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Effect of Longitudinal Hollows on Behavior and Capacity of High Strength Reinforced Concrete One Way Slabs

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Abstract

This work involves experimental study for the effect of longitudinal hollows on behavior of HSC one way slabs. Six slabs of 1000×450×70 mm were tested. The parameters of the study are number, diameter and volume of the hollows and flexural reinforcement ratio (ρ). The hollows were made by embedding PVC pipes. Presence of hollows reduces cracking and ultimate capacities of the slab. The reductions are larger with increasing number, diameter and volume of hollows. Maximum reduction in cracking capacity is 26.9 % when 32 % hollows are used with ρ = 0.45 %. Using 32 % hollows reduces the ultimate capacity by 12.9 % when ρ = 0.45 % and by 20.3 for ρ = 1.2 %. Using 32 % hollows with ρ = 1.2 % prevents the flexural failure to finally take place due to the bearing failure at supporting region. Increasing (ρ) has significant effect on ultimate capacity and this effect is smaller in hollowed slab than in solid slab. Presence of hollows increases deflection values and makes load – deflection response softer especially in advanced loading stages. Also, crack width values at service stage increases with increasing volume of the hollows. Longitudinal hollows have convergent effects in reduction of the ultimate capacity and ultimate loads that result to very small effect on slab adequacy for carrying the applied loads. This makes it is useful using the hollows in construction of one way slabs especially when HSC is used.

Keywords: one way slab, hollow, high strength, cracking, ultimate capacity

1. Introduction

Hollows or openings are used in concrete members especially in R.C. slabs for construction and services purposes. Different types of hollows can be used such as longitudinal, transversal and vertical. In such floors, hollows are running in the longitudinal direction of the R.C slabs that are called as hollow core slabs [Khalil et al. 2012]. Many benefits can be obtained when technique of longitudinal hollows is used. The important benefit is reducing slab own weight [Al-Azzawi & Abed 2016]. Since a large portion of building's weights is caused by the dead loads, and self-weight of the slab forms the large portion of the dead loads, then using hollowed slab results to significant reduction in total weight of building [Wariyanto et al. 2017]. This reflects on economic design for

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[illegible] ctions [Stanton 1992]. The other benefit of using the longitudinal hollows is using it as a ducts for passing the mechanical or electrical requirements [Khalil et al 2012, Al-Azzawi & Abed 2016, Buettner & Becker 1998]. Also, the hollows make the slabs more adequate for isolation and fire resistance [Al-Azzawi & Abed 2016].

The hollow core slabs technique is often used in preparation precast units (reinforced or prestressed) that used for roofing the buildings as shown in Figure 1. Precast hollow core slabs are popular in the construction industry due to their wide benefits such as: saving materials, saving energy, reducing construction cost and time and giving lightweight roofing [Wariyanto et al. 2017, Ibrahim et al. 2016, Wijesundara et al. 2012]. Using hollows in construction of the slabs is adequate alternative for using lightweight materials to produce lightweight concrete slabs because of the significant effects for these materials on slab behavior and the large reductions in slab capacity due to using these materials in addition to the practical difficulties accompanied to production of lightweight concrete [Al-Azzawi & Abed 2016].

Figure 1. Hollow core slab precast units

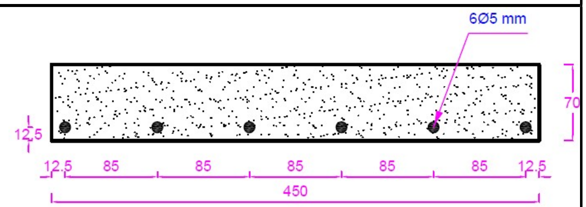
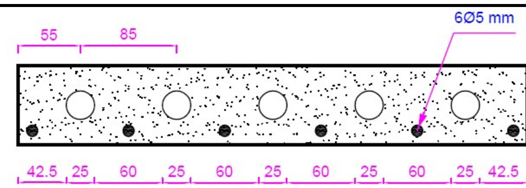
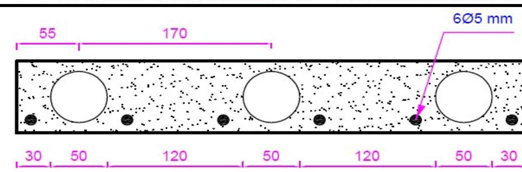
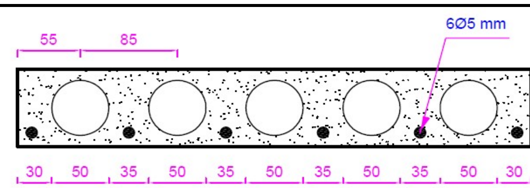
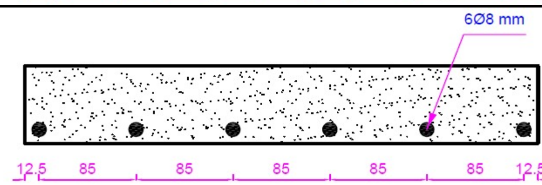
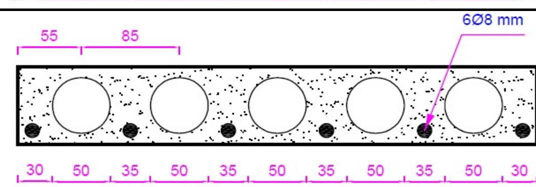
2. Research Significant

The structural principle for using the longitudinal hollows in the slabs is removing the ineffective concrete in tension zone of slab section [Al-Azzawi & Abed 2016]. Using of high strength concrete results in lesser depth for compression zone (larger depth for ineffective concrete region at tension zone). This makes HSC slabs more efficient for using these hollows. Based on this principle, this research is devoted to study the effect of longitudinal hollows on behavior and capacity of HSC slabs. The parameters of this study are number of hollows, diameter of hollows and volumetric ratio of hollows. Since the reinforcement has important effects on slab capacity and distribution of stresses along slab section depth, it is considered as one of parameters of this study. This study will provide important conception for structural designers on behavior of HSC hollow core slabs and their adequacy in roofing and gives them good choices for the optimum design.

3. Experimental Program

The experimental program consists of testing six simply supported reinforced concrete one way slabs . All slabs have the same dimensions. They have an overall length of 1000 mm (900 mm center to center of supports), a width of 450 mm and a height of 70 mm. Four slabs were reinforced by 6 ϕ 5 mm (ρ = 0.45 %) while the other two were reinforced by 6 ϕ 8 mm (ρ = 1.2 %). Two slabs of them are solid while the other four are hollowed by different numbers and diameters of the hollows. The details of these slabs and the hollows are illustrated in Table 1.

Table 1. Details of tested slabs and parameters of the study

Slab Name	% ρ	Details of hollows	Volumetric Ratio of hollows	Distribution of reinforcing bars and hollows
S_1	0.45	Solid	0	
S_2	0.45	5 ϕ 25 mm	8 %	
S_3	0.45	3 ϕ 50 mm	20 %	
S_4	0.45	5 ϕ 50 mm	32 %	
S_5	1.2	Solid	0	
S_6	1.2	5 ϕ 50 mm	32 %	

4. Materials and Mix Proportions:

Ordinary Portland Cement (type I) and natural fine aggregate (sand) with 4.75 mm maximum size and crushed coarse aggregate (gravel) with 10 mm maximum size are used to production of the concrete used for casting specimens of the study. Also, superplasticizer admixture are used to reducing the amount of water and giving the workability required for placing and vibration especially at using pipes that results in narrow spaces between them that complicates these processes. Table 2 shows quantities for used materials by weight for production of one cubic meter of concrete. These quantities were taken from some previous works [Kheder et al. 2005] with slight modifications.

Table 2. Quantities of materials for one cubic meter of concrete

Material	Cement	Sand	Gravel	Water	superplasticizer
Quantity	550 kg	700 kg	1000 kg	155 liter	10 liter

5. Steel Reinforcing Bars

Deformed steel bars are used in this work with nominal diameters of 5 mm (in four slabs) and 8 mm (in two slabs) for longitudinal reinforcement in tension side (bottom side) and plain bars of diameter 3 mm are used for longitudinal reinforcement in compression side (top side) without stirrups except two of 3 mm plain bar stirrups at each side used for fixing the bars and the pipes in their positions during the casting as shown in Figure 2. The laboratory tensile tests on bars showed that the average yield stress for 5 mm diameter was 607 MPa while for 8 mm diameter was 588 MPa.

6. PVC Pipes for Hollows

To make the continuous longitudinal hollows within the slabs, PVC pipes are used. Two diameters are used : ϕ 1 in or 25.4 mm (ϕ 25 mm as a nominal size) and ϕ 2 in or 50.8 mm (ϕ 50 mm as a nominal size). The pipes are installed with reinforcing cage as shown in Figure 2.

Figure 2. Steel reinforcement cage with PVC pipes

7. Hardened Mechanical Properties Results

Table 3 shows test results of mechanical properties obtained for hardened concrete. These properties are concrete compressive strength (f'_c), splitting tensile strength (f_t), modulus of rupture (f_r). Each value presented in this table represents the average value of three specimens.

Table 3. Tests results of mechanical properties for hardened concrete

f'_c (MPa)	f_t (MPa)	f_r (MPa)
63.7	4.26	5.89

8. Tests and Measurements of Slabs

All slabs were tested using a hydraulically universal testing machine of 3000 kN capacity under monotonic loads up to ultimate load at the Structural Laboratory of the Faculty of Engineering of Al-Mustansiriya University as shown in Figure 3.

The load was applied by two line loads through two steel rods with distance 300 mm between them at mid of slab span (the distance from the support to load arm is 300 mm). Vertical deflections are measured at mid of slab span using dial gauge of (0.01 mm) accuracy as shown in Figure 4. Loading was read at increments of 2.5 kN. At each load reading the deflection values were recorded. When the first crack appears, the load corresponding it was recorded.

Also, crack width is measured at loading stages of 20 kN and 40 kN using concrete crack microscope shown in Figure. (5) that has 0.02 mm resolution.

Figure 3. Slab inside testing machine

Figure 4. Dial gauge position

Figure 5. Concrete crack microscope

9. Results of Tested Slabs

Table 4 summarizes results of first cracking load (P_{cr}), ultimate load (P_u), reduction ratio in P_{cr} and P_u due to presence of longitudinal hollows and ratio between them for all tested slabs.

Table 4. Results of Tested Slabs

Slab Name	Hollows details	Volumetric ratio of hollows	Reinf. Ratio (ρ)	P_{cr} kN	Reduction in (P_{cr})	P_u kN	Reduction in (P_u)	$\frac{P_{cr}}{P_u}$
S_1	None	0	0.45 %	13	---------	31	-------	0.42
S_2	5 ϕ 25 mm	8 %	0.45 %	12	7.7 %	29.5	4.8 %	0.41
S_3	3 ϕ 50 mm	20 %	0.45 %	11	15.4 %	28.5	8.1 %	0.39
S_4	5 ϕ 50 mm	32 %	0.45 %	9.5	26.9 %	27	12.9 %	0.35
S_5	None	0	1.2 %	14	---------	64	-------	0.22
S_6	5 ϕ 50 mm	32 %	1.2 %	11	21.4 %	51	20.3 %	0.22

10. Discussion of Results

10.1 First Cracking Loads

From Table 4 it is can noted that presence of hollows reduces first cracking load. The reduction is larger as diameter or number of hollows increases. Maximum reduction (26.9 %) was in case of higher ratio of hollows (32 %) and low reinforcement ratio (ρ = 0.45 %). The reduction slightly decreases with increasing reinforcement ratio.

10.2 Ultimate Loads

From Table 4 it can be noted that presence of the hollows reduces the ultimate load, The reduction is larger as diameter or number of hollows increases. For low reinforcement ratio (ρ = 0.45 %), maximum reduction (12.9 %) was in case of higher ratio of hollows (32 %). The reduction increases with increasing reinforcement ratio. It becomes 20.3 % when ρ = 1.2 %.

10.3 Cracking to Ultimate Loads Ratio

From Table 4 it is seems that the ratio between cracking to ultimate loads decreases with increasing diameter or number of hollows. Also, this ratio significantly decreases as reinforcement ratio increases. Maximum ratio was 0.42 for solid slab having low reinforcement ratio (ρ = 0.45 %), while minimum ratio was 0.22 for solid and hollowed slab having high reinforcement ratio (ρ = 1.2 %).

10.4 Failure Modes

All slabs were failed by flexural mode except the slab (S_6) which was failed by local bearing at support region between outer pipes. The reason of occurring this type of failure is high ratio of reinforcement for the slab (S_6) (ρ = 1.2 %) with weakness in shear and bearing strength due to presence of high ratio of hollows that causes small concrete section area. The high reinforcement ratio requires high load to occur flexural failure that is significantly influenced by reinforcement area, therefore, the bearing failure, that is influenced by concrete area, took place under a load lower than that load required to incidence the flexure failure.

10.5 Crack Pattern

Figure 6 shows crack patterns for all tested slabs and effect of longitudinal hollows on number, width and propagation way of cracks at the tension sides of slabs. From this figure, it was noted that with increasing hollows volume the cracks become more and wider. This difference is clear from comparison the pattern of the slabs (S_1) and (S_4). Also, the cracks become more and wider in case of high reinforcement ratio as shown in pattern of the slabs (S_5) and (S_6). For the slab (S_6), there are further cracks at failure region near support and crashing of the concrete in this region due to the local failure.

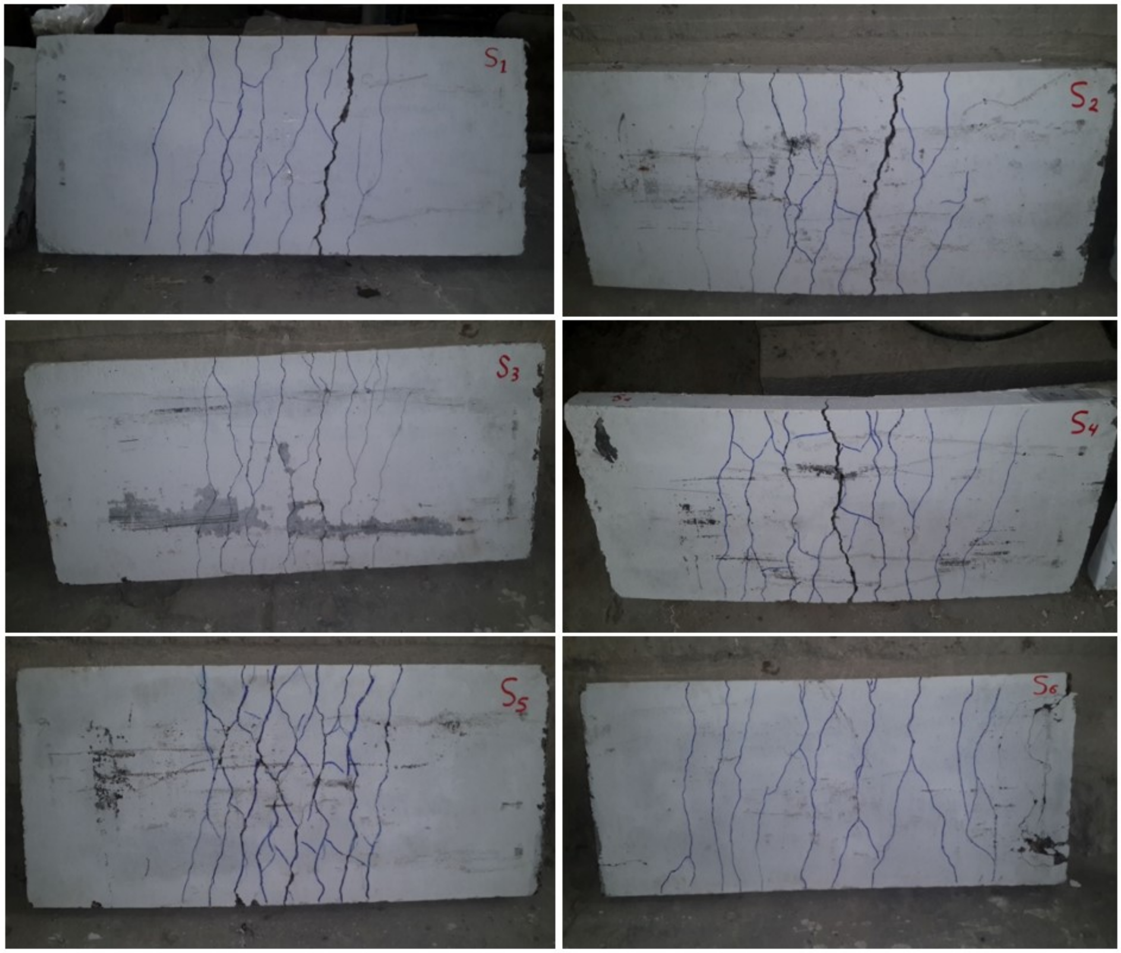


Figure 6. Pictures of crack pattern for all tested slabs

10.6 Effect of Number of Hollows

From Table 5 it is noted that presence of hollows decreases both cracking and ultimate capacities. The reduction in these capacities is larger with increasing number of hollows. Effect of number of hollows on cracking capacity is larger than its effect on ultimate capacity.

Table 5. Effect of hollows number on P_{cr} and P_u

Slab Name	Hollows Number	Reduction in (P_{cr})	Reduction in (P_u)
S_1	0	---------	-------
S_3	3 ϕ 50	15.4 %	8.1 %
S_4	5 ϕ 50	26.9 %	12.9 %

From Figure 7 it is noted that presence of hollows effects on load – deflection response where the deflection values of the hollowed slabs (S_3) and (S_4) are larger than deflection values of solid slab (S_1) for all loading stages. These differences become larger with progressing the loading. At any load stage, the deflection value increases with increasing the number of hollows. This means, as increasing hollows number, the load deflection response of the slab becomes softer because these hollows have significant effects on slab stiffness due to their effect on moment of inertia of the slab. Increasing hollows number results in higher deflection value at failure.

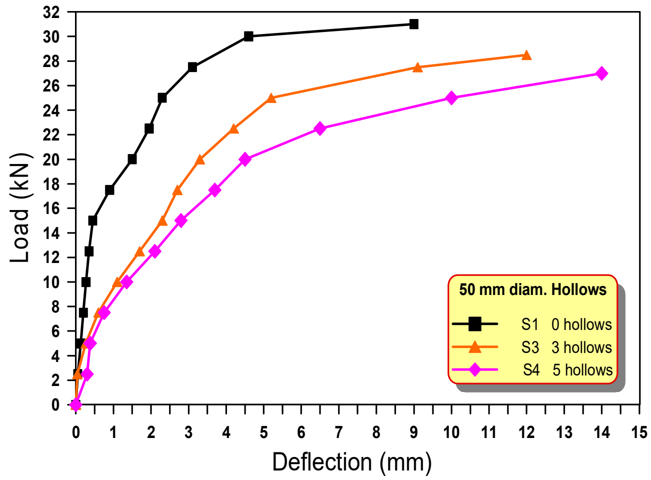


Figure 7. Load – deflection plot for slabs (S_1), (S_3) and (S_4)

10.7 Effect of Diameter of Hollows

From Table 6 it is noted that increasing hollows diameter causes reduction in cracking and ultimate capacities. Using 50 mm diameter hollows have significant effect on reducing cracking and ultimate capacities in comparison with using 25 mm diameter hollows. Effect of hollows diameter of on cracking capacity is significantly larger than its effect on ultimate capacity.

Table 6. Effect of hollows diameter on P_{cr} and P_u

Slab Name	Diameters of Hollows	Reduction in (P_{cr})	Reduction in (P_u)
S_1	0	---------	-------
S_2	5 ϕ 25 mm	7.7 %	4.8 %
S_4	5 ϕ 50 mm	26.9 %	12.9 %

From Figure 8 it is noted that increasing hollows diameter effects on load – deflection response where the deflection values of the hollowed slabs (S_2) and (S_4) are larger than deflection values of solid slab (S_1) for all loading stages. These differences become more pronounced with progressing the loading. At any load stage, the deflection value increases with increasing the diameter of hollows. This means, as increasing hollows diameter, the load deflection response of the slab becomes softer especially when 50 mm hollows are used. Increasing hollows diameter results in higher deflection value at failure.

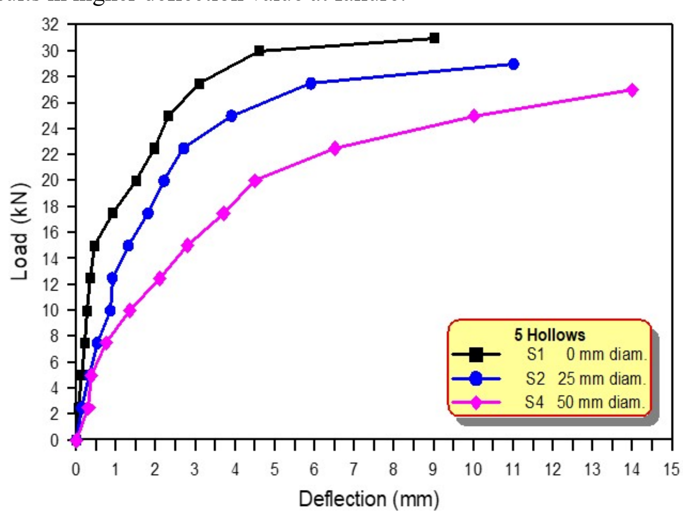


Figure 8. Load – deflection plot for slabs (S_1), (S_2) and (S_4)

10.8 Effect of Volumetric Ratio of Hollows

From Table 7 it is concluded that cracking and ultimate capacities are reduced with increasing volume of hollows made in the slab. The reductions in both capacities are approximately proportional with increasing hollows volume ratio from 0 % to 32 %. Effect of hollows volume on cracking capacity is larger than its effect on ultimate capacity.

From Figure 9 it is shown that load – deflection response is significantly influenced by volumetric ratio of hollows. As this ratio increases, the deflection value increases at any load stage. In earlier stages of loading, the responses of solid and different hollowed slabs are fairly convergent but they diverge with progressing the loading achieving to final stages where the differences between deflection values are large. This means, volume of the hollows has significant effect on slab stiffness so that its load deflection response becomes softer. At failure, increasing hollows volume leads to higher deflection value.

It is seem that volume of hollows has the main effect on capacity and behavior of slab, while effect of diameter and number of hollows represent reflection to amount of hollows volume. Therefore, the distribution of these hollows and the distance between them have no effect when the volume of them are constant.

Table 7. Effect of hollows volumetric ratio on P_{cr} and P_u

Slab Name	Volumetric ratio of hollows	Reduction in (P_{cr})	Reduction in (P_u)
S_1	0	---------	-------
S_2	8 %	7.7 %	4.8 %
S_3	20 %	15.4 %	8.1 %
S_4	32 %	26.9 %	12.9 %

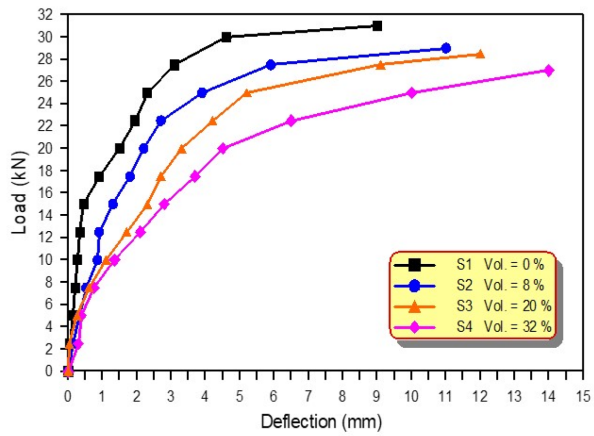


Figure 9. Load – deflection plot for slabs (S_1), (S_2), (S_3) and (S_4)

10.9 Effect of Volumetric Ratio of Hollows with Varying (ρ)

From Table 8 one can note that effect of hollows on cracking capacity decreases with increasing reinforcement ratio (ρ) while its effect on ultimate capacity increases with increasing this ratio. For all values of (ρ) effect of hollows on cracking capacity is larger than its effect on ultimate capacity.

Table 8. Effect of hollows volumetric ratio on P_{cr} and P_u with varying (ρ)

ρ %	Slab Name	Volumetric ratio of hollows	Reduction in (P_{cr})	Reduction in (P_u)
0.45	S_1	0	---------	-------
0.45	S_4	32 %	26.9 %	12.9 %
1.2	S_5	0	---------	-------
1.2	S_6	32 %	21.4 %	20.3 %

From Figure 10 one can note that effect of the hollows on load – deflection response is approximately corresponding for both values of (ρ) with more convergence between responses of solid and hollowed slabs in earlier stage of loading in case of high (ρ). On contrast of low (ρ) (Figure 10-a), hollows lead to smaller deflection at failure in case of high (ρ) (Figure 10-b) due to the rapid failure of slab (S_6).

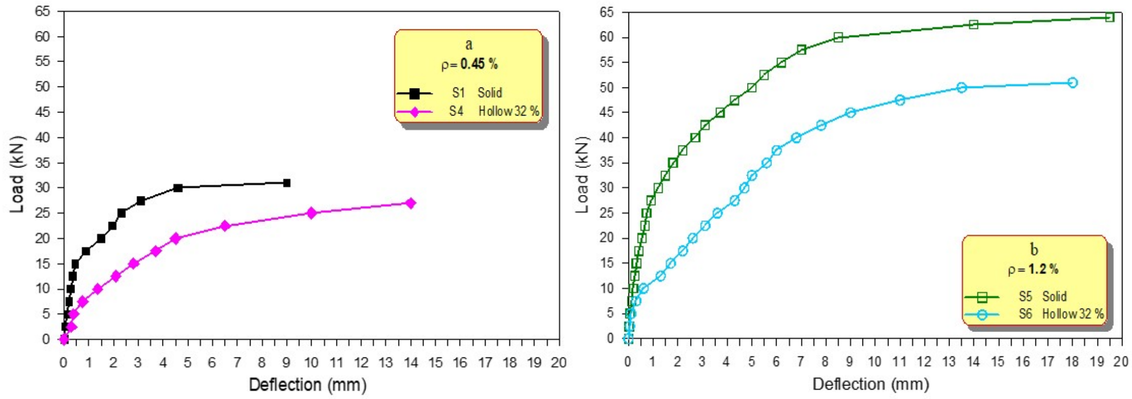


Figure 10. Load – deflection plot for slabs (S_1), (S_4), (S_5) and (S_6)

10.10 Effect of (ρ) for Solid and Hollowed Slabs

From Table 9 it is concluded that increasing reinforcement ratio (ρ) has slight effect on cracking capacity while its effect on ultimate capacity is significant. Effect of (ρ) on cracking capacity of hollowed slab is larger than its effect on cracking capacity of solid slab, while its effect on ultimate capacity of hollowed slab is smaller than its effect on ultimate capacity of solid slab.

From Figure 11 it is noted that increasing reinforcement ratio (ρ) improves load – deflection response and makes it stiffer for both solid and hollowed slabs. In earlier loading stage, effect of (ρ) in stiffening slab behavior is more pronounced in hollowed slab (Figure 11-b) due to the larger share of reinforcement in moment of inertia in comparison with the solid slab (Figure 11-a). Also, increasing (ρ) leads to higher deflection value at failure.

Table 9. Effect of (ρ) on P_{cr} and P_u for solid and hollow slabs

Type	Slab Name	ρ %	Increasing in (P_{cr})	Increasing in (P_u)
Solid	S_1	0.45	---------	-------
	S_5	1.2	7.7 %	106.5 %
Hollow 32 %	S_4	0.45	---------	-------
	S_6	1.2	15.8 %	88.9 %

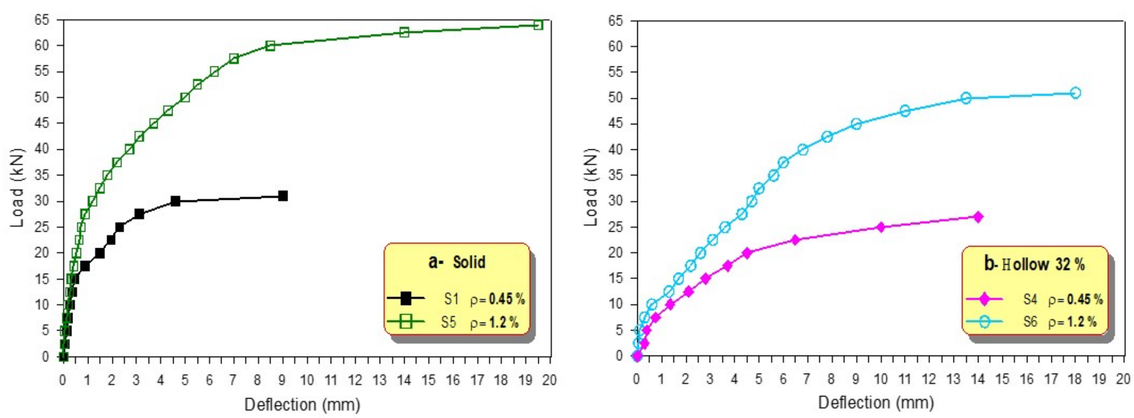


Figure 11. Load – deflection plot for slabs (S_1), (S_4), (S_5) and (S_6)

10.11 Crack Width

Crack width is one of serviceability requirements of concrete members in some structures so that it must be calculated and compared with the limits listed in specifications and codes to consider these members are adequate for strength of external conditions. In this study, crack width was measured at two levels of loading (20 kN and 40 kN). The load of 20 kN approximately represents the service stage of loading for slabs reinforced by 0.45 % where it forms (65% to 74%) of ultimate loads of these slabs, while the load of 40 kN approximately represents the service stage of loading for slabs reinforced by 1.2 % where it forms (62% to 78%) of ultimate loads of these slabs.

From Figure 12 it can be noted that crack width value increases with increasing hollows volume for all loading stages. Also, these values decreases with increasing (ρ) at the same loading stage. The ratio of increasing in crack width due to hollows is smaller in case of high reinforcement. At service loading stages (20 kN and 40 kN), crack width value increases with increasing (ρ).

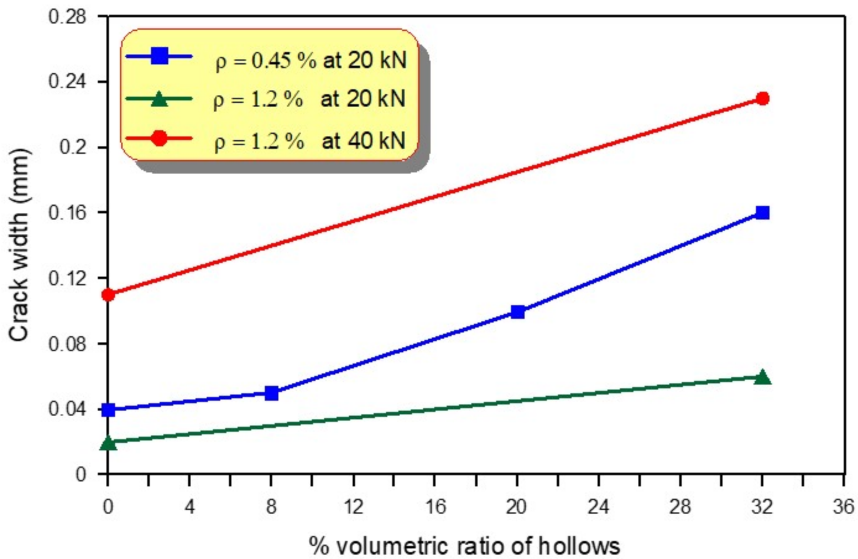


Figure 12 Crack width versus hollows volumetric ratio with varying (ρ)

10.12 Deflection and Stiffness Values at Cracking and Service Stages

Table 10 shows the details of the deflection and stiffness values for all slabs at cracking and service stages. Stiffness values express slab rigidity at a stage of loading. Stiffens value is approximately computed by the ratio of load to deflection values at a point of load – deflection diagram, i.e. it represents the slope of the line extended from origin to that point. Service stage is considered at point of 20 kN for slabs of 0.45 % reinforcement and at point of 40 kN for slabs of 1.2 % reinforcement as previously mentioned. Values that listed in this table aids to understand the effect of hollows on deflection and stiffness values at these important stages of loading (cracking and service stages).

For cracking stage results, it is noted that presence of hollows significantly increases deflection values at this stage. This effect for hollows is smaller with increasing (ρ). From stiffness values, it is noted that the hollows significantly reduces stiffness of the slab. The reduction in stiffness is larger with increasing hollows volume. The reduction is smaller in case of highly reinforced slabs. Increasing (ρ) leads to smaller deflection values and larger stiffness values for both solid and hollowed slabs.

For service stage results, it is noted that presence of hollows increases deflection values at this stage. This effect for hollows is smaller with increasing (ρ). From stiffness values, it is noted that the hollows reduces stiffness of the slab. The reduction in stiffness is larger with increasing hollows volume. The reduction is smaller in case of highly reinforced slabs. Increasing (ρ) leads to larger deflection values and slightly larger stiffness values for both solid and hollowed slabs.

Table 10. Deflection and stiffness values at cracking and service stages

Slab Name	(ρ%)	Ratio of hollows Volume	Δ_{cr} mm	$\Delta_{cr\ Hollow} / \Delta_{cr\ Solid}$	Cracking Stiffness P_{cr} / Δ_{cr} kN/mm	$\Delta_{serv.}$ mm	$\Delta_{serv.\ Hollow} / \Delta_{serv.\ Solid}$	Service Stiffness $P_{serv.} / \Delta_{serv.}$ kN/mm
S1	0.45	0 %	0.37	---------	35.1	1.5	-------	13.3
S2	0.45	8 %	0.89	2.41	13.5	2.2	1.47	9.1
S3	0.45	20 %	1.34	3.62	8.2	3.3	2.2	6.1
S4	0.45	32 %	1.23	3.32	7.7	4.5	3	4.4
S5	1.2	0 %	0.3	---------	46.7	2.7	-------	14.8
S6	1.2	32 %	0.88	2.93	12.5	6.8	2.52	5.9

11. Benefit for Design Considerations

Using longitudinal hollows in reinforced concrete slabs has two contradictory effects on its adequacy to carrying the applied loads. The positive effect is reducing part of dead loads due to reducing slab self-weight that form an important portion of total loads applied on the slab. The negative effect is reducing the ultimate capacity as previously shown in this research.

Slab self-weight forms about 40 % of total ultimate loads applied on the slab. This means that the approximate ratio of reduction in ultimate loads due to presence of hollows can be expressed by the following relation:

Ratio of reduction in ultimate loads = 0.4 × hollows volumetric ratio (1)

Effect of hollows volume on ultimate capacity is studied in this research where the reduction in ultimate capacity of the slab is proportional with volumetric ratio of hollows as shown in Figure 13. The fitting line of the points of this relation that is drawn in this figure shows the average relation between them, as follows:

Ratio of reduction in ultimate Capacity = 0.412 × hollows volumetric ratio (2)

From above two equations, it is noted that hollows cause convergent reductions in both ultimate capacity and ultimate loads. This means that in the resultant, the longitudinal hollows has very small effect on loads carrying adequacy of the slabs. This conclusion assures the structural benefit of using the longitudinal hollows in construction of the one way slabs in addition to service benefits.

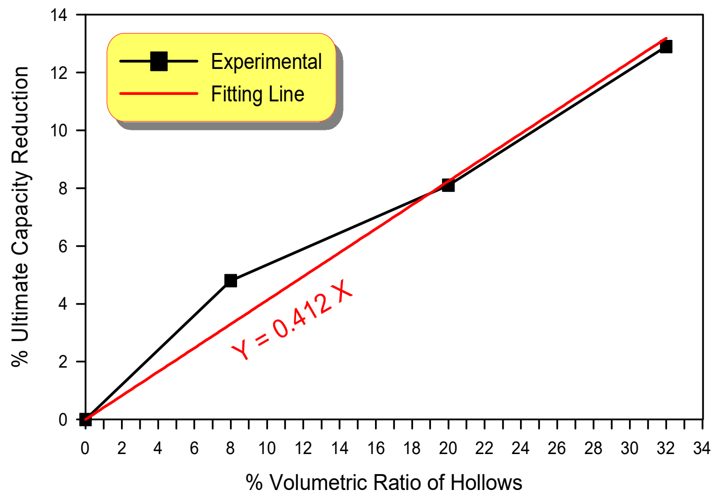


Figure 13. Relation between reduction in capacity and hollows volume

The reversal effects of the hollows on cracking capacity, deflection, stiffness and crack width can be treated by using high strength concrete (HSC) in construction of slabs. Using HSC leads to improvement in rupture modulus (f_r) that increase cracking capacity and reduce crack width. Also, using HSC improves elasticity modulus (E_c) that increases slab stiffness and reduces deflection value.

Eventually, it is useful to using longitudinal hollows in construction of one way slabs especially with using HSC.

12. Conclusions

1- Using longitudinal hollows in HSC one way slab reduces its cracking capacity. This reduction is larger with increasing hollows volume and decreasing reinforcement ratio. Maximum reduction is 26.9 % in case of 32 % hollows volumetric ratio with ρ = 0.45 %.

2 - Using this type of hollows reduces the ultimate capacity of HSC one way slab. This reduction is larger with increasing hollows volume and increasing reinforcement ratio. Maximum reduction for slab of 32 % hollows is 12.9 % when ρ = 0.45 % and 20.3 % when ρ = 1.2 %.

3- All slabs were failed by flexural mode except the slab (S_6) that has high flexural reinforcement ratio where it failed by local bearing at support region between outer pipes due to large flexural capacity that prevent flexural failure and weakness of concrete shear and bearing capacities due to presence of hollows.

4- Increasing diameter the same number of hollows or number of the same diameter of them causes reductions in cracking and ultimate capacities.

5- The criteria of hollows effect is the volume of these hollows while diameter or number of hollows are effective through increasing their volume.

6- Load – deflection response is significantly influenced by presence of hollows. This response is softer with increasing hollows volume. Hollows effect is larger in advanced loading stages. Also they leads to larger displacement at failure. Hollows effect on slab response is approximately corresponding for both low and high

values of (ρ).
7- (ρ) has slight effect on cracking capacity but significant effect on ultimate capacity for both solid and hollowed slabs.
8- Increasing (ρ) improves load – deflection response and makes it stiffer and leads to larger deflection at failure for both solid and hollowed slabs.
9- Crack width increases with increasing hollows volume and decreases with increasing (ρ). Hollows effect on crack width is smaller in case of high (ρ).
10- At cracking and service stages, hollows increases deflection values and reduces stiffness of the slab. This effect for hollows is smaller with increasing (ρ).
11- Structurally, using of longitudinal hollows has very small effect on loads carrying adequacy of the slabs because their effect on ultimate capacity is generally small and they have positive effect through reducing self-weight slab that contributes to reducing the ultimate applied loads on slabs that substitutes the reduction in ultimate capacity of the slab.
12- Using HSC leads to improvements in mechanical properties of concrete that increase cracking capacity and slab stiffness in addition to reducing crack width and deflection. This positive action substitutes the negative action for using hollows on these values. Therefore, HSC is very useful in hollowed slabs.
13. It is necessary to attention in design of slab regions near supports through providing appropriate amount of shear reinforcement at this region to avoid the local failures especially in case high flexural reinforcement or in case of small supporting area as in flat slabs system or in case of presence of holes under the slab through the supporting beams or walls.

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