kg/m³)) | 10.0 |

**TABLE X4.3 Factor Characterizing Drying Conditions**

| Conditioning Environment | Mid-depth RH of Test Specimen, % | Factor $A$ for Portland Cement | |
|---|---|---|---|
| | | Normal Weight Concrete | Light-Weight Concrete |
| 60 to 80°F (15.6 to 26.7°C) atmospheric conditions | any | 1.0 | 1.0 |
| 120 to 160°F (48.9 to 71.1°C) 20 to 35 % RH | 70 to 75 | 0.7 | 0.7 |
| 190 to 200°F (87.8 to 93.3°C) 0 to 5 % RH | 70 to 75 | 0.45 | 0 |
| 120 to 200°F (48.9 to 93.3°C) 5 to 35 % RH | less than 70 | 0 | 0 |

### X4.3 Calculation of Moisture Content

X4.3.1 The average moisture content, $m_a$, is the volume fraction of moisture ($ft^3/ft^3$ (or $cm^3/cm^3$)) in the material relative to its dry condition; where dry condition is defined as that resulting when the material is heated in an oven at $221 \pm 1°F$ ($105 \pm 0.5°C$) until no further weight loss occurs.

X4.3.2 The average moisture content of the cement paste can be estimated from the known value of $RH$ at mid-depth (assuming the material has never been subject to rewetting) by calculating first the moisture content in the cement paste as follows:

$$m_c = A \cdot m_e$$

X4.3.3 The average moisture content of the test specimen is then calculated as follows:

$$m_a = v \cdot m_c$$

X4.3.4 Calculate the average moisture content of a standard conditioned test specimen as follows:

$$m_s = v \cdot m_{es}$$

where $m_{es}$ is the value of $m_e$ in Table X4.1 pertaining to the standard $RH$ level.

### X4.4 Correction Procedure

X4.4.1 The correction procedure starts with the selection of an empirical factor to reflect the permeability of the material as suggested in Table X4.2. With known values of $m_a$ and $m_s$ calculate the products $bm_a$ and $bm_s$. On the nomogram (Fig. X4.1) draw lines from point $R$ to values of $bm_a$ and $bm_s$ on the right-hand scale. From the point representing the actual fire resistance time ($FR$) on the left-hand scale draw a line parallel to $R$-$bm_a$ to intersect the curve. From this point on the curve
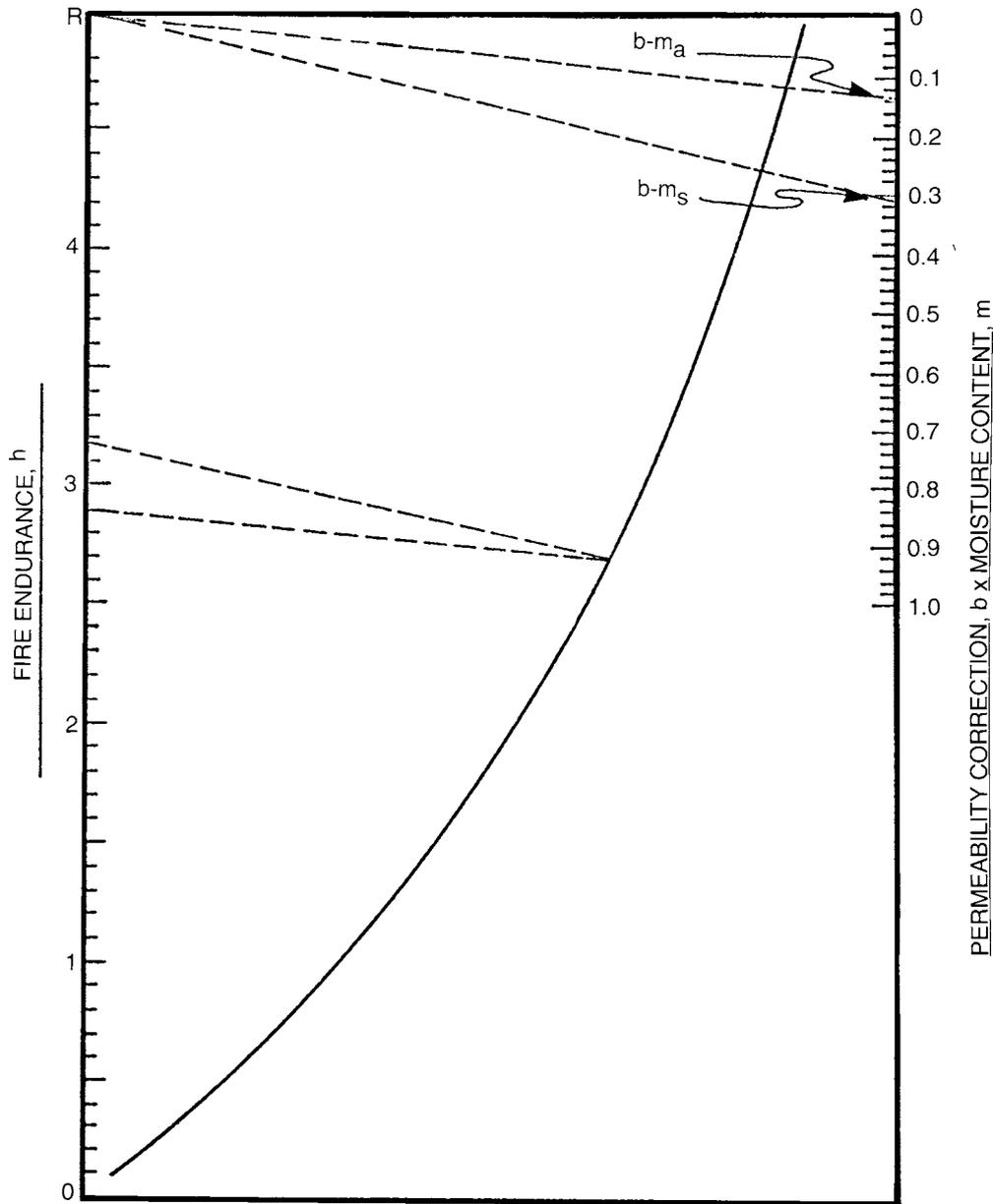
**FIG. X4.1 Nomogram for Correcting Fire Resistance for Nonstandard Moisture Content**

draw a line parallel to $R\text{-}bm_s$ and find the corrected fire resistance on the *FR* scale.

### X4.5 Illustrative Example

X4.5.1 A wall made from normal weight concrete having 23.2 volume % of paste, was conditioned at 200°F (93°C) and 5 % *RH* until the *RH* at its mid-depth was reduced to 70 %. It had a 2.90-h fire resistance. Determine the adjusted fire resistance.

X4.5.1.1 *Step 1*—Calculate $m_a$ as follows:
For 70 % *RH*,

$$m_e = 0.225$$

(see Table X4.1)

For 200°F (93°C) and 5 % *RH* conditioning, for normal weight concrete

$$A = 0.45$$

(see Table X4.3)

$$..m_c = 0.45 \times 0.225 = 0.101$$

(see X4.3.1)

For $v = 0.232$

$$m_a = 0.232 \times 0.101 = 0.0234$$

(see X4.3.3)

that is, the concrete contains 2.34 volume % moisture at time of test.

X4.5.1.2 *Step 2*—Calculate $m_s$ as follows:
As an example, if the standard moisture level is assumed to correspond to a mid-depth *RH* of 75 %, then $m_e = 0.24$

$$m_s = 0.232 \times 0.24 = 0.0557$$

(see X4.3.4)

that is, the standard moisture level is 5.57 volume %.

X4.5.1.3 *Step 3*—Calculate $b_m$ as follows:

$b$ = 5.5 (see Table X4.2).
$bm_a$ = 5.5 × 0.0234 = 0.129
$bm_s$ = 5.5 × 0.0557 = 0.306

X4.5.1.4 *Step 4*—Draw lines on the nomogram from point $R$ to $bm_a$ and $bm_s$ (see Fig. X4.1).

X4.5.1.5 *Step 5*—Draw a line from the *FR* ordinate, 2.90, parallel to line $R$-$bm_a$ to intersect the curve.

X4.5.1.6 *Step 6*—Draw a line parallel to $R$-$bm_s$ from a point on the curve, to intersect the *FR* ordinate scale. The value of $FR = 3.19$ is the adjusted fire resistance; that is, the fire resistance that would have resulted if the specimen had been tested at the standard moisture level, here assumed to correspond to 75 % *RH* at mid-depth.

## X5. COMMENTARY

### X5.1 Introduction

X5.1.1 This commentary has been prepared to provide the user of Test Methods E119 with background information on the development of the standard and its application in the fire protection of buildings. It also provides guidance in the planning and performance of fire-resistance tests and in the reporting of results. No attempt has been made to incorporate all the available information on fire-resistance testing in this commentary. The serious student of fire-resistance testing is strongly urged to peruse the referenced documents for a better appreciation of the history of fire-resistant design (1, 2)[10] and the intricate problems associated with testing and with interpretation of test results.

X5.1.2 Floors and walls designed as fire separations have been recognized for many years as efficient tools in restricting fires to the area of origin, or limiting their spread (3-11). Prior to 1900, relative fire safety was achieved by mandating specific materials. By the year 1900, the appearance of a multitude of new materials and innovative designs and constructions accelerated the demand for performance standards. The British Fire Prevention Committee, established in 1894, was the first to produce tables listing fire resisting floors, ceilings, doors and partitions (5). Test furnaces in the United States were constructed shortly after 1900 at the Underwriters Laboratories Inc., Columbia University, and the National Bureau of Standards (NBS) (1, 12). These early furnaces eventually led to the development of Test Methods E119.

### X5.2 Historical Aspects

X5.2.1 Test Methods E119 was first published by ASTM as C19 in 1918. A number of refinements have been made in the standard since that time, such as the classification of beams and of floor and roof constructions based on conditions of support. Several provisions, including the temperature-time curve and the major apparatus, remain essentially unchanged. The roots of fire-resistance testing as we define it today can be traced back to about 1800. A comprehensive review of early fire-resistance testing has been published (1).

### X5.3 Fire-Load Concept

X5.3.1 Specifications for fire resistance in regulatory documents continue to be based largely on the fire-load concept

developed by NBS in the 1920s and reported in the 1928 NFPA Quarterly by Ingberg. The concept incorporates the premise that the duration of a fire is proportional to the fire loading, that is, the mass of combustible materials per unit floor area. The relationship between the mass of combustible materials and fire duration was established on the basis of burnout tests in structures incorporating materials having calorific or potential heat values equivalent to wood and paper, that is, 7000 to 8000 BTU/lb (16.3 to 18.6 MJ/kg). The fire-load of noncellulosic materials such as oils, waxes, and flammable liquids were interpreted on the basis of their equivalent calorific content (5, 13-15). In the simplest terms, the above premise states that 10 lb of combustible materials per square foot (50 kg/m$^2$) of floor area will produce a fire of 1 h duration.

X5.3.2 Increasing sophistication in the knowledge of materials and the fire process has resulted from numerous research activities (9, 11, 13-27). It is now generally conceded that fire severity as well as the temperature-time relationship of a fire depends on several factors, including:

1. Fire load—Amount and type.
2. Distribution of this fire load.
3. Specific surface characteristics of the fire load (5, 27).
4. Ventilation, as determined by the size and shape of openings (17-19, 21, 27-29).
5. Geometry of the fire compartment—Size and shape.
6. Thermal characteristics of the enclosure boundaries.
7. Relative humidity of the atmosphere.

For the purposes of this commentary, fire severity is defined as a measure of the fire intensity (temperature) and fire duration. It is expressed in terms of minutes or hours of fire exposure and in Test Methods E119 is assumed to be equivalent to that defined by the standard temperature-time (*T-t*) Curve, that is, the area under the *T-t* curve (27).

### X5.4 Scope and Significance

X5.4.1 Test Methods E119 is intended to evaluate in terms of resistance time, the ability of a test specimen to contain a fire, or to retain its structural integrity, or both during the test conditions imposed by the standard. It also contains standard conditions for measuring heat transfer through membrane elements protecting combustible framing or surfaces.

X5.4.2 The end-point criteria by which the test result is assessed are related to:

1. Transmission of heat through the test specimen.

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[10] The boldface numbers in parentheses refer to the list of references at the end of this test method.

2. Ability of the test specimen to withstand the transmission of flames or gases hot enough to ignite combustible material.

3. Ability of the test specimen to carry the load and withstand restraining forces during the fire-resistance test period.

4. Temperatures of the steel under some conditions.

X5.4.3 It is the intent that classifications shall register comparative performance to specific fire-test conditions during the period of exposure and shall not be construed as having determined suitability under other conditions or for use after the exposure.

X5.4.4 The standard, although being specific about the element of construction to be tested, enables the testing laboratory to determine whether the test specimen is "truly representative" of the construction intended for evaluation. This is necessary because of the wide variation in construction details. For instance, wall test specimens generally do not contain electric switches and outlets, that in some designs may affect test results. Floor test specimens may or may not contain electrical raceways and outlets or pull boxes for power and communication wiring. Cover plates over trench headers are also present in some designs. The testing laboratory is in the best position to judge the effects of such items.

## X5.5 Test Furnaces

X5.5.1 Test Methods E119 does not provide specific construction details of the furnace. Readers are urged to consult reference documents for a more comprehensive review of furnace design and performance (25).

## X5.6 Temperature-Time Curve

X5.6.1 A specific temperature-time relationship for the test fire is defined in the standard and in Appendix X1. The actual recorded temperature in the furnace is required to be within specified percentages of those of the standard curve. Accuracy in measuring temperature is generally easier to achieve after 1 h due to stabilizing of the furnace and the slope of the $T$-$t$ curve. The number and type of temperature-measuring devices are outlined in the standard. Specific standard practices for location and use of these temperature-measuring devices are also outlined in the standard. However, no uniformity of the temperatures within the fire chamber is specified.

X5.6.2 The standard $T$-$t$ curve used in Test Methods E119 is considered to represent a severe building fire (5). The curve was adopted in 1918 as a result of several conferences by eleven technical organizations, including testing laboratories, insurance underwriters, fire protection associations, and technical societies (1, 16, 30). The $T$-$t$ relationship of these test methods represents only one fire situation. Data are available to evaluate the performance of test specimens under fire exposure conditions that may be more representative of particular fire situations, that is, using different $T$-$t$ relationships to simulate specific fire conditions (9, 11, 16, 19, 22, 23, 27, 29, 31, 32).

X5.6.3 Furnace pressure is not specified and is generally slightly negative. The pressure may have an effect on the test results, and the test conditions should always be carefully controlled.

## X5.7 Test Specimen

X5.7.1 The test specimen is required to represent as closely as possible the actual construction in the field, subject to the limits imposed by the test facilities.

X5.7.2 All test specimens are required to be conditioned so as to attain prior to testing a moisture content comparable to that in the field. For uniformity, the standard moisture content is defined as that in equilibrium with an atmosphere of 50 % relative humidity at 73°F (23°C). Massive concrete units which may require unusually long drying periods may be fire-resistance tested after a 12-month conditioning period. Appendix X4 describes how the test result should be corrected to account for any variation from the standard moisture condition (33).

X5.7.3 With few exceptions, only the interior face of exterior wall test specimens and the ceiling portion or underside of floor or roof test specimens are exposed to the standard fire (24, 25). This practice is rationalized on the assumption that the outside face of exterior walls is not usually subjected to the same fire as the interior face and that the fire exposure of the upper side of a floor or roof is seldom as intense as that of the underside.

X5.7.4 Although the standard does not contain specific criteria for judging the impact of through joints nor "poke-through" devices, such as electrical or telephone outlets, it should be recognized that these components should be evaluated with respect to structural-performance and temperature-rise criteria if they constitute a significant part of the tested construction.

X5.7.5 For obvious reasons, symmetrical walls and partitions are tested only on one side. Asymmetrical walls and partitions may be required to be tested with either or both sides individually exposed to the fire. If both sides are exposed, the report should indicate the fire-resistance classification for each case.

## X5.8 Loading

X5.8.1 Floors and roofs are required to be loaded during test to provide a maximum load condition determined by the applicable nationally recognized design criteria. This practice allows for more confidence in extrapolating testing results. For instance, the maximum length of a floor test specimen in most test facilities is 16 ft (4.9 m). It is, therefore, necessary to extrapolate developed fire-resistance ratings to much longer spans.

X5.8.2 When a floor or roof is designed for a specific use, such as used in prefabricated housing units, the test specimen may be tested with a restricted load condition. The loading condition used for such tests shall be defined in the test report. The standard does not require specific loading devices. Some laboratories use large containers of water; others use a system of hydraulic rams for floor and roof test specimens. When a uniformly distributed load is simulated by point-loading (several, small-area loads), it is recommended that the load at any such area not exceed 25 % of the total load and that the individual point-loading have a width at least equal to the depth of the floor. Wall furnaces are generally equipped with hydraulic rams.

X5.8.3 The standard requires that loadbearing walls and partitions sustain the applied test load during the fire resistance and hose-stream tests. A former requirement that loadbearing walls and partitions also sustain twice the specified superimposed test load after cooling but within 72 h of the test period has been deleted from these test methods as being unrealistic. Non-loadbearing walls and partitions are not loaded during the test but are restrained on all sides. This restraint may impose more stress than a load on top. Committee E05 has several times reviewed the loading procedures for framed walls and partitions. It was the committee's unanimous decision that such a wall be tested either with calculated maximum design load or with a load expected to occur in practice. The method used to compute the design loads must be reported.

X5.8.4 Some important stresses, such as those caused by creep and shrinkage in the wall itself and its supporting frame must be present, and designers should recognize these stresses in his their analysis. Committee E05 has investigated the possibility of openings occurring at a joint at corners of non-loadbearing enclosures due to differential movement. While the possibility exists that this will occur, the committee has not found it feasible to amend the test based on data available.

X5.8.5 Double walls pose a unique problem as to load application. Which wall should be loaded? Or should both be loaded simultaneously? Committee E05 has devoted considerable time to debating this problem, and recommends the decision be made by the user after an analysis of the loading conditions anticipated in service both before and after a fire. Such loading conditions are to be reported.

### X5.9 Integrity

X5.9.1 All walls and partitions that qualify for a fire-resistance classification of 1 h or more are required to be subjected to the cooling impact and erosion effects of a stream of water applied as described in Practice E2226 under specified pressures. In this hose stream test, the ability of the test specimen to resist disintegration under adverse conditions is examined. The requirement for a hose stream test was earlier removed from the test procedure for columns and floor or roof test specimens because of impracticality and the possibility of excessive damage to the furnace.

### X5.10 Conditions of Tests

X5.10.1 Columns are generally tested with all four sides exposed to the test fire. However, it is possible to test a column with fewer sides exposed. The standard requires that test specimens be tested under conditions contemplated in the design. The former general practice of testing columns with pin connection at top and bottom to simulate the most critical condition is no longer a criterion.

X5.10.2 Columns are required to sustain successfully the design load during the test period. The standard also permits columns to be loaded up to 1-¾ times the design load prior to the fire-resistance test if desired by the submitter. Such loading,

however, shall not be construed as having had a deleterious effect on the fire-resistance test performance. Instead of loading, steel columns, whose protective covering does not carry load, may be assigned a fire-resistance classification on the basis of the temperature of the steel only. With such columns, the protective cover shall be restrained against longitudinal expansion. Wood columns are tested for load-carrying ability only.

X5.10.3 From test results, it has been established that variations of restraint conditions can considerably influence the time of fire resistance for a structure or a structural element. Restraints are generally beneficial to fire resistance; however, there are conditions where restraint can have a detrimental effect on the performance of a test specimen during a fire-resistance test (34, 35). The users of test results are advised to study the reference documents as well as Appendix X3 and Table X3.1.

X5.10.4 An unrestrained classification for a steel beam or for a reinforced concrete beam tested in a restrained condition can be assessed from the steel temperature records (see 7.3.4 and 8.7). It is also possible to evaluate the protective cover of non-loaded steel beams by measuring the steel temperatures (see 7.3.5 and 8.9).

X5.10.5 The classification is only applicable to beams used with a floor or roof construction that has a comparable or greater capacity for heat dissipation from the beam than the floor or roof with which it is tested.

### X5.11 Other Observations

X5.11.1 No limitation is imposed on the deformation of the test specimen during or after the test period. It is assumed that the deflection or deformation of a test specimen is limited only by its ability to stay in place (under load where specified) during the test period.

X5.11.2 A complete record of deformation during the fire-resistance test may be helpful in the application of test results, and shall be reported.

X5.11.3 Other observations, such as the evolution of unusual quantities of visible smoke, vapors, or gases that may affect the proper decision regarding use of the test results, should be reported.

### X5.12 Protective Membranes

X5.12.1 The standard provides criteria for evaluating the protection that membrane elements can offer to combustible framing and paneling, for example, joists, wall studs, and paneling or boards on the unexposed side of a test specimen, and other combustible materials. The results of these tests are reported as protective membrane ratings.

### X5.13 Future

X5.13.1 ASTM Committee E05 on Fire Standards through Subcommittee E05.11 is continually striving to update Test Methods E119. Users of these test methods are encouraged to contact the committee for further information.

## X6. ASBESTOS PADS

### X6.1 History of Asbestos Pads

X6.1.1 Asbestos pads were used in the U.S. and other countries for many years. The health concerns with the use of any asbestos products have led the industry away from asbestos pads usage.

X6.1.2 The change from asbestos pads to the thermocouple pads described in Annex A1 did not require the requalification of any fire-resistance test results that had been evaluated by the use of asbestos pads.

### X6.2 Previous Requirements for Asbestos Pads

X6.2.1 *Asbestos Pads*—Asbestos pads used in the measurements of unexposed surfaces of specimens were felted amosite asbestos, free of organic additives, and exhibited the following properties:

X6.2.1.1 Length and width, $6 \pm \frac{1}{8}$ in. (152 ± 3 mm).

X6.2.1.2 Thickness, 0.40 ± 0.05 in. (10.2 ± 1.3 mm). The thickness measurements were made under the light load of a ½-in. (13-mm) diameter pad of a dial micrometer gage.

X6.2.1.3 Dry weight, 0.260 ± 0.026 lb (0.12 ± 0.01 kg).

X6.2.1.4 Thermal conductivity (at 150°F (66°C), 0.38 ± 0.027 Btu·in./h·ft²·°F (0.055 ± 0.003 W/m·K).

X6.2.1.5 Hardness indentations were 0.157 ± 0.07 in. (4.0 ± 1.8 mm) or 10–25 (modified Brinell). Indentations were determined in accordance with Test Method C569. Modified Brinell values of hardness were obtained by the relationship:

$$\text{Hardness} = \frac{2.24}{y}$$

where $y$ = the measured indentation in inches.

X6.2.1.6 The pads were sufficiently soft so that, without breaking, they were able to be shaped to contact over the whole surface against which they were placed.

## X7. LOADING FOR TEST SPECIMENS

### X7.1 General

X7.1.1 This appendix is intended to provide guidance for the design procedures to follow in developing a full-specified load condition for a test specimen. A full specified load condition is that level of loading for which no load restriction is associated with the rating assigned to that specimen. The guidelines in this appendix are aimed at arriving at a level of loading based on a uniformity of approach with other similar types of construction.

X7.1.2 Fire resistance tests have been historically conducted using loads based on maximum allowable stresses to simulate a fully specified load condition. Tests conducted under reduced loads, such as loads limited by serviceability criteria or based on historical load calculations, should be considered a restricted load use condition.

X7.1.3 This appendix provides examples that can be used as guidance and is not meant to prohibit the use of other non-USA standards.

### X7.2 Superimposed Load Calculation

X7.2.1 To calculate the superimposed load, $w_s$, required for test purposes:

Let:

$w$ = total specified load, psf (kPa),
$w_L$ = specified live load, psf (kPa),
$w_D$ = specified dead load, psf (kPa),
$w_s$ = required superimposed load on test specimen, psf (kPa),
$w_d$ = dead load of test specimen or element, psf (kPa),
$W_s$ = required superimposed line load on test specimen, plf (kN/m),
$P_s$ = required superimposed load on column specimen, kip (kN),
$P_d$ = dead load on column or stud element, kip (kN),

$P$ = total specified load on column specimen, kip (kN),
$L$ = span, ft (mm),
$s$ = tributary width of beam, joist or slab, ft (mm),
$r$ = dead-to-live-load ratio,
$M_n$ = nominal moment strength, kip ft (kN.m),
$\phi M_n$ = design moment strength, kip ft (kN.m),
$P_n$ = nominal axial strength, kip (kN),
$\phi P_n$ = design axial strength, kip (kN),
$\phi$ = strength reduction factor,
$\alpha$ = load factor on total specified load,
$\alpha_L$ = live load factor, and
$\alpha_D$ = dead load factor.

Given that:

$$w = w_D + w_L$$

and:

$$\alpha w = \alpha_D w_D + \alpha_L w_L$$

also:

$$r = \frac{w_D}{w_L}, \text{ substituting } w_D = r w_L$$

then:

$$\alpha = \frac{\alpha_D r w_L + \alpha_L w_L}{r w_L + w_L}$$

therefore:

$$\alpha = \frac{r \alpha_D + \alpha_L}{r + 1}$$

X7.2.1.1 For the ASCE 7-05[11] (to include Supplement No. 1), where, $\alpha_L$ = 1.6 and $\alpha_D$ = 1.2, this results in the values listed below for ratios of $r$ = 0.25:1 through $r$ = 3:1.

[11] Minimum Design Loads for Building and Other Structures, ASCE/SEI 7-05, 1801 Alexander Bell Dr., Reston, VA 20191.

| $r$ | $\alpha$ |
|---|---|
| 0.25:1 | 1.520 |
| 1:1 | 1.400 |
| 1.5:1 | 1.360 |
| 2:1 | 1.333 |
| 2.5:1 | 1.314 |
| 3:1 | 1.300 |

X7.2.1.2 If bending strength governs: then:

$$\phi M_n = \left[\frac{\alpha w s L^2}{8}\right] \quad \text{or} \quad w = \left[\frac{1}{\alpha s}\right] \cdot \left[\frac{8\phi M_n}{L^2}\right]$$

but:

$$w = w_d + w_s$$

thus:

$$w_s = \left[\frac{1}{\alpha s}\right] \cdot \left[\frac{8\phi M_n}{L^2}\right] - w_d$$

X7.2.1.3 If axial strength governs: then:

$$\phi P_n = \alpha P \quad \text{or} \quad P = \frac{\phi P_n}{\alpha}$$

but:

$$P = P_d + P_s$$

thus:

$$P_s = \frac{\phi P_n}{\alpha} - P_d$$

X7.2.1.4 To calculate the superimposed load required for testing:

*(1)* Establish the strength of the structural element to be tested (for example, design moment strength, $\phi M_n$, for beams, slabs or joists).

*(2)* Calculate the required superimposed load, $w_s$, if bending strength governs:

$$w_s = \left[\frac{1}{\alpha s}\right] \cdot \left[\frac{8\phi M_n}{L^2}\right] - w_d$$

and, if axial strength governs:

$$P_s = \frac{\phi P_n}{\alpha} - P_d$$

*(3)* The applied load calculated for a slab spanning between beams, may require a line load to be added. If such is the case, an additional line load necessary to load the structural member in the full-specified load condition shall be calculated. A line load is defined as the load per unit length along the structural member in question.

X7.2.2 It is important to consider the weight of the testing apparatus if it bears on the specimen and the way the load is transferred in the determination of the load to be applied, including whether the testing apparatus loads from the top or bottom, and the length of the specimen versus loading apparatus.

X7.2.3 For a test specimen that is fire tested to meet the maximum load condition in accordance with the Allowable Stress Design and the Strength Design method, the load imposed on the test specimen during the fire test should be the more severe loading condition calculated in accordance with the two design methods.

X7.2.4 Clauses 15, 20, 29 and 36 of the standard specify that the loading of the test specimen shall be the maximum load condition allowed under nationally recognized structural design criteria unless limited design criteria are specified and a corresponding reduced load applied.

X7.2.4.1 For timber, masonry, and steel structural members and specimens, the nationally recognized structural design criteria include design methods in accordance with Allowable Stress Design (ASD) and Strength Design also referred to as Load and Resistance Factor Design (LRFD). For reinforced concrete members, including prestressed and post tensioned concrete structures, the Strength Design method is the only nationally recognized design method.

X7.2.4.2 For test specimens where the loading is required to comply with the requirements of the Allowable Stress Design method, the load capacity is determined based on the section properties of the test specimen. The required imposed load on the test specimen is the load determined per the Allowable Stress Design method minus the self-load of the test specimen.

X7.2.4.3 For test specimens where the loading is required to comply with the requirements of the Strength Design method, the design strength of the member is determined based on the section properties of the test specimen. In the Strength Design method the dead and live load are factored (multiplied) by 1.2 and 1.6 respectively and combined to arrive at the factored load. The effects of the factored loads are required to be equal to the factored resistance. In the field the self-load load is not the only dead load, other imposed dead loads, for example, partition loads, equipment loads, and superimposed dead loads from the floors above, etc. are also present. Since the loading on the test specimen should be such as to produce the same initial load effects in the test specimen as would be induced in the structural element under full specified load (that is, live and dead load), the ratio of dead to live load to which the specimen will be subjected to in the field will depend upon the structural function of the specimen. In X7.2.1 the dead to live load ratio to which the specimen will be subjected in the field that is representative of the in-service condition of the specimen should be used. Examples using either or both ASD and LRFD design calculations methods are given for concrete and structural steel floor and roof specimens in X7.3, concrete columns in X7.4, wall and floor wood specimens in X7.5 and cold formed wall and floor steel specimens in X7.6.

### X7.3 Concrete and Structural Steel Floor and Roof Specimens

X7.3.1 For purposes of testing steel and concrete specimens, the selected ratio of dead load to live load should be such that the total test load represents the practical upper limit of the anticipated service load. Since, in strength design, the design strength, $\phi R_n$, of an entity is expressed as a function of the total factored load, $\alpha w$, it is apparent that for a given value of $\phi R_n$, the load, $w$, will be greatest when the load factor, $\alpha$, is least. In any event, $\alpha$, does not vary greatly for different ratios of dead load to live load and hence, for floor and roof specimens, a dead-to-live-load ratio of unity may be assumed for test purposes. The strength of materials used in arriving at the resistance of the specimen should be measured by coupon or

cylinder tests or determined by mill reports that may be deemed to be representative of the strength of materials at the time of test.

X7.3.2 Typical examples using the load and resistance factor design method are illustrated as follows:

**Example 1 (Load and Resistance Factor Design Method)**

*(1) Structural Steel Specimen*—See Fig. X7.1.

*(2) Construction:*

*(a)* Concrete slab—2.5 in. (65 mm) thick cover, 145 pcf (2300 kg/m³), 3000 psi (21 MPa).

*(b)* Steel deck—3 in. (76 mm) composite, 10 ft (3000 mm) span.

*(c)* Beam—W10×30, 17 ft-5 in. (5300 mm) span; $F_y = 50$ ksi.

*(d)* Protection—Sprayed fire protection material.

*(3) Loadings:*

*(a)* Composite deck slab—Required superimposed load. (Calculated outside of example)—135 psf (6.46 kPa).

*(b)* Due to dead load of slab, deck & protection—58 psf (2.78 kPa).

*(c)* Due to dead load of beam & protection—34 plf (0.49 kN/m).

*(d)* $\alpha_D = 1.2$, $\alpha_L = 1.6$ and dead-to-live-load ratio $r = 1.0$, thus $\alpha = 1.4$. (See X7.2.)

*(4) Calculation for Test Loading:*

*(a)* Design moment strength of beam, $\phi M_n$, determined in accordance with the AISC Specification for Structural Steel Buildings (2005),[12] for the conditions listed above:

$$\phi M_n = \phi Z F_y = (0.9)(36.6)(50)(ft/12 \text{ in.}) = 137.25 \text{ kip ft } (186.11 \text{ kN.m})$$

where:

$\phi$ = resistance factor,
$Z$ = plastic section modulus, in.³, and
$F_y$ = yield stress, ksi.

*(b)* Superimposed load for beam:

$$w_s = \left[\frac{1}{\alpha s}\right] \cdot \left[\frac{8\phi M_n}{L^2}\right] - w_d$$

$$w_s = \left[\frac{1}{1.4(10)}\right] \cdot \left[\frac{8 \times 137.25(1000 \text{ lb/kip})}{(17.417)^2}\right] - 58$$

$$= 201 \text{ psf } (9.62 \text{ kPa})$$

*(c)* Superimposed load for floor slab:

$$w_s = 135 \text{ psf } (6.46 \text{ kPa})$$

*(d)* Required superimposed load on test specimen:

$$w_s = 135 \text{ psf } (6.46 \text{ kPa})$$

*(e)* Additional line load required for beam:

$$W_s = (201 - 135)(10) - 34 = 626 \text{ plf } (9.2 \text{ kN/m})$$

**Example 2 (Load and Resistance Factor Design Method)**

*(1) Prestressed Concrete Specimen*—See Fig. X7.2.

*(2) Construction:*

*(a)* Concrete slab—8 in. (203 mm) thick, 17.4 ft (5300 mm) span.

*(b)* Non structural topping—2 in. (50 mm) thick.

*(c)* $f_c' = 5000$ psi (20 Mpa).

*(3) Loadings:*

*(a)* Due to dead load of slab—63 psf (1.96 kPa).

*(b)* Due to dead load of topping—25 psf (0.58 kPa).

*(c)* $\alpha_D = 1.2$, $\alpha_L = 1.6$, $r = 1.0$, $\alpha = 1.4$. (See X7.2.)

*(4) Calculations for Test Loading:*

*(a)* Design Moment Strength is determined in accordance with ACI 318[13] Building Code requirements for structural Concrete (2005).

$\phi M_n$ = design moment strength
$\phi M_n$ = 13.29 k-ft/ft (8 in. thick slab with 1½ in. strand cover @ 6⅜-in. Φ strands)

$$w_s = \left[\frac{1}{\alpha s}\right] \cdot \left[\frac{8\phi M_n}{L^2}\right] - w_d$$

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[12] ANSI/AISC 360–05, Specification for Structural Steel Buildings, March 2005, American Institute of Steel Construction, Inc., Chicago, IL.

[13] ACI 318-05, Building Code Requirements for Structural Concrete, American Concrete Institute, PO Box 9094, Farmington Hills, MI 48333-9094.
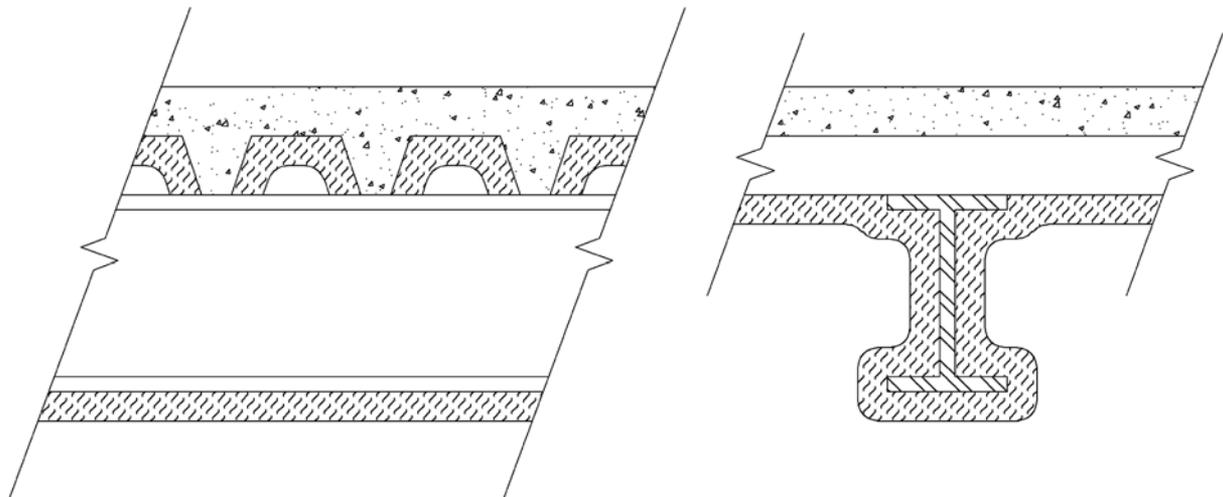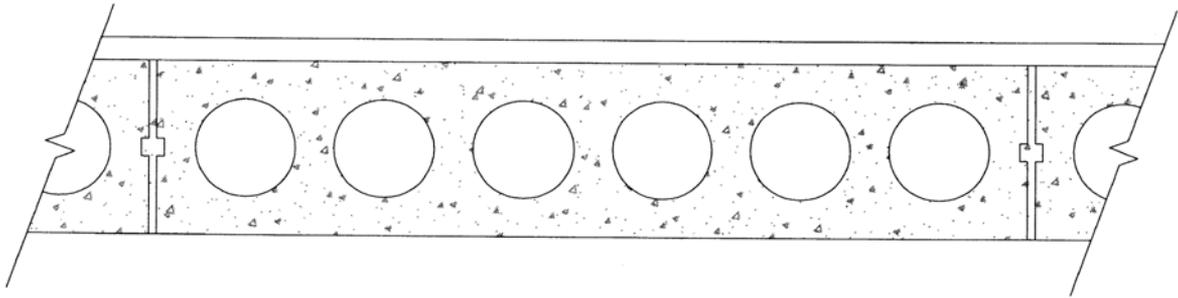


**FIG. X7.1 Structural Steel Specimen**

FIG. X7.2 Prestressed Concrete Specimen

$$= \left[ \frac{1}{1.4(1)} \right] \cdot \left[ \frac{8 \times (13.29)(1000 \text{ lb/kips})}{(17.4)^2} \right] - (63 + 25)$$

$$= 162.84 \text{ psf} (7.8 \text{ kPa})$$

## X7.4 Concrete Columns

X7.4.1 Unlike floor and roof elements, concrete columns directly support the building frame as well as the superimposed dead and live loads. For this reason, concrete column loads are usually dead load dominant. The dead-to-live-load ratio for concrete columns is taken as 2.5 as opposed to floor elements where a dead-to-live-load ratio of 1.0 is more representative.

**Example 1 (Load and Resistance Factor Design Method)**

*(1) Reinforced Concrete Column.*

*(2) Construction:*

*(a)* Concrete column—16 × 16 in. (400 × 400 mm) (Tied column).

*(b)* Length—120 in. (3048 mm) (assume short column behaviour, that is, slenderness ignored).

*(c)* Longitudinal reinforcement—8 × No. 8 bars (total $A_s = 6.32$ in.$^2$) (4000 mm$^2$).

*(d) $f_c'$*—4000 psi (27.58 MPa).

*(e) $f_y$*—60 000 psi (413.69 MPa).

*(3) Loadings:*

*(a)* Due to dead load of column:

$$w_2 = \frac{16(16)(120)(\text{in.}^3)(150)}{12^3} = 2667 \text{ lb} = 2.67 \text{ kips} (11.85 \text{ kN})$$

*(b)* $\alpha_D = 1.2$, $\alpha_L = 1.6$ and dead-to-live-load ratio $r = 2.5$ thus $\alpha = 1.314$. (See X7.2.)

*(4) Calculations for Test Loading:*

*(a)* Design axial strength, $\phi P_n$, for tied columns, at zero eccentricity determined in accordance with ACI 318[13] and the conditions listed above:

$$\phi P_n = 678.5 \text{ kips} (3018 \text{ kN})$$

*(b)* Required Superimposed Load on Test Specimen ($P_s$):

$$P_{service} = \frac{\phi P_n}{\alpha} = \frac{678.5}{1.314} = 516.36 \text{ kips} (2297 \text{ kN})$$

*(c)* The required superimposed load on the test specimen equals:

$$P_s = P_{service} - W_d = 516.36 - 2.67 = 513.69 \text{ kips} = (2285 \text{ kN})$$

where:
| | |
|---|---|
| $\phi P_n$ | = design axial strength, and |
| $P_{service}$ | = total unfactored axial load. |

## X7.5 Wood Specimens

X7.5.1 Fire resistance tests of wood floor and roof specimens are normally conducted using maximum allowable stresses to simulate a full-specified load condition. Tests conducted under serviceability criteria or other criteria would be considered a restricted load use condition.

X7.5.2 One specific example of a restricted load use condition is for certain load-bearing fire-rated wood stud wall specimens that were tested at load levels based on historical load calculations. In these wall specimens, the adjusted compression stress parallel to grain ($F_c'$) is restricted to 78 % of maximum $F_c'$ value for such members having a slenderness ratio ($l_e/d$) of 33.

X7.5.3 Typical examples for wood construction using both the allowable stress design method and load and resistance factor design method are illustrated as follows:
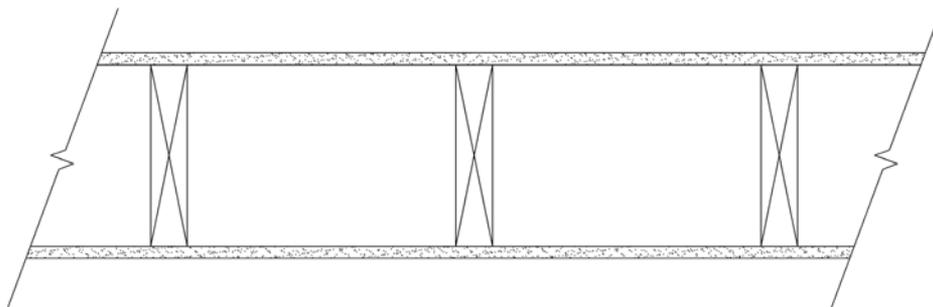


FIG. X7.3 Wood Wall and Floor Specimen

**Example 1 (Allowable Stress Design Method)**

*(1) Wood Wall Specimen—See Fig. X7.3.*

*(a)* The strength related to compression parallel to grain usually governs the design of wood stud wall specimens. The maximum design load typically applied to the wall is the sum of the allowable design load for each of the studs in the tested specimen.

*(2) Construction:*

*(a)* Studs—S-P-F No. 2, 2 in. × 4 in. (nominal) @ 16 in. (400 mm) o.c., 115.5 in. (2933 mm) long.

*(b)* Plates—S-P-F No. 2, 1.5 in. × 3.5 in.—1 bottom plate 120 in. (3048 mm) long; 2 top plates 120 in. (3048 mm) long.

*(c)* Sheathing—½ in. (13 mm) Type X gypsum board each side.

*(d)* Number of studs—9.

*(3) Calculation for Test Loading:*

*(a)* Dead load of wall specimen per stud—0.03 kips/stud (0.13 kN/stud).

*(b)* Compressive load of stud parallel to grain, $P_a$, determined in accordance with the National Design Specification® for Wood Construction (NDS®)[14] and ASTM D6513-00 using Allowable Stress Design (ASD) for the conditions listed above:

$F_c^*$ = reference compression design value multiplied by all applicable adjustment factors except $C_P$

$F_c^* = F_c C_D C_M C_t C_F C_i$   (Table 4.3.1, NDS® 2005)[14]

= (1150 psi)(1.0)(1.0)(1.0)(1.15)(1.0) = 1323 psi

= (9.12 MPa)

where:

$F_c$ = reference compression design value parallel to grain = 1150 psi (7.93 MPa),

$C_D$ = load duration factor = 1.0,

$C_M$ = wet service factor = 1.0,

$C_t$ = temperature factor = 1.0,

$C_F$ = size factor = 1.15 (nominal 2 in. × 4 in. studs, No. 2 grade S-P-F), and

$C_i$ = incising factor = 1.0.

*(c)* For buckling of compression member perpendicular to the plane of wall, $C_P$, column stability factor:

$$C_P = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1 + (F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}}$$

$$= \frac{1 + (385\ psi/1323\ psi)}{(2)(0.8)}$$

$$- \sqrt{\left[\frac{1 + (385\ psi/1323\ psi)}{(2)(0.8)}\right]^2 - \frac{385\ psi/1323\ psi}{0.8}}$$

[14] National Design Specification® for Wood Construction (NDS®) 2005 Edition, ANSI/AF&PA NDS-2005, American Forest & Paper Association, Inc., Washington D.C., 2005.

$$C_P = 0.807 - \sqrt{(0.807)^2 - 0.364} = 0.271$$

where:

$$F_{cE} = \frac{0.822E_{min}'}{(l_e/d)^2}$$
$$= \frac{(0.822)(510\ 000\ psi)}{(33)^2}$$
$$= 385\ psi\ (2.65\ MPa)$$

$E_{min}'$ = adjusted modulus of elasticity design value for beam and column stability multiplied by all applicable adjustment factors

= $E_{min}C_M C_t C_i C_T$   (Table 4.3.1, NDS® 2005)[14]

= (510 000 psi)(1.0)(1.0)(1.0)(1.0) = 510 000 psi (3516 MPa),

$E_{min}$ = reference modulus of elasticity design value for beam and column stability

= 510 000 psi (3516 MPa),

$C_T$ = buckling stiffness factor = 1.0,

$l_e/d$ = slenderness ratio of compression member = 115.5 in. / 3.5 in. = 33,

$c$ = 0.8 for sawn lumber, and

$F_c'$ = adjusted compression design value parallel to grain,

= $F_c^* C_P$ = (1323)(0.271) = 359 psi (2.48 MPa).

$$P_a = F_c'A$$
$$= (359\ psi)(5.25\ in.^2)$$
$$= 1885\ lb/stud$$
$$= 1.88\ kips/stud\ (8.36\ kN/stud)$$

where:

$A$ = area of cross-section = (3.5 in.)(1.5 in.) = 5.25 in.² (3387 mm²).

*(d)* Buckling of compression member in plane is prevented by the sheathing which normally provides support throughout its length, thus $C_P$ = 1. Load calculation will be greater for this failure mode.

*(e)* Compressive load of plate perpendicular to grain, $Q_a$, determined in accordance with the NDS® using ASD for the conditions listed above:

*(f)* Adjusted compression design value perpendicular to grain, $F_{c\perp}'$:

$$F_{c\perp} = F_{c\perp}C_M C_t C_i C_b$$

= (425 psi)(1.0)(1.0)(1.0)(1.0) (Table 4.3.1, NDS® 2005)[14]

= 425 psi

= (2.93 MPa)

where:

$F_{c\perp}'$ = reference compression design value perpendicular to grain = 425 psi, and

$C_b$ = bearing area factor = 1.0.

$$Q_a = F_{c\perp}'A$$
$$= 425 \text{ psi } (5.25 \text{ in.}^2)$$
$$= 2231 \text{ lb/stud}$$
$$= 223 \text{ kips/stud } (992 \text{ kN/stud})$$

$$Q_a > P_a$$

*(g)* Therefore, compression perpendicular to grain does not govern. Load per stud is based on buckling perpendicular to plane of wall or 1.88 kips/stud.

*(4) Loadings:*

*(a)* $P_d$, dead load of wall/stud = 0.03 kips/stud (0.13 kN/stud).

*(b)* Superimposed load per stud, $P_s$:

$$P_s = P_a - P_d$$
$$= 1.88 \text{ kips/stud } (8.36 \text{ kN/stud}) - 0.03 \text{ kips/stud } (0.13 \text{ kN/stud})$$
$$= 1.85 \text{ kips/stud } (8.23 \text{ kN/stud})$$

*(c)* Required Superimposed Line Load for Test Specimen:

$$W_s = P_s \times (\text{number of studs})/(\text{wall length})$$
$$= 1.85 \text{ kips/stud } (9 \text{ studs})/[120 \text{ in. } (1 \text{ ft}/12 \text{ in.})]$$
$$= 1.6 \text{ kips/ft } (23.34 \text{ kN/m})$$

**Example 2 (Load and Resistance Factor Design Method)**

*(1) Wood Wall Specimen*—See Fig. X7.3.

*(a)* The strength related to compression parallel to grain usually governs the design of wood stud wall specimens. The maximum design load typically applied to the wall is the sum of the allowable design load for each of the studs in the tested specimen.

*(2) Construction:*

*(a)* Studs—S-P-F No. 2, 2 in. × 4 in. (nominal) @ 16 in. (400 mm) o.c., 115.5 in. (2933 mm) long.

*(b)* Plates—S-P-F No. 2, 1.5 in. (38 mm) × 3.5 in. (89 mm), 1 bottom plate 120 in. (3048 mm) long, 2 top plates 120 in. (3048 mm) long.

*(c)* Sheathing—½ in. (13 mm) Type X gypsum board each side.

*(d)* Number of studs—9.

*(3) Loadings:*

*(a)* Dead load of wall specimen per stud: 0.03 kips/stud.

*(b)* $\alpha_D = 1.2$, $\alpha_L = 1.6$ and dead-to-live-load $r = 0.25$ thus $\alpha = 1.520$. (See X7.2.)

*(4) Calculation for Test Loading*

*(a)* Compressive load of stud parallel to grain, $P_a$, determined in accordance with the National Design Specification® for Wood Construction (NDS®)[14] using Load and Resistance Factor Design (LRFD) for the conditions listed above:

$F_c^*$ = reference compression design value multiplied by all applicable adjustment factors except $C_P$

$F_c^*$ = $F_c C_M C_t C_F C_i K_F \phi_c \lambda$   (Table 4.3.1, NDS® 2005)[14]

= (1150 psi)(1.0)(1.0)(1.15)(1.0)(2.4)(0.9)(0.7) = 2000 psi

where:

$F_c$ = reference compression design value parallel to grain
= 1150 psi (7.93 MPa),
$C_M$ = wet service factor = 1.0,
$C_t$ = temperature factor = 1.0,
$C_F$ = size factor = 1.15 (nominal 2 in. × 4 in. studs, No. 2 grade S-P-F),
$C_i$ = incising factor = 1.0,
$K_F$ = format conversion factor = 2.16/$\phi_c$ = 2.16/0.9 = 2.4,
$\phi_c$ = resistance factor for compression = 0.9, and
$\lambda$ = time effect factor = 0.7.

*(b)* For buckling of compression member perpendicular to the plane of wall, CP, column stability factor:

$$C_P = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1 + (F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}}$$

$$= \frac{1 + (577 \text{ psi} / 2000 \text{ psi})}{(2)(0.8)}$$

$$- \sqrt{\left[\frac{1 + (577 \text{ psi} / 2000 \text{ psi})}{(2)(0.8)}\right]^2 - \frac{577 \text{ psi} / 2000 \text{ psi}}{0.8}}$$

$$C_P = 0.805 - \sqrt{(0.805^2 - 0.361)} = 0.269$$

where:

$$F_{cE} = \frac{0.822 E_{min}'}{(l_e/d)^2}$$
$$= \frac{(0.822)(765\,000 \text{ psi})}{(33)^2}$$
$$= 577 \text{ psi } (3.98 \text{ MPa})$$

$E_{min}'$ = adjusted modulus of elasticity design value for beam and column stability multiplied by all applicable adjustment factors
= $E_{min} C_M C_t C_i C_T K_F \phi_s$ (Table 4.3.1, NDS® 2005)[14]
= (510 000 psi)(1.0)(1.0)(1.0)(1.0)(2.0)(0.75)
= 765 000 psi (5274 MPa),
$E_{min}$ = reference modulus of elasticity design value for beam and column stability
= (510 000 psi (3516 MPa),
$C_T$ = buckling stiffness factor = 1.0,
$K_F$ = format conversion factor = 1.5/$\phi_s$ = 1.5/0.75 = 2.0,
$\phi_s$ = resistance factor = 0.75,
$l_e/d$ = slenderness ratio of compression member
= 115.5 in. / 3.5 in. = 33,
$c$ = 0.8 for sawn lumber, and
$F_c'$ = adjusted compression design value = $F_c^* C_P$ = (2000)(0.269) = 538 psi (3.7 MPa).

$$P_a = F_c'A$$
$$= (538 \text{ psi})(5.25 \text{ in.}^2)$$
$$= 2824 \text{ lb/stud}$$
$$= 2.82 \text{ kips/stud } (12.54 \text{ kN/stud})$$

where:

$A$ = area of cross-section = (3.5 in.)(1.5 in.)
= 5.25 in.$^2$ (3387 mm$^2$).

*(c)* Buckling of compression member in plane is prevented by the sheathing which normally provides support throughout its length, thus $C_P = 1$. Load calculation will be greater for this failure mode.

*(d)* Compressive load of plate perpendicular to grain, $Q_a$, determined in accordance with the NDS® using LRFD for the conditions listed above:

*(e)* Adjusted compression design value perpendicular to grain, $F_{c\perp}'$:

$$F_{c\perp}' = F_{c\perp}C_MC_tC_bC_iK_F\phi_c\lambda \quad \text{(Table 4.3.1, NDS® 2005)}^{14}$$
$$= (425 \text{ psi})(1.0)(1.0)(1.0)(1.0)(2.08)(0.90)(0.7)$$
$$= 557 \text{ psi}$$
$$= (3.84 \text{ MPa})$$

where:
$F_{c\perp}$ = reference compression design value parallel to grain = 425 psi (2.93 MPa),
$C_b$ = bearing area factor = 1.0,
$K_F$ = format conversion factor = 1.875/ $\phi_c$ = 1.875/0.9 = 2.08,
$\phi_c$ = resistance factor = 0.90, and
$\lambda$ = time effect factor = 0.7.

$$Q_a = F_{c\perp}' A$$
$$= 557 \text{ psi } (5.25 \text{ in.}^2)$$
$$= 2942 \text{ lb/stud}$$
$$= 2.92 \text{ kips/stud } (12.99 \text{ kN/stud})$$

$$Q_a > P_a$$

*(f)* Therefore, compression perpendicular to grain does not govern. Load per stud is based on buckling perpendicular to plane of wall or 2.82 kips/stud.

*(g)* Superimposed load per stud, $P_s$:

$$P_s = \frac{P_a}{\alpha} - P_d$$
$$= \frac{2.82 \text{ kips/stud}}{1.520} - 0.03 \text{ kips/stud } (0.13 \text{ kN/stud})$$
$$= 1.82 \text{ kips/stud}$$
$$= (8.1 \text{ kN/stud})$$

where:
$P_d$ = dead load of wall specimen/stud = 0.033 kips/stud (0.15 kN/stud).

*(h)* Required Superimposed Line Load on Test Specimen:

$$W_s = P_s \times \frac{\text{(number of studs)}}{\text{(wall length)}}$$
$$= \frac{(1.82 \text{ kips/stud})(9 \text{ studs})}{(120 \text{in.} \times (1 \text{ ft/12 in.}))}$$
$$= 1.6 \text{ kips/ft } (23.34 \text{ kN/m})$$

### Example 3 (Allowable Stress Design Method)

*(1) Wood Floor Specimen*—See Fig. X7.3.

*(2) Construction:*

*(a)* Joists—S-P-F No. 2, 2 in. × 10 in. (nominal) @ 16 in. (400 mm) o.c., 150 in. (3810 mm) span.

*(b)* Subfloor—½ in. (13 mm) plywood.

*(c)* Ceiling—⅝ in. (16 mm) Type X gypsum board—2 layers, direct applied.

*(3) Calculation for Test Loading:*

*(a)* Dead load of floor specimen: 10.4 psf (0.5 kPa).

*(b)* Allowable bending moment of member, $M_a$, determined in accordance with the National Design Specification®

for Wood Construction (NDS®) using Allowable Stress Design (ASD) for the conditions listed above:

$F_b'$ = reference compression design value multiplied by all applicable adjustment factors
$F_b'$ = $F_bC_DC_MC_tC_LC_FC_{fu}C_iC_r$ (Table 4.3.1, NDS® 2005)[14]
$\quad$ = (875 psi)(1.0)(1.0)(1.0)(1.0)(1.1)(1.0)(1.0)(1.15)
$\quad$ = 1107 psi
$\quad$ = (7.63 MPa)

where:
$F_b$ = reference bending design value = 875 psi (6.03 MPa),
$C_D$ = load duration factor = 1.0,
$C_M$ = wet service factor = 1.0,
$C_t$ = temperature factor = 1.0,
$C_L$ = beam stability factor = 1.0,
$C_F$ = size factor = 1.1,
$C_{fu}$ = flat use factor = 1.0,
$C_i$ = incising factor = 1.0, and
$C_r$ = repetitive member factor = 1.15.

$$M_a = F_b'S = (1107 \text{ psi})(21.39 \text{ in.}^3) = 23\,679 \text{ in.}-\text{lb}$$

where:
$S$ = section modulus = 21.39 in.$^3$.

*(c)* Allowable linear joist loading based on $M_a$, $W_{Ma}$:

$$W_{Ma} = 8Ma/L^2 = 8(23\,679 \text{ in.}-\text{lb})/(150 \text{ in.} \times (1 \text{ ft/12 in.}))^2 = 101 \text{ plf}$$

where:
$L$ = span of member = 150 in. (3810 mm).

*(d)* Allowable joist loading by area based on $M_a$, $w_{Ma}$:

$$w_{Ma} = W_{Ma}/s = (101 \text{ lb/ft})/(16 \text{ in.} \times (1 \text{ ft/12 in.})) = 75.8 \text{ psf } (3.63 \text{ kPa})$$

where:
$s$ = spacing of joists = 16 in. (400 mm).

*(e)* Allowable shear of member, $V_a$, determined in accordance with the NDS®[14] using ASD for the conditions listed above:

$F_v'$ = reference shear design value multiplied by all applicable adjustment factors
$F_v'$ = $F_VC_DC_MC_tC_i$ (Table 4.3.1, NDS® 2005)[14]
$\quad$ = (135 psi)(1.0)(1.0)(1.0)(1.0) = 135 psi
$\quad$ = (0.93 MPa)

where:
$F_v$ = reference shear design value = 135 psi (0.93 MPa).

$$V_a = (2/3) F_v' A$$
$$= (2/3)(135)(13.88)$$
$$= 1249 \text{ lb } (5.56 \text{ kN})$$

where:
$A$ = area of cross-section = 13.88 in.$^2$ (8955 mm$^2$).

*(f)* Allowable linear joist loading based on $V_a$, $W_{Va}$:

$$W_{Va} = 2V/L$$
$$= 2(1249 \text{ lb})/(150 \text{ in.} \times (1 \text{ ft/12 in.}))$$
$$= 199.8 \text{ plf } (2.94 \text{ kN/m}^2)$$

*(g)* Allowable joist loading by area based on $V_a$, $w_{Va}$:

$w_{Va} = W_{Va}/s = (199.8 \text{ lb/ft})/(16 \text{ in.} \times (1 \text{ ft}/12 \text{ in.})) = 150 \text{ psf (7.18 kPa)}$

$$w_{Va} > w_{Ma}$$

*(h)* Therefore, shear does not govern. Load is based on allowable moment or 75.8 psf (3.63 kPa).

*(4) Loadings:*

*(a)* $w_d$, dead load of specimen = 10.4 psf (0.50 kPa).

*(b)* Required Superimposed Load for Test Specimen:

$w_s = w_{Ma} - w_d = 75.8 \text{ psf} - 10.4 \text{ psf} = 65.4 \text{ psf (3.13 kPa)}$

*(c)* Check Live Load Deflection:

$$\Delta_{live} = \left[ \frac{5w_s L^4}{384EI} \right]$$

$$= \left[ \frac{5 \left( 65.4 \text{ psf } (16 \text{ in.}) \left( \frac{1 \text{ ft}}{12 \text{ in.}} \right)^2 \right) (150 \text{ in.})^4}{384(138.5 \times 10^6 \text{ lb·in.}^2)} \right]$$

$$= 0.346 \text{ in. or } P/434$$

where:

$EI$ = bending stiffness = $(1\ 400\ 000)(98.93) = 138.5 \times 10^6$ lb-in.$^2$,

$E$ = modulus of elasticity = 1 400 000 lb/in.$^2$, and

$I$ = moment of inertia = 98.93 in.$^4$.

*(d)* Check Total Load Deflection:

$$\Delta_{total} = \left[ \frac{5w_{Ma} L^4}{384EI} \right]$$

$$= \left[ \frac{5 \left( 75.8 \text{ psf } (16 \text{ in.}) \left( \frac{1 \text{ ft}}{12 \text{ in.}} \right)^2 \right) (150 \text{ in.})^4}{384(138.5 \times 10^6 \text{ lb·in.}^2)} \right]$$

$$= 0.400 \text{ in. or } P/375$$

### Example 4 (Load and Resistance Factor Design Method)

*(1) Wood Floor Specimen*—See Fig. X7.3.

*(2) Construction:*

*(a)* Joists—S-P-F No. 2, 2 in. × 10 in. (nominal) @ 16 in. (400 mm) o.c., 150 in. (3810 mm) span.

*(b)* Subfloor—½ in. (13 mm) plywood.

*(c)* Ceiling—⅝ in. (16 mm) Type X gypsum board—2 layers, direct applied.

*(3) Loadings:*

*(a)* Dead load of floor specimen: 10.4 psf (0.48 KPa).

*(b)* $\alpha_D = 1.2$, $\alpha_L = 1.6$ and dead-to-live-load $r = 0.25$ thus $\alpha = 1.520$. (See X7.2.)

*(4) Calculation for Test Loading:*

*(a)* Allowable bending moment of member, $M_a$, determined in accordance with the National Design Specification® for Wood Construction (NDS®)4[14] using Load and Resistance Factor Design (LRFD) for the conditions listed above:

$F_b'$ = reference shear design value multiplied by all applicable adjustment factors

$F_b'$ = $F_b C_M C_t C_L C_F C_{fu} C_i C_r K_F \phi_b \lambda$ (Table 4.3.1, NDS® 2005)[14]

= (875 psi) (1.0)(1.0)(1.0)(1.1)(1.0)(1.0)(1.15)(2.54) (0.85)(0.7)

= 1673 psi

= (11.53 MPa)

where:

$F_b$ = reference bending design value = 875 psi (6.03 MPa),

$C_M$ = wet service factor = 1.0,

$C_t$ = temperature factor = 1.0,

$C_L$ = beam stability factor = 1.0,

$C_F$ = size factor = 1.1,

$C_{fu}$ = flat use factor = 1.0,

$C_i$ = incising factor = 1.0,

$C_r$ = repetitive member factor = 1.15,

$K_F$ = format conversion factor = $2.16/\phi_c$ = 2.16/0.85 = 2.54,

$\phi_b$ = resistance factor for bending = 0.85, and

$\lambda$ = time effect factor = 0.7.

$$M_a = F_b' S$$
$$= (1673 \text{ psi})(21.39 \text{ in.}^3)$$
$$= 35\ 785 \text{ in.-lb}$$
$$= 2982 \text{ ft-lb}$$

where:

$S$ = section modulus = 21.39 in.$^3$.

*(b)* Required Superimposed Load on Test Specimen:

$$w_s = \left[ \left( \frac{1}{\alpha s} \right) \left( \frac{8M_a}{L^2} \right) \right] - w_d$$

$$= \left[ \left( \frac{1}{1.520 \left( 16 \text{ in.} \left( \frac{1 \text{ ft}}{12 \text{ in.}} \right) \right)} \right) \left( \frac{8(2982 \text{ ft·lb})}{\left( 150 \text{ in.} \left( \frac{1 \text{ ft}}{12 \text{ in.}} \right) \right)^2} \right) \right] - 10.4 \text{ psf}$$

$$= 65 \text{ psf (3.11 kPa)}$$

where:

$s$ = spacing of members = 16 in. (400 mm),

$L$ = span of members = 150 in. (3810 mm), and

$w_d$ = dead load of specimen = 10.4 psf (0.5 kPa).

## X7.6 Cold Formed Steel Specimens

X7.6.1 Anticipated service loading on cold formed steel specimens differs frequently from that determined by the formula in X7.3. This is due partly to the fact that the dead-to-live-load ratio is normally much less than unity (1:4 is more typical), but also to the serviceability limit state of deflection, which often governs the design of these specimens. The two following formulas apply if a given condition governed by bending strength or deflection is to be used:

*(1)* Governed by bending stress (strength limit state):

$$w_s = \left[ \frac{1}{\alpha s} \right] \cdot \left[ \frac{8\phi M_n}{L^2} \right] - w_d$$

*(2)* Governed by deflection (serviceability limit state):

$$\Delta = \frac{(w_s)s5L^4}{384EI_d}$$

$$w_s = \frac{384EI_d \Delta}{s5L^4}$$

where:

$E$ = modulus of elasticity of element (ksi),

$I_d$ = moment of inertia of section based on deflection determination (in.$^4$), and

$\Delta$ = deflection of element (in.).

X7.6.2 Fire resistance tests of floor and roof specimens are normally conducted using strength limit state criteria (formula

1) to simulate a full specified load condition. Tests conducted under serviceability limit state criteria (formula 2) would be considered a "restricted" load use condition. Care should be taken to report the criteria used so that these criteria can be related to design assumptions for building specimens.

X7.6.3 Typical examples for cold-formed steel construction are illustrated as follows:

**Example 1 (Load and Resistance Factor Design Method)**

*(1) Cold Formed Steel Floor Specimen*—See Fig. X7.4.
*(2) Construction:*
*(a) Subfloor*—⅝ in. thick plywood.
*(b) Joist*—CFS C Section—1⅝ in. (41 mm) × 8 in. (203 mm) × ½ in. (13 mm) × 0.06 in. (1.5 mm) @ 16 in. (400 mm) o.c., 14.0 ft (4267 mm) span.
*(c) Ceiling*—⅝ in. (16 mm) thick Type X gypsum board.
*(3) Loadings:*
*(a)* Dead load of floor specimen—10.44 psf (0.5 kPa).
*(b)* $\alpha D = 1.20$, $\alpha L = 1.60$ and dead-to-live-load ratio $r = 0.25$ thus $\alpha = 1.520$. (See X7.2.)
*(4) Calculation of Test Loading:*
*(a)* Design moment strength of joist, $\phi M_n$, determined in accordance with the LRFD provisions of the AISI Standard[15] "North American Specification for the Design of Cold-Formed Steel Structural Members" for the conditions listed above, assuming fully braced to resist lateral instability and perforated webs:

$$\phi M_n = \phi_b S_c F_c$$
$$= 0.90\,(1.161)(50)$$
$$= 52.25 \text{ kip.in.}$$
$$= 4.354 \text{ kip.ft}$$
$$= (5.90 \text{ kN.m})$$

where:
$F_c$ = compressive limit stress for laterally supported flexural member = 50 ksi, and
$S_c$ = compressive section modulus based on the moment of inertia of the effective cross section = 1.161 in.$^3$
*(b) Required Superimposed Load on Test Specimen:*
*(1)* Governed by bending (full specified load condition):

$$w_s = \left[\left(\frac{1}{\alpha s}\right)\left(\frac{8\phi M_n}{L^2}\right)\right] - w_d$$
$$= \left[\left(\frac{1}{1.520\left(16 \text{ in.}\left(\frac{1 \text{ ft}}{12 \text{ in.}}\right)\right)}\right)\left(\frac{8(4.354(1000 \text{ lb/kip}))}{(14)^2}\right)\right] - 10.44 \text{ psf}$$
$$= 77.25 \text{ psf (3.70 kPa)}$$

*(2)* Governed by deflection ($\Delta = L/360$) (restricted load use condition):

$$w_s = \frac{384 E I_d \Delta}{s5L^4}$$
$$= \frac{384(29\,500)(5.886)(14(12 \text{ in./ft})/360)}{16(5)(14(12 \text{ in./ft}))^4}$$
$$= 0.0004883 \text{ ksi}$$
$$= 70.31 \text{ psf}$$
$$= (3.37 \text{ kPa})$$

where:
$I$ = 5.886 in.$^4$, and
$E$ = 29 500 ksi.

**Example 2 (Load and Resistance Factor Design Method)**

*(1) Cold Formed Steel Wall Specimen*—See Fig. X7.5.
*(2) Design:*
*(a)* Axial load capacity calculated in accordance with the LRFD provisions of the AISI Standard[15] "North American Specification for the Design of Cold-Formed Steel Structural Members."
*(b)* Axial load only.
*(c)* Unsheathed design.
*(d)* Lateral support provided by bridging (2 rows).
*(3) Construction:*
*(a) Studs*—CFS C-Section 1⅝ in. (41 mm) × 3⅝ in. (92 mm) × ½ in. (13 mm) × 0.044 in. (1.12 mm) × 16 in. (400 mm) o.c., 8 ft (2438 mm) long; $F_y$ = 33 ksi.
*(b) Track*—1³⁄₁₆ in. × 3⅝ in. × 0.044 in.
*(c) Sheathing*—½ in. (13 mm) thick Type X gypsum board each side.
*(4) Loadings:*
*(a)* Dead load of wall specimen—41.1 plf (0.60 kN/m).
*(b)* $\alpha_D = 1.20$, $\alpha_L = 1.60$ and dead-to-live-load ratio $r = 0.25$ thus $\alpha = 1.520$. (See X7.2.)
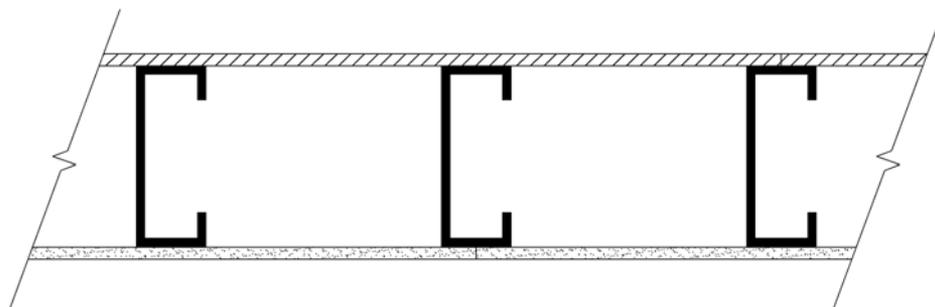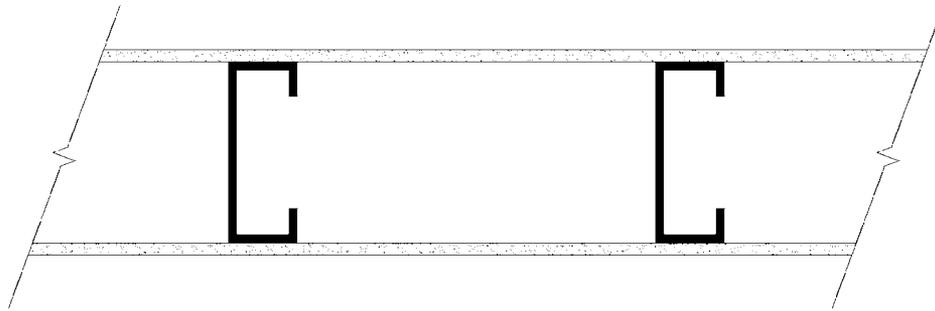*(5) Calculation of Test Loading:*

**FIG. X7.4 Cold Formed Steel Floor Specimen**

**FIG. X7.5 Cold Formed Steel Wall Specimen**

*(a)* Design compressive strength of stud, $\phi P_n$, determined in accordance with the AISI[15] Standard North American Specification for the Design of Cold-Formed Steel Structural Members:

$$\phi P_n = \phi_c A_e F_n, = 0.85(0.225)(26.5) = 5.068 \text{ kips} = (22.54 \text{ kN})$$

where:

$A_e$ = effective cross-sectional area calculated at a stress equal to $F_n$ = 0.225 in.$^2$, and

$F_n$ = compressive limit stress = 26.5 ksi.

*(b)* Superimposed load for stud:

$$P_s = \phi P_n / \alpha - P_d$$

where:

$P_d$, dead load of wall specimen/stud = 41.1 plf

$$P_s = (5.068(1000 \text{ lb/kip})/1.52) - 41.1(16/12) = 3279 \text{ lb}$$

*(c)* Required superimposed line load on test specimen:

$$\begin{aligned} W_s &= P_s/\text{stud spacing} \\ &= 3279/(16) \\ &= 204.9 \text{ lb/in.} \\ &= 2.459 \text{ kips/ft} \\ &= (35.88 \text{ kN/m}) \end{aligned}$$

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