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State of the Art of One and Two-Way Voided Reinforced Concrete Slabs

Hend S. Zayan[a*], Aseel H. A. Abdaljader[a], Ibtihal A. Mawlood[a], Akram Sh. Mahmoud[b]

[a]*Dams and Water Resources Department, Engineering Cellage, University of Anbar, Iraq.*

[b]*Civil Engineering Department, Engineering College, University of Anbar, Iraq.*

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ABSTRACT

A voided slab is an innovative type of reinforced concrete slab system developed recently, that has proven its excellence in terms of its structural, environmental, and economic benefits. The self-weight of a slab can be considerably reduced using different shapes of void formers like spherical, cubical, and donut. All researchers confirm that the self-weight of the slab decreases by up to 40%. Various researchers have carried out experimental and numerical studies for studying one-way flexural strength and punching shear strength of voided reinforced concrete slabs. However, the one-way or two-way flexural strength of the voided slab still needs to be acutely investigated. This paper deals with the survey on many titles of selected high impacted journals to illustrated almost criteria of investigations of these types of slabs. The main outcomes of this paper are the term environmental protection, sustainable and plastic waste reduction had a role not a little in this research, as 16% of the research on this topic were studied. Also, the plastic material governs the subject of the raw materials used to make the voids;43% of researches used this material.

1. Introduction

Slabs are an essential component of structural buildings and come in two varieties: one-way and two-way. The newest tendency is to produce a voided slab that reduces the slab's self-weight but with the same efficiency. A large number of researches dealt with this topic and researched the various characteristics, efficiency, types of loads, shapes, sizes and proportions of voids, type of material used to manufacture voids, and ratio of voids into slab (Dadzie & Kaliluthin, 2022). There are a good number of reviews on this topic, but either it deals with a specific topic about it (Al-Mohammad & Al-Bayati, 2022; Gamal et al., 2023; Adil et al., 2019), or collects research until 2018 (Al-Azzawi & Omar, 2018).

* *Corresponding author.*
E-mail address: hind.saad@uoanbar.edu.iq

A voided slab is made out of hollow plastic voids that are positioned between the compression and tension steel reinforcements within the slab soffit. There are vairy shapes for voids like (Cylinder, Sphere, Hexahedron, Donut, Cuboid, and others). Recently, sustainability and solid waste treatment and environmental preservation have emerged through the use of plastic waste as voided slab to reduce the self-weight of slabs and reduce environmental pollution in the same time figure (1) (Azizian et al., 2021; Dadzie & Kaliluthin, 2022; Fazaa Rajab et al., 2022).

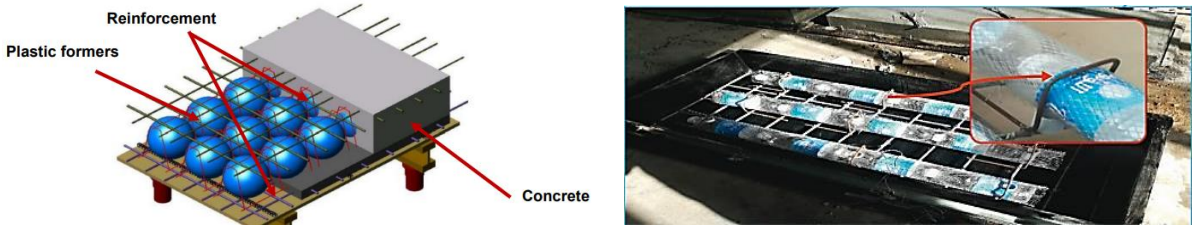


Fig. 1 Types of voided slab (Fazaa Rajab et al., 2022)

The idea behind voided slabs is to remove the inefficient concrete from the core of a flexural slab and replace it, as seen in figure (2), with hollow plastic formers (Gamal et al., 2023).

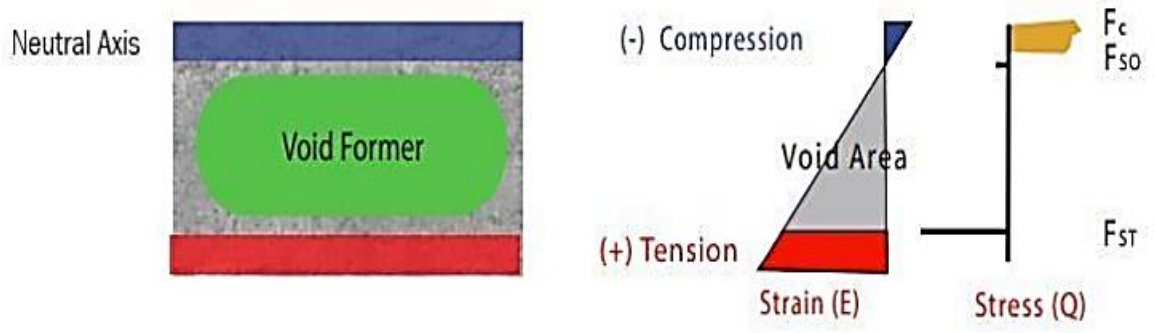


Fig. 2 Stress-strain diagram for voided slab(Gamal et al., 2023)

The methodology of this survey may be summarized in figure (3). This work, however, reviews the key factors that influence the selection of appropriate shear connecters for one- and two-way voided slabs.

Fig. 3 State of systematic literature review

2. Literature review

The building of the coffered ceiling dome of the Pantheon in Rome, which was finished in 125 A.D., is the first known example of a voided slab system figure (4). Before the completion of the Florence Cathedral in 1436, the dome, which has a circumference of 42.67 m, was the largest unreinforced concrete dome in the world (Gamal et al., 2023).

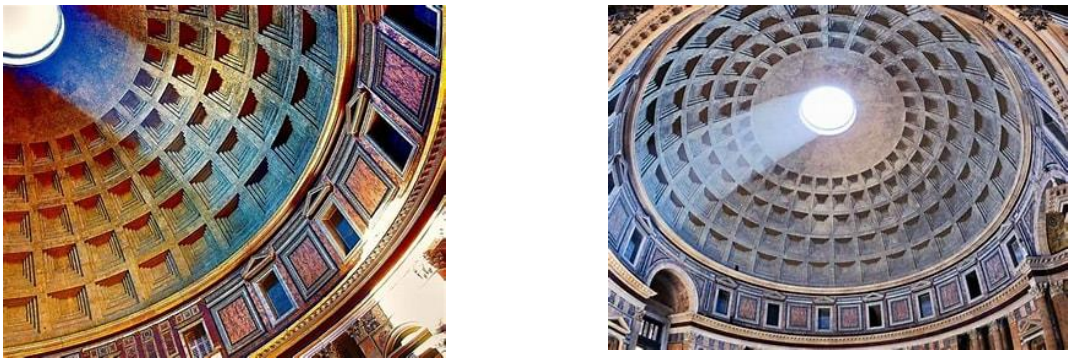


Fig. 4 Overhead view for the pantheon dome, Rome(Gamal et al., 2023)

Sagadevan and Rao (2019b) studied the effect of investigated the effect of punching shear on biaxial voided slabs, he used sphere and cubic shape for voids, figure (5). He found that depending on where the voids are located, the crucial section is modified to account for their presence. Furthermore, the punching shear capacity is only predicted by taking into account the effective concrete area. Following the adjustments, the forecasts made by the three construction standards produce outcomes that are satisfactory.

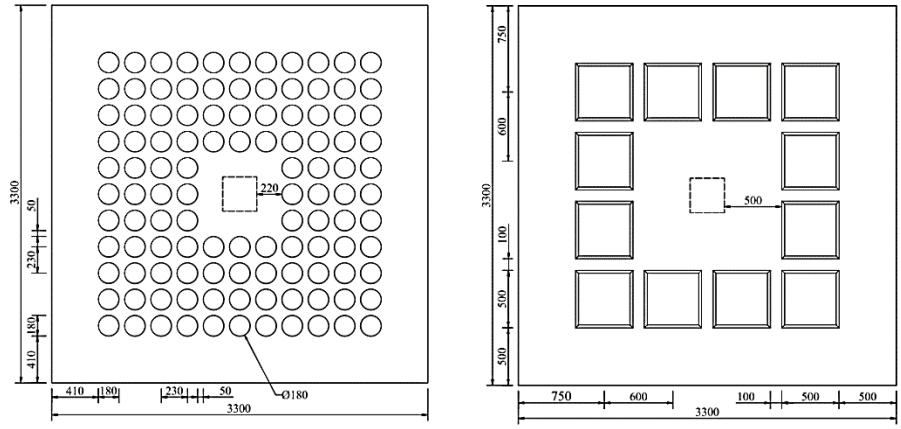


Fig. 5 Type of voids in slabs(Gamal et al., 2023)

Paik & Na (2019) investigate the comparison of the voided slab system's and the regular reinforced concrete slab's carbon dioxide emissions during construction. In comparison to the solid reference slab, there was a 38% reduction in deflection at ultimate load and a 6.7% reduction in ultimate strength, figure (6). He found that the total emissions of CO_2 for the ordinary reinforced concrete slab are 257,230 kg CO_2 and for voided slab system are 218,800 kg CO_2. Building material transportation ranks second in terms of CO_2 emissions, contributing 3417 kg.

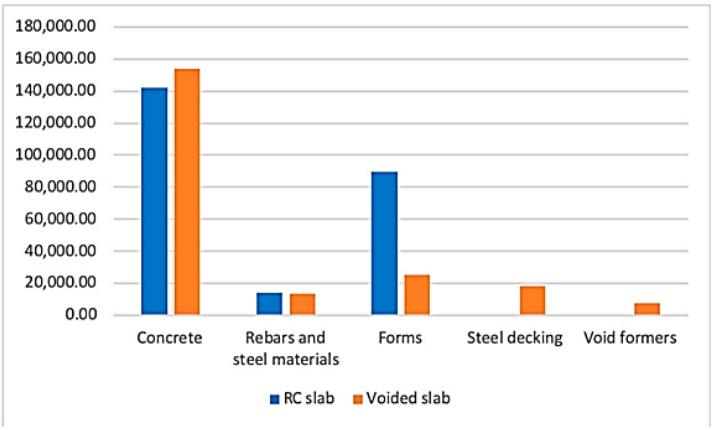


Fig. 6 The CO_2 emissions of the building materials(Paik & Na, 2019)

Al-Shaarbaf et al. (2020) studied the experimental behavior of normal and high-strength void one-way slab strips made of self-compacted concrete (SCC) under monotonous loading conditions. In comparison to the reference solid slab, the ultimate load was reduced by almost 20%, at ultimate load the deflection was decreased by up to 11%. As opposed to standard strength SCC slabs, equivalent voided slabs of intermediate high strength SCC (void's dia. 75 mm) had an increase in ultimate load of around 48.3% and an increase in deflection at ultimate load of about 27%. But for equivalent voided slabs of intermediate high strength SCC (void's dia. 50 mm) in comparison to the solid reference slab, there was a 38% reduction in deflection at ultimate load and a 6.7% reduction in ultimate strength.

3. Results and discussion:

The survey used in this study was taken from thirty published studies. These gathered documents are grouped in accordance with the voided slab's types (one-way or two-way), concrete type, ratio of voids in slab and voided size and shape. The first item provided is a synopsis of the salient features of the articles that were identified during the literature review. The foundation for the development of numerous experimental program variables was laid by this study, which also helped identify the major figures in the field.

3.1. Type of researches

Table (1) showed that 73% of researches are practical research and theoretical researches are 16.6% (Nareshnayak & Rao, 2022; Gohel & Patel, 2023). Some articles 10%, are investigating the topic practically and theoretically.

Table 1 – Type of researches for voided slabs

Type of articles	No. of articles
Practical research	22
Theoretical research	5
Both	3
Sum	30

Pandharipande & Pathak (2019) examined the suitability of using hollow plastic balls (bubble duck) in light-weight reinforced concrete slabs, by using different size of voids Bubble Deck Slab (B.D.S) (B.D.S of 50 mm dia. and B.D.S of 100 mm dia.). The ultimate load carrying capability of B.D.S 50 mm is 8.5% greater than that of (B.D.S 100 mm) and 22.58% less than that of a normal slab. The self-weight of (B.D.S 50 mm) is smaller than a

typical slab by 2.85% and higher than (B.D.S 100 mm) by 23.52%. Theoretically the author used for finite element analysis on slab specimens is ANSYS WORKBENCH 16.0. Using B.D.S of 100 mm is advised in practice since it is more advantageous in preserving the concrete because: It reduces weight by 23.52% more than B.D.S of 50 mm.

Lakshmi Kanth and Poluraju (2023) studied the effect of the position of voids (recycled hollow spheres) in the voided flat slabs. He found that the High-density polyethylene (HDPE) voids that replaced the non-functioning concrete had no effect on the voided slab's load-carrying capacity, regardless of the percentage of voids, however, the placement of the voids is very important for punching shear of the slab. Theoretically the author used for finite element analysis ABAQUS program on voided slabs, figure (7).

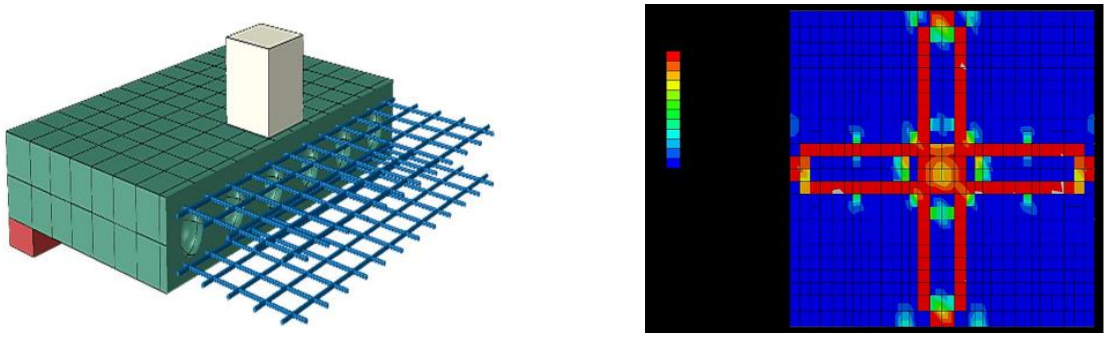


Fig. 7 Finite Element Results(Lakshmi Kanth & Poluraju, 2023)

3.2. Type of slabs

The main characteristics of voided slabs that shown in table (2) used in this article for one-way or two-way slabs. Regarding the total research number, 33% was for one-way slabs compared for two-way slabs 67%.

Table 2 – Characteristics of slab's type.

Type of slabs	No. of articles
One-way	10
Two-way	20
Sum	30

Hussein et al. (2020) investigated by using 24 slab specimens with various size and characteristics. In addition to using different sizes of voids (64,80,100) mm. The researcher found that the bubble deck slab uses less concrete than other options. This implies that a sizable quantity of raw materials (gravel, sand, and cement) can be spared. The percentage of embodied energy and CO_2 emission savings grew with the bubble's diameter. The range of this increase is 0.73–4.17%.

Sagadevan and Rao (2022) investigated the effect of critical shear crack theory (CSCT) to biaxial voided slab. The load-rotation behavior of a biaxially voided slab was found to be identical to that of a solid slab, with the exception of instances where the void was positioned within 0.5d from the column's face. The improved critical shear crack theory (CSCT) predictions showed a high degree of scatter, with a mean and standard deviation of 0.412 and 0.752, respectively.

Al-Gasham et al. (2019) examined how the size of voids affected the way one-way slabs behaved structurally, by using different sizes of voids (60 mm, 70 mm, and 90 mm) and the concrete that he used is self-compacting concrete (SCC), figure (8). In comparison to a solid slab, the self-weight of the slabs was reduced by around 6.4% to 21.6% when balls were present. The ideal situation where the strength was reduced relative to the control slab was when 60 mm balls were used, which is equivalent to half the thickness of the slab. When compared to the

control slab, the impact of balls increased significantly for various sizes, particularly for balls with a 90 mm diameter, where the declines were recorded as follows: 21.3%, 23.7%, 67.0%, and 79% for strength, stiffness, ductility, and toughness, respectively. Furthermore, utilizing balls with a 90 mm diameter altered the failure mechanism from flexural to shear.

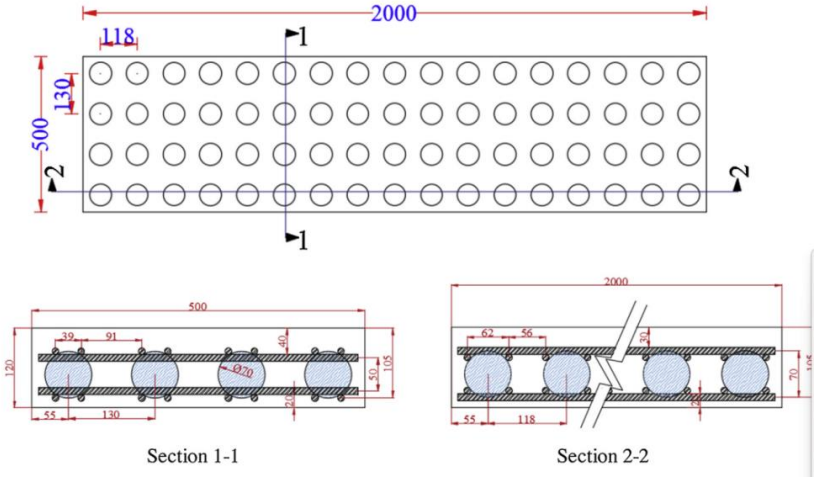


Fig. 8 Details of One-Way slab Specimen(Al-Gasham et al., 2019)

3.3. Type of concrete

The most widely used type is ordinary concrete 70% of the articles, while 10% used self-compacting concrete. High strength and GFRP just 6%. Finally light weight and steel sheet are 3% (Ayyad et al., 2021; Mahdi & Ismael, 2020).

Table 3 – Characteristics of concrete

Type of concrete	No. of articles
Ordinary concrete	21
Self-compacting concrete	3
High-strength concrete	2
Light-weight concrete	1
Concrete with GFRP fibers	2
Concrete with steel sheets	1
Sum	30

Al-Azzawi and Mtashar (2023) studied the effect of voids into two-way slabs with various thickness (100 and 125 mm). Steel fibres has been added (1%) with layers of GFRP into the concrete. High-density polystyrene measuring (200 x 200 x 50) mm was used to create the voids in the slabs, and a center hole measuring (50 x 50 x 50) mm was added to give the voids a donat-like shape. These voids are created in the inefficient concrete areas to result in a 34%–38% decrease in weight. The results showed larger stiffness at cracking (52.5 kN/mm), and at ultimate load (35.7 kN/mm), larger energy absorption (1098.7 kN mm), and more ductility index (1.35). For a voided slab, the addition of 1% steel fibers results in a 30% reduction in deflection and a 31% rise in ultimate loads.

Al-Shaarbaf et al. (2020) used high strength self-compacted concrete (SCC) voided slab, by using three ratio of voids and two sizes of voids (50,75) mm. In specimens (3V50NM and 6V50NM), it has been shown that a decrease in ultimate deflection of roughly (38% and 42%) is connected to an increase in the void ratio of roughly

(6.54% and 13.1%). In specimen 3V75NM, the percentage drop is decreased to 11%, and the void ratio is equivalent to 14.7%. For the identical control specimen, it was discovered that there is an increase in deflection of approximately 48.5% at failure load. The ultimate strength for the SCC voided slab (50mm) was, in comparison to the solid reference slab, reduced by roughly 6.7% and the deflection at ultimate load was reduced by 38%. whereas the vacant slab had (75mm), compared to the reference solid slab, there was an approximate 20% reduction in the ultimate load and an approximate 11% drop in the deflection at the ultimate load, figure (9).

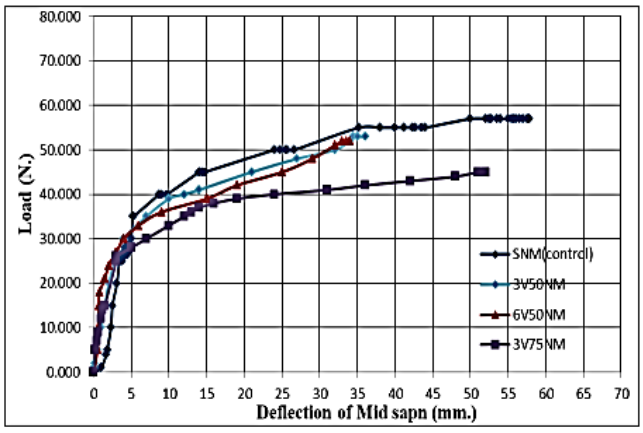
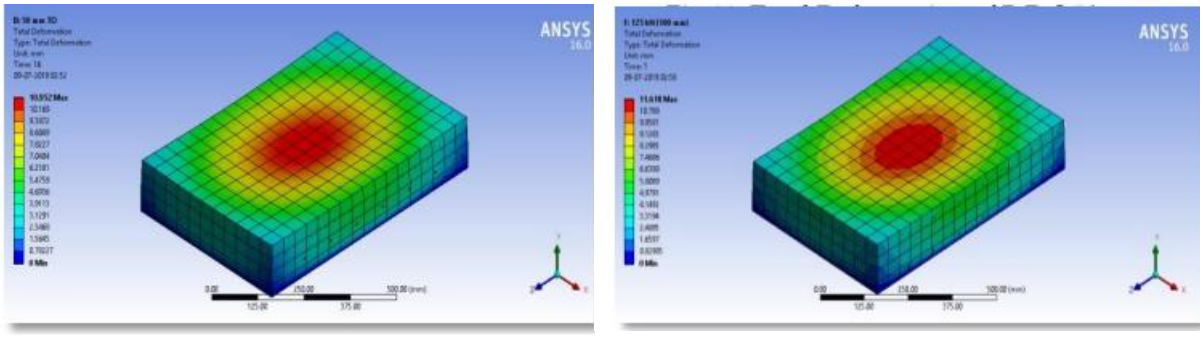


Fig. 9 Effect of void ratio on load-central deflection behavior of tested specimens(Al-Shaarbaf et al., 2020)

Pandharipande & Pathak (2019) investigated the behavior of light weight voided slab and conventional slabs with various void's size Bubble Deck Slab (B.D.S) (B.D.S of 50 mm dia. and B.D.S of 100 mm dia.). He found that the ultimate load carrying capability of B.D.S 50 mm is 8.5% greater than that of B.D.S 100 mm and 22.58% less than that of a normal slab, figure (10). The B.D.S 50 mm has a dead weight that is 2.85% less than a normal slab and 23.52% more than a B.D.S 100 mm. It is recommended to use B.D.S of 100 mm in practice as it is more beneficial in saving the concrete.



(a) Total Deformation of B.D.S 50 mm (b) Total Deformation of B.D.S 100 mm

Fig. 10 Total Deformation of B.D.S (Pandharipande & Pathak, 2019)

3.4. Shape of voids

There are several types of voids, bubble voids, cube voids, U-Boot voids, and donut voids as shown in figure (11). Table (4) show that bubble voids is 50% of the total published research (Urgessa & Haghighi, 2023; Lee et al., 2019), so it is more common and used in scientific research for the abundance of this material in the markets and the availability of its raw material. The term environmental protection and mitigation of plastic waste damage

has increased in the last decade, and attempts to dispose of these wastes have entered the building industry (Orientilize et al., 2021). Thus, a good number of research (16%) has investigated the possibility of using plastic bottles as voids in slabs. Square voids also have a share of research, 10% of researches on cubic voids and 13% of researches on U-Boot voids (Sagadevan & Rao, 2019a; Sagadevan & Rao, 2020). Some of researches use plastic tubes as voids (6%). And last one is plastic voids in shape of donut (3%)(Chung et al., 2018).

(a) Bubble voids (b) Cube voids (c) U-Boot voids

Fig. 11 Types of voids (Chung et al., 2018)

Table 4 – Shape of voids

Shape of Voids	No. of articles
Bubble or Sphere	15
bottle	5
U-Boot	4
cube	3
Plastic Tube	2
Donut Shape	1
Sum	30

Nimnim and Alabdeen (2019) used sphere and cubic voids with high strength concrete flat slab, with various thickness (0.5, 0.6, 0,65) D/H. He found that using voids can reduce self-weight by up to 21.6%. Because of the ultimate loading capacity, structural behavior, and cracking, spherical voids are more useful in voided slabs than cubic voids. The crack width decreased by 18.2% to 27.8% after using voids with high strength concrete slabs. Elevating the reinforcement ratio from 0.26 percent to 0.26 percent results in a reduction in deflection within the 11.6%–35.9% range for high strength voided slab specimens (ball shapes D=60 mm).

Mohammed et al. (2020) Utilize the idea of producing sustainable environmentally concrete by employing voided one-way slab by using empty plastic bottles as voids, figure (12). They found that its very useful to reduce slab-weight and reduced the wastes in same time.

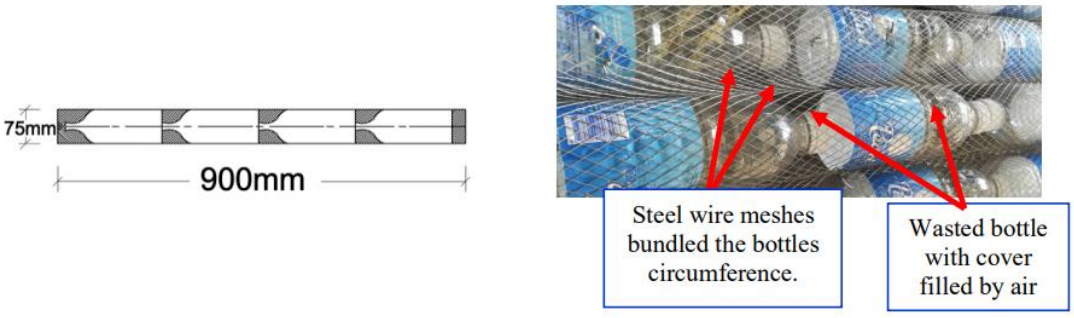


Fig. 12 Plastic bottle voids(Mohammed et al., 2020)

The load-displacement curves for the solid and voided ones were nearly the same from the start until the load reached the last stages, at which point the deeper the voided slab, the greater the strengths and the smaller the displacement at the same load level. The decreasing of void ratio leads to decreasing in toughness of voided one-way slabs (Mohammed et al., 2020).

3.5. Raw Material of voids

The raw material of the voids is the same importance that the shape such as (plastic material, and polyethylene material, polystyrene material, and bottles). Table 5 show that Plastic is the most used raw material in researches 43%, due to the availability of the raw material in abundance. Polyethylene and polypropylene used in 16% of researches, it is often used for the square shape because of the presence of these shapes in the market as U-Boot shape. While polystyrene material used in only 10% of researches. Recently it also entered within the sustainable and the environment protection from plastic waste by using plastic waste bottles as voids in slabs, 13% of the research used in this article talked about this topic.

Table 5 – Raw materials of voids

Type of concrete	No. of articles
Plastic	13
polyethylene	5
polystyrene	3
polypropylene	5
bottles	4
Sum	30

Rampariya and Choudhary (2020) and Chung et al. (2022) investigated the use of the voided slab for a bridge deck with various span length (15,20 & 25) m. At these long spans, the weight will be heavy, and in order to reduce self-weight with the same efficiency, plastic voids were used. The findings indicate that the volume of concrete can be decreased by 19.2%, 36.7%, and 38.3% for 15 m, 20 m, and 25 m, respectively. In addition to using the staad-pro program to analyze the results of the same type above.

Lakshmi Kanth and Poluraju (2023) used high-density polyethylene (HDPE) recycled hollow spheres the flat slab to find the bunching shear. Two groups were used for this article, rebars with an 8 mm diameter was used to reinforce Group-A, and rebars with a 6 mm diameter was used to reinforce Group-B. then finite element program ABQUS were used to illustrating the experimental results and performing a parametric study. It was observed that the results of the finite element analysis were essentially consistent with the findings of the experiments.

Hammood et al. (2023) used polystyrene sphere voids with two-way slabs with various opening. According to the test results, punching modes caused all of the connections to fail, and the strength reductions grew as the

opening size decreased, reaching a critical limit of 35%. Placing the two apertures next to the column corners on the diagonal of the slab is the ideal configuration for the openings. When compared to a connection without apertures, this configuration decreased strength deterioration to 4.7%; this ratio was also lower than when one opening was added next to the column face by roughly 45%. The two apertures closest to the column faces, however, caused the greatest strength drop—13.8%. Occlusions also reduced the toughness and ductility of connections. In comparison to the NO connection, there were reductions in ductility of 34.4%−51.4% and toughness of 48.1–74%.

Fazaa Rajab et al. (2022) studied the ductility, toughness, flexural strength, and stiffness of reinforced concrete hollow one-way voided slabs using plastic bottle. It improves the flexural behavior while using less self-weight and concrete. For the same thickness section, the ductility of the voided specimens is improved by approximately 100%. The decreased ultimate deflection resulted in a decrease in the toughness of the voided testing specimen.

4. Conclusions:

From the review of selected papers chosen for studying the behavior of voided slabs having various types and shapes of voids, the following conclusions may be presented:

1. All researches confirm the same information that the voids reduced self-weight for the slabs by up to 40%.
2. Very little articles deal with theoretical finite element methods almost 17%. Most of it is laboratory practical researches.
3. The researches have deals with two-way slabs (67%) are more than researches with one-way slabs (33%).
4. Ordinary concrete was the most useful in researches.
5. Very few studies used other types of concrete like self-compacting, light weight, and high strength concrete, they are less than 6%.
6. The sphere or bubble voids were the most useful in researches by up to 50%.
7. The term environmental protection, sustainable and plastic waste reduction had a role not a little in this research, as 16% of the research on this topic were studied.
8. The plastic material governs the subject of the raw materials used to make the voids;43% of researches used this material.
9. No study focuses on the use of voids with high temperature.
10. Many researches study the effect of voided with self-compacting concrete. It found that the ultimate strength for the SCC voided slab in comparison to the solid reference slab, reduced by roughly 6.7% and the deflection at ultimate load was reduced by 38%.

Notations

Bubble Deck Slab	B.D.S
Self-Compacting Concrete	SCC
critical shear crack theory	CSCT
High density polyethylene	HDPE
polyethylene terephthalate	PET

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