Fire Resistance of Flat Plate Voided Concrete Slab Systems

Introduction

Concrete and steel are noncombustible materials; that is, they will not ignite or burn when subjected to fire or heat. Because reinforced concrete assemblies and systems are inherently fire resistant, no additional fire protection is required to meet common minimum fire ratings prescribed in the building codes. These inherent material properties reduce fire risk and require minimum ongoing maintenance over the lifetime of a building.

Flat plate voided concrete slab systems, which have been used for many years in Europe and other parts of the world, are becoming increasingly popular in the U.S. because of many inherent benefits that can be provided. Descriptions of the various types of flat plate voided concrete slab systems are given in the next section. Information and guidelines on how to determine the fire resistance for these systems are also provided as are results from fire tests. The data shows that the design of flat plate voided concrete slab systems for fire protection is the same as that for other reinforced concrete structures and that a ¾ in. cover to the bottom reinforcing bars will provide a minimum 2-hour fire-resistance rating, which meets minimum required fire-resistance ratings for floor assemblies in common occupancies.

Flat Plate Voided Concrete Slab Systems

Various types of voided concrete slabs have been used throughout the years, including one-way Sonotube systems and two-way joist (waffle slab) systems that are constructed using dome forms. Contemporary systems, pioneered primarily by BubbleDeck® and Cobiax®, utilize hollow, plastic balls made out of high-density, recycled polyethylene (HDPE), which are commonly referred to as void formers (see Figure 2). The void formers reduce the weight of the slab significantly compared to a solid slab of the same thickness; they are judiciously located in zones where concrete is not needed and where the flexural strength and load transfer to supports are not compromised.

In applications where 30 to 50 foot spans are required, the overall depth of the slab can range from 10 to 21.5 in. It is common at column locations that void formers are omitted so that a solid concrete section is
available to resist two-way shear stresses (see Figure 3). Where additional shear strength is required, shear reinforcement, such as headed shear stud reinforcement, can easily be accommodated, as shown in the Figure.

Flat plate voided concrete slabs systems are designed and detailed in accordance with requirements of ACI 318 (ACI 2014) just like any other two-way slab system. It is important to note that the void formers do not contribute to the nominal flexural and shear strengths of the slab system; their only role is to provide voids in the slab. Stiffness and shear modification factors are provided for deflection and shear strength calculations, respectively, which are used in design to take into account the presence of the voids within the slab. No modification factors are required for flexure because the voids do not have an impact on flexural strength; nominal flexural strength is based on compression in the concrete and tension in the reinforcing bars, just as in any other two-way slab system. Additional design and detailing information, including a worked-out design example, can be found in CRSI (2014).

In addition to reduction in dead load, there are other noteworthy benefits that can be realized by utilizing a voided slab system, including economical long spans without forming and casting of beams, low floor-to-floor heights, and vibration resistance. See CRSI (2014) and manufacturers’ literature for more information.

Fire-Resistance Ratings

In general, fire-resistance rating (or, fire rating), is the period of time (usually expressed in hours) a building element, component, or assembly maintains the ability to contain a fire, continues to perform a given structural function, or both. Fire ratings are determined by tests or by the methods prescribed in Section 703.3 of the International Building Code (IBC) (IBC 2015).

**Required Fire-Resistance Ratings**

Required fire-resistance ratings for elements in buildings are given in Table 601 of the IBC based on the construction type (I through V). Types I and II are types of construction where the building elements are of noncombustible materials, which includes reinforced concrete. The minimum fire-resistance rating for floor elements in Type I construction is 2 hours.

**Test Methods to Determine Fire-Resistance Ratings**

IBC Section 703.2 permits the test procedures in ASTM E119 (ASTM 2016a) and UL 263 (UL 2015) for determining fire-resistance ratings of building elements, components, and assemblies. Standard fire tests are conducted by placing an assembly in a furnace and subjecting it to a fire that follows a standard time-temperature curve. Fire-resistance rating of an assembly is determined by the duration of the test until one of the following end-points is reached:

- **Fire passage end-point** (Walls, partitions, floors, and roofs)
  Cotton waste ignites as a result of flames or hot gases passing through holes, cracks, or fissures in the assembly.

- **Heat transmission end-point** (Walls, partitions, floors, and roofs)
  Temperature of the unexposed surface of the assembly rises an average of 250°F above its initial temperature.
• Structural end-point (All assemblies and members)
  Test specimen is unable to sustain the applied loading (collapse).

The results from fire tests on flat plate voided concrete slabs systems are summarized below.

Reinforced concrete meets the requirements of being a noncombustible material that are set forth in ASTM E136 (ASTM 2016b), and reinforced concrete assemblies are generally classified as restrained assemblies in accordance with ASTM E119. Restrained assemblies perform better during a fire compared to assemblies that are unrestrained.

Calculations to Determine Fire-Resistance Ratings

Section 703.3 of the IBC permits the use of calculations performed in accordance with Section 722 as one of the acceptable ways of determining fire-resistance ratings for structural members. The fire-resistance ratings provided in that section are based on ASTM E119 fire tests. For reinforced concrete, values of minimum member thickness/size and minimum concrete cover over reinforcement are provided for various fire-resistance ratings. Thus, in order to satisfy a required fire-resistance rating based on Type I or II construction, reinforced concrete thickness/size and cover to the reinforcement must be specified that are at least equal to the values in the appropriate tables in Section 722.

Requirements for minimum thickness of reinforced concrete floor and roof slabs and for minimum concrete cover over reinforcement in slabs are given in IBC Sections 722.2.2 and 722.2.3.1, respectively. Generally, reinforced concrete slab systems that are proportioned in accordance with the provisions in Chapter 8 of ACI 318 and that have minimum cover to the reinforcement as specified in Section 20.6 easily satisfy minimum fire resistance requirements.

The minimum slab thicknesses provided in IBC Table 722.2.2.1 are for slabs with a uniform thickness, such as a typical one-way or two-way slab system. A method to determine the thickness of slabs with ribbed or undulating soffits to be used for fire-resistance ratings is given in IBC Section 722.2.2.1.3. This method is applicable for systems with the cross-sectional profiles illustrated in IBC Figure 722.2.2.1.3 (see Figure 4).

The slab thickness for this type of construction to be used in determining the fire resistance ratings in accordance with IBC Table 722.2.2.1 is determined as follows:

For \( s \geq 4t \), thickness = \( t \)

For \( s \leq 2t \), thickness = \( t_e \)

For \( 4t > s > 2t \), thickness = \( t + (4t/s-1)(t_e - t) \)

where

\( s \) = spacing of ribs or undulations

\( t \) = minimum thickness

\( t_e \) = equivalent thickness of the slab calculated as the net area of the slab divided by the width, in which the maximum thickness used in the calculation shall not exceed \( 2t \).

In the case of hollow core prestressed slabs where the cores are of constant cross-section throughout the
In a similar fashion, an equivalent thickness for a voided slab system can be determined by dividing the net volume of concrete by the respective floor area. Figure 5 shows examples of such calculations for both BubbleDeck® and Cobiax® systems with spherical void formers. The overall slab thicknesses $t$ in the figure are the minimum available for both systems. Equivalent thicknesses obtained by this method are greater than 5 in., which is the minimum slab thickness that provides a 2-hour fire-resistance rating for concrete mixes with siliceous aggregate (see IBC Table 722.2.2.1). Equivalent thicknesses for voided slab systems with overall slab thicknesses greater than the minimum thicknesses considered here are greater than the corresponding values in the figure. It is shown below that concrete cover to the reinforcing bars on the fire side is the controlling parameter in the determination of the fire resistance for voided slab systems. The calculations presented here support those findings.

The minimum thickness of concrete cover to the positive flexural reinforcement of reinforced concrete slabs with flat undersurfaces is given in IBC Table 722.2.3(1). This table is applicable for (1) solid or hollow core one-way slabs or two-way slabs and (2) slabs that are either cast-in-place or precast. It is evident from the table that a typical concrete cover of $\frac{3}{4}$ in. provides a fire resistance of 4 hours for restrained assemblies regardless of the unit weight of the concrete or the type of aggregate used in the concrete mixture.

**Fire-Resistance Tests on Flat Plate Voided Concrete Slab Systems**

Numerous fire tests have been performed on BubbleDeck® systems and Cobiax® systems in accordance with the provisions in DIN 4102-02 (DIN 1977). The time-temperature curve used to test specimens in the DIN requirements is the same as that prescribed in ISO 834 (ISO 1999). A comparison of the ISO 834 and ASTM E119 time-temperature curves is given in Figure 6. It is evident from this figure that there are some differences in the curves. However, it has been determined that the differences in severity between the two tests are negligible (Harmathy 1987). Criteria to determine the fire-resistance rating are also basically...
the same. Therefore, it follows that the results obtained from specimens tested in accordance with the DIN requirements would essentially be the same as those that would be obtained if the specimens were tested in accordance with ASTM E119 requirements.

The fire tests have revealed that the concrete cover to the reinforcing bars on the fire side is the controlling parameter in the determination of the fire resistance in all of the tests. It was found that the voids act as a thermal isolator: the heat from the fire is dammed below the void. This leads to slightly higher temperatures in the reinforcing bars positioned below the voids. A cover of ¾ in. to the main flexural reinforcing bars resulted in a fire resistance rating of at least 2 hours. The fire ratings obtained from the Cobiax® tests have been verified by finite element analyses.

The void formers were found to be intact after the fire tests. The internal temperature remained below the melting temperature of the HDPE, which is approximately between 200 and 300 degrees Fahrenheit.

Summary

It is evident from the findings of fire tests that concrete cover to the reinforcing bars on the side of the fire is the controlling parameter in the determination of the fire resistance for flat plate voided concrete slab systems. A ¾ in. cover to the bottom reinforcing bars will provide a minimum 2-hour fire-resistance rating, which meets minimum required fire-resistance ratings for floor assemblies in common occupancies.

Figure 6 – Comparison of ISO 834 and ASTM E119 time-temperature curves.
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Historical: None

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