A Comparative Study of Post Tension Voided Slab

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Abstract:
Nowadays, several researches are concerned with studying the effect of voids in concrete elements specially voided slabs. The concept of voided concrete slabs depends on removing inactive concrete parts without affecting performance of the elements. This can be accomplished by replacing inactive concrete by hollow plastic forms. There are many systems that adopt this concept like cobiax, bubble deck, U-boot, Bee plate, and donut. This research reviews many experimental and numerical studies concerning voided slabs to shed light on their design methods, their advantages and disadvantages, their comparison with other common flooring systems, and finally the possibility of their application in Egypt.

Keywords: Reinforced Concrete, Voided slabs, bubble deck, Air deck slab.

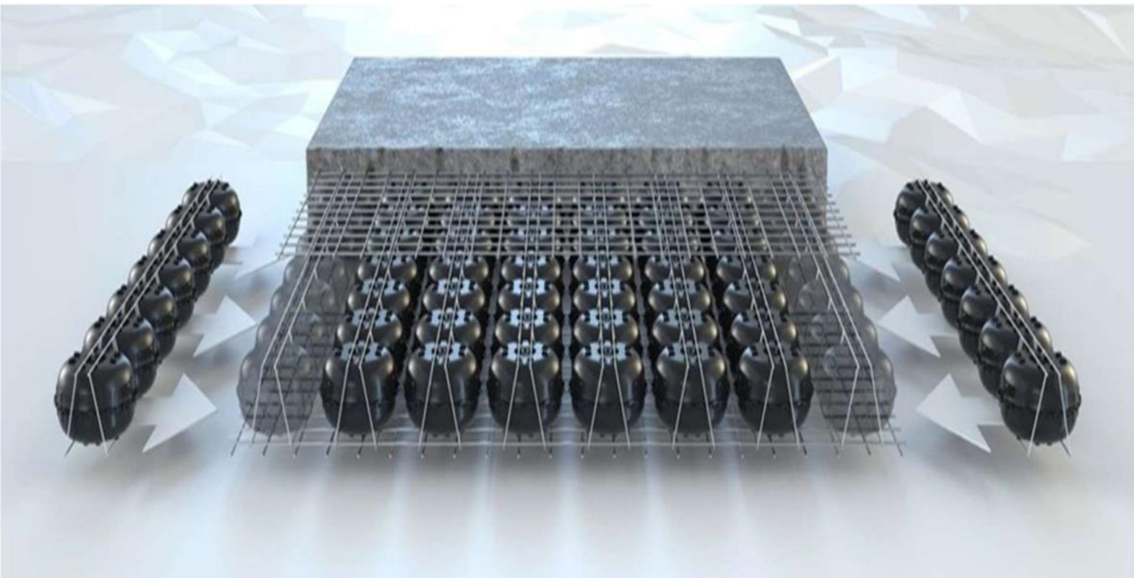
INTRODUCTION

A PT (Post-Tensioned) voided slab is a type of concrete slab that incorporates tendons (high-strength steel wires or bars) to enhance its structural capacity. The tendons are stretched and anchored at the slab's edges, creating a compressive force that counteracts the tensile stresses induced by loads. The voids in the slab, typically created using hollow blocks or formwork, help reduce the overall weight and material usage. In order to construct a flat plate for long span and considering slab thickness, RCC slab was not an advisable option. Hence there is technology suggested PT voided slab wherein PT reduces section sizes by controlling deflection and void will further reduce concrete self-weight. A post-tensioned one-way void slab is proposed in a column free area measuring 121 ft. × 69 ft. with a grid of 3 hidden beams (beams having depth same as that of slab depth and hence aren't visible from underneath), as a result forming a one-way spanning flat plate of 400mm total virtual thickness. The void slab is made to rest directly on 14 columns at periphery, 4 at corners and remaining 10 on side edges. 550 voids of size 520mm × 520mm × 200mm are used. Adoption of void slab resulted a flat bottom and achieved considerable reduction of concrete (6 to 7 %). This reduction in concrete volume plus reduced reinforcement caused overall reduction in self- weight of slab resulting in lighter floor. Reduction in self-weight of the slab and provision of hidden beams, eliminated the need of providing columns in the interior area. Hence, even by using less materials, the structural requirements remains intact and the overall cost is reduced. Also the primary requirement of clear headroom space is achieved. Nowadays, several research are concerned with studying the effect of voids in concrete elements specially voided slabs. The concept of voided concrete slabs depends on removing inactive concrete parts without affecting performance of the elements. This can be accomplished by replacing inactive concrete by hollow plastic forms. There are many systems that adopt this concept like cobiax, bubble deck, U-boot, Bee plate, and donut. This research reviews many experimental and numerical studies concerning voided slabs to shed light on their design methods, their advantages and disadvantages, their comparison with other common flooring systems, and finally the possibility of their application in Egypt.

HISTORY OF VOIDED SLAB SYSTEM

In building construction, slabs are very important structural elements to save space, which make them one of the most concrete consuming elements. There are variety of flooring systems used, and each has its own advantages as well as disadvantages. For example: Solid slabs are characterized by high stiffness and high resistance of lateral loads, but the beams may cause many architectural obstacles. On the other hand, flat slabs provide architectural flexibility and ease of implementation, but are characterized by large thickness and high weight. Pre-stressed slabs allow for long spans but are expensive most of time and require special labor. The main obstacle, in case of horizontal slabs, is the high weight, which limits the span, where large spans lead to large slab thickness in order to control deflection as a serviceability requirement in design codes. Large thickness leads to large slab weight and consequently greater loads on columns and foundations, ending with an increase in concrete sections and reinforcement amounts, which negatively affects the construction cost. For the foregoing reasons, major developments of reinforced concrete have focused on reducing the weight or overcoming concrete's natural weakness in tension. Over the years, building materials have increased in quality when it comes to strength, and lighter materials can be implemented into structures. However, there has still been a lot of innovation and evolution in the voided slab concept to decrease the dead load and volume of material used. The first known example of a voided slab system dates back to the construction of the coffered ceiling dome of the Pantheon in Rome, which was completed in 125 AD. The dome spans over 42.67 m and was the largest unreinforced concrete dome in the world until the construction of the Florence Cathedral in 1436. The engineers and constructors of the Pantheon eliminated the concrete at locations in the slab where the entire cross section is not needed to resist the loads. The voids in the dome were formed with external voided formwork adding a decorative element to the roof due to its unique shape. Unreinforced concrete domes would never be designed today due to code restrictions, but the dome of the Pantheon is still standing strong nearly 2000 years later. In Europe, around 1990, Jorgan Breuning of Denmark invented voided slab technique by using hollow polyethylene plastic spheres embedded in regions of low normal stresses of the structure. Recent developments on voided slab technology have been made in Europe that have improved the efficiency of the two-way flat plate floor system to unprecedented spans reaching nearly 16 m. While the concept of removing the non-working "concrete" dead load remains the same, the improvement comes from the fact that these are biaxially loaded slabs. The main effect of the voided slab system is to decrease the overall weight by as much as 30% to 35% when compared to a solid slab of the same capacity. In voided two-way slabs, a hard shell with struts is created through the use of appropriately located cavities formed by void formers. This is achieved by placing hollow spheres made of recycled plastic between the upper and lower static reinforcement of the concrete slab while displacing concrete where it has no structural benefit. Voided slabs can be used in skyscrapers, larger span halls like theatres, pedestrian bridge deck or parking areas. In this idea, they might now be tried for a lightweight pedestrian bridge deck.

What Are Voided Slabs?



OBJECTIVES: -

Design and Analysis:

- **Structural Analysis:** Using software like STAAD. Pro, SAP2000, or ANSYS to analyze the slab's behavior under different loading conditions (dead, live, and wind loads).
- **Design of Tendons:** Determining the number, size, and spacing of tendons based on the required prestressing force.
- **Anchorage Design:** Selecting appropriate anchorage systems to ensure the tendons are securely fixed to the slab.
- **Span-to-Depth Ratio:** This ratio significantly influences the slab's deflection and cracking behavior.
- **Prestressing Force:** The magnitude of the prestressing force affects the slab's stiffness and stress distribution.
- **Tendons' Shape and Layout:** The arrangement of tendons can optimize the prestressing force distribution.
- **Void Configuration:** The size, shape, and spacing of voids can impact the slab's weight and structural efficiency.

Construction Methods

- **Formwork:** Designing and fabricating formwork for the slab, including the voids.
- **Concrete Placement:** Developing a concrete mix design and specifying the placement procedure to ensure proper compaction and curing.
- **Tendon Installation:** The process of installing and tensioning tendons requires precision and care.

Material Properties:

- **Concrete:** The compressive strength of concrete is crucial for the slab's load-carrying capacity.
- **Tendons:** The tensile strength, ductility, and relaxation characteristics of tendons are essential.
- **Anchorage System:** The strength and reliability of the anchorage system are critical.

Case Studies:

- **Existing Structures:** Analyzing real-world examples of PT voided slabs to understand their performance and benefits.
- **Failure Analysis:** Discussing potential failure modes and preventive measures.

Cost-Benefit Analysis:

- **Economic Evaluation:** Comparing the cost of PT voided slabs with traditional reinforced concrete slabs.
- **Environmental Impact:** Assessing the environmental benefits of using PT slabs, such as reduced material consumption.

Self weight

On account of the voids, a new concrete material must be defined in Builder Floor Pro with unit weight (W_e) adjusted to reflect that of the solid equivalent slab.

Deflections (SLS)

For the same span arrangement and boundary conditions, the deflection of a slab is governed by the stiffness of the slab expressed by the product of modulus of elasticity (E) and the second moment of area (I), namely (E*I). For equivalent deflection response, the following governs:

$$E*I = E_e*bh^3/12$$

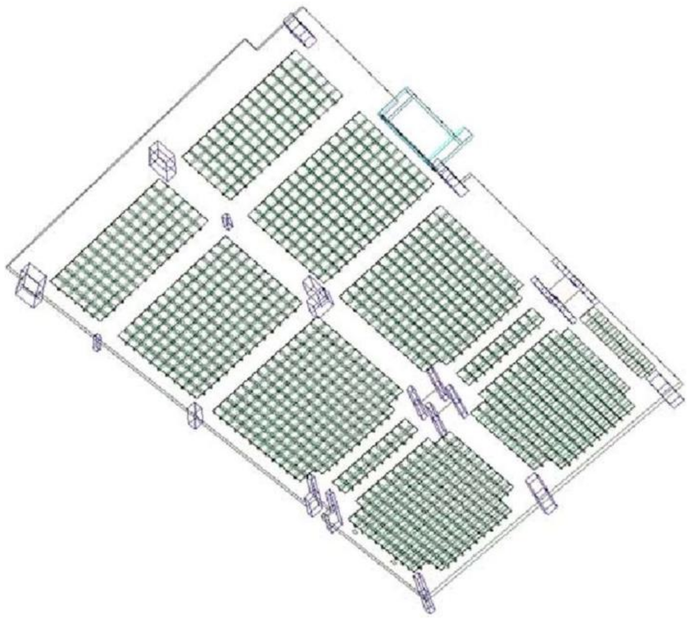
Where, the suffix (e) is specific to the equivalent slab Hence: $E_e = 12*E*I / (b*h^3)$

Strength (ULS)

The amount of reinforcement calculated to resist the demand moment depends on the width of the section (b), depth of the section (h), and the concrete strength (f'c). It is assumed that the compression zone will be limited to the solid portion of the voided slab. Hence, for practical purposes, the reinforcement calculated for the equivalent slab described in 2-1 will apply to the prototype voided slab too.

Post-Tensioned Slabs

The voided slab construction, as illustrated in Figure does not lend itself to easy installment of post-tensioning tendons, since the hollow spheres are generally pre-assembled in a cage with a reinforcement mesh on the top and bottom of the multi-sphere arrangement. Post-tensioned tendons have to be woven through the cage for installation. Since, to accommodate top and bottom added reinforcement, the depth of the cage is typically much smaller than the depth of the slab, an optimum drape for tendons placed within the cage cannot be achieved. One alternative is to group the tendons in one direction within the solids strips between the column supports, and reinforce the slab in the orthogonal direction using conventionally reinforcement. Current ACI-318-11, does not permit the tendons to be limited to groups in both directions, but the layout is practiced in other parts of the world, where ACI-318 does not govern.
The design of a post-tensioned slab includes crack control, in addition to deflection control and provision of reinforcement for safety. Using ACI 318, the crack control is achieved through limits imposed on hypothetical extreme fiber tensile stresses.
Application of Floor Pro computer program and the modeling scheme proposed above for conventionally reinforced slabs accounts for the deflection and strength requirements of the slab, as well as for stress values of solid regions shown in figure f or the voided construction at the interior of the panels, the values obtained are on the low side. The substitute model has a larger cross- sectional area and section modulus, both of which will result in lower computed stresses.



Voided Slab or Waffle Construction with Solid Bands Between Supports

For design, it is recommended to use the code-stipulated limit of allowable stress for solid regions, but a smaller value for the voided sections. Recognizing that in designs based on ACI-318, (i) the stress due to axial compression from prestressing is typically one third of the value from bending, and (ii) the axial compression for the solid region is typical maintained at 1 MPa, one may arrive at what would be an acceptable range of fiber stress in the voided regions, the keep the stresses within the code limits.
An alternative to the above is to view on the computer screen the reported values of the axial force and moment at design time and using a spread sheet convert them to the values of the actual voided slab unit to arrive at the stresses in the prototype.

Advantages and disadvantages of voided slabs

The most obvious advantage to flat plate voided slabs is the reduction in concrete. If designed efficiently, voided slabs can reduce the volume of concrete up to 35% compared to solid flat plate concrete slabs with similar spans and strength. According to some products, 1 kg of recycled plastic replaces 100 kg of concrete. The reduction in concrete results in less dead load applied to the rest of the structure, which will decrease the size of the columns and foundations.

Lower self-weight of the slab will also reduce the effective seismic weight of the structure leading to a lower base shear for the seismic lateral loads. This would also reduce the size of the lateral force resisting system members, which would result in even more concrete savings and ultimately, reduce the cost of the structure.

Reducing the amount of concrete needed for a project, would also have a positive environmental impact. One of the main components of concrete is Portland cement, which creates high levels of carbon-dioxide emissions into the environment during production. But this is another important advantage to implement voids into the slabs to reduce the volume of concrete.

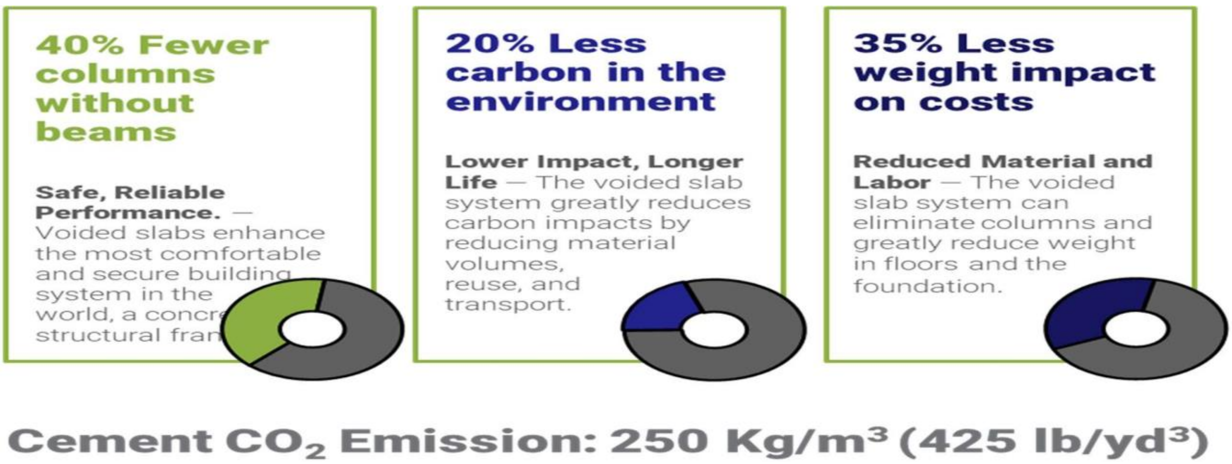
Another benefit to flat plat voided concrete slabs compared to other systems is the reduction in floor-to-floor heights, especially for two-way slabs, where no beams are needed, which allows reducing floor-to-floor heights or create more plenum space for the mechanical, electrical, and plumbing systems.

A typical composite steel structure would have a concrete filled steel deck at least 4” deep that is supported 93by steel members ranging from 30.48 cm to 76.2 cm, depending on the loads and span. A concrete pan-joist system would have joists ranging from around 45.72 cm to 71.12 cm deep, which is another version of a one-way voided slab.

Build Without Beams

- 100% recycled void formers replace concrete volume
- Less CO2 impact from initial cement production
- A smaller, lighter concrete foundation
- Less costly excavation
- Reduced building height and associated vertical costs
- Fewer columns without beams
- Reduced construction material in the waste stream
- Lower ongoing HVAC and maintenance costs
- More flexible building-use space in the same footprint and height

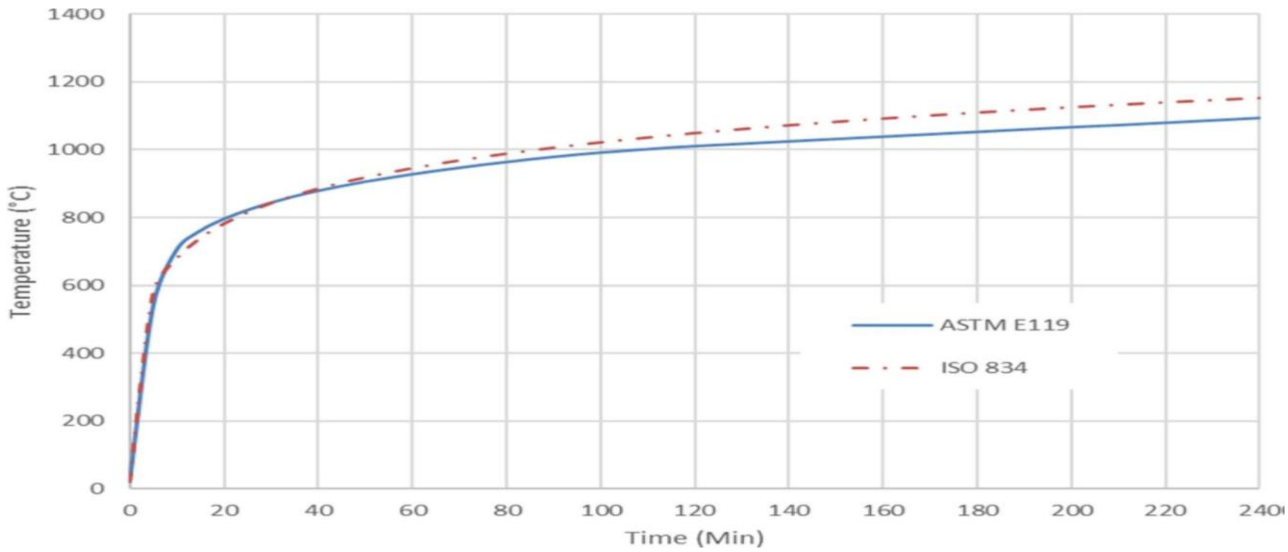
Reduced Carbon Footprint



Fire resistance

All the fire tests on the flat plate–voided concrete slab systems 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. The voids acted as a thermal isolator; the heat from the fire was dammed below the void. This led to slightly higher temperatures in the reinforcing bars positioned below the voids. A cover of 20 mm to the main flexural reinforcing bars resulted in a fire-resistance rating of at least 2 h. 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 93 and 149°C 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 20 mm cover to the bottom reinforcing bars will provide a minimum 2-h fire-resistance rating, which meets minimum fire-resistance ratings are required for floor assemblies in common occupancies.



fire resistance graph

Fire Rating of Voided Slabs

- IBC 2021 APPROVED
- Up to 2 hrs

Fire Rating of Voided Slab

Earthquake and Dynamic Loading

The dynamic properties of a building and its earthquake behavior have to be assessed individually on a project by project base with the verification methods recommended by the respective codes.

In case of an earthquake the reduced dead load of the Cobiax slab influences beneficially the horizontal forces acting on the bracing elements of the building structure (typically shear walls and lift cores). These forces – mainly driven by the horizontal member's dead load – are reduced if the dead load of the slab is reduced. Up-to-date 3D dynamic modelling software will take into account the reduced dead load of the slabs and compute the deformation and moments accordingly.

Compared to a solid slab of same thickness, the Cobiax slab has an improved vibration performance. Cobiax flat slabs have higher natural frequencies for common practice live loads compared to solid slabs due to their reduced dead load.

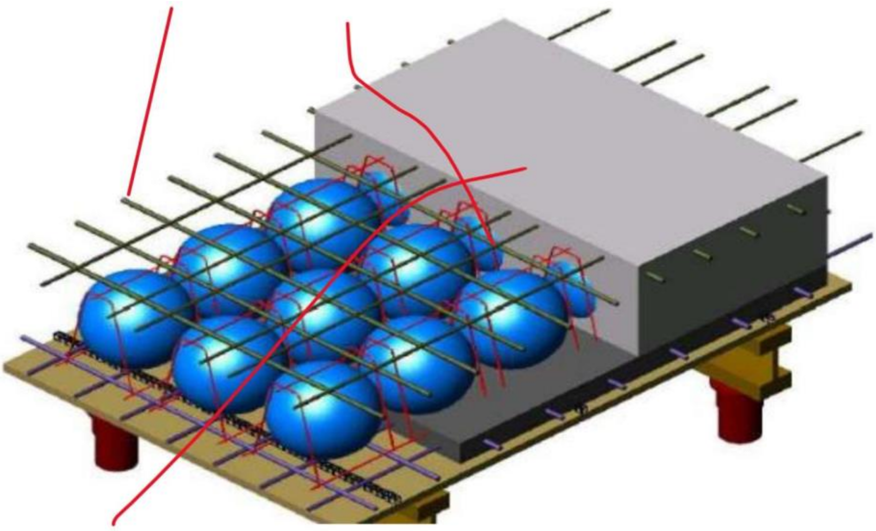
Durability

The durability of bubble deck slab is not fundamentally different from ordinary solid slabs. The concrete is standard structural grade concrete and combined with adequate bar cover provides most control of durability commensurate with normal standards for solid slabs. When the filigree slabs are manufactured, the reinforcement module and balls are vibrated into the concrete and the standard and uniformity of compaction is such that a density of surface concrete is produced which is at least as impermeable and durable, arguably more so, to that normally produced on site. Bubble deck slab joints have a chamfer on the inside to ensure that concrete surrounds each bar and does not allow a direct route to air from the rebar surface. This is primarily a function of the fire resistance but is also relevant to durability.

Components of voided slabs

Voided slabs consist of three basic components: concrete, reinforcement, and plastic formers.

Reinforcement **Plastic formers**



Concrete

Component parts of slab

CONCLUSION

Based on what has been reviewed from previous research, it can be concluded that voided slabs are considered a promising structural system due to their distinct environmental and structural advantages. They also represent a highly economical system, through its application, it is possible to save large quantities of building materials and reuse other environmentally harmful materials.

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