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THE FLEXURAL BEHAVIOR OF HOLLOW CORE CONCRETE SLABS WITH DIFFERENT SHAPE

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Hollow slabs are slabs of reinforced concrete in which voids allow the concrete to be reduced in size. This type of slab results in reduced raw materials Consumption and increased insulating properties to achieve sustainability goals. This paper reported an experimental research program focused on the study of the bending behaviour of the elements of hollow slabs of normal-strength concrete. Three models of the one-way concrete slab were cast, It had dimensions of 1020 mm length, 420 mm width, and 100 mm thickness. The first model did not contain holes (solid) and the second model contained five circler opening holes with a 50 mm diameter, while the third model contained five square opening holes with 44 mm dimension, where the area of the second and third model were the same despite the difference in the shape of the opening. The results showed that the bearing capacity of the circular hollow core slab is higher by 12% compared to the square hollow core slab according to the type of voids and both of holes made the hollow core slab with a decrease in load capacity of 11% to 25% when compared to the solid slab. The solid slab has lower deflection value compared to the two hollow slabs whose weight is reduced by 23% compared to the solid slab.

Keywords: Hollow core slab, opening holes, normal strength concrete

1 INTRODUCTION

The slab is a significant part of the structural building. It consumes a large amount of material. As the load demand increases, the slab thickness increases, leading to additional construction expenditure [1]. To make affordable slabs with long spans without median support and small depths in, leading single and multi-story buildings, Hollow Core Slabs (HCS) were introduced [2,3]. A HCS is a precast concrete slab usually used as flooring construction in multi-story buildings. The popularity of pre-cast concrete is associated with low earthquake areas and economical buildings due to the rapid assembly of buildings, low self-weight (less materials), etc. [4]. HCS not only reduces the structure dead load and makes it lightweight, but also offers thermal comfort that provides significant cooling and heating power and it's also a way to isolate the sound [5]. Fig.1. showed the pre-cast hollow core slabs [4].

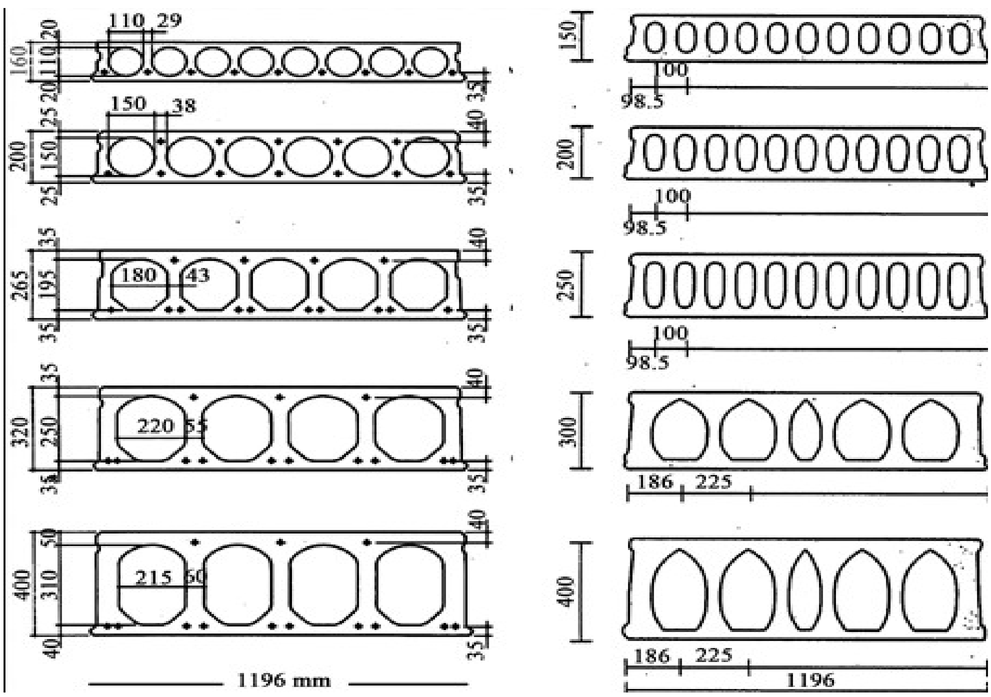


Fig. 1. Hollow core pre-cast concrete slabs

A hollow precast reinforced concrete slab has voids that extend the entire slab length making the slab much lighter than a substantial solid reinforced concrete slab of equivalent strength and thickness. These hollow core slab voids can be used for mechanical or electrical operations. Weight reduction of concrete leads to reduces the costs of transportation and the costs of materials [4].

The hollow concrete slab offered an efficient prestressed member for deflection control, load capacity, and span range. The outstanding fire resistance was one more characteristic of the hollow core concrete slab [5]. Due to the lower dead load of HCS compared to that of solid slab units, longer-span slabs can be designed and built [2]. Some researchers studied the concrete slabs that cast-in-place and its effects on the flexural behavior of pre-cast hollow core concrete slabs, and other researchers focused on design and numerical modeling for shear strength parameters of hollow core slabs [6].

Chung et al. (2011) [7], presented the flexural capabilities of the biaxial hollow concrete slab using donut type void. The donuts are arranged in two dimensions within the slabs to decrease the dead weight, two-dimensional flexural tests were done by using a special loading frame to verify the behavior of the flexural capacity of this biaxial hollow slab. Salman (2012) [8], studied the flexural capacities of two-way hollow core slabs of reinforced concrete with plastic sphere-shaped voids. Fifteen RC square slabs of 1000 mm x1000 mm have been tested to find the ultimate load capacity in flexural and deflection, the bubble slabs result in an improvement in the ultimate load capacity by about 30% and a decrease in the deflection at 0.7. Mutashar, (2017) [9] presented a study on the flexural behavior of sustainable ten one-way reactive powder concrete (RPC) samples of voided slabs of 416 mm width, 1700 mm length, and 125 mm or 100 mm thick). In this study two types of voided slabs were considered: the first one (hollow core slab) was made of plastic pipes of 75 mm diameter arranged at a clear spacing of 25 mm between pipes and a length of 1500 mm in a longitudinal direction and the other voided slab (bubble deck) made by using plastic balls of the same diameter and same spacing in both directions, the results showed that the presence of voids in a hollow core and bubble slabs reduced the weight by 43% and 18% compared to the solid slab and that reflected on the sustainability objectives. The main objective of this research is to examine the flexural behavior of one-way voided slab of hollow type compared with the solid slab.

2 SCOPE OF THE STUDY

The study plans an empirical discovery to compare the traditional concrete solid slabs and the concrete hollow core slabs with different shapes of voids in terms of serviceability and load-deflection performance. Where circular and square voids were used in the same number with a constant concrete area in both cases to clarify the effect of the type of hole on the slab and what is the best way to provide it with good bearing capacity and at the same time take into account the economic aspect because this type of slabs reduces the volume of concrete in the buildings.

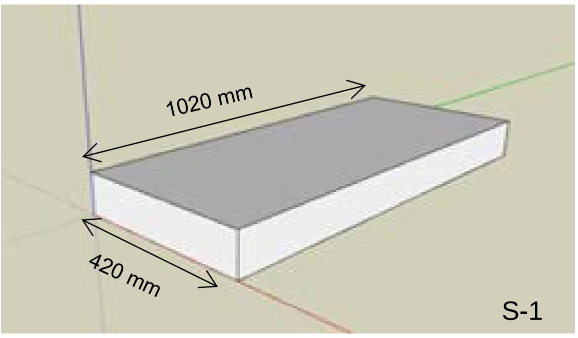
3 EXPERIMENTAL WORK

The experimental study consists of the cast and tested three models of one-way concrete slab with a rectangular cross-sectional area of 420 mm width, 100 mm depth, and 1020 mm length which were cast and tested. One of these models is a solid slab and the second is a hollow core slab with five circular opening holes with a 50 mm diameter and 1020 mm length and a distance between one and another 30 mm while the third model is a hollow core slab containing five square opening holes with a dimension of 44 mm and a length of 1020 mm, where the area of the second and third model are the same despite the difference in the shape of the opening holes. The specimens were designed according to American Concrete Institute ACI 318-19 [10]. The dimensions and voids of the slab have been existing in Table 1. Fig. 2(a-b) presented the geometry section of these slabs.

Table 1. Details and labels of the tested slabs

Slab coding	Length(mm)	Width (mm)	Depth (mm)	Type of void	Vol. of voids to total vol%
S-1	1020	420	60	-	-
S-2	1020	420	117	Pipe	23
S-3	1020	420	345	cork	23

*(S) is the symbol of Slab, (1, 2 and 3) are the number of the slabs



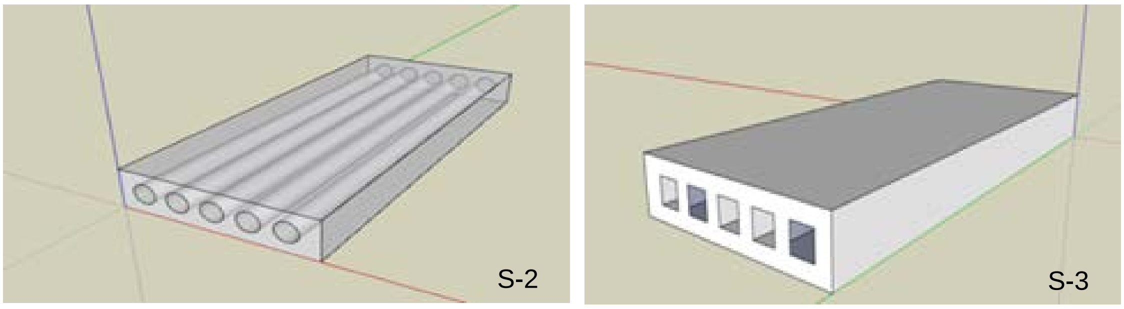


Fig. 2a. Three-dimensional view of reinforced concrete slabs

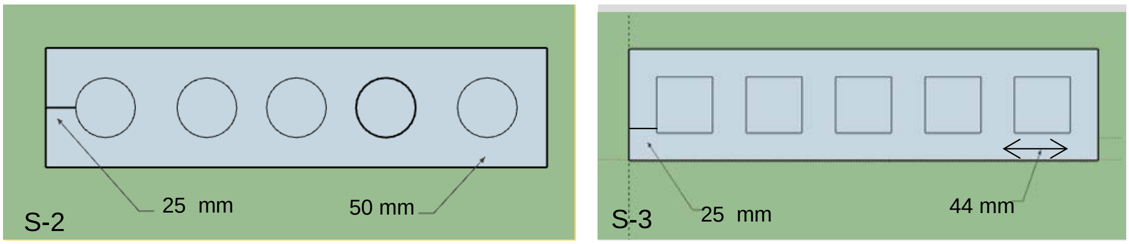


Fig. 2b. Details section of reinforced concrete slabs (S-2) and (S-3)

3.1 Materials

The materials used in this mixture and the proportions of the concrete mixture required to reach a compressive strength that is equal to 47 MPa are shown in Table 2. Under the applied loads, the slab was designed to fail by tension mode. Mesh steel reinforcement with a diameter of Ø5 mm at a spacing of 50 mm c/c was used in the slab in both directions as a top and bottom layer. Fig. 3 present the reinforcing steel mesh that used in this study.

Table 2. Normal strength concrete mix

Material	Quantity kg/m^3
Cement	400
Sand	800
coarse aggregate (max. size 12.5mm)	1200
Water/cement (33%)	132
Super plasticizer liter/m^3 (3 % of the cement)	12

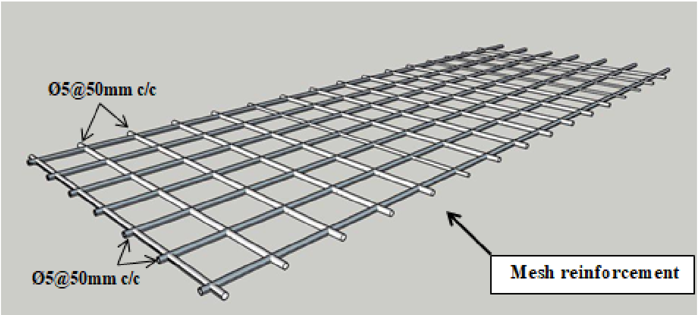


Fig. 3. Steel bars reinforcement details

For the experimental study, three molds with a rectangular cross-sectional area of 420 mm width, 100 mm depth, and 1020 mm length used for specimens casting were made of plywood shown in Fig. 4. One of these molds was solid with no holes and the second was made with five circular opening holes using plastic circular pipes to go throw in it with a 50 mm diameter and 1020 mm length while the third mold was containing five square opening holes using square cork with a dimension of 44 mm and a length of 1020 mm as shown in Fig.5. Table 3 summarizes the properties of the reinforcing bars. Fig.6 shows the testing of the steel bar section of the reinforcing steel mesh which displayed the point of failure that occurred in the middle section of the longitudinal steel and not in the contact point with the transverse steel, which could be a weak point in the reinforcing steel mesh.

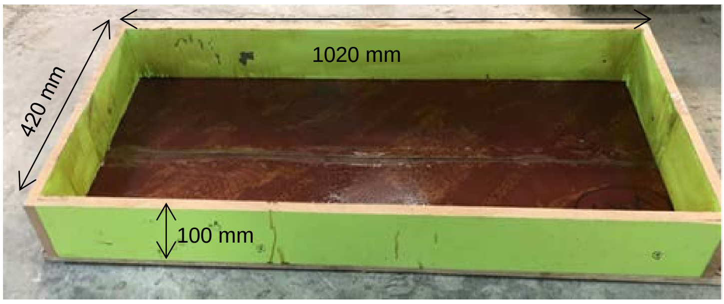


Fig. 4. Plywood molds of slabs

Fig. 5. Slab preparation before casting

Table 3. Steel reinforcing properties

Diameter (mm)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation ΔL %
5	1720	1930	11.9

Fig. 6. Tested steel bars

3.2 Test set-up

A hydraulic testing machine was used for testing all slabs up to failure. The specimen's test is a test that is simply supported by using a two-point load. The slab clear span was 900 mm and 300 mm was the clear distance between point loads which were the same condition for all slabs, as can be seen in Fig. 7. Figures 8 and 9 show the specimen of slab being tested and the location of the dial gauge at the midpoint. The test was conducted at the building construction material laboratory in Civil Engineering Department.

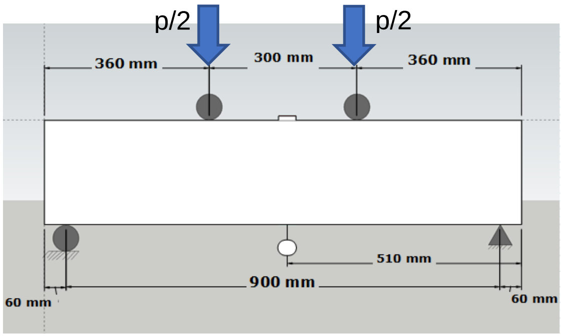


Fig. 7. Details of the tested slab

Fig. 8. Slab specimen testing

Fig. 9. Dial gauge location

4 RESULTS AND DISCUSSIONS

All necessary notices and measurements were observed for each slab specimen. The first crack and final load (ultimate load) are recorded. The results of the tests were logged, summarized, and made available in Table 4. Fig. 10 demonstrates the failure modes of the tested slabs in the present work.

Fig. 10. Failure modes of the tested slabs

The tests of NSC slabs have shown that the general effects of flexural loading in all slabs can be described as follows: In the early stage of the loading at the tension zone in the lowest of the mid-span, the first cracks appeared, at this point the load is known as the first crack load. These cracks widened and escalated with an increase in loads, and other cracks appeared and developed in the same area. Additional loading caused cracks to propagate and expand faster; Some of these cracks extended to the compression zone till failure occurred at the capacity of maximum load.

In general, with the gradual increase in the load exposed to the concrete slab, the deflection rises with the load linearly in an elastic stage. When the cracks begin to develop, the slab deflection increases at a faster rate and the curve of load deflection is almost linear until the flexural reinforcement yielding. After that, the deflection increases continuously without a noticeable increase in the load. wherever there are voids, the deflection increases, due to the transition between the uncracked and cracked sectional moment of inertia and load transfer from concrete to the holes. It should be noted that the presence of voids in the slabs reduces the amount of concrete and thus reduces the dead load.

The results of the tested slabs display that the ultimate load for slabs (S-2) and (S-3) decreased by 11% and 25% respectively when compared to slab (S-1), while the deflection increased by 10.5% and 31.5% for slabs (S-2) and (S-3) respectively as shown in Fig. 11 and Fig. 12, The solid slab (S-1) has the less deflection value in comparison with the two hollow slabs which are reduced in weight by 23% compared to solid slab, that because the absence of the voids in the solid slab will increase the stiffness and effect of the cracks of first and ultimate loading with increasing loading stages. The effect of the type of void (circular or square) for slabs (S-2 and S-3) lead to an increase in the ultimate load capacity of slab (S-2) by 12% and a decrease in deflection 19% compared to slab (S-3) in the same loading stage. The hollow core slab with square holes (S-3) has the lowest value of ultimate load 48.1 kN as presented in Table 4, this is because the circler hole can transmit stress across a crack and counteract crack growth. Fig. 13. shows the behavior of the Load-deflection relationship for (S-1, S-2, and S-3) slabs.

Table 4. Loads and deflections results for first and final stages of loading.

Slab coding	First cracking load (Pcr) kN	Deflection at cracking load (Δcr) mm	Ultimate load (Pu) kN	% of difference in ultimate load	Ultimate deflection (Δu) mm	% of difference in ultimate deflection
S-1	18	8	60	0	19	0
S-2	13.4	6	54.1	11-	21	-10.2
S-3	12.5	9	48.1	25-	25	-31.5

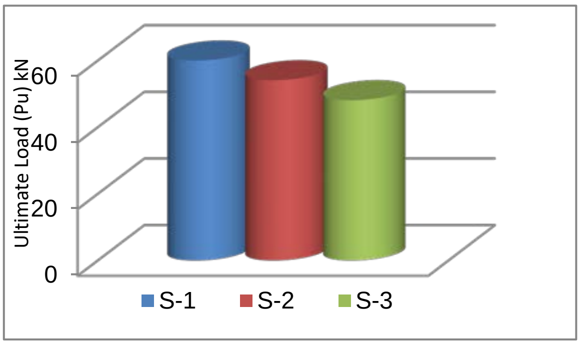


Fig. 11. Ultimate load for the three slabs

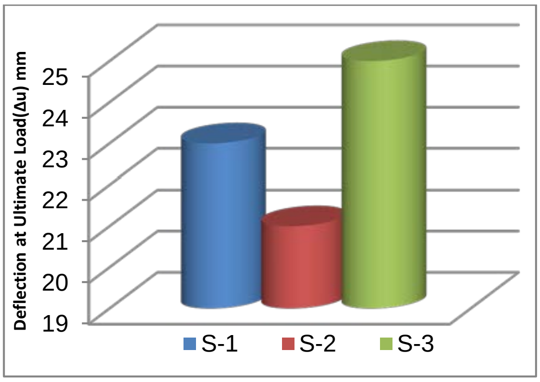


Fig. 12. Deflection at ultimate load for the three slabs

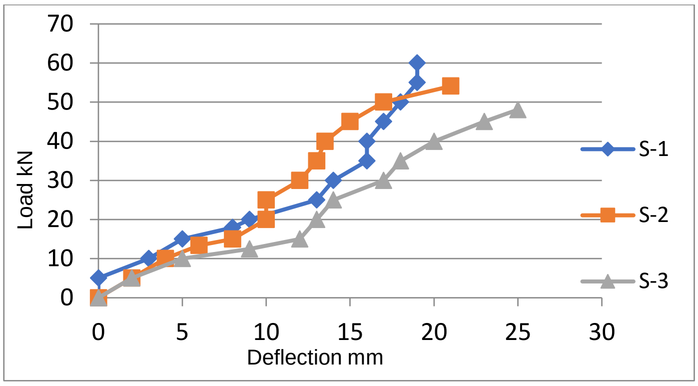


Fig. 13. Load-deflection relationship for the three slabs

From the previous study by Mutashar, (2017) [9] of hollow core slab with circular voids using reactive power concrete with 1% steel fiber, the decrease in ultimate load was 16% and the deflection was decreased also by 40% compared to solid slab. The type of concrete and the presence of steel fiber led to this improvement when compared to the results of this study in spite of the difference in the number and size of the circular voids based on the dimensions of the slab. Therefore, the obtained results are considered good compared to the previous study.

5 CONCLUSION

Based on the results obtained through the experimental tests conducted in this research, the following conclusions can be listed as follows:

- The experimental study proved that the addition of holes in the one-way concrete slabs leads to a reduction in the concrete flexural bearing in addition to a decrease in the volume of the concrete used in the same section (decrees dead load).
- The flexural bearing of the circular hole model was higher than that of the square hole model, and the circular holes are more efficient in terms of restricting the spread of cracks, because the stresses in the circular model are distributed over the circumference of the specimen, which gives a higher bearing unlike the model that contains sharp corners, where there will be weak areas in this section and the starting point of failure, and this leads to the occurrence of a deep crack that is concentrated in certain points.
- The deflection of the concrete models was greater in the model with square holes than in the solid model and model with circular holes, the model with the circular holes was the least among them and by a very small percentage than the solid model.
- This investigation showed that the hollow core slab with circular holes meets the requirements of sustainability and is appropriate for the building designed with live loads of more than 10 kN/m2.

6 ACKNOWLEDGMENTS

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