Restrained vs. Unrestrained

To most structural engineers, code officials and architects, the terms "Restrained" and "Unrestrained" are typically interpreted as referring to the connection of structural elements at ambient temperatures. However, in the fire protection industry, restrained and unrestrained are addressed at elevated temperatures, introducing the concept of "thermal restraint".

The issue of thermal restraint causes some controversy in determining whether an assembly should be considered restrained or unrestrained. The classification of an assembly in one of these categories has a bearing on the thickness of Spray-Applied Fire Resistive Material (SFRM) needed to satisfy code requirements. Higher SFRM thicknesses are typically required for unrestrained ratings.

In order to determine whether an assembly is restrained or unrestrained, one may refer to the actual "Fire Test Standards of Building Construction and Materials". According to Appendix X3 of ASTM E119 and Appendix C of UL 263, "Floor and roof assemblies and individual beams in buildings shall be considered restrained when the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures. Construction not complying with this definition is assumed to be free to rotate and expand and shall therefore be considered as unrestrained".

To assist in determining this condition, ASTM E119 and UL 263 also list general construction classifications and whether they denote a restrained or unrestrained condition. This table of classifications, which at one time appeared in the UL Fire Resistance Directory, has been attached for reference purposes. According to UL, this information is intended as a guide for the determination of restrained conditions and is not meant as a specification. Engineering judgment must therefore be exercised to determine what constitutes restraint to "substantial thermal expansion".

Furthermore, the current UL Fire Resistance Directory states the following: "Restrained conditions for the fire test assemblies are provided by construction floor, beam, and roof test assemblies within nominal 14 ft x 17 ft frames of composite steel/concrete cross sections having an approximate stiffness (EI/L) of 850,000 kip-in and 700,000 kip-in along the 14 ft and 17 ft sides, respectively". This description provides structural engineers with the stiffness of UL's test frame so that they have a basis of comparison when determining conditions of restraint for beams on a project.

Due to the level of analysis and interpretation required, there is often confusion as to whether a building's construction shall be specified as restrained or unrestrained. Ultimately, the determination of the conditions of restraint remains in the hands of the structural engineer and the authority having jurisdiction. The level at which these conditions are addressed by the various code bodies differs between organizations. The International Building Code (IBC) addresses restrained vs. unrestrained criteria referring directly to Appendix X3 of ASTM E119. IBC clearly addresses restrained classification in its Section 703.2.3.

After determining restrained vs. unrestrained conditions, the appropriate restrained or unrestrained fire resistance rating must be utilized. Restrained and unrestrained fire ratings specified for both beams/joists and assemblies are used to determine the required fire protection material thicknesses which are listed in the UL Directory. Due to the difference in thickness requirements between restrained and unrestrained hourly ratings, its correct determination is critical to the life safety integrity of the building.

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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 provides 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 tests of loaded beams in the restrained condition only, where 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. Test Methods E119 do not provide for tests of loaded beams in the unrestrained condition. However, the alternative unrestrained beam ratings can be determined (in addition to the restrained beam rating) from the restrained loaded beam tests based on specific temperature criteria for concrete reinforcement or steel beams specified in the standard. 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.

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. It should also be mentioned that the loaded unrestrained beam test in this comparison did not fully conform to Test Methods E119, because they do not provide for tests of loaded beams in the unrestrained condition.

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.