

Calculating Fire Resistance

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If you've ever worked on or with construction documents that involve fire-resistive construction, you're probably familiar with UL design numbers, GA file numbers, or building code prescriptive item numbers. These numbers identify construction assemblies that have been specifically tested for fire resistance. In order to be approved, an assembly must be installed as tested; any modification will likely be disapproved by the building official. However, in today's construction, some unique assemblies can't be identified using a previously tested assembly number; and having a special test performed for a project-specific assembly may break the budget. Fortunately, there are other methods to determine the fire resistance of an assembly without the financial impact and still comply with the building code.

Calculating fire resistance has been a part of model building codes for many years. The *Uniform Building Code* provided UBC Standard 7-7 which established criteria for calculating fire resistance of steel, concrete, wood, and masonry. The *International Building Code* has taken UBC Standard 7-7 and integrated much of the document directly into IBC Section 721.

Section 721 provides methods for calculating fire-resistance for individual construction materials and components that are integrated into a fire-resistive assembly. The fire-resistive time periods provided in this code section are based on historical testing of materials using ASTM E 119, which is an essential requirement of allowing alternate methods for determining fire resistance per Section 703.3: "The application of any alternative methods listed in this section shall be based on the fire exposure and acceptance criteria specified in ASTM E 119."

Specifically, the IBC provides alternate methods for calculating fire resistance in concrete, concrete masonry, clay brick and tile masonry, steel assemblies, and wood assemblies. The intent of this article isn't to explain in detail the various methods of calculating fire resistance for each material and assembly, but, rather, to provide a broad overview of what's available in the code and to cover some general concepts in calculating fire resistance.

Concrete Masonry

We'll start first with concrete masonry since it's a common material used in fire-resistive construction throughout the country, especially in single-story to low-rise type structures. Concrete masonry uses portland cement and aggregates to obtain its fire-resistive qualities; however, it's the aggregate that has the greatest impact on a concrete masonry unit's fire-resistance rating.

The IBC divides aggregates into four categories: pumice or expanded slag; expanded shale, clay or slate; limestone, cinders or unexpanded slag; and, calcareous or siliceous gravel. These are listed from lightweight aggregates to normal weight aggregates. As the weight of the aggregate increases, the fire-resistive rating of concrete masonry decreases; thereby, requiring thicker walls to achieve an equivalent fire rating when comparing lightweight masonry to normal weight masonry. Speaking of wall thickness...

The thicknesses provided in the IBC are the "equivalent thicknesses" required, and not the actual thicknesses. Since concrete masonry is considered hollow, the equivalent thickness is the effective fire-

resistive thickness determined by dividing the net volume of the unit by the product of the length and width of the unit. For example, a standard 8x8x16 concrete masonry unit, with a net volume of 563 cubic inches, will have an equivalent thickness of 4.73 inches.

With the equivalent thickness and type of aggregate material at hand, consult Table 721.3.2 to determine the fire-resistance rating. If the masonry is made of expanded slag aggregate, the fire-resistance rating would be at least 4 hours. If an equivalent thickness is between two thicknesses in the chart, the fire-resistance rating can be interpolated. In the case of mixed, or “blended,” aggregates, then the ratios of the various aggregates used are applied to the individual fire-resistance ratings for each aggregate to achieve the overall unit fire-resistance rating.

Brick and Tile Masonry

The fire-resistance of brick and tile (clay) masonry is similar to that of concrete masonry, by utilizing equivalent thicknesses in the calculation. However, because of clay masonry’s limited material composition, the shape of the brick—hollow versus solid, filled versus unfilled—has a significant impact on the fire-resistance rating. In brick terminology, solid really isn’t solid. To be considered solid, the cores of the brick cannot exceed 25% of the surface in the plane containing the cores.

Steel

Steel construction, on the other hand, has limited resistance to fire, although it is considered a noncombustible material. Steel loses its tensile strength very quickly as it absorbs heat from a fire. This has been a major concern investigated by the National Institute of Standards and Technology (NIST) following the World Trade Center collapse in 2001¹. At 1,022 degrees F., steel will lose approximately 50% of its yield strength; a temperature that can be reached in less than 10 minutes in a fire with a normal fuel load such as that in a typical office, leading to imminent collapse.

To protect steel from this premature collapse, steel members must be insulated from fire. Several methods are provided in the IBC, including concrete encasement, spray-applied fire-resistant materials, masonry protection, and gypsum board protection. The key to calculating steel fire-resistance protection is understanding the weight-to-heated-perimeter ratio, commonly referred to as the W/D ratio.

The W/D ratio for a steel shape is determined by dividing the weight per linear foot (W) by the exposed surface area of the steel member (D); the higher the ratio, the greater the member’s fire-resistance, thus requiring less protection when calculating ratings for the various types of protection. The ratio can be increased by using a heavier member, or using a member with reduced exposed area (steel tube versus wide flange). The IBC provides some W/D ratios for common wide-flange shapes, as do some of the manufacturers of spray-applied fire-resistant materials.

Concrete

Like concrete masonry, concrete is a very fire-resistant material, which is why it is used throughout most Type I and II mid- to high-rise structures. The fire-resistance characteristics of concrete includes those of concrete masonry (they’re both cement-based materials) and steel (used for reinforcing). However, concrete has a unique characteristic that isn’t common in most other fire-resistant materials: the ability to shape the material into a variety of precast and cast-in-place shapes. Concrete, used commonly for floor systems and structural frames, has been thoroughly tested in a variety of horizontal applications.

For any material, the fire exposure in a horizontal application is more severe than in a vertical condition. Therefore, based on its performance in horizontal fire endurance tests, concrete can be expected to perform equally or better in a vertical, or wall, condition.

Like masonry, concrete's fire-resistance is based on the type of concrete aggregate used and the equivalent thickness. But unlike masonry, the unique shapes provided by concrete construction require different calculations to determine the equivalent thickness based on the type of shape. These calculations can be somewhat daunting at first, but once you understand the formulas, the equivalent thickness can be quickly and easily derived. After determining the equivalent thickness, the fire-resistance ratings are determined using Tables in the IBC. For walls, the fire-resistance ratings are determined by Table 721.2.1.1, and Table 721.2.2.1 for floors and roofs.

For horizontal construction, the steel reinforcing becomes critically important--just as with structural steel. And, like concrete encased structural steel, the concrete insulates the steel reinforcing from the extreme temperatures of a fire. Therefore, adequate coverage of the steel reinforcing needs to be provided. IBC Table 721.2.3(1) provides the minimum cover for steel reinforcing based on aggregate type, required fire-resistance rating, and restrained versus unrestrained conditions. You can obtain the latter from your structural engineer.

Multiwythe Construction

Calculating fire resistance for multiwythe construction consisting of concrete masonry, clay masonry, or concrete, is provided in the IBC in Sections 721.3.3, 721.4.1.3 and 721.2.1.2, respectively. The calculated fire-resistance of multiwythe construction is generally greater than the sum of the individual fire-resistance ratings for each wythe of the wall, based on the theory that the thermal break of the airspaces and the overall wall thickness have a significant impact on a wall's ability to resist fire.

Wood Assemblies

Finally, fire-resistance ratings for wood frame construction are relatively straight forward to calculate compared to those of the previous materials. Fire-resistance ratings are determined by the sum of the assigned ratings to each of the assembly's components including the membrane on the fire-exposed side, framing, and any time assigned for additional protective measures; the time does not include the membrane on the unexposed side. For example, to obtain a 1-hour rated wall, you can use wood studs (regardless of depth) at 16 inches on center to get 20 minutes. Then, add a layer of 5/8-inch regular gypsum board on the exposed side for an additional 30 minutes. We're now up to 50 minutes--10 minutes shy of our 1-hour minimum rating. So, we add glass fiber insulation to the spaces between the studs to get another 15 minutes, for a total of 65 minutes. If insulation is not desired, use Type X gypsum board instead of regular gypsum board, which adds 40 minutes to the 20 minutes for framing, for a total of 60 minutes--1 hour--of fire-resistive protection. All of these assigned numbers can be found in Tables 721.6.2(1 through 5). Additionally, these assigned values can be added to the fire-resistance ratings determined for each of the other materials discussed earlier in this article, thereby providing more flexibility to the type of assembly used.

Much of what is provided in the building code for calculated fire-resistance is based on information first released as early as 1918 and 1942². But new technology will eventually lend itself to new ways of determining fire-resistance. In the area of steel construction, "fire-resistant" steel is available, having the ability to retain almost 67% of its yield stress at 1,112 degrees F. About 3-1/2 years ago, a Chinese

company announced it had developed a form of steel that can withstand temperatures of 1,080 degrees F. for up to 2.5 hours without yielding! Furthermore, spray-applied fireproofing took a hit in the 1970's when the hype surrounding asbestos made its way into every aspect of building construction, but found new light during the same time period when intumescent technology was introduced to the construction industry.

Experience from tragedies such as the World Trade Center will always have an impact on how building codes are modified to some degree. But, extreme cases aside, resistance to the typical structural fire remains the foremost concern of building code development. For that reason, as innovative materials and technologies are developed, building codes will continue to adapt, and are expected to provide the same, or even greater, flexibility as they currently provide.

¹ “Fire Protection of Structural Steel in High-Rise Buildings,” NIST, July 2004, http://www.bfrl.nist.gov/pdf/GCR04_872.pdf

² The Time-Temperature Curve of ASTM E 119 has been a part of that standard since it was first published in 1918 as C19. BMS 92, “Fire Resistance Classifications, Building Materials and Structures,” was published by the National Bureau of Standards (NBS--the precursor of the National Institute of Standards and Technology, NIST) in 1942. For the most part, much of the information found in this standard is still considered relevant to this date.

To comment on this article, suggest other topics, or submit a question regarding codes, contact the author at ron@specsandcodes.com.

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