

# Frequently Asked Questions (FAQ) About Flat Plate Voided Concrete Slab Systems

## Introduction

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. Such benefits include reduced weight, which results in smaller seismic forces and larger allowable superimposed loads for given span lengths; economical longer spans without beams; reduced floor-to-floor heights; accelerated construction schedules; and inherent fire resistance that meets the fire-rating requirements in the International Building Code (IBC).

Various types of flat plate 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 (Mota 2010). Contemporary proprietary systems pioneered by BubbleDeck® and Cobiax® utilize hollow, plastic balls made of high-density, recycled polyethylene (HDPE) that are spaced regularly within the overall thickness of the concrete slab. These are commonly referred to as void formers. The BubbleDeck® system is usually constructed as a semi-precast system (Figure 1a); however, a cast-in-place system is also available (Figure 1b). The Cobiax® system is typically employed as a cast-in-place system (Figure 1c).

CRSI routinely receives inquiries concerning various aspects on the design and construction of flat plate voided concrete slab systems. This Technical Note contains a collection of typical questions, which mainly came from design professionals, including structural engineers, architects, field inspectors, code enforcement officials, and contractors.

Specific questions and responses are provided below to frequently asked questions (FAQ). Additional information on these and other topics can be found in *Design Guide for Voided Concrete Slabs* (CRSI 2014a).



**Figure 1 – Void formers (a) BubbleDeck® – Semi-precast system (b) BubbleDeck® – Cast-in-place system (c) Cobiax USA® – Cast-in-place system (Photos courtesy of BubbleDeck and Cobiax USA).**

More information on this publication can be obtained by visiting [www.crsi.org](http://www.crsi.org).

## Analysis Methods

**How are flat plate voided slab systems analyzed? How do the void formers impact the stiffness of the overall system?**

Just like other two-way slab systems, flat plate voided slab systems are permitted to be analyzed and designed by any procedure satisfying equilibrium and geometric compatibility in accordance with ACI 8.2.1.1. The direct design method of ACI 8.10 or the equivalent frame method of ACI 8.11 is

permitted where applicable; finite element analysis can be used in any case and is recommended.

Because the voids reduce the self-weight of the system, the application of self-weight reduction for flat plate voided slabs needs to be applied properly in commercial slab design software programs, which automatically calculate self-weight based on full slab thickness. For flat plate voided slabs, an additional load case must be considered: a uniform load of 70 percent of the self-weight reduction must be applied over the entire slab surface in a direction opposite the gravity loads to account for the reduction in self-weight.<sup>2</sup> Assuming 70 percent of the self-weight reduction is a good, conservative starting point in the design process because 70 to 80 percent of the of the total slab area is typically “covered” with voids. A more accurate calculation can always be performed once the actual net void former area has been determined.

A stiffness correction factor, which can be obtained from manufacturers’ literature for the various void formers, must also be applied when using software programs, mainly for calculation of deflections. Depending on the software, either the modulus of elasticity of the concrete  $E_c$  is multiplied by this factor and input accordingly or the global stiffness factor of the slab is multiplied by this factor. Uncracked flat plate voided slab systems typically have a slightly less (about 87–93%) flexural stiffness than solid slabs with the same thickness.

## Strength Requirements

**What are the design requirements for flat plate voided slab systems? Does ACI 318 contain flexure and shear design provisions for such systems? Do you check shear the same way as a solid flat plate?**

**Flexural Strength Requirements.** 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.

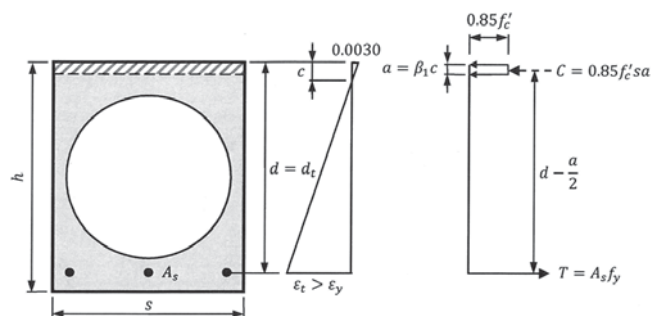
The slab is divided into column strips and middle strips and the flexural design strength requirements in ACI 8.5

<sup>1</sup> All references to ACI 318 (ACI 2014) are given as “ACI” followed by the appropriate section number.

<sup>2</sup> Self-weight reduction is equal to the weight of the solid slab assuming no void formers minus the weight of the slab with void formers. The weight of the slab with void formers is equal to the volume of concrete per square foot times the unit weight of the concrete. The volume of concrete is obtained by subtracting the volume of concrete displaced per square foot (which is the volume of one void former times the number of void formers per square foot) from the overall slab thickness.

must be satisfied, namely, the design strength  $\Phi M_n$  must be greater than or equal to the required strength  $M_u$  at the critical sections. The strength reduction factor  $\Phi$  is determined in accordance with ACI 21.2 and is equal to 0.90 for tension-controlled sections, that is, sections where the net tensile strain  $\epsilon_t$  in the extreme layer of the longitudinal tension reinforcement at nominal strength is greater than or equal to 0.005. Like any two-way reinforced concrete slab system, flat plate voided concrete slabs should be designed as tension-controlled sections for overall efficiency.

The nominal strength  $M_n$  at a section is determined based on the equilibrium and strain compatibility assumptions in ACI 22.2.1 through 22.2.3. Illustrated in Figure 2 are the strain and stress distributions at a section in a flat plate voided concrete slab at nominal strength where positive reinforcement is required. The discussion that follows is also applicable to sections where negative reinforcement is required.



**Figure 2 — Strain and stress distributions in a flat plate voided concrete slab.**

Under design loads that are typical for usual building occupancies, the depth of the equivalent stress block  $a$  will be within the zone of solid concrete between the compression edge of the slab and the void formers (the concrete cover to the edge of the void former depends on the size of the void former and can be obtained from the manufacturers’ literature). This has been confirmed by numerous laboratory flexural tests using various overall slab depths and void former sizes. Thus, the equation for nominal strength  $M_n$  is the same as that for any reinforced concrete flexural member:

$$M_n = A_s f_y \left( d - \frac{a}{2} \right)$$

where  $a = A_s f_y / 0.85 f'_c s$  and  $s$  is the center-to-center spacing of the void formers.

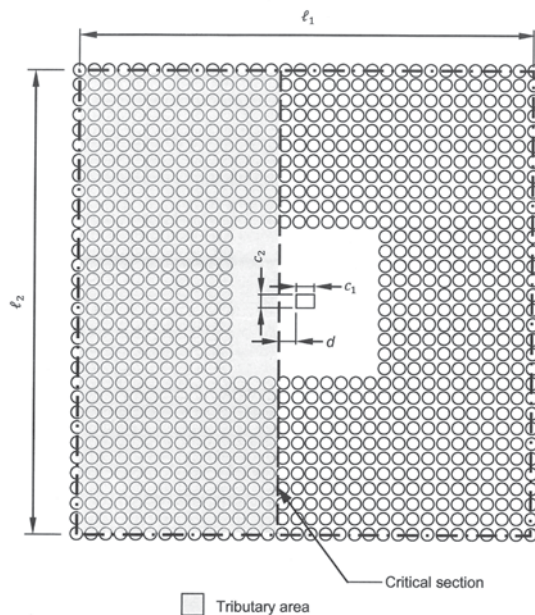
Required strength  $M_u$  is determined using the load combinations in ACI Table 5.3.1. The required amount of flexural reinforcement  $A_s$  at a section can be obtained by setting  $\Phi M_n = M_u$  and solving for  $A_s$ . Minimum flexural reinforcement requirements are given in ACI Table 8.6.1.1. For Grade 60 reinforcement,  $A_{s,min} = 0.0018hs$ .



**Shear Strength Requirements.** Both one-way and two-way shear requirements must be satisfied for flat plate voided concrete slabs. For one-way shear, the following equation must be satisfied at the critical section, which is located a distance  $d$  from the face of the support (see Figure 3 and ACI 22.5):

$$V_u \leq \phi V_c = \phi 2\lambda f_{sr} \sqrt{f'_c} \ell_2 d$$

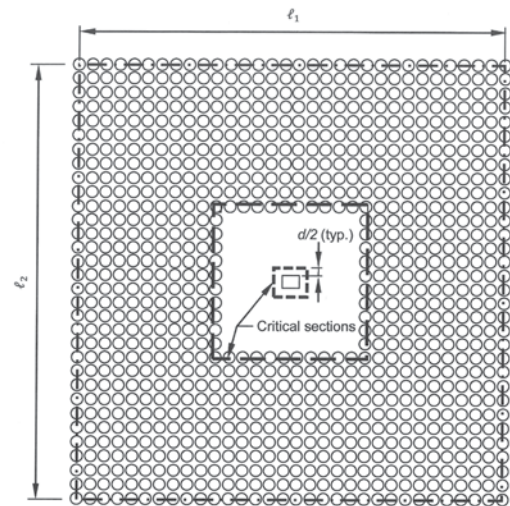
In this equation, strength reduction factor  $\phi = 0.75$  and  $\ell_2$  is the width of the critical section (which can be taken as the center-to-center spacing of the columns). The factor  $f_{sr}$ , which is not in ACI 318, is the shear reduction factor that is obtained from the manufacturers' literature; this factor modifies the design shear strength due to the presence of the void formers in the slab. Depending on the void former,  $f_{sr}$  is in the range of 0.50 to 0.60. A solid section of concrete is usually provided around the columns (see Figure 3). It is evident that the critical section for one-way shear typically traverses through a portion of the slab that is solid and mostly through portions that contain void formers. The factor  $f_{sr}$  is applied to the design shear strength assuming that the solid slab section around the column is not present, which is conservative. However, the weight of the solid section should be included when calculating the required shear force  $V_u$ . Except for long, narrow slabs, one-way shear is seldom critical, but it must be checked to ensure that one-way shear provisions are satisfied.



**Figure 3 – Critical section for one-way shear.**

Two-way or punching shear is usually the critical of the two types of shear. In slabs without shear reinforcement, the shear stresses due to direct shear forces and bending are resisted by the concrete slab section around a column. The critical sections for flat plate voided concrete slabs are depicted in Figure 4. Shear requirements

must be checked at critical sections located a distance  $d/2$  from the face of the column and  $d/2$  from the edge of the solid section of concrete around the column.



**Figure 4 – Critical section for two-way shear.**

At the critical section located a distance  $d/2$  from the face of the column, a solid section of concrete is present and the following equation must be satisfied (see ACI Table 22.6.5.2):

$$v_u \leq \phi v_c = \text{Minimum of } \begin{cases} \phi 4\lambda \sqrt{f'_c} \\ \phi \left(2 + \frac{4}{\beta}\right) \lambda \sqrt{f'_c} \\ \phi \left(2 + \frac{\alpha_s d}{b_o}\right) \lambda \sqrt{f'_c} \end{cases}$$

In these equations,  $\beta$  = ratio of long-to-short dimension of the column;  $\alpha_s = 40$  for four-sided critical sections, 30 for three-sided critical sections, and 20 for two-sided critical sections; and,  $b_o$  = perimeter of the critical section.

At the critical section located a distance of  $d/2$  from the outer edge of the solid section of concrete around the column, the design shear strength  $\phi v_c$  must be multiplied by the shear reduction factor  $f_{sr}$ , which was discussed previously for one-way shear. The area of the solid section of slab must be made large enough so that two-way shear strength requirements that account for the presence of the void formers are satisfied at that critical section.

The use of headed shear stud reinforcement has proven to be a cost-effective way of increasing the design shear strength of two-way slabs without increasing the overall slab thickness and/or the plan dimensions of the supporting columns (see Figure 5). ACI 22.6.6.1 contains provisions for two-way slabs with shear reinforcement, including headed shear stud reinforcement, which can be used in flat plate voided concrete slabs.

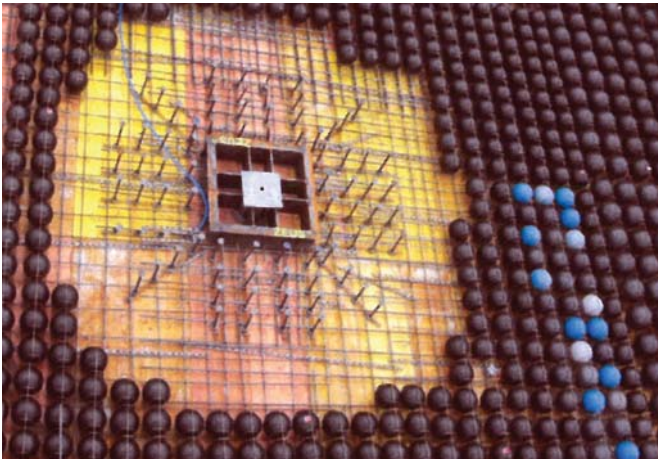


Figure 5 — Headed shear stud reinforcement. (photo courtesy of Cobiax Technologies AG).

## Serviceability Requirements

### What is the required overall slab thickness to satisfy deflection requirements?

Unlike other two-way reinforced concrete slab systems, empirical serviceability requirements for flat plate voided concrete slabs are not specifically provided in ACI 8.3.1. Because this system is similar to two-way joist and two-way slab systems, the overall thickness can be initially estimated by  $\ell_n/36$  where  $\ell_n$  is the clear span length in the long direction of a panel measured face-to-face of supports (see ACI Table 8.3.1.1 for minimum thickness of nonprestressed two-way slabs without interior beams and with drop panels).

In lieu of using an estimated thickness, it is recommended that deflection calculations be performed in accordance with ACI 24.2 to determine an appropriate overall slab thickness. Immediate deflections must include effects of cracking and reinforcement on member stiffness, where stiffness is a function of the modulus of elasticity of the concrete  $E_c$  (determined in accordance with ACI 19.2.2) and the effective moment of inertia  $I_e$ , which may be calculated by ACI Equation (24.2.3.5a) [ACI 24.2.3.1].<sup>3,4</sup>

For flat plate voided concrete slab systems,  $I_e$  can be approximated by adding the average  $I_e$  of the column strip in one direction to the average  $I_e$  of the middle strip

<sup>3</sup> For members with low reinforcement ratios, such as two-way slabs, it has been suggested that ACI Eq. (24.2.3.5a) overestimates member stiffness and that the equation for  $I_e$  in Scanlon and Bischoff (2008) provides more realistic results.

<sup>4</sup> The effective moment of inertia  $I_e$  is a function of the cracking moment  $M_{cr}$ , which in turn is a function of the modulus of rupture  $f_r = 7.5\lambda\sqrt{f'_c}$  where  $\lambda$  is the modification factor that accounts for the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength  $f'_c$ . Scanlon and Bischoff (2008) recommends using  $f_r = 5.0\lambda\sqrt{f'_c}$  and ACI Committee 435 (ACI 1995) recommends using  $f_r = 4.0\lambda\sqrt{f'_c}$  in deflection calculations for two-way slabs to account for the contribution of shrinkage restraint to cracking.

in the orthogonal direction. The average  $I_e$  for a column strip or a middle strip is used to account for positive and negative regions in the strips.

Calculated deflections must be less than or equal to the maximum permissible deflections in ACI Table 24.2.2. A minimum overall thickness is established based on immediate deflection calculations assuming a void former thickness and corresponding top and bottom cover to the void formers, which can be obtained from manufacturers' literature. Two-way shear stresses should also be checked at critical locations at this stage; if it has been decided that shear reinforcement will not be used, the overall slab thickness or the supporting column sizes must be increased accordingly if it is found that factored shear stresses are greater than allowable values.

Time-dependent deflections can be calculated in accordance with ACI 24.2.4.1 based on the overall slab thickness determined for immediate deflections.

### Are there vibration criteria available for flat plate voided systems?

Acceptance criteria are available for human comfort and sensitive equipment. Recommended acceleration limits for human comfort (walking and rhythmic excitations) for vibrations due to specific activities were developed by the International Organization of Standardization (ISO 1989) and have been successfully implemented in a wide variety of situations. Limits for different occupancies are provided in terms of root-mean-square (rms) accelerations as multiples of a baseline curve. Suggested peak accelerations based on these multipliers are given in Figure 6.

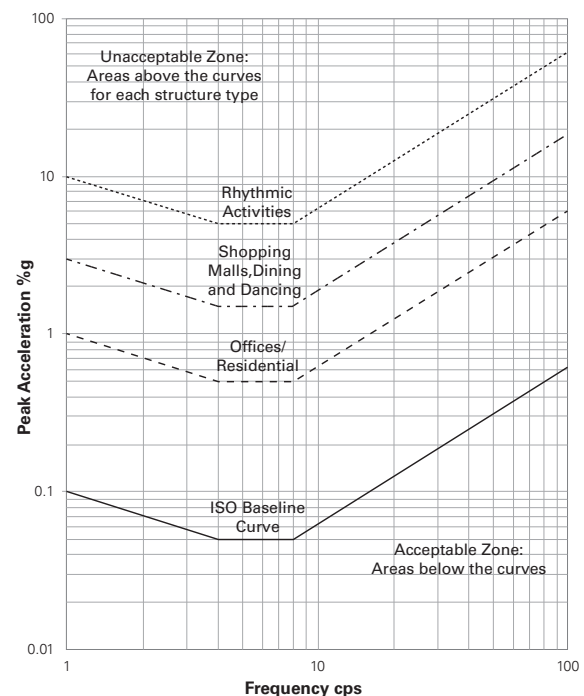


Figure 6 — Recommended peak acceleration for human comfort (ISO 1989).



Flat plate voided concrete slab systems designed in accordance with the minimum serviceability criteria discussed above have been found to readily satisfy vibration acceptance criteria for human comfort under typical service conditions and occupancies. The acceptance criteria for walking excitations are easily satisfied by providing an overall slab thickness based on deflection requirements only. Minimum overall slab thicknesses that satisfy acceptance criteria for walking excitations as a function of span length are given in Figure 7. This figure is based on normal-weight concrete with a compressive strength of 4,000 psi and mild reinforcement with a yield strength of 60,000 psi. Superimposed loads customarily specified in commercial and residential occupancies were used in the analysis. As an example, if 30-ft spans are required, a flat plate voided concrete slab with a minimum thickness of 10 in. must be provided to satisfy the acceptance criteria for walking (maximum span length is equal to 30.5 ft from the Figure).

Acceptance criteria for rhythmic excitations are directly related to the fundamental frequency of a floor system. Minimum overall slab thicknesses that satisfy the acceptance criteria for various types of rhythmic excitations as a function of span length are given in Figure 8 based on the same material and load assumptions used for walking excitations. A 13.5-in.-thick flat plate voided concrete slab with a maximum span length of 30.8 ft must be used if 30-ft spans are required for jumping exercises and aerobics (which have the most stringent acceptance criteria of all the considered rhythmic excitations).

For sensitive equipment, the expected maximum velocity due to walking-induced vibrations is inversely proportional to the stiffness of a floor system; thus, to satisfy the acceptance criteria in such cases, floor

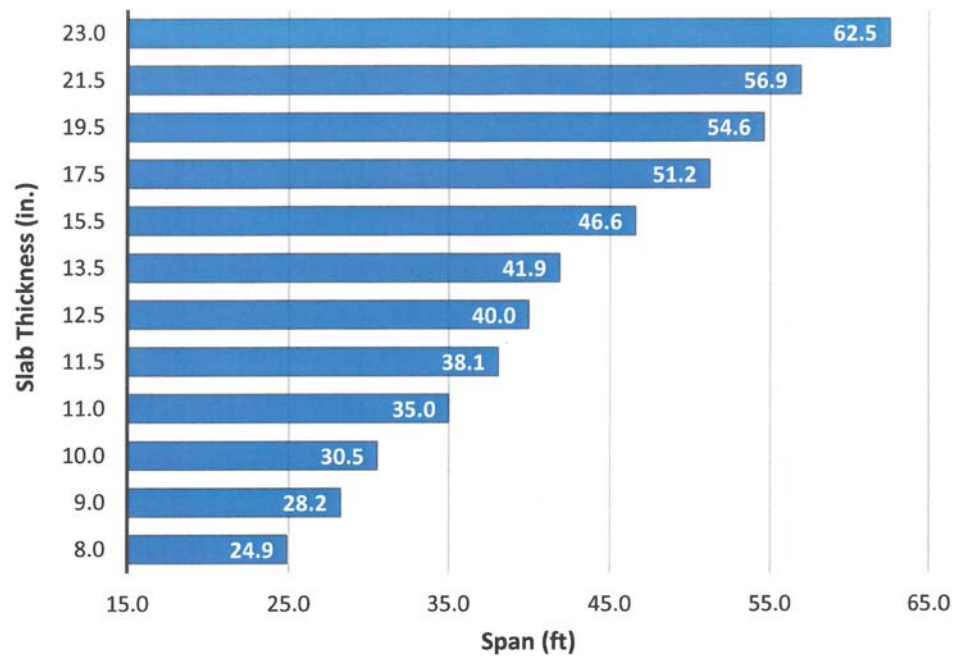


Figure 7 — Minimum slab thickness / maximum span lengths for walking excitations.

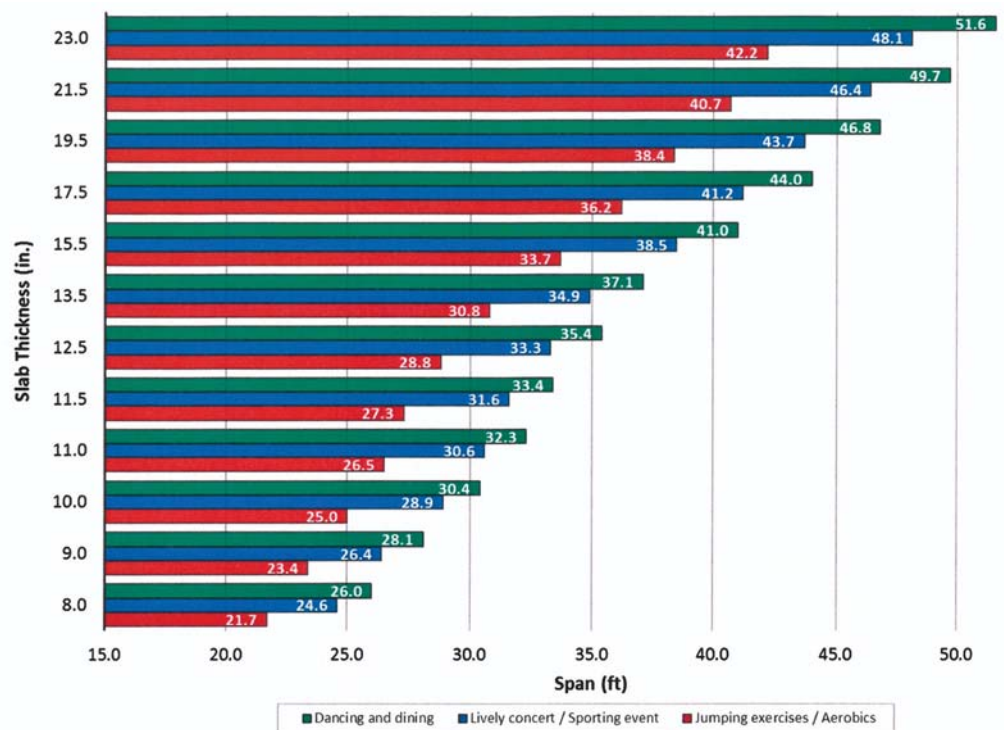


Figure 8 — Minimum slab thickness / maximum span lengths for walking excitations.

systems must be provided that are very stiff. Minimum overall slab thicknesses that are to be used to satisfy acceptance criteria as a function of span length and walking pace based on the same material and load assumptions noted above are given in Figure 9. Results are presented for a maximum velocity  $V$  of 8,000, 1,000, and 130  $\mu\text{in./sec}$ . These velocities correspond to, for example, residences and computer systems; micro, eye, and neuro surgery; and, manufacturing highly-sensitive microelectronic equipment, respectively. A thicker (stiffer) slab is required to satisfy the acceptance criteria

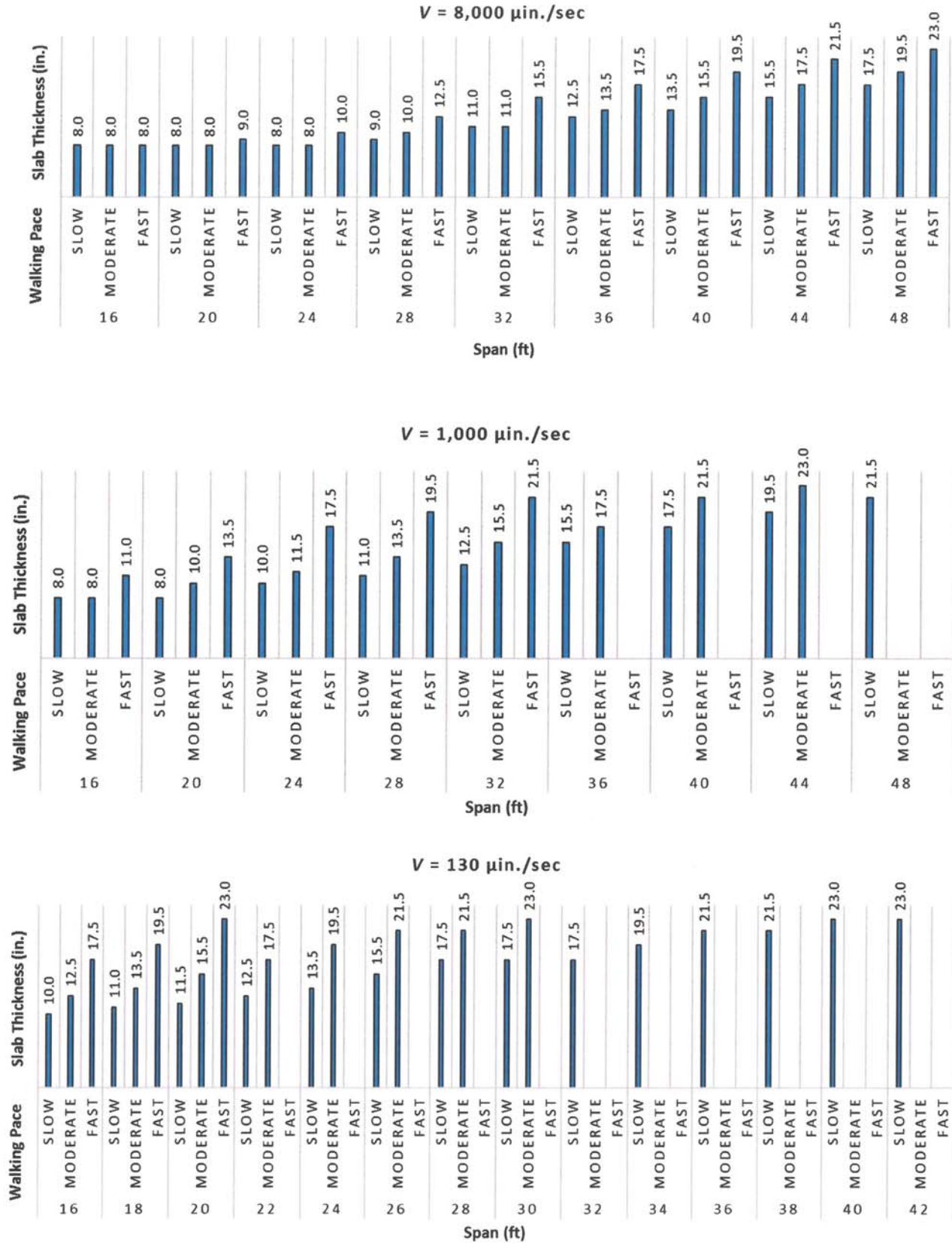


Figure 9 – Minimum slab thickness / maximum span lengths for sensitive equipment.

for faster walking paces. Slab thicknesses that are not provided for certain walking paces and span lengths means that a flat plate voided concrete slab system is unable to satisfy the acceptance criteria in those cases. Other stiff reinforced concrete floor systems, such as two-way joist or grillage systems, should be considered instead.

Additional information on vibration of flat plate voided concrete slab systems (and other reinforced concrete floor systems), including approximate methods to determine natural frequency and worked-out design examples, can be found in *Design Guide for Vibrations of Reinforced Concrete Floor Systems* (CRSI 2014b). Included in the *Design Guide* is a report that summarizes the findings of the experimental vibration study performed at the University of Wisconsin – Madison.

### **What is a typical column spacing and slab depth for a 40 psf live load?**

Flexural strength, shear strength, and serviceability requirements all play a role in determining the overall slab depth required for a given span length and superimposed loads. Because the voids reduce the self-weight of the system, a flat plate voided concrete slab system can typically span longer distances than conventionally reinforced flat plate systems of equal overall depth for given superimposed loads. Similarly, flat plate voided concrete systems can carry larger superimposed loads for a given span length. Another way to compare spans achievable with flat plate voided slabs versus conventional flat plate systems is to consider that for the same volume of concrete per square foot, flat plate voided slabs facilitate spans that are 35 to 40 percent greater than flat plates, mainly because of the greater section properties of the flat plate voided slab.

Many solutions are available for required span and loading criteria. As an example, an overall slab thickness of 9 in. is required for 26-ft spans based on the following assumptions: 24-in.-square columns, a live load of 40 psf, a superimposed dead load of 10 psf, 4,000-psi normalweight concrete, Grade 60 reinforcement, no shear reinforcement, and walking excitations only. Longer spans and/or smaller columns are possible if shear reinforcement is provided in the 9-in. slab (two-way shear stresses govern). In the case of 35-ft spans, an overall slab thickness of 12.5 in. is required; 24-in. columns with shear reinforcement can be used in this case. A 23-in.-thick slab with shear reinforcement can span 50 ft with 36-in. columns.

CRSI's *Reinforced Concrete Concept* is an online tool for preliminary slab design that provides design and construction teams with comparative evaluations and estimates for the most popular reinforced concrete structural floor systems, including flat plate voided concrete slabs. The user enters material properties, span and column dimensions, and superimposed loads, and

the program provides estimates of concrete and reinforcement quantities for flat plate, flat slab, wide-module joist, two-way joist, one-way beam supported slab, and flat plate voided slab systems. This free tool can be used to determine required slab thickness for any span and loading condition, and can be accessed at <http://www.crsi.org/index.cfm/rcconcept>.

### **Are there any limitations when voided slabs are used as cantilevers?**

Reducing the dead load and corresponding bending moments and shear forces on cantilevers using flat plate voided slab systems has been successfully employed in projects. Cantilevered flat plate voided slabs are attainable provided all the applicable requirements for strength and serviceability are satisfied. It is recommended to check with the manufacturer in cases where cantilevered slabs are proposed.

## **Fire Resistance**

### **Regarding fire rating, have there been any issues or concerns getting permits/approvals? As a follow-up, have voided slabs reached 1-hour or 2-hour ratings?**

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 IBC (ICC 2018).

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.

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.

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 essentially the same as that prescribed in ISO 834 (ISO 1999). ISO 834 and ASTM E119 time-temperature curves are also essentially the same, and it has been shown the differences in severity between the two tests are negligible (Harmathy 1987).



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.

Fire tests in accordance with DIN 4102 have revealed that the 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. It was found that the voids act as thermal isolators, that is, the heat from the fire is dammed below the voids. This leads to slightly higher temperatures in the reinforcing bars that are positioned below the voids. A cover of  $\frac{3}{4}$  in. to the main flexural reinforcing bars resulted in a fire-resistance rating of at least 2 hours. 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°F.

A fire test to supplement those performed previously was conducted in June of 2017 at the Fire Testing Laboratory of NGC Testing Services in Buffalo, NY. The test assembly consisted of an 8-in.-thick concrete slab that was 14 ft by 18 ft (the plan dimensions were limited by the size of the furnace test frame). The slab contained 4-in.-thick ellipsoidal void formers with a diameter of  $12\frac{3}{8}$  in. that were spaced  $13\frac{3}{4}$  in. on center within the cage modules. A total of 140 void formers were used in the slab. Normalweight concrete with siliceous aggregate and a design compressive strength of 5,000 psi was specified. Slab reinforcement consisted of ASTM A615 Grade 60 #4 bars spaced 12 in. on center in both primary directions at the top and bottom of the slab with a  $\frac{3}{4}$ -in. clear cover. The cage modules were tied to these reinforcing bars, and a 13-in.-wide strip of solid concrete was provided around the perimeter of the slab. Construction of the assembly followed typical construction procedures used in the field for these types of

systems. The layout of the void formers in the slab prior to casting of the concrete is shown in Figure 10.

The assembly was tested in accordance with the requirements of ASTM E119. The edges of the slab on all 4 sides were supported vertically by the test frame; no restraint was provided for thermal expansion or rotation. As such, the assembly was unrestrained during the duration of the fire test, which is conservative for cast-in-place concrete slab systems. The assembly was loaded during the entire time of the test with a uniformly distributed load of 80 psf using water-filled steel tanks. The vertical deflection of the assembly was measured throughout the test with 3 plumb bobs located at the center and quarter points of the slab.

At 2 hours and 52 minutes, the test was terminated because the temperature recorded at one of the thermocouples at the unexposed surface exceeded the ASTM E119 individual limiting temperature rise of 325 degrees F. Throughout the duration of the test, the assembly supported the applied loading with no signs of collapse. The underside of the assembly after the fire test is shown in Figure 11. Although the concrete had spalled at various locations, the exposed reinforcing bars exhibited minor to no damage due to the fire.

IBC Table 722.2.2.1 provides minimum slab thickness of reinforced concrete floor and roof assemblies to achieve fire-resistance ratings based on aggregate type. Flat plate voided concrete slab systems are similar to slabs with ribbed or undulating soffits, so an equivalent slab thickness must be calculated for use in Table 722.2.2.1.

In general, the equivalent thickness of a flat plate voided concrete system is equal to the net volume of concrete divided by the floor area. The net volume of concrete is equal to the volume of concrete of a solid slab minus the average concrete displaced by the void formers:

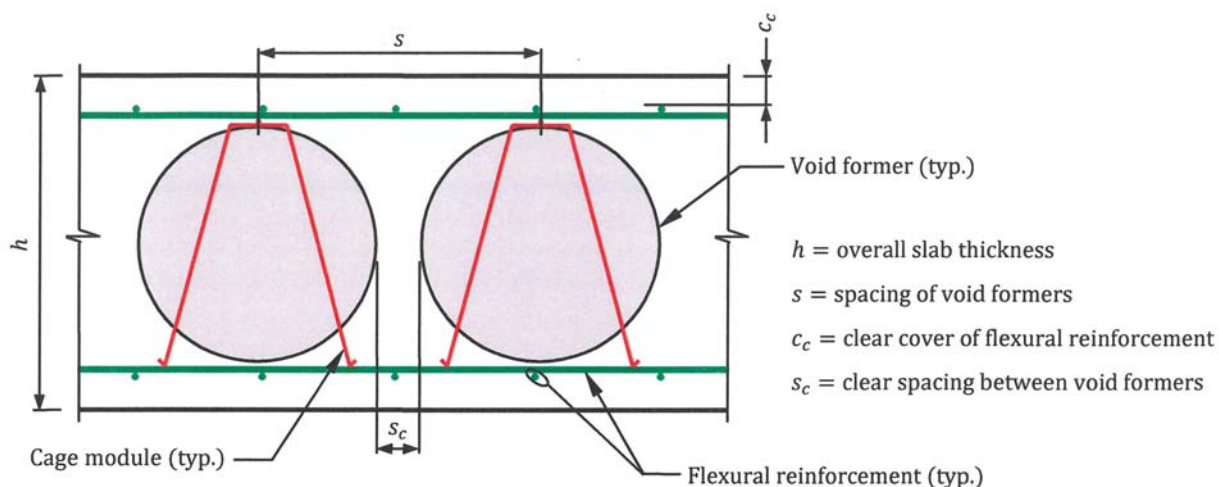


Figure 10 — Layout of void formers in test assembly.





**Figure 11 – Underside of test assembly after fire testing.**

Volume of solid 8 in. slab =  $8/12 = 0.67$  cu ft/sq ft

For the void formers used in the test assembly, average concrete displaced = 0.18 cu ft/sq ft

Net volume of concrete =  $0.67 - 0.18 = 0.49$  cu ft/sq ft

Thus, the equivalent thickness of the test assembly = 0.49 ft = 5.9 in.

An equivalent thickness of 5.9 in. corresponds to a 2-hour fire-resistance rating for a normalweight concrete mix with siliceous aggregate (according to Table 722.2.2.1, a 5-in. thickness is required for a 2-hour rating and a 6.2-in. thickness is required for a 3-hour rating). The fire rating based on equivalent thickness is essentially the same as that determined from the fire test.

Based on the results from the fire test, it can be concluded that the flat plate voided concrete assembly

constructed of the materials and in the manner described previously achieved a 2-hour unrestrained assembly rating when exposed to fire in accordance with the test method prescribed in ASTM E119. This test confirms the appropriateness of the application of Appendix X3 of ASTM E119 and Section 703.3 of the International Building Code (ICC 2018) for flat plate voided concrete slabs.

## Sound Control

### ***Is there information available for the sound transmission class and impact insulation class for voided systems?***

Sound Transmission Class (STC) is the measure, in decibels (dB), of how much airborne sound a floor or wall assembly blocks. STC ratings only measure sound blocked in the 125 to 4,000 Hz range, which correspond

to normal and amplified speech. An assembly with an STC rating of 50 can reduce 110 dB of airborne sound generated on one side of the assembly to 60 dB of airborne sound on the other side. This is the equivalent of reducing the noise level of a rock concert to the level of normal speech. To determine STC ratings of assemblies, measurements are taken in a laboratory in accordance with the requirements in ASTM E90 (ASTM 2009). The methodology for calculating the STC is given in ASTM E413 (ASTM 2016b).

Impact Insulation Class (IIC) ratings measure how much structure-borne sound is blocked in floor/ceiling assemblies. The higher the IIC, the better the floor/ceiling assembly is at blocking the impact noise. Impact sound transmission loss of floor/ceiling assemblies is measured in a laboratory and must conform to the requirements in ASTM E492 (ASTM 2016c). A tapping machine is used to generate impact noise: the machine drops five hammers in rapid succession at equal intervals on the test specimen. Impact sound pressure levels are measured in the receiving room below the test specimen. The information from these tests is then used to determine the IIC, which is calculated in accordance with ASTM E989 (ASTM 2012).

Section 1207 of the IBC contains sound transmission requirements that apply to common interior walls, partitions, and floor/ceiling assemblies between (1) adjacent dwelling units and sleeping units or (2) dwelling units and sleeping units and adjacent public areas such as halls, corridors, stairways, or service areas. For airborne sound, a minimum value of 50 is required for the STC if the measurements are performed in a laboratory or 45 if field tested. For impact sound, a minimum value of 50 is required for the IIC if the measurements are performed in a laboratory or 45 if field tested. It is important to check sound transmission requirements with the local building authority that has jurisdiction over the project.

While STC and IIC ratings of 50 are the minimum prescribed by the IBC, it is not uncommon to stipulate STC and IIC ratings of 60 or higher, especially in high-end properties. While an STC of 60 is readily achievable, IIC values of 60 generally require the use of resilient flooring (vinyl) or carpet and are difficult to attain using hard surfacing such as ceramic tile.

Sound insulation tests have been performed on the BubbleDeck® and Cobiax® systems in the laboratory and in completed buildings. For the thinnest concrete slabs (8 and 9 in.) without any floor coverings or ceilings, airborne sound reduction indices (similar to STC) of 55 and 56 dB were obtained, respectively. These indices are calculated in accordance with ISO standards (ISO 1978, ISO 1982, and ISO 1995). Impact sound pressure levels (similar to IIC) of 76 dB were also obtained. The fundamental methods for the actual measurements and the mathematical calculations behind the ASTM and

ISO acoustic standards are similar; however, they are significantly different in the details of tests and how the numerical results are processed. It is recommended to contact the manufacturers for the latest information on sound control for the various systems.

## Void Formers

### ***Are the plastic balls a proprietary product?***

The plastic balls in flat plate voided concrete slab systems are commonly referred to as void formers and are proprietary products.

### ***What are the sizes of the voids in voided systems? What is the spacing between the voids and what is the thickness of the concrete above and below the voids?***

BubbleDeck® produces spherical void formers that range in diameter from 7<sup>1</sup>/<sub>8</sub> in. to 17<sup>3</sup>/<sub>4</sub> in. Recommended minimum slab thickness for these void formers are 9 in. to 22<sup>3</sup>/<sub>4</sub> in.

Cobiax® produces both ellipsoidal (Slim-Line) and spherical (Eco-Line) void formers. The heights of the Slim-Line void formers range from 4 in. to 8<sup>5</sup>/<sub>8</sub> in. (corresponding to slab depths of 8 in. to 13<sup>1</sup>/<sub>2</sub> in.). Slim-Line void formers have been stacked to accommodate slabs as thick as 30 in. Eco-Line void formers range in diameter from 8<sup>7</sup>/<sub>8</sub> in. to 17<sup>3</sup>/<sub>4</sub> in. (corresponding to slab depths of 13<sup>1</sup>/<sub>2</sub> in. to 23 in.).

The minimum clear spacing between the void formers is 1 in. and the thickness of the concrete above and below the void formers depend on the cover required for the reinforcing bars, the type and size of the void former, and other geometrical requirements. Specific information on these dimensions can be obtained from product catalogues obtained from the manufacturers.

## Construction Considerations

### ***What are the construction sequences for the cast-in-place and semi-precast systems?***

Typical site installation of a cast-in-place voided concrete slab is as follows:

1. Formwork is erected and bottom reinforcing bars are placed.
2. Cage modules that contain the void formers are placed and tied perpendicular to the top layer of bottom reinforcing bars.
3. Top reinforcing bars are placed directly on and tied to the cage modules.
4. First layer of concrete is cast, which covers the bottom reinforcing bars and the lower portion of the cage modules. This layer of concrete essentially anchors the cage modules and prevents possible upward

movement due to buoyancy when the second layer of concrete is placed.

5. Second layer of concrete is cast to the required overall thickness of the slab system.

In the semi-precast system, a precast concrete layer essentially replaces the horizontal formwork of the cast-in-place system described above. Installation of this system is as follows:

1. Cage modules with top and all the bottom structural reinforcement are precast into 3-in.-thick panels.
2. The panels are set on shoring that is spaced 7 ft on center.
3. On site, a layer of concrete is cast to the required overall thickness.

In addition to around the columns, void formers are typically omitted around the perimeter of the slab for a width of at least 2 ft (but not less than 1 ft). Reinforcement details similar to those used in other two-way slab systems can be provided along the edges.

An emerging trend in the construction of flat plate voided slab systems is tying together assembled cages

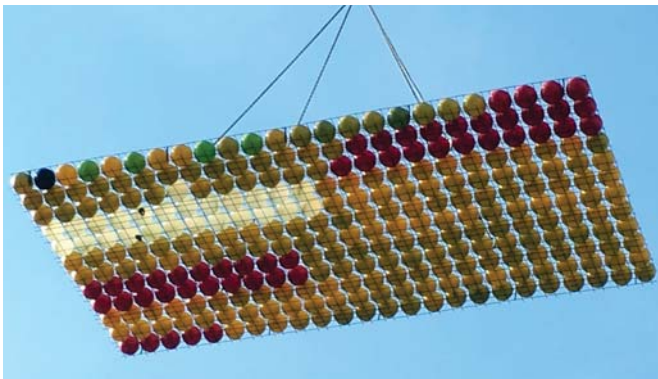


Figure 12 — Section of BubbleCage mat being lifted into place (Photo courtesy of BubbleDeck).

as one mat and lifting them into place. This helps in reducing overall construction time. Depicted in Figure 12 is a 12 ft by 20 ft section of a BubbleCage mat being lifted by a crane for final placement.

**In the cast-in-place system, can the concrete be placed in one lift?**

The entire depth of the slab can be placed in one lift in a cast-in-place system. However, the cage modules must be anchored directly to the formwork to prevent buoyancy forces from lifting them upward due to the fluid concrete. The more common approach is to use two lifts as described above in the construction sequence.

**What kind of concrete should be used for casting? Should self-consolidating concrete be used in order to get concrete under the voids?**

Just like other typical two-way slab systems, normal-weight concrete with a specified compressive strength of 4,000 psi is usually the most efficient for flat plate voided concrete slab systems with conventional reinforcement.

In the cast-in-place system, the flowability of the concrete mixture forming the bottom layer is particularly important. The concrete must flow in between and beneath the void formers and must be consolidated (see Figure 13). In addition, concrete must flow between the cage modules, the flexural reinforcing bars, and any conduits or other embedded items in the slab. A fully consolidated bottom concrete layer is also important for architectural reasons where the underside of the slab is to be left exposed. The concrete must be vibrated and admixtures can be added to the concrete mixture that help facilitate concrete placement.

The grid of the void formers provides a convenient visual indication for the operator of a needle vibrator to follow the concrete flowing beneath the void formers; this helps in obtaining a consistently consolidated slab.

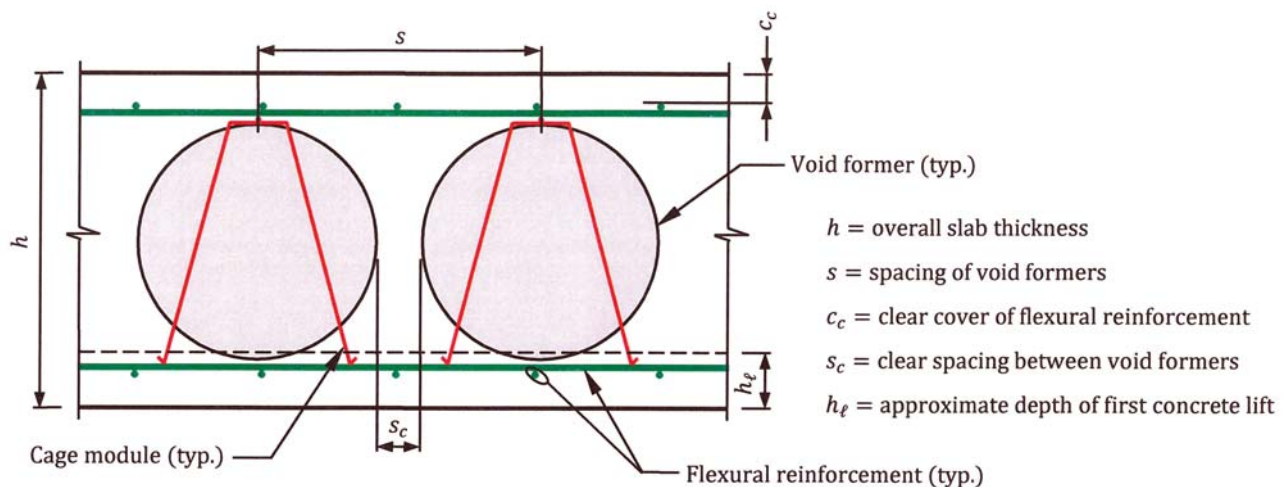


Figure 13 — Typical cross-section of a cast-in-place flat plate voided concrete slab.



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Concrete flows readily around the rounded shapes of the void formers. Like any concrete mixture, prolonged vibration may result in segregation of the aggregates and should be avoided.

Self-consolidating concrete is not required in order to get concrete under the void formers and around reinforcing bars and embedded items. A properly vibrated normalweight concrete mix is typically adequate and is generally the most cost effective.

### ***Is there a cold joint concern when using the cast-in-place system?***

When casting concrete for the cast-in-place systems, a horizontal cold joint is created whenever the bottom layer of concrete dries and hardens before the top layer is cast. In cast-in-place systems, the friction between the two layers (weight of top layer of concrete on the unfinished surface of the first layer of concrete) helps in transferring horizontal shear between the two layers. In addition, for both cast-in-place and semi-precast systems, the vertical bars of the cage modules that contain the void formers, which are embedded in the concrete layer that is cast first, act as shear dowels and provide sufficient interlocking between the two concrete layers. Manufacturers' literature contains the size of the vertical bars in the cage modules for the various void formers. This information can be used to verify by calculation that the provided vertical bars are adequate to transfer the horizontal shear between the concrete layers.

### ***For the semi-precast system, what are the typical details between the precast units at the bottom of the assembly?***

Precast panels as large as 11 ft by 40 ft have been used in projects in North America. These panels are located adjacent to each other to form the floor and roof systems of the structure. In order to provide an aesthetic finish, a ¼- to ½-in. bottom bevel/fillet is usually formed along the edges of adjacent panels. Similar to other types of precast units, the resulting ½- to 1-in.-wide grooves can be taped, filled with silicone caulk, or left intact in cases where the precast components are made with geometrically precise fit. This joint is generally not conducive to wet cement paste leakage. For wider gaps, backing rod and silicone caulk may be considered to close the opening and to allow cement paste to fill the gap from above.

To facilitate lowering the precast panels into place, chamfers that are 1-in. wide and at a 45-degree angle are often provided along the upper edges of the panels. Dowel bars are used to horizontally connect the precast panels together.

### ***Can voided slab systems be cambered?***

Flat plate voided concrete slab systems can be cambered just like any other flat plate reinforced concrete system.

### ***Are there any special considerations for embedded items?***

Small items, such as electrical juncture boxes and pipes less than 3 in. in diameter, can be installed within the depth of a flat plate voided slab with essentially minor or no interference with the void formers. Larger items, like MEP conduits, usually require modification of the regular pattern of the void formers; some of the plastic balls are either omitted or shifted to accommodate larger embedded items. The structural engineer and architect of record should be notified whenever changes are proposed to the layout of the void formers.

It is always good practice to coordinate all the trade drawings with the structural drawings prior to construction. In this way, the placement/shop drawings for the void formers can include any modifications required for embedded items or large openings.

### ***Are there any special considerations for coring through voided slabs?***

Holes can easily be diamond-core-drilled through the cast-in-place and semi-precast voided systems. There is essentially no limit on the size and location of holes as long as it can be shown by analysis that all the pertinent strength and serviceability requirements are satisfied. Cutting through one or more void formers is not an issue because they are not required for strength. In order to prevent the creation of a space or draft for fire to spread, the space between the cored opening and the pipe/chase should be appropriately sealed to meet the required fire rating.

The provisions in ACI 8.5.4 can be used as a guide for openings in slab systems without beams. Openings adjacent to columns must be analyzed carefully; a portion of the critical section resisting two-way shear stresses may need to be considered ineffective depending on the size and location of the opening (ACI 22.6.4.3).

Just like any other cast-in-place or precast concrete floor system, it is important to have structural drawings and placement/shop drawings of the flat plate voided concrete slab system when determining locations for cores and other types of penetrations through the slab. The information on the drawings should be verified in the field.

### ***Can post-installed anchors be used with voided slabs? What if an anchor hits a void?***

Post-installed anchors can be used provided the void formers are located by any rational method, including visual observation of the soffit, placement/shop drawings,

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nondestructive testing, or any combination thereof. The minimum thickness of concrete cover at the underside of the plastic balls should be established using nondestructive testing techniques. It is important to note that for spherical void formers, minimum concrete thickness is applicable only at the center point of each sphere (the minimum concrete thickness is 2 in. for a ¾-in. cover and 2 layers of #5 flexural reinforcement); a substantial increase in concrete thickness occurs away from the center point. In contrast, minimum concrete thickness extends over a larger horizontal region for elliptical void formers.

Numerous types of anchoring systems are available for a variety of situations. The type and size of anchor depends on the magnitude of load that needs to be supported. For relatively small loads, screw-type anchors installed in concrete between the void formers may be sufficient. For larger loads, one technique that has been used is to install anchors into the voids, which are then partially filled with adhesive or mortar. Through-bolting the slab is an option for heavy loads. In addition to checking global strength and serviceability requirements, local shear stresses must be checked at the location of each through-bolt; the load must be adequately spread over the slab surfaces to avoid any local punch-through failures. This usually entails providing plates at the location of the through-bolts, which may not be architecturally feasible.

If an anchor unintentionally penetrates or comes near a void former, the anchor should be relocated. Knowing the spacing and the size of the void formers enables the anchor to be located where there is sufficient concrete between the voids.

Holes drilled into the slab for temporary use during the construction phase (for example, dowels fixing braces attached to the top side of the slab) should be sealed after use to avoid void formers from unintentionally being filled with water, which may later freeze and cause damage.

It is recommended to consult with anchoring manufacturers where it is anticipated that post-installed anchors will have an important impact on the project.

## **Availability and Cost**

### ***What is the availability of the voids in different parts of the country? How many plants are making the voids?***

It is recommended to contact BubbleDeck® and Cobiax USA® to obtain the latest information on availability. Representatives are available that can assist through every phase of a project.

### ***What is the cost of a voided slab system?***

It is recommended to contact BubbleDeck® and Cobiax USA® to obtain the latest information on cost.

When comparing costs of different types of structural systems, it is important that the costs are calculated using the same span and loading conditions for each system. The following cost-savings items should also be considered, to name a few: (1) reduction of concrete displaced by the voids, (2) the design of the columns and foundations due to the reduced dead load, and (3) the reduced structural depth and its impact on all the vertical runs in the building.

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**Historical:** None. New Technical Note.

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