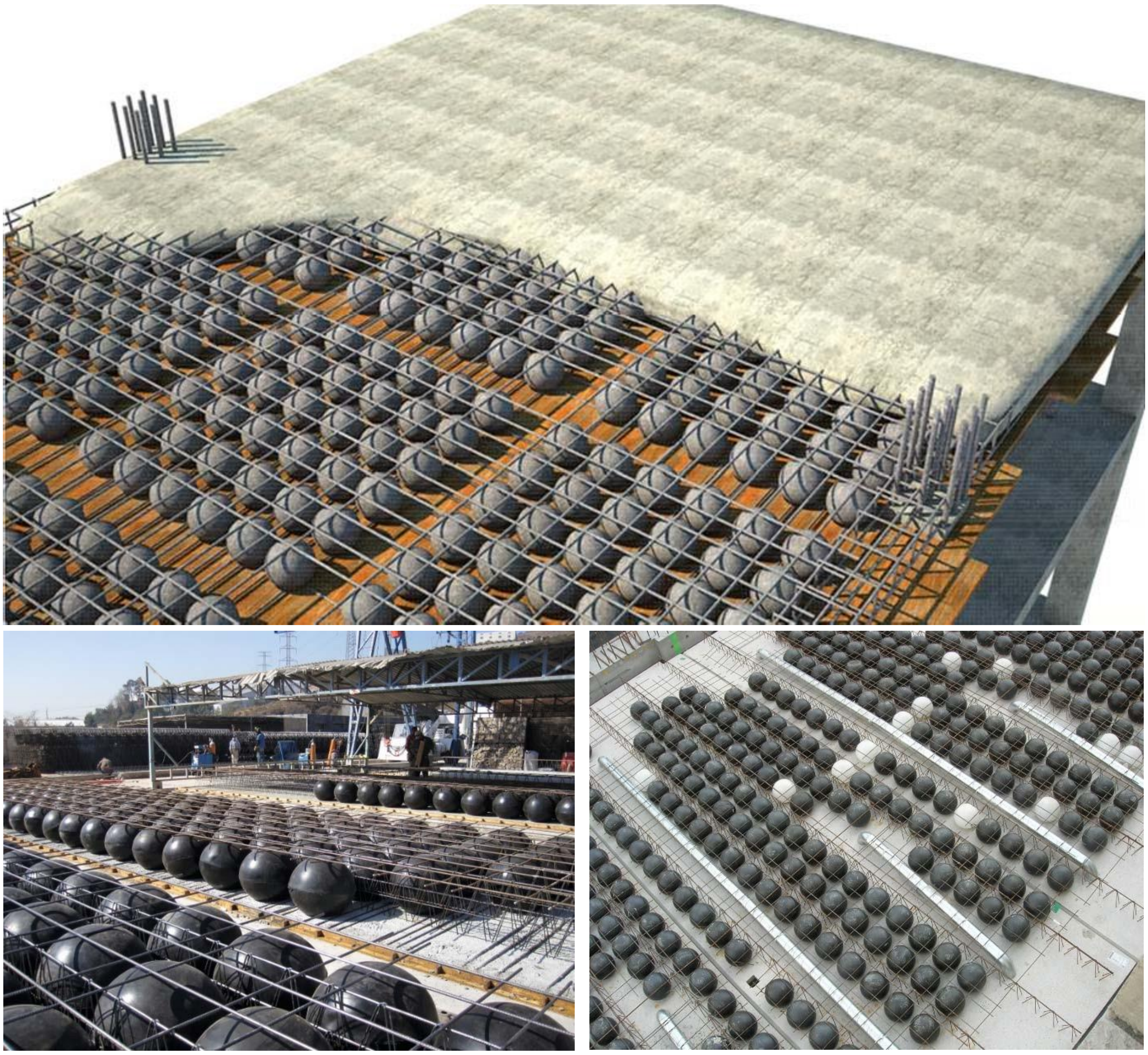
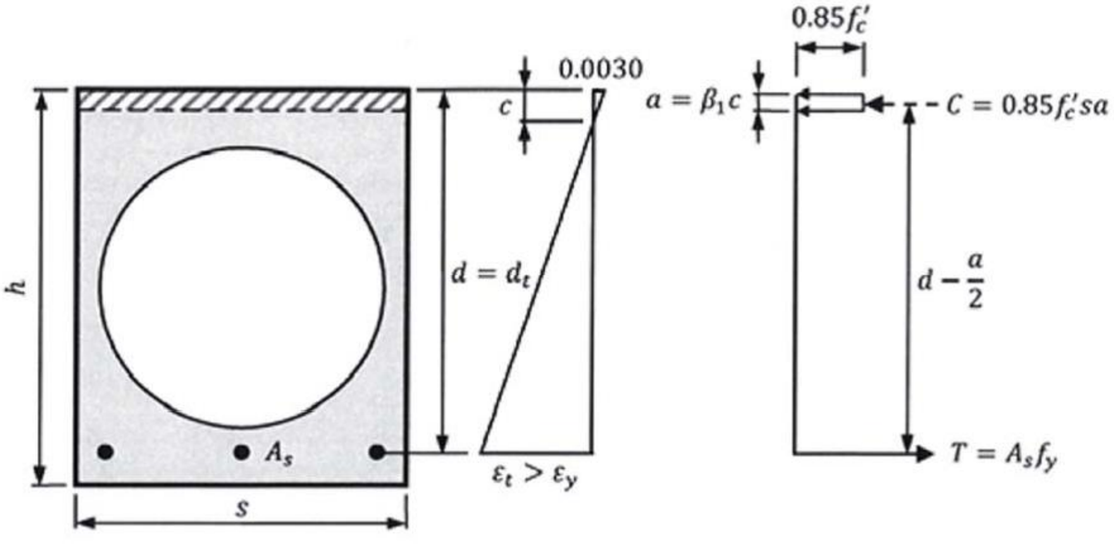
Flat Plate Voided Biaxial Slab Systems or Bubble Deck



Flat plate voided biaxial slab systems or bubble deck has been developed since 1990 under the concept of Hollow core precast slab. However, the load resistant criteria of hollow core precast slab and flat plate voided biaxial slab systems or bubble deck are one-way and two-way slabs respectively.

Consideration of load resistances under the concept of stain compatibility shows that the area of compressive stress is far away from the neutral axis, results the area of tensile stress is large. This leads to pop up the idea of removing some areas (area of tensile stress) below the neutral axis.



One of the techniques used to create spaces in concrete slabs is putting spherical or elliptical Plastic voided formers in slabs before pouring concrete by providing some reinforcements and cage modules to define spacing and height of the plastic balls.

Plastic Voided Long Span Slab Systems

Plastic voided formers were invented and developed in Europe, and they are made of High-Density Recycled PolyEthylene (HDPE plastic ball) with properties as follows.

Material: HDPE

Compressive strength: 30,000 kN/m^2

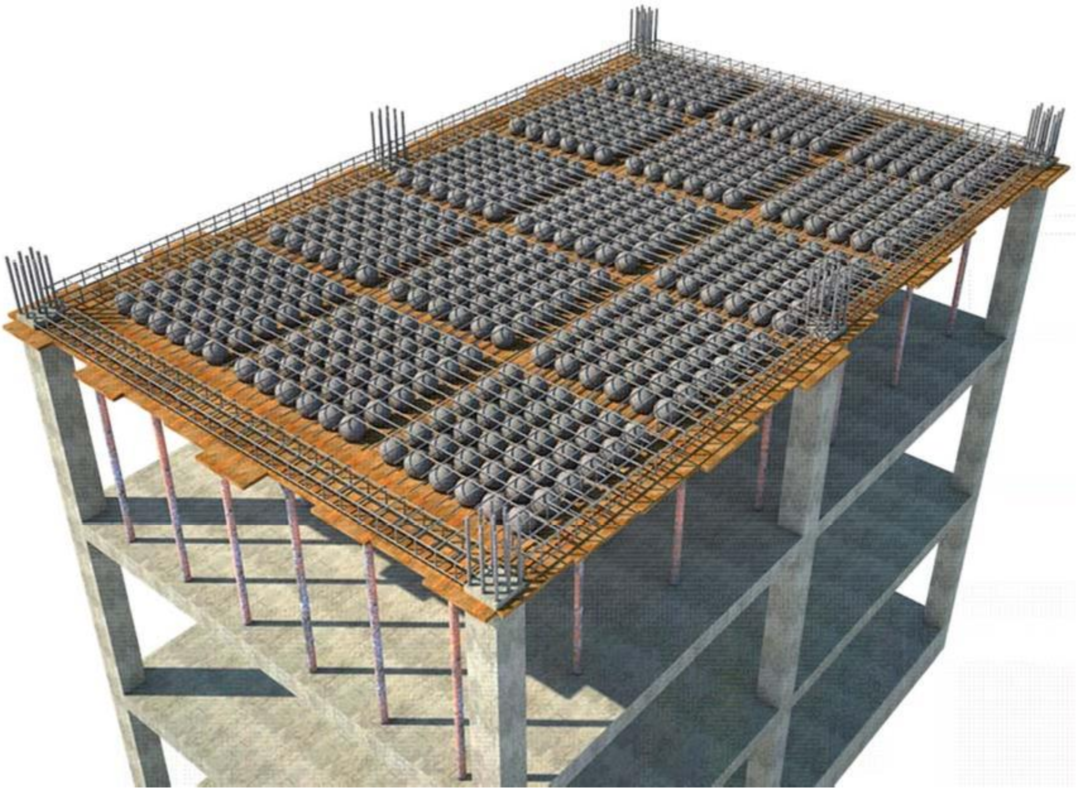
Poisson's Ratio: 0.42

Thermal Expansion: 2.0x10^{-5}

Density: 10.01 kN/m^3

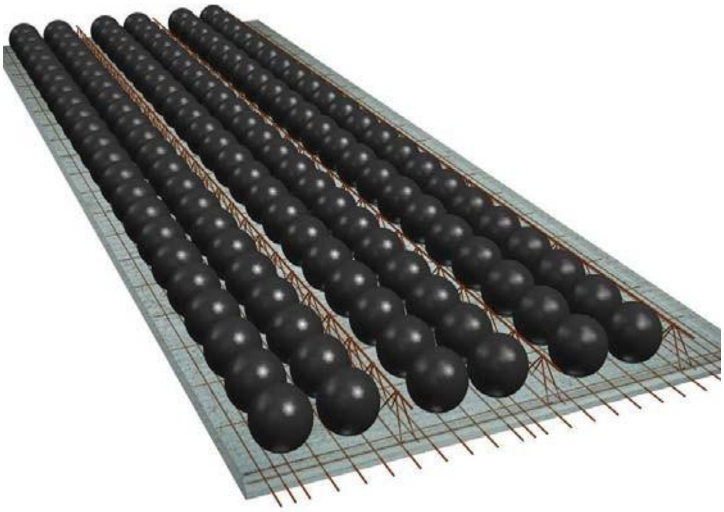
Spherical or elliptical plastic voided formers have been used popularity by two companies in the United States of America, Bubble Deck and Cobiax. Whereas U-boot beton system is the system created by Italia proving various shapes of plastic formers to create I-section slabs which increases the stiffness of slabs. Every system consists of its properties as follows.

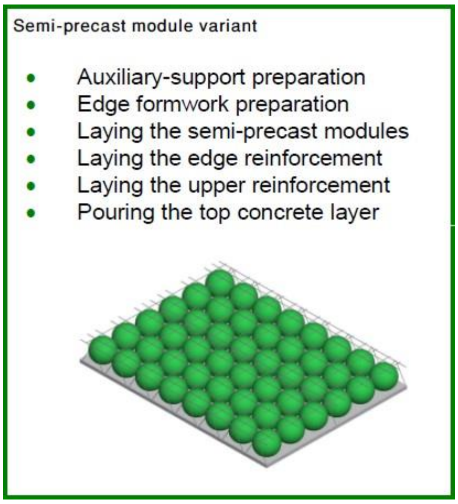
1. **Bubble Deck System**



1.1 Semi-Precast System

This system is done by casting some thickness at the bottom part of the hold slab which works as formworks attaching with reinforcements and cage modules above it as shown in **Figures** below.



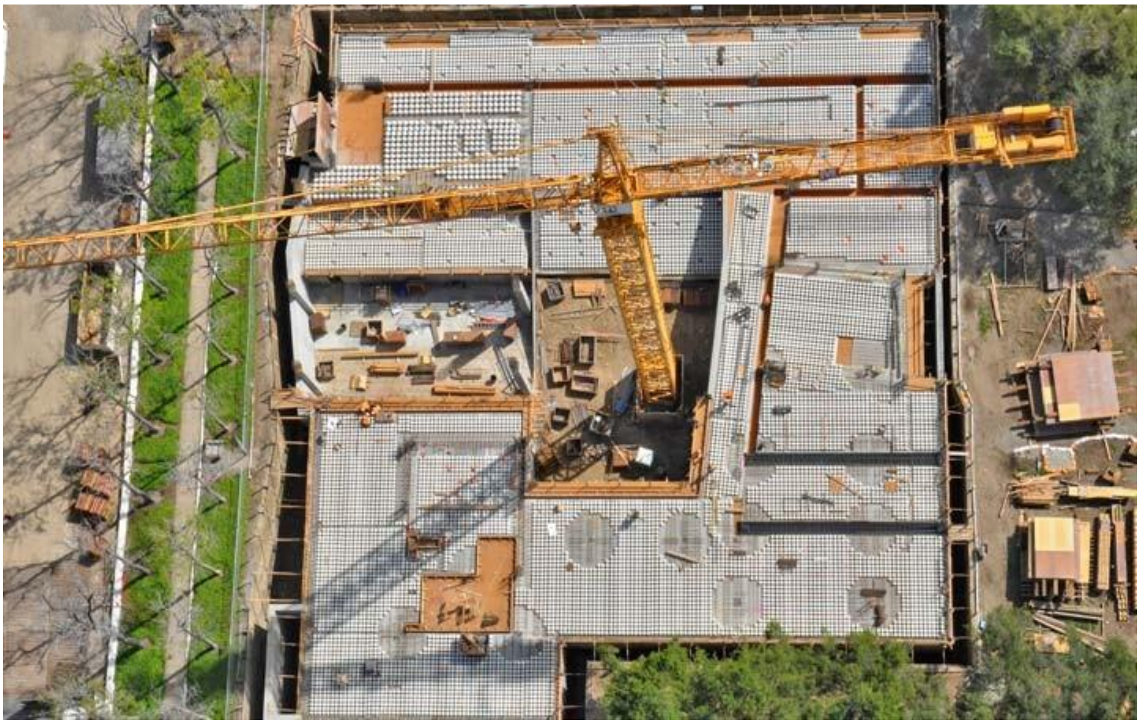


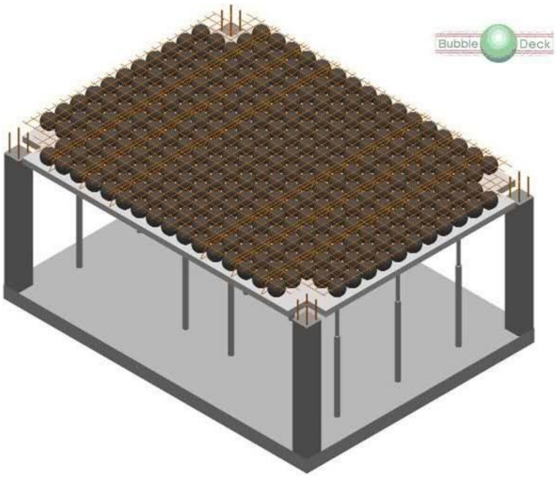
Semi-precast module variant

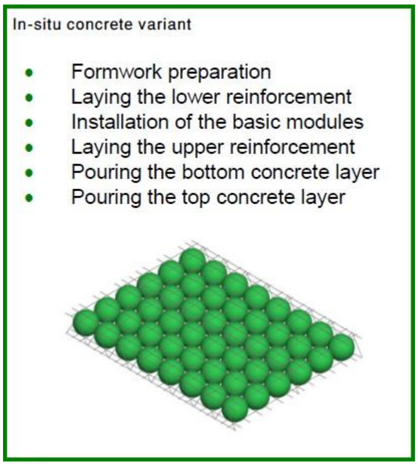
- Auxiliary-support preparation
- Edge formwork preparation
- Laying the semi-precast modules
- Laying the edge reinforcement
- Laying the upper reinforcement
- Pouring the top concrete layer

1.2 Cast-in-place system

This system is done by placing the reinforcements, cage modules and plastic balls conforming to their locations specified in the designed drawing plan, then finishing by pouring concrete.





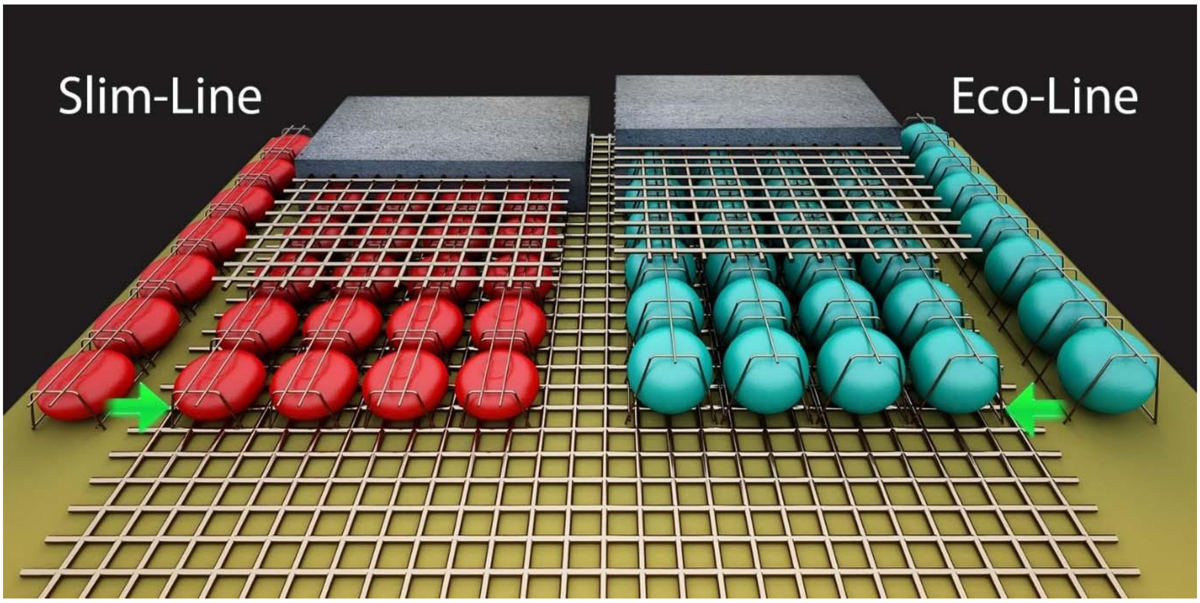


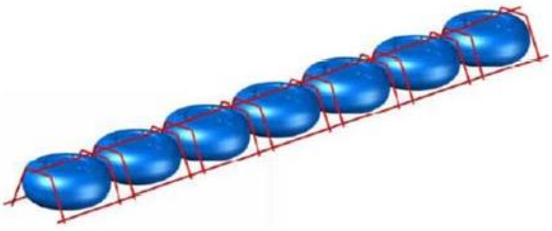
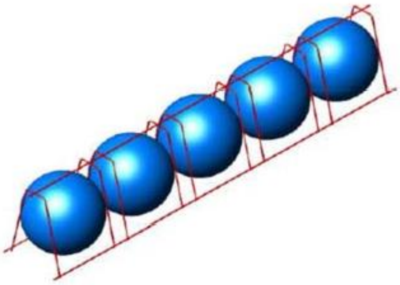
In-situ concrete variant

- Formwork preparation
- Laying the lower reinforcement
- Installation of the basic modules
- Laying the upper reinforcement
- Pouring the bottom concrete layer
- Pouring the top concrete layer

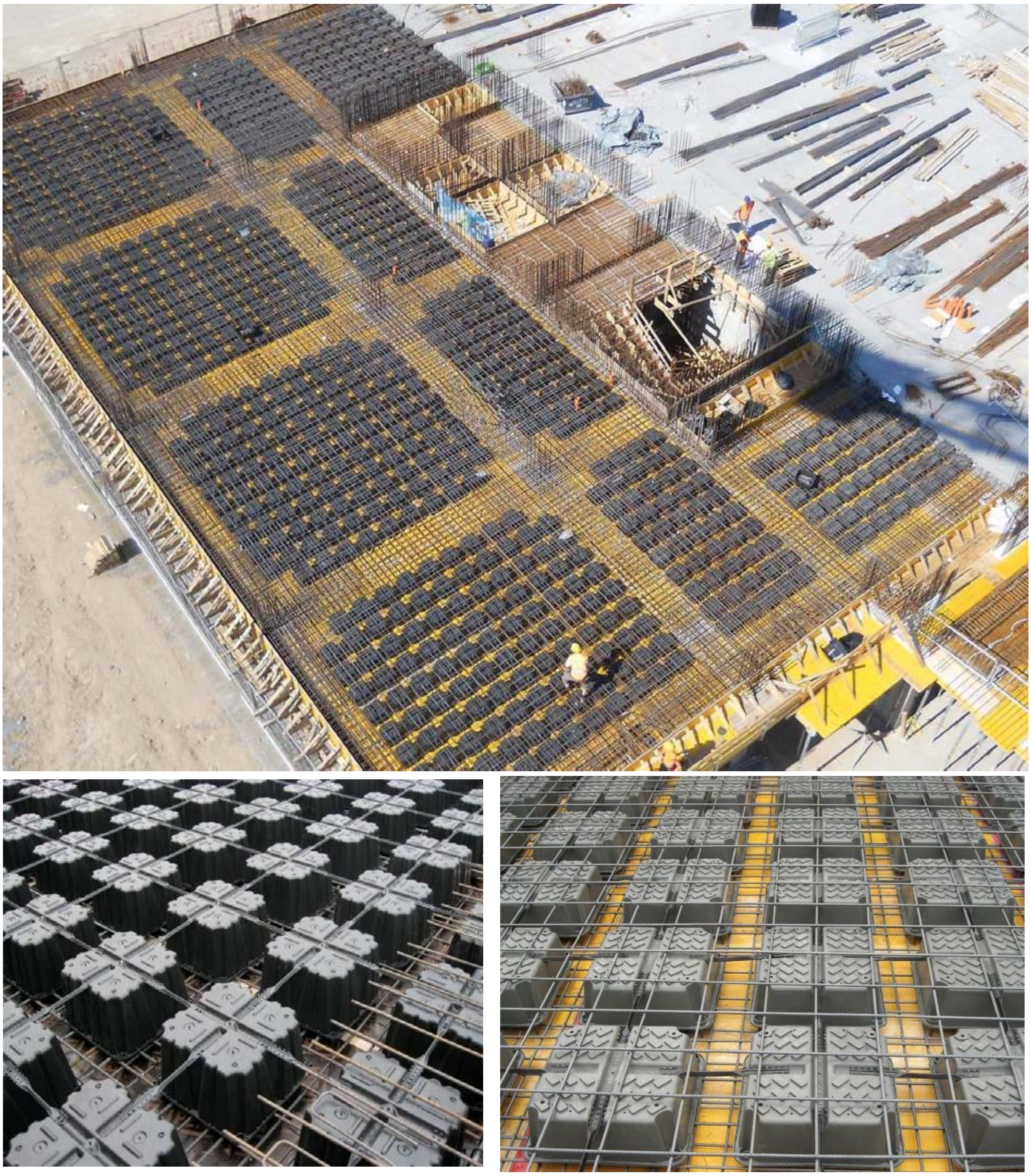
2. Cobiax System

Cobiax system is one of the cast-in-place slab systems providing two types of plastic balls, spherical and elliptical plastic balls. The plan and side views of elliptical plastic balls are circle and capsule shapes, respectively. The installation of the hold systems starts by installing formworks and bottom reinforcement followed by placing and attaching plastic balls with the bottom reinforcement conforming to the drawing plan. Next, install the top reinforcement. Casting concrete is divided into two layers. The first layer covers the bottom reinforcement and some parts of the plastic balls in order to anchor the plastic balls and cage modules not to move. After the first layer is set (normally after 2-3 hours), pour the last layer until the entire thickness of the slab is finished. The advantage of this system is it provides two types of plastic balls (spherical and elliptical shapes) as shown in **Figures** below. The elliptical shaped plastic balls will give the thickness of slabs thinner than spherical shaped plastic balls.



Cobiax **Slim-Line** cage modules, designated **CBCM-S-xxx** (identified by a number [xxx] which is the respective void former's height in mm).	Cobiax **Eco-Line** cage modules, designated **CBCM-E-xxx** (identified by a number [xxx] which is the respective void former's height in mm).
	
For slab depths 200 mm to 340 cm	**For slab depths 350 mm to 600$^+$ mm**

3. U-Boot Beton System



This system is created by Italy providing spaces in slabs by using plastic boxes as shown in **Figures** below.

This type of slab is used in order to create I-shaped slab section that provides more stiffness to the slab (**Figures** below). The concrete casting is similar to Cobiax System, which is cast-in-place and pour concrete into two layers.

Voided Post-Tensioned Slab Design

Flat plate voided biaxial slab systems or bubble deck was first used in reinforced concrete slabs. Later on, it was developed and used in post-tensioned slabs. Nowadays, the computer software, Finite Element Method (FEM) is used to analyze the values of internal forces and deflection of structures, and bring these values to the step of design. The design steps are as follows.

Step 1: Choose type of plastic ball

Step 2: Define properties of materials

Step 3: Define dead load, live load and others

Step 4: Check shear strength

Step 5: Define the areas and locations of voided and solid slabs

Step 6: Define directions and profiles of tendon in slabs

Step 7: Analyze the slab by using FEM

Step 8: Define design strip

Step 9: Check stresses at top and bottom edges of slabs

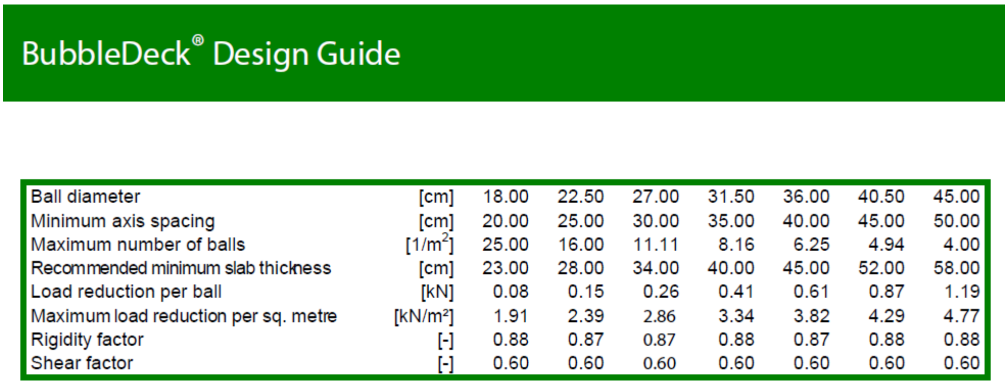
Step 10: Check the allowable compressive stress

STEP1: PLASTIC BALLS SELECTION

This article will talk about only the widely used plastic balls, which are spherical plastic balls manufactured by Bubble Deck, Elliptical and Spherical plastic balls manufactured by Cobiax. The properties of these balls will be input into the FEM software to create the modelling.

STEP2: PROPERTIES OF MATERIALS

The properties of both products are as follows.



BubbleDeck® Design Guide

Ball diameter	[cm]	18.00	22.50	27.00	31.50	36.00	40.50	45.00
Minimum axis spacing	[cm]	20.00	25.00	30.00	35.00	40.00	45.00	50.00
Maximum number of balls	[1/m^2]	25.00	16.00	11.11	8.16	6.25	4.94	4.00
Recommended minimum slab thickness	[cm]	23.00	28.00	34.00	40.00	45.00	52.00	58.00
Load reduction per ball	[kN]	0.08	0.15	0.26	0.41	0.61	0.87	1.19
Maximum load reduction per sq. metre	[kN/m^2]	1.91	2.39	2.86	3.34	3.82	4.29	4.77
Rigidity factor	[-]	0.88	0.87	0.87	0.88	0.87	0.88	0.88
Shear factor	[-]	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Main parameters of Cobiax cage modules

Slab depth	[mm]	**200**	**225**	**250**	**275**	**300**	**325**	**350**	**400**	**450**	**500**	**550**	**600**
		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Recommended Cobiax cage module type	[-]	**CBCM-S-100**	**CBCM-S-120**	**CBCM-S-140**	**CBCM-S-160**	**CBCM-S-180**	**CBCM-S-200**	**CBCM-S-220**	**CBCM-E-270**	**CBCM-E-315**	**CBCM-E-360**	**CBCM-E-405**	**CBCM-E-450**
Dead load reduction* per m²	[kN/m²]	**-1.40**	**-1.64**	**-1.88**	**-2.10**	**-2.32**	**-2.56**	**-2.80**	**-2.86**	**-3.34**	**-3.82**	**-4.29**	**-4.77**
Stiffness correction factor	[-]	**0.92**	**0.92**	**0.92**	**0.92**	**0.91**	**0.91**	**0.91**	**0.92**	**0.91**	**0.90**	**0.90**	**0.89**
Shear reduction factor	[-]	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.55**	**0.55**	**0.55**	**0.55**	**0.55**
Cage module support height	[mm]	**110**	**130**	**150**	**170**	**190**	**210**	**230**	**275**	**320**	**366**	**411**	**457**
Void former height	[mm]	100	120	140	160	180	200	220	270	315	360	405	450
Void former horizontal diameter	[mm]	315	315	315	315	315	315	315	270	315	360	405	450
Spacing between void formers	[mm]	35	35	35	35	35	35	35	30	35	40	45	50
Void former centre line spacing	[mm]	350	350	350	350	350	350	350	300	350	400	450	500
Number of void formers per m²	[-]	8.16	8.16	8.16	8.16	8.16	8.16	8.16	11.11	8.16	6.25	4.94	4.00
Concrete displacement per m²	[m³/m²]	0.056	0.066	0.075	0.084	0.093	0.102	0.112	0.114	0.134	0.153	0.172	0.191
Void formers per cage module**	[-]	7	7	7	7	7	7	7	8	7	6	5	5
Equivalent area per cage module	[m²]	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.72	0.86	0.96	1.01	1.25

*) assuming a concrete density of **25 kN/m²** **) made to fit the 2.50 m long cages

Sectional Area Ratio

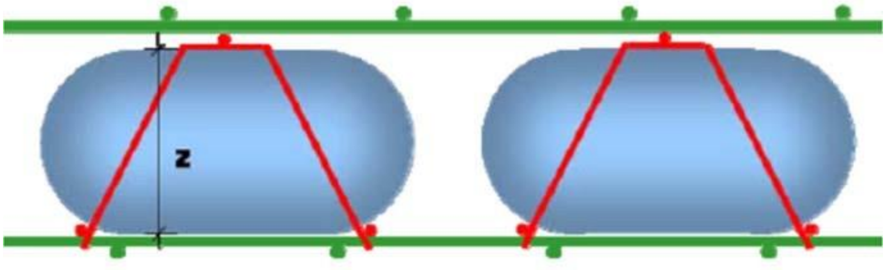
Check the spacing between a plastic ball to another and check the thickness of the slab. Then calculate the sectional area ratio. For example, choose the spherical plastic balls with 100 mm of diameter, clear spacing between one ball to another is 30 mm, the thickness of the slab is 210mm. Therefore,

Area = 210 x (100 + 30) = 27,300 mm^2

Ball area = $\frac{II}{4}D^2$ = 7,854 mm^2

Section area ratio $= \frac{Area - Ball\ area}{Area} = \frac{27{,}300 - 7{,}854}{27{,}300} = 0.71$

In case the elliptical plastic ball is used, its top and side views look like circle and capsule, respectively as shown in **Figure** below.



Example: The elliptical plastic balls with 170 mm of diameter are used. The height of balls is 110 mm, clear spacing between one ball to another is 30 mm. The thickness of the slab is 210mm.

Solution

Area = 210 x (170 + 30) = 42,000 mm^2

Ball area = $\frac{II}{4}110^2 + 110 \times (170 - 110) = 16{,}103$ mm^2

Sectional area ratio = $\frac{Area - Ball\ area}{Area} = \frac{42{,}000 - 16{,}103}{42{,}000} = 0.62$

Weight Ratio Calculation

After defining the thickness, calculate the self-weight per square meter of slab by considering full thickness of the entire slab. Then find the loss of weight from the **Table**.

For example: The thickness of slab is 0.23 m, its self-weight is 552 kg/m^2, diameter of plastic ball is 18 cm.

From the **Table**, the self-weight can be reduced 1.91 kN/m^2 or 1.91 x 101.97 = 194.76 kg/m^2.

Weight ratio = $\frac{552 - 194.76}{552} = 0.65$

Rigidity Factor or Stiffness Correction Factor

When spaces are presented in the thickness of slab, its stiffness is reduced. Therefore, the moment of inertia (I) is amended by following the value from the **Table** called Rigidity factor or Stiffness correction factor, I_{pvs}/I_{slab}.

Where,

I_{pvs} = moment of inertia of plastic voided slab

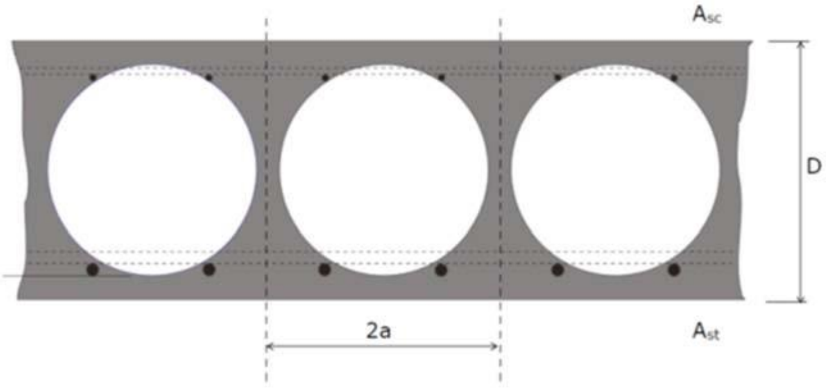
I_{slab} = moment of inertia of solid slab

In case the calculation does not follow the value from the **Table**, it can be used a simplified formula to find I_{pvs} per unit width (only for spherical ball): Ipvs = $\frac{D^3}{12} - 0.124a^3$

Where,

D = overall thickness of slab

A = distance from the center of one void to the center of a solid section

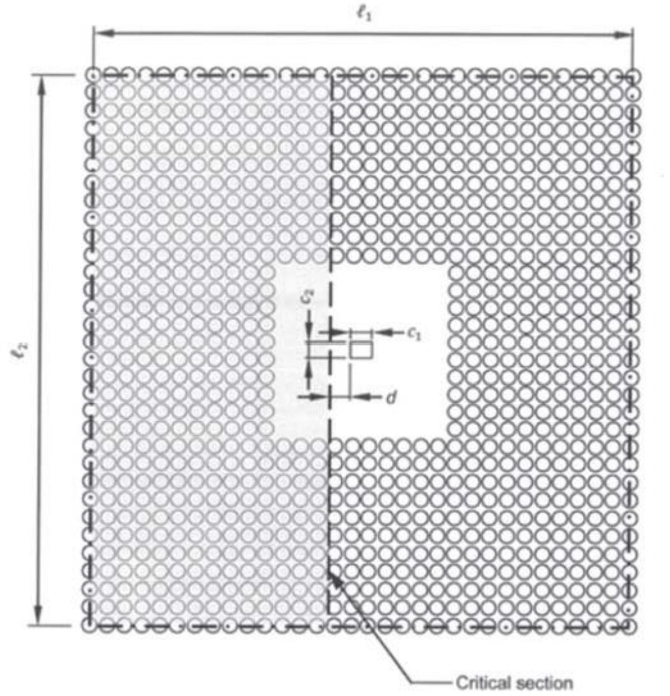


Basic Bubbledeck Geometry

STEP3: DEFINE DEAD LOAD, LIVE LOAD OR OTHER

STEP4: CHECK SHEAR STRENGTH

4.1 One-way shear or Beam shear

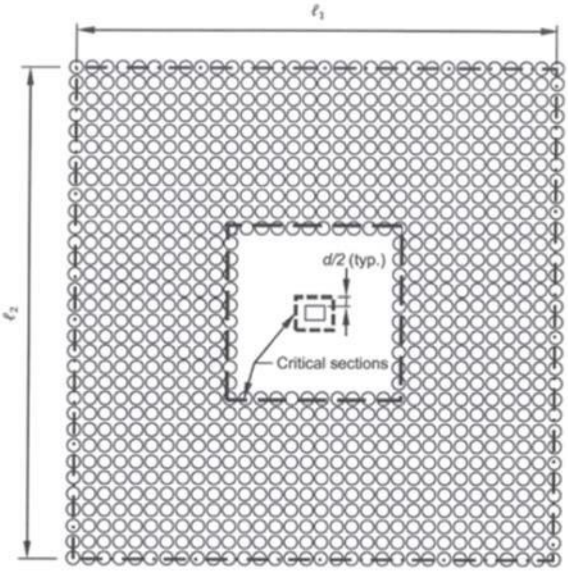


Check one-way shear at the distance d from the surface of a column. It shows that the critical section covers both in the area of full and voided slabs. For weight calculation, it is necessary to reduce the weight caused by voided slab. Then the designed shear strength is defined as:

$\emptyset V_c = \emptyset 0.53 f_{sr}\sqrt{f_c'} \cdot b \cdot d$ where, f_{sr} = voided shear reduction factor

The value of f_{sr} runs between 0.50 – 0.60 specified from the manufacturer.

4.2 Two-way shear or Punching shear



Two-way shear is checked at two different critical sections, at d/2 from the surface of a column and at d/2 from the edge of full slab. The weight shall be reduced due to voided slab.

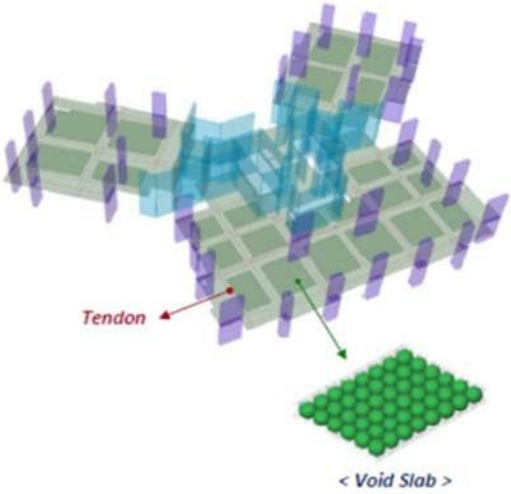
The designed shear strength of slab at d/2 from the column surface is defined as:

$$\emptyset V_c = minimum\ of\ \left\{\begin{array}{c} \emptyset 1.06\sqrt{f_c'} \cdot b_o \cdot d \\ \emptyset(0.53 + \frac{1.06}{\beta})\sqrt{f_c'} \cdot b_o \cdot d \\ \emptyset 0.265(2 + \frac{\alpha_s \cdot d}{\beta})\sqrt{f_c'} \cdot b_o \cdot d \end{array}\right\}$$

Whereas the designed shear strength of slab at d/2 from the edge of full slab, falled onto the area of voided slab, is defined as:

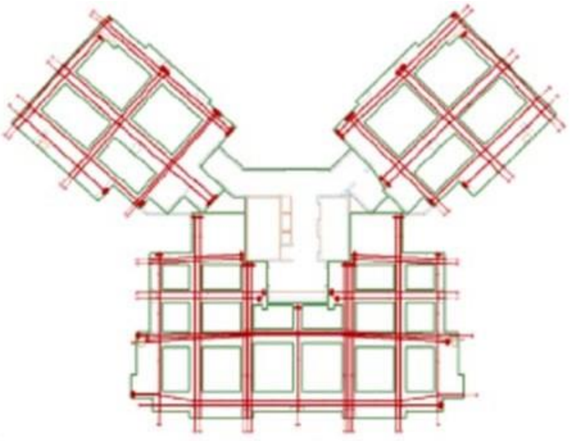
$$\emptyset V_c = minimum\ of\ \left\{\begin{array}{c} \emptyset 1.06\sqrt{f_c'} \cdot b_o \cdot d \\ \emptyset(0.53 + \frac{1.06}{\beta})f_{sr} \cdot \sqrt{f_c'} \cdot b_o \cdot d \\ \emptyset 0.265(2 + \frac{\alpha_s \cdot d}{\beta})f_{sr} \cdot \sqrt{f_c'} \cdot b_o \cdot d \end{array}\right\}$$

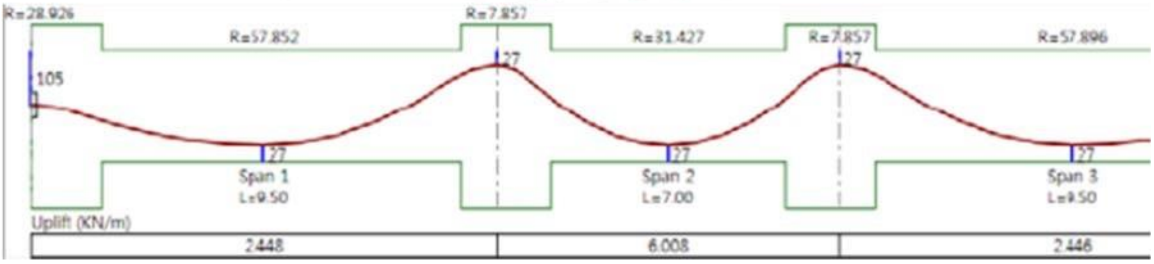
STEP5: DETERMINATION OF SOLID AND VOIDED SLAB AREAS



Normally, after the designed shear strength is checked, the full slab will be casted at the area of critical punching shear in order to provide tendons.

STEP6: PROFILES OF TENDONS

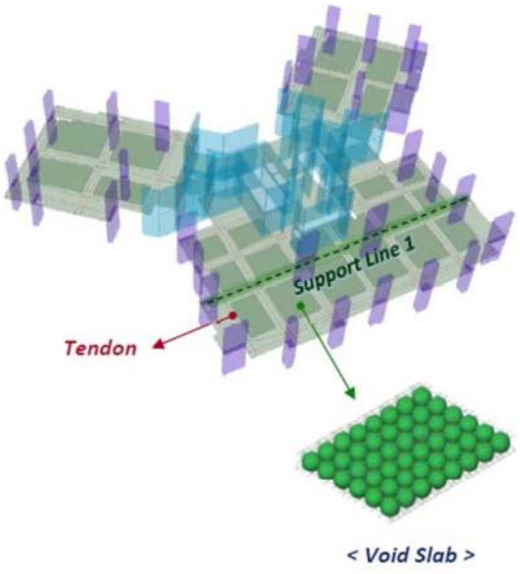


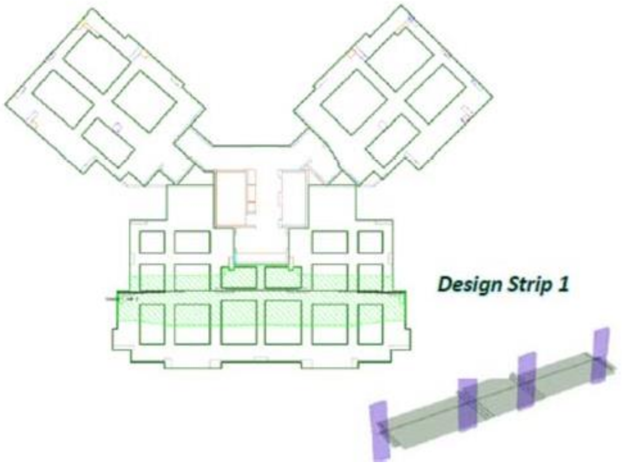


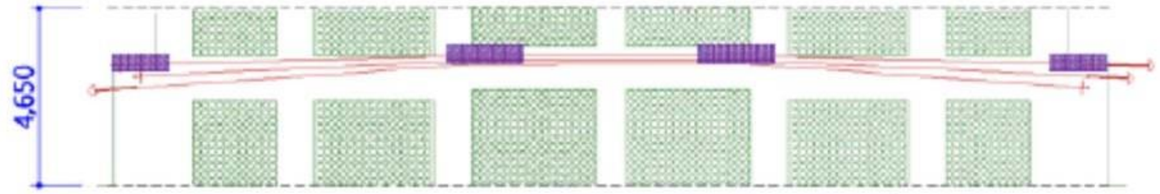
STEP7: ANALYZED THE STRUCTURE USING FEM

For full slab, use all parameters as normal; however, the amended parameters will be used with voided slab as discussed in **Step2**.

STEP8: DESIGN STRIP







< Design Strip 1 >

STEP9: CHECK STRESSES AT THE TOP AND BOTTOM OF SLABS

$$\sum = \frac{P}{A'} \pm \frac{P\cdot e\cdot c}{I'} \pm \frac{M\cdot c}{I'} \le Allowable\ stress$$

Where,

A' = Sectional area ratio x Solid sectional area

I' = Rigidity factor x I_{slab}

The value of allowable stress in the referenced articles is used only 90% of the normal allowable stress.

At Transfer

Allowable compressive stress = $0.9 \times 0.60 f_c'$

Allowable tensile stress = $0.9 \times 0.795\sqrt{f_{ci}'}$

Where, f_{ci}' is the compressive stress at transfer.

At Service

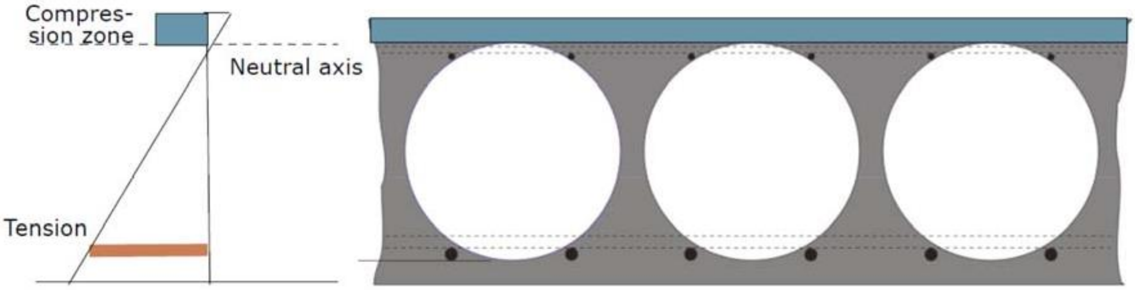
Allowable compressive stress = $0.9 \times 0.45 f_c'$

Allowable tensile stress = $0.9 \times 0.159 \sqrt{f_{ci}'}$

Where, f_c' is the compressive stress at 28 days.

STEP10: CHECK THE ALLOWABLE COMPRESSIVE STRESS

According to the previous assumption for flexural stress design, for voided slab, the compressive zone will be at full slab or at the neutral axis downward to the top of the balls as shown in **Figure** below.

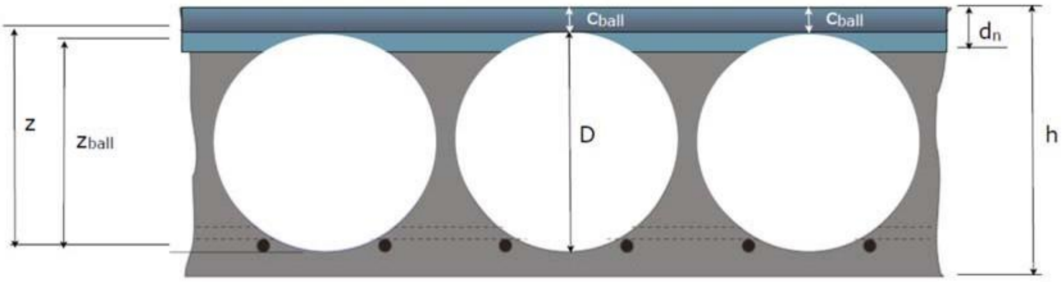


Stress distribution trough BubbleDeck under normal loading

The nominal moment of slab can be calculated by using general formula:

$$M_n = A_s \cdot f_y \left(d - \frac{a}{2}\right), where, a = \frac{A_S \cdot f_y}{0.85 \cdot f_c' \cdot b}$$

If the slab is subjected to large loads, the neutral axis may move downward lower than the top of the balls which lead the compressive zone occurs in voids. According to the researches from Germany, it can be summarized as a specification as shown in DIN 1045 that it can be checked by using a simplified method which is, the voided slab moment to full slab moment ratio shall not greater than 0.2. The distances of stress block and strain compatibility will be distributed, and this can be calculated to find the stress block by using a normal method.



Compression zone can encroach on bubble zone for heavily reinforced slabs

$\mu_{ms} = \frac{M_u \cdot 1.96 D}{f_c' h^3} \leq 0.2$, where, D = Diameter of a ball

h = Thickness of slab

M_u = Designed moment

Videos of some example

1. Bubble Deck System

2012 NOVA Award Winner -- Bubble Filled Concrete Deck (BubbleDeck)

Construction Innovation Forum 2012 NOVA Award Winner

YOUTUBE.COM

2. Cobiax System

Cobiax Installation and Concrete pouring

- Installation of the Cobiax modules on the slab formwork - Simple cutting to length of the modules in lengths -...

YOUTUBE.COM

3. U-boot Beton (U-boot) System

UBoot Beton® Disposable formworks for lightened structures in reinforced concrete cast on site

YOUTUBE.COM

References

1. “Frequently Asked Questions (FAQ) About Flat Plate Voided Concrete Slab System”, CRSI (Concrete Reinforcing Steel Institute)
2. “ECONOMIC Application of Post-Tensioning in Korean Residence Building”, DAELIM Industrial Co.,Ltd. , Adapt Corporation (2012)
3. “Bubble Deck Design Guide for Compliance with BCA using AS3600 and EC2”, Bubble deck company (Australia and New Zealand) (2008)
4. “Plastic Voided Slab Systems : Applications and Design”, C.J. Midkiff (2013) 5.“The Biaxial Hollow Deck;

   The way to new solutions”, Bubble deck company 6.“Engineering Manual Issue 2010”, Cobiax(2010)
7. “Analysis of Bubble Deck Slab Design by Finite Element Method”;M.Pandey, M.Srivastava (2016)

PHOTO CREDIT

1. Bubble Deck
2. Cobiax
3. U-Boot Beton

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