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Behavior of reinforced concrete segmental hollow core slabs under monotonic and repeated loadings

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Abstract. This study investigated experimentally the response of thick reinforced concrete specimens having hollow cores with critical parameters. The investigation includes testing of twelve specimens that are solid and hollow-core slab models. Each specimen consists of two pieces, the piece dimensions are (1.2 m) length, (0.3 m) width and (20 cm) thickness tested under both monotonic and repeated loading. The test program is carried out to study the effects of load type, core diameters, core shape, number of cores, and steel fiber existence. Load versus deflection at mid span, failure modes, and crack patterns were obtained during the test. The test results showed that core shape and core number has remarkable influenced on cracking pattern, ultimate load, and failure mode. Also, when considering repeated loading protocol, the ultimate load capacity, load at yielding, and ductility is reduced.

Keywords: monotonic load; repeated load; reinforced concrete; hollow-core slab

1. Introduction

The building slabs might possibly exist in three constructional forms such as solid slabs, ribbed slabs, and voided or hollow-core slabs (HCS). Slabs with voids or cores required for electrical and mechanical purposes or for fire resistance as well as longitudinal cores of substantial dimensions reduces weight and costs. Basically, slabs with cores can be utilized as roof deck or furnish floor. Furthermore, these slabs meet modern standard as sound barriers which is able to prevent the sound of footsteps. Reinforced concrete slabs with voids are constructed through agreeing focuses:

1- The slab section (with hollow cores) is defined as I-section continuous part and considered as a ribbed slab with bottom and top flanges see Fig. 1.
2- The panel width is typically 2.4 m wide with standard span length normally 7 m.
3- The ratio of thickness to span: $\frac{h}{L} = \frac{1}{10} - \frac{1}{5}$
4- The restrictions of slab section (shown in Fig. 1) are based on ACI-318 (2014) code:

- $b_w \geq 100$ mm
- $s \leq 800$ mm
- $b_f = b_w +$ dia. of core.
- $h_w \leq 3.5\ b_w$
- $h_f \geq s/2$, $h_f \geq 50$ mm
- b_w : web width

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- h_w : web height.
- h_f : flange height.
- b_f : flange width.

The main aim of research is to study the performance of one-way slabs with longitudinal voids. The test program is carried out to study the effects of load type, core diameters, core shape, number of cores, and steel fiber existence.

2. Literature review

Celal (2011) studied the shear behavior of precast prestress HCS. The length of bearing, voids shap (circular and non-circlar) and different thickness were investigated. The line load was applied at the mid span of the specimens. The expremental results showed that the bearing length shows effectiveness in reducing computed the shear capacity. In addition, the non-circular shap improves the shear capacity about 4% for thickness 200mm and 49% for thickness 250 mm compare with HCS specimens with circular voide. The effect of different thickness showed variance in values, where the thickness 300 mm was more efficient for shear resistance. Also, the thickness of 200 mm was less efficient in shear resistance compared with thickness 250 mm.

Rahman *et al.* (2012) performed an experimental study on prestressed and precast voided slabs. These slabs were tested in the laboratory under various shear span lengths with loads up to failure and their ultimate loads were recorded. It was noted that the failure mode turned from flexure failure mode to shear – flexure failure mode for slabs with greater depth. Furthermore, the test results were analyzed and revealed that the current equations of ACI code showed lower values of the shear- flexural capacity for these voided slabs.

Cuenca and Serna (2013) assess experimentally the shear performance of use fiber reinforcement concrete (FRC) of 26 HCS specimens. Two different quantities of hooked steel fibers (50-70) kg/m^3 were used. For both, the steel fiber size is 40 mm length and 0.62 mm diameter with 65% an aspect ratio. Also, a different percentage of shear span to depth ratio (a/d) (2.3 - 4.4 and 8.6) was studied. The results of the test indicated that the hollow core slabs with

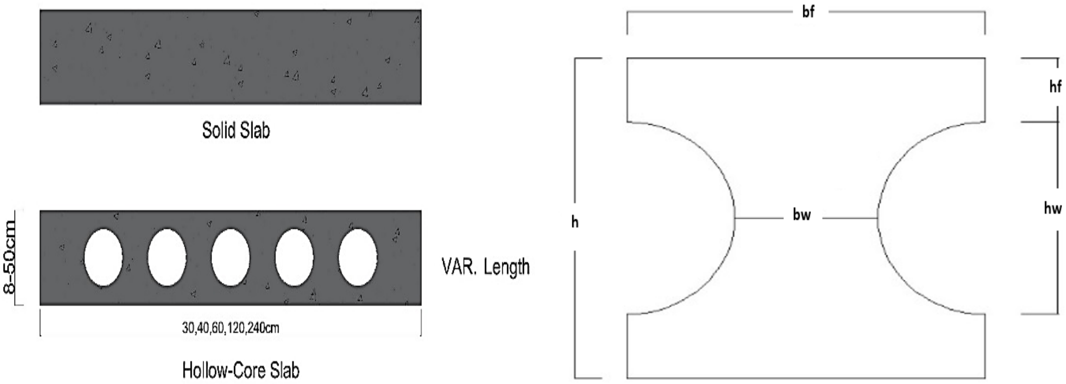

Fig. 1 Hollow-core slab section

hooked steel fibers showed an increase in the failure load and much higher deflection capacity than the hollow core slabs without hooked steel fibers.

Brunesi *et al*. (2014) scrutinized the shear strength capacity of prestressed concrete hollow core slabs using three different approaches (experimental approach, analytical approach and numerical approach). These specimens grouped according to thickness, void shape (circular and non-circular holes), hole size ratios, arrangements of pre-stressed steel strands and initial pre-stress levels. After that, the experimental data used to assess the traditional design codes. From finite element approach, the detailed numerical model was verified with single precast prestressed hollow-core slabs. The numerical results used to develop alternative design approach of Precast Prestressed Hollow Core which failed by web-shear.

Lee (2014) studied the shear behavior of slabs with longitudinal hollow core through large number of shear tests. The experimental results confirmed that the minimum shear reinforcement requirement for deep slabs is too severe, and therefore the shear strength of slab is far high that predicted by the equation in ACI 318 codes. Thus, a new simple shear strength model was suggested; this model achieves safety on shear strength capacity for the slab's depth up to 500 mm deep.

Baran (2015) made a research focused on the flexural performance of hollow-core slabs. Both empirical and numerical technique was adopted to predict the overall slab behavior. The results indicated that a composite action was significant at the uncracked state levels. Both cracking moment and initial stiffness of slabs was enhanced by installing a topping slab. In contrast, the ultimate moment capacity was observed to be limited. the shear strength based on the ACI code and AASHTO specifications is much higher than that obtained numerically.

Kankeris and Prakash (2016) studied the failure modes and response of slabs having hollow cores. They included hybrid strengthening methods; externally bonded and near surface mounted (NSM). The fiber reinforced polymer (FRP) bars was used in the experimental program. Seven slab specimens were constructed and tested in laboratory after they were strengthened. Test results revealed that the first strengthening method (bonded overlay) increased the flexural capacity by 89% with almost same ductility when compared to the reference slab. Whereas the second method (NSM) FRP bar increased the capacity by about 100% with lesser ductility.

Al-Azzawi and Abed (2017) presented an investigation on the behavior of moderately thick hollow core slabs with various variables. This study conducts cast and test of slabs having (2000 mm), (600 mm), and (250 mm) (length, width, theckness), respectively. Load deflection curves were recorded. And the other part (numerical part), the (FE) procedure was utilized to show the behavior of those slabs by employed ANSYS program. The FE analysis displayed a good agreement as compared with the experimental results with a difference about (5% - 8.70%) in ultimate loads and (0.7-9.29)% in deflection. A parametric study conducted by utilizing ANSYS program to discuss the effects of concrete shape of the core, compressive strength, and size, applied load protocol and steel reinforcement ratio effect

Dudnik *et al*. (2017) explored the affect of add steel fiber in concrete to resist the shear failure at HCS specimens. The study conducts a series of HCS tests with different steel fiber ratio. The steel fiber was used hooked ends with length 30 mm and diameter of 0.56 mm. The main variables were the volume of steel fiber (0.38%, 0.5% and 0.76%), the thickness of HCS specimens (300 mm and 410 mm), and the shear span to depth percentage ratio (3 and 3.5). The test was done under applied one line load near to the support with different shear span to depth percentage ratio. The result of shear strength form equations of ACI 318M-14 compared with the experimental result. The result showed the shear strength of the HCS specimens with a 300 mm thickness without steel fiber was 100% and 87% of the web shear cracking from ACI 318M-14, the specimens with steel fiber increase in shear strength up to 30%. The shear strength of the HCS specimens with a 410mm thickness without steel fiber was 70% of the web shear cracking calculated according to ACI 314M-14. The specimens with steel fibers showed increase in shear strength of about 55% to 90% compared with the HCS specimens without steel fiber. The steel fiber generally enhances the ductility.

Prakashan (2017) tested four slabs having hollow cores in addition to a reference solid slab in the laboratory. The flexural capacity of hollow core slabs was assessed using conventional flexural capacity equation. The comparison among the specimens in terms of serviceability and load - deflection response was conducted by using the test results. It was found that the ordinary flexural capacity equation can be also applied to predict the flexural response of hollow core slab.

Wariyatno (2017) tested three specimens (a reference solid slab, slab having hollow cores using PVC pipe to make longitudinal voids in “Type I” . Another void material was used to make hollow cores in slab which is the Styrofoam and termed as “Type II”). It was concluded that the voids in both slabs “Type I” & “Type II” cause a reduction in weight as compared to the solid slab by about 24% and 25%, respectively. Flexural load capacity and stiffness of “Type II” (hollow core) slab is higher than the “TypeI” slab. However, hollow core slab “Type II” gives lower flexural load capacity and stiffness than the slab without voids (solid) for different reinforcement ratio. The failure mode is recognized as shear failure for both hollow core slabs, whereas, the failure mode is recognized as flexure failure for solid slab.

Al-Azzawi and Abdul Al-Aziz (2017) and (2018) conducted an experimental program on lightweight concrete hollow core slabs. They studied the effectiveness of void shapes, shear span to effective depth percentage ratio. They tested seven slabs having hollow cores of (1.1 m) length, (0.6 m) width and (0.12 m). The maximum weight reduction was 19.28% and 17.37% due to aggregate type and cross section voids, respectively. The reduction in shear span to effective depth percentage ratio showed increase in ultimate load, ductility and energy dissipation capacity. The decrease of first cracking and ultimate loads of lightweight concrete solid slab was over (16.37%) and (5%), respectively. The decrease of first cracking and ultimate loads of lightweight concrete hollow core slab was (12.1%) and (5.2 %) respectively as compared to the solid slab.

Yousif *et al*. (2018) investigated experimentally the effectiveness of hollow length technique on the shear resistance of the thick hollow core slabs. The reduction in the length of the longitudinal voids and side longitudinal voids in the shear region was studied for the hollow core slabs. For getting lightweight concrete type, the recycle material was used by changing crushed brick as an aggregate instead of the gravel.

Based on previous studies, it can be concluded that the response of normal reinforced concrete thick slab with hollow cores is still unwell understood. However, many above review of relevant research tested hollow cores thin slabs. In this research, the one-way RC thick slabs with and without longitudinal voids were adopted experimentally by creating circular and square voids at middle plane of the cross section with varying void diameter.

3. Details of experimental test

Experimental program comprises casting twelve small-scale (1:4) one way solid and hollow-core reinforced concrete thick slab specimens taking into consideration the scaling of steel reinforcement by using quarter diameter of bar in the slab specimen. Sizes of voids, shape of voids, loading type were investigated in experimental program as shown in Table 1. The value of shear span effective depth ratio (a/d) is constant in all cases. In the monotonic test, loading was applied with loading rate (2-2.5 kN/min). The repeated test, loading was applied based on a load protocol suggested by FEMA 461(2007). In this adopted load protocol, the load is subjected in several stages, the first stage consists of 10 cycles with amplitude ten percent of the deflection at failure in the monotonic case. The second stage consists of 3 cycles with amplitude 1.2 times the deflection amplitude in the first stage. In each of the subsequent steps, the 20 percent increasing in deflection amplitude is applied three times at a frequency of 1 Hz until failure. The slabs are subjected to two-line loads as shown in Fig. 2.

Table 1 Reinforced concrete slabs specimens

Slab No.	Description	Type of load
Slab-1	Solid slab	Monotonic
Slab-2	Circular Hollow-core slab (50 mm one core size)	=
Slab-3	Circular Hollow-core slab (100 mm one core size)	=
Slab-4	Circular Hollow-core slab (50 mm Two core size)	=
Slab-5	Square Hollow-core slab (57 mm x 57 mm)	=
Slab-6	Circular Hollow-core slab with S.F (100mm one core size)	=
Slab-7	Solid slab	Repeated
Slab-8	Circular Hollow-core slab (50 mm one core size)	=
Slab-9	Circular Hollow-core slab (100mm one core size)	=
Slab-10	Circular Hollow-core slab (50mm Two core size)	=
Slab-11	Square Hollow-core slab (57 mm x 57 mm)	=
Slab-12	Circular Hollow-core slab with S.F (100 mm one core size)	=

Fig. 2 Testing machine

Table 2 Properties of materials

Properties of concrete material				
Property	Experimental		ACI318M (2014)	
	Without steel fibers	With steel fibers		
Compressive strength (f'_c) (MPa)	37.865	42.7	-	
Splitting tensile strength (f'_{ct}) (MPa)	4.78	7.196	3.09 (0.5$\sqrt{f'_c}$)	
Modulus of rupture (f_r) (MPa)	6.8	9.046	3.83 (0.62$\sqrt{f'_c}$)	
Modulus of elasticity (E_c) (MPa)	-		29010.8 (4700$\sqrt{f_c'}$)	29926.2 ($W_c^{1.5}0.043\sqrt{f_c'}$)

Properties of steel reinforcement material		
Property	Test results	
Nominal diameter (mm)	8	10
Measured diameter (mm)	8.08	10.06
Yield stress (f_y) (MPa)	589.91	524
Ultimate stress (f_u) (MPa)	737.6	650
Modulus of elasticity (E_c) (MPa)	200000	200000

3.1 Details of the slab specimens

For the slab specimens, the properties of the hardened concrete and steel reinforcement which used for manufacturing the prototype of these slabs are summarized in Table 2.

The nominal dimensions of slab specimens have two pieces with (1200 mm) in length, (300 mm) breadth and (200 mm) depth. These slabs have (1100 mm) clear span with constant shear span effective depth percentage or ratio of (2.29). Two types of concrete are used (with steel fibers and without steel fibers). The following slabs are tested: solid slab, two hollow core slabs with circular void size (100 mm) with and without steel fibers, one hollow-core slab with circular void size (50 mm), two hollow-cores slab with circular core size (50 mm), and one hollow-core slab with square core size (57 mm x 57 mm). The hollow voids of these slabs are molded by using (PVC) pipes and square plate longitudinal through slabs with (2 mm) thickness. The design of both solid and voided slabs was conducted based on the ACI 318 code (2014). The main longitudinal steel reinforcement consists 3 bars with (Ø10 mm) and spacing 100 mm. While the secondary transverse reinforcement consists of 8 bars with (Ø8 mm) and spacing 150 mm. Also, concrete cover is 20 mm as shown in Fig. 3.

Table 3 presents the mix proportions to produce 1 m^3 of the concrete, the target 28-day cube strengths and the measured cube strength of testing.

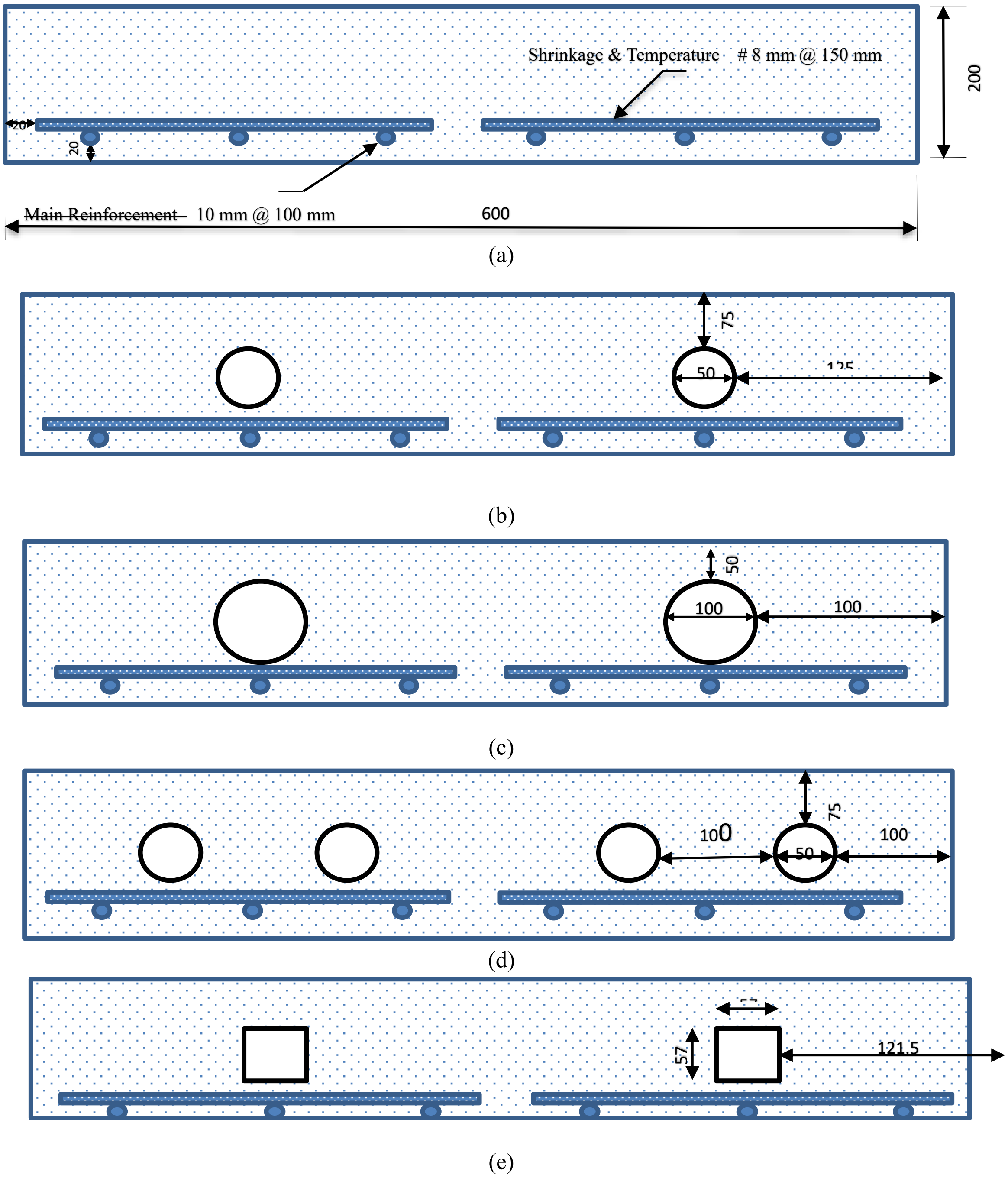

Fig. 3 Cross sections of slabs (All dimensions in mm) (a) Solid slab (b), (c) & (d) Circular Hollow-core slab with core diameter (50,100 mm) (e) Square Hollow-core slab with dimensions (57 x 57) mm

Table 3 properties of mix design

	Target 28-day compressive strength	Measured concrete strength of testing	Cement kg/m^3	W/C	Sand Kg/m^3	Coarse aggregate kg/m^3	Super. % by wt. of cement	Silica% Rep.by cement
Without S.F	35	37.83	360	0.25	800	790	1.5	40
With S.F	40	42.9	=	=	=	=	=	=

3.2 Testing of the slab specimens

Twelve simply supported slab specimens were tested at the Civil Engineering Lab., Al-Nahrain University by using a 250 kN capacity hydraulic universal testing machine. The tests were conducted. At first, the slabs were supported along their short sides by solid steel support with the clear span 1100 mm. Stiffened steel plates with breadth (50 mm) were put over the supports and under load actuator to distribute loads over the concrete's surface. I-section (steel beam) was installed above the slab with length (500 mm) and depth (200 mm) to apply the two-line loads as shown in Figs. 4 and 5(b). The mid span deflection is measured by applying the dial-gages at bottom face of slab. Strain gauge was installed on the longitudinal steel bar before the concrete was poured. Strain gauge- reinforcement bar joint was then protected against water penetration during casting, using a combination of urethane sealant, plastic black tape and rubber adhesive.

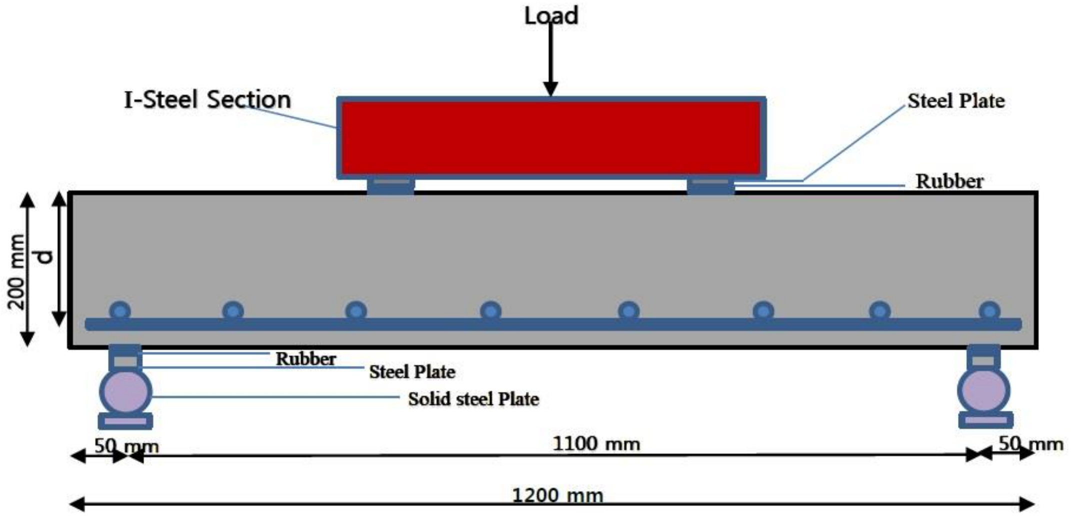

Fig. 4 Details of slab testing

(a) (b)

Fig. 5 (a) Photograph of the mold of hollow-core slab and (b) Photograph of hollow-core slab testing setup

The strain gauges used were foil-type, three-wired temperature-compensating; with resistance of 120 Ω. The developments of cracks and load at failure were monitored with the deflections during the experimental test. The applied load procedure for both monotonic case and repeated case was described previously in section 3. The applied loads were recorded directly from the hydraulic load actuator that has been adjusted using load cells, prior the test is started.

4. Experimental results and discussion

The behavior of reinforced concrete segmental hollow core slabs in terms of the cracks pattern, ultimate load and failure mode are investigated by testing twelve slab specimens. In particular, the main parameters examined in the testing of slabs were the effect of load protocol (i.e., monotonic and repeated loading), core shape, and core size and concrete type on the overall behavior.

4.1 Loads and crack pattern at failure

The current tests recorded the concrete crack pattern developing on the lower surface slab specimens at different applied load stages. For solid slab in monotonic test, cracks are initiated earlier at about (35.73%) of ultimate load, while for solid slab in repeated test cracks are initiated at about (39.28%) of ultimate load with same material properties and a/d percentage ratio. This is attributed the fact that there is a gradual loss of stiffness for specimens resulting from repeated loading causing reduction of ultimate loads in contrast, the crack loads do not influence.

For circular hollow core slabs with dia. =50 mm (one void size and two void size) cracks are developed at about (42.04%) and (43.46%) respectively of the ultimate load in monotonic test. In the repeated case the other two slab specimens (i.e., slab-8 & slab-10), cracks are developed at about (40.39%) and (26.92%) of the ultimate load respectively. This is because the effect of repeated load cycles on the slabs' stiffness is obvious of two cores size.

Table 4 Description and test results of samples

Slab No.	Weight reduction (%)	First cracking load (Pcr) (kN)	Deflection at cracking load (mm) Δ_{cr}	Ultimate load (Pu) (kN)	Deflection at ultimate load (Δu) (mm)
S1	0	108.59	8.427	332.7	25.89
S2	3.27	110.56	6.34	283	19.9
S3	13.08	79.9	6.78	250.79	18.33
S4	6.54	120.21	7.38	276.57	17.11
S5	5.41	88.98	5.9	226.9	16.42
S6	13.08	130.99	8.51	355.81	25.19
S7	0	109.99	6.60	303.3	23
S8	3.27	108.85	5.91	269.5	16.85
S9	13.08	104.316	5.65	285.2	17.2
S10	6.54	70.25	4.34	261	14.77
S11	5.41	128.16	6.5	220.69	12.25
S12	13.08	109.99	7.3	246.8	21.7

Table 5 Description and other test results of samples

Slab No.	Load at Yielding (kN)	Deflection at Yielding (mm) Δ_Y	Ductility $\frac{\Delta_u}{\Delta_Y}$ 100 %	Energy (kN.mm)	Mode of failure	$\frac{P_{cr}}{P_u}$ 100 %
S1	218.85	13.14	1.97	2309	Shear	35.73
S2	249.57	11.47	1.735	1202	Shear	42.04
S3	247.17	14.256	1.286	1112	Shear-Flexural	31.86
S4	244.2	12.204	1.402	1185	Shear	43.46
S5	218.23	15.29	1.074	925	Shear	39.22
S6	268.98	13.03	1.93	3451	Flexural	36.89
S7	198.78	12.67	1.815	24246	Flexural	39.28
S8	235.78	10.712	1.573	16968	Shear	40.39
S9	217.8	14.025	1.226	15873	Shear	81.75
S10	230.45	11.535	1.301	12637	Shear	26.92
S11	205.78	14.358	0.853	9245	Shear	58.07
S12	232.56	12.25	1.77	24237	Flexural	44.57

For circular hollow core slab (dia. 100 mm core size without steel fibers) and square hollow core slab with dimension (57 x 57) mm cracks are developed at about (31.86%) and (39.22%) respectively in monotonic test. While the repeated test results showed that cracks developed at about (81.75%) and (58.07%) respectively. The reason for that may be due to different core shapes (circular and square).

On the other hand, the obvious difference in cracks percentage between circular hollow core slab (dia. 50 mm) and circular hollow core slab (dia. 100 mm without steel fibers) of (1.5 litter by weight of cement) due to core diameters or problem in test setup.

For circular hollow core slab (dia. 100 mm with steel fibers) cracks are initiated at about (36.89%) of ultimate load in monotonic test. the same slab specimen under repeated loading, cracks are developed at about (44.57%).

The crack patterns for the tested slabs are shown in the Figs. 6 to 17. The experimental results and specimens' description are summarized in Tables 4 and 5.

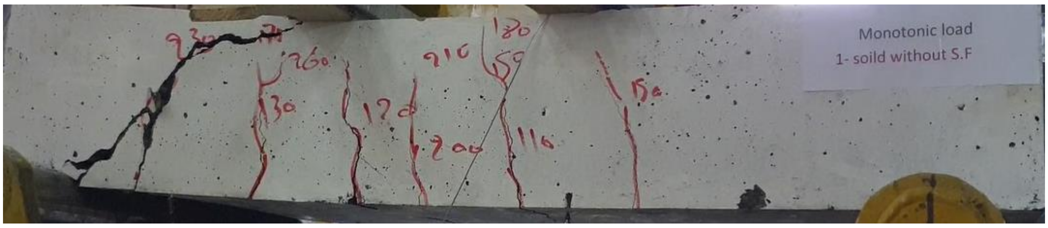

Fig. 6 Crack pattern at ultimate load for Solid (Slab-1) monotonic test

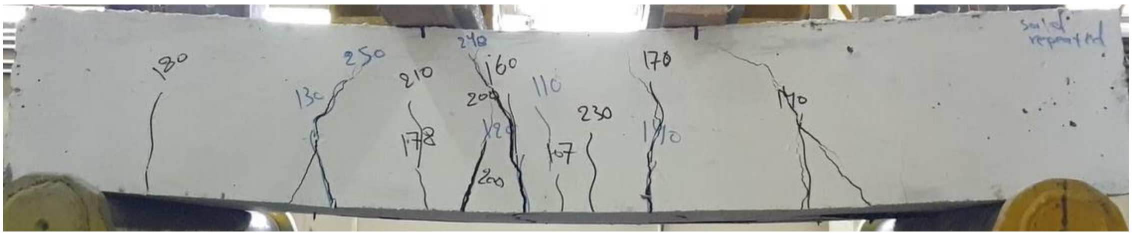

Fig. 7 Crack pattern at ultimate load for Solid (Slab-7) repeated test

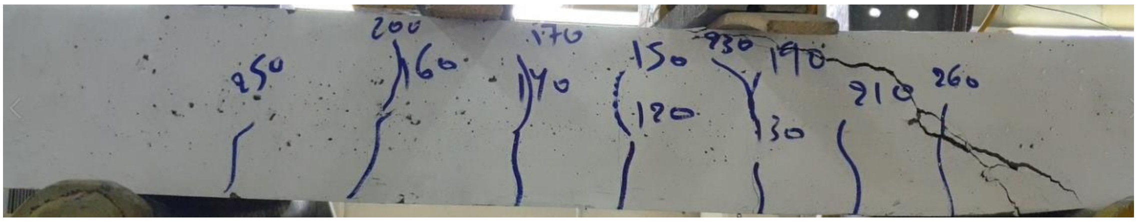

Fig. 8 Crack pattern at ultimate load for HCCS (50mm One Core) (Slab-2) monotonic test

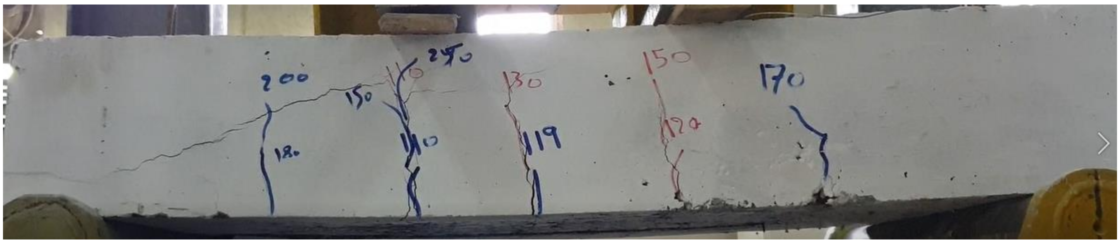

Fig. 9 Crack pattern at ultimate load for HCCS (50 mm One Core) (Slab-8) repeated test

Fig. 10 Crack pattern at ultimate load for HCCS (100 mm) (Slab-3) monotonic test

Fig. 11 Crack pattern at ultimate load for HCCS (100 mm) (Slab-9) repeated test

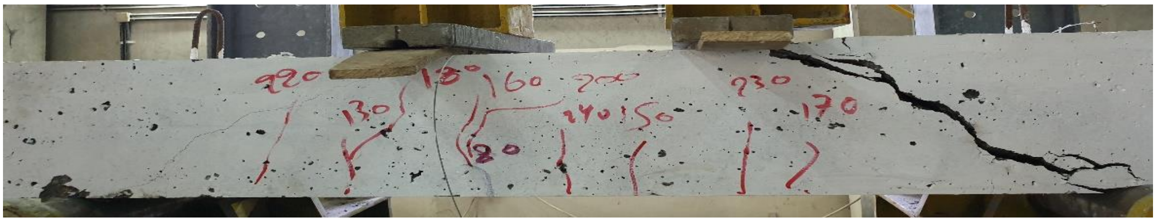

Fig. 12 Crack pattern at ultimate load for HCCS (50 mm Two Core) (Slab-4) monotonic test

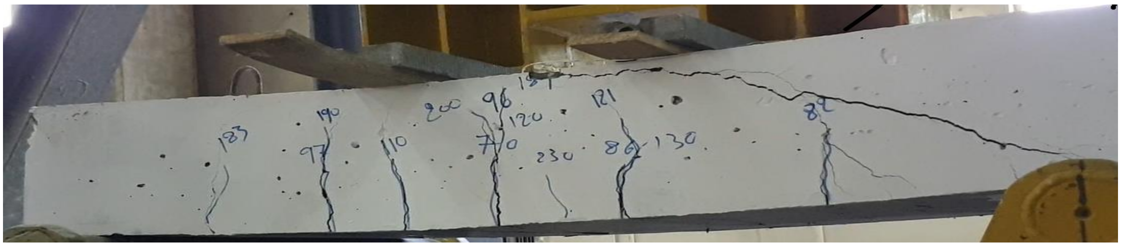

Fig. 13 Crack pattern at ultimate load for HCCS (50 mm Two Core) (Slab-10) repeated test

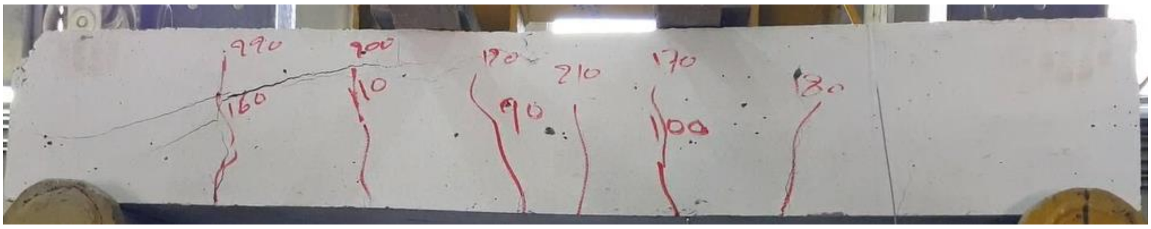

Fig. 14 Crack pattern at ultimate load for HSCS dimensions (57x57) mm (Slab-5) monotonic test

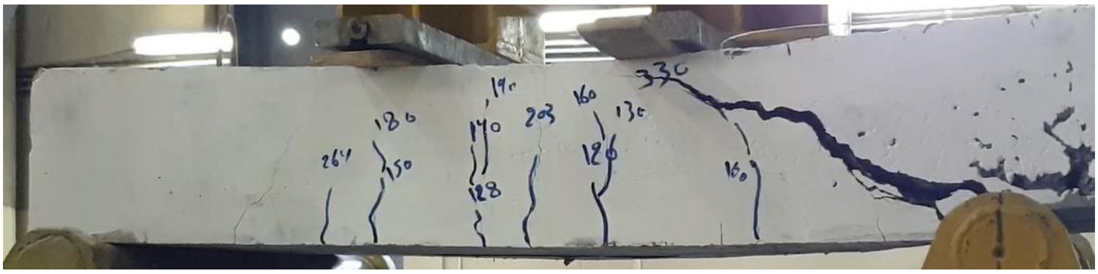

Fig. 15 Crack pattern at ultimate load for HSCS dimension (57x57) mm (Slab-11) repeated test

Fig. 16 Crack pattern at ultimate load for HCCS (100 mm) with S. F (Slab-6) monotonic test

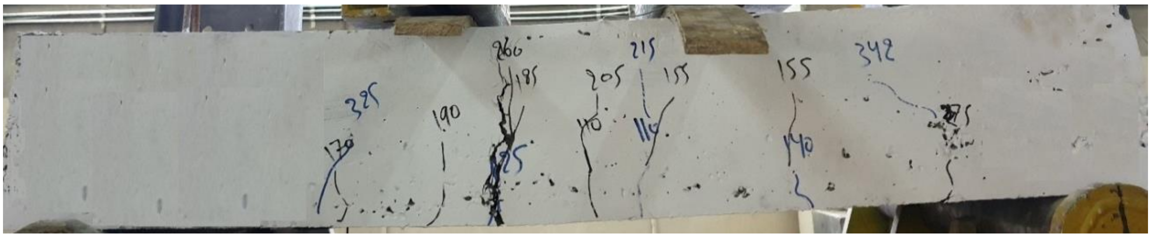

Fig. 17 Crack pattern at ultimate load for HCCS (100 mm) with S. F (Slab-12) repeated test

4.2 Loads at yielding and ductility

In this study, the yielding loads, ultimate load, and ductility for tested specimens are measured during both monotonic and repeated tests. In general, the specimens tested under repeated loading show obvious decrease at yield load compared with ultimate load. This is due to that the loading and reloading at stress level above the steel yielding strength of the specimen does not produce a significant reduction in the stiffness of the slab. Moreover, the slabs tested under repeated loading had a ductility that is much smaller compared to that subjected to monotonic loading. Since considerable vertical cracks occurred on the bottom surface of the specimens subjected to repeated loading. The measured yield load, ultimate load, deflections and ductility are presented in Table 5.

For solid slab in repeated test, load at yielding decreases at about (9.2%) and ultimate load decreases at about (7.9%), compared with solid slab in monotonic test. Also, ductility in repeated test decreases by about (7.87%). Load- strain curve for solid slab in monotonic test is shown in Fig. 18.

For circular hollow core slab (slab-8), yielding load decreases at about (5.5%) as well as ultimate load decreases at about (4.7%), compared with circular hollow core (slab-2). Ductility in repeated test decreases at about (9.3%). Load - strain curve for circular hollow core slab in monotonic test (slab-2) is shown in Fig. 19.

For comparison between (slab-3 and slab-9) in order to clarify the effect of load protocol on 100 mm circular hollow-core slab, seems the rate of decreasing in yielding load of (Slab-9) at about (11.8%).

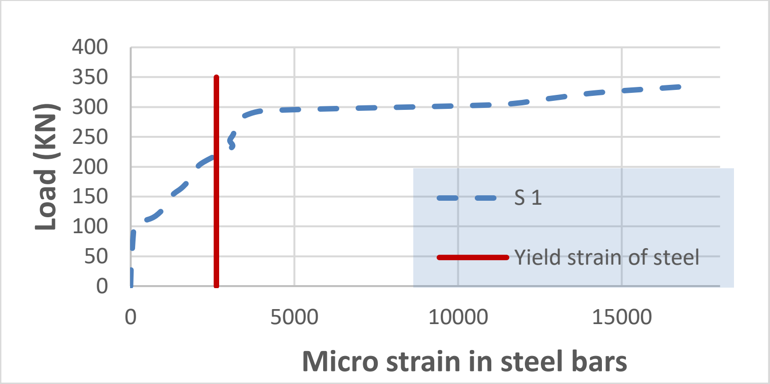

Fig. 18 Load strain curves for solid slab (S1)

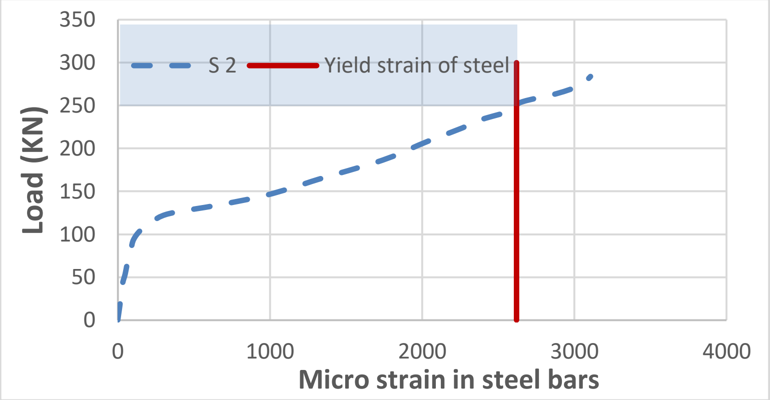

Fig. 19 Load strain curves for (S2)

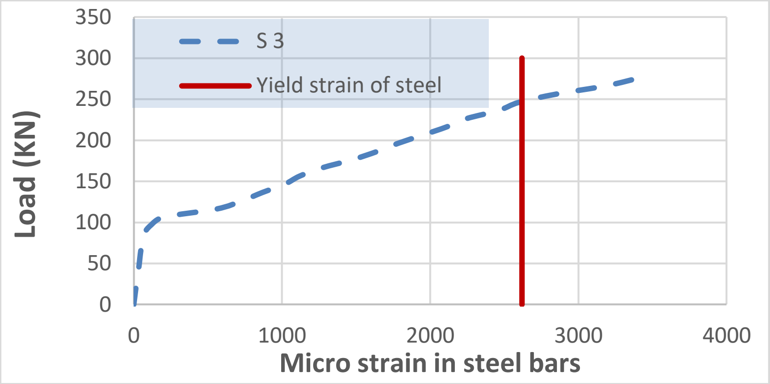

Fig. 20 Load strain curves for slab (S3)

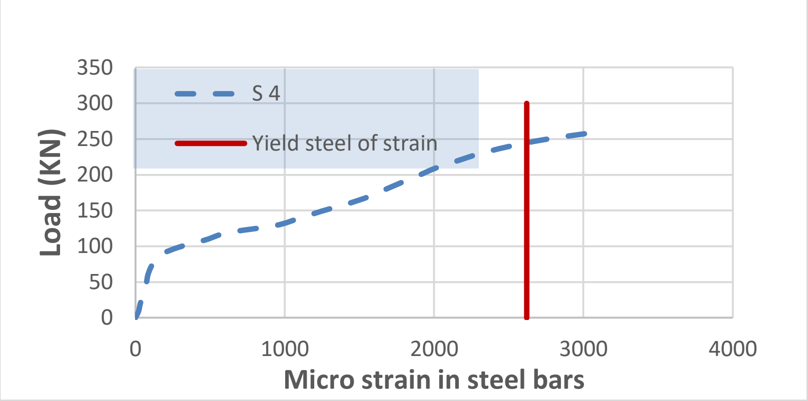

Fig. 21 Load strain curves for slab (S4)

In contrast, ultimate load increases at about (13.2%) of (slab-9). Furthermore, it was recognized that ultimate load of the specimen under repeated load display higher than the specimen under monotonic load, and did not agree with trend of other specimens. The reason for the non-conformity of this specimen became obvious with unexpected shear failure mode. On the other hand, ductility in repeated test decreases at about (4.7%). Load - strain curve for slab-3 is shown in Fig. 20.

Another comparison between (slab-4 and slab-10) was conducted. The purpose of this comparison is to illustrate the core number influence on overall performance of the hollow core slab. The rate of decreasing in (slab-10) at about (5.6%) and (5.5%) of yielding load and ultimate load, respectively, compared with (slab-4). The ductility reduces at about (7.2%). When tested specimens with square hollow-core under monotonic and repeated loading (slab-5 and slab-11). Load at yielding and load at ultimate capacity in (slab-11) decreases at about (5.7%) and (2.7%), respectively. Because of repeated loading effect. Load - strain curves for specimens (slab 4) and (slab5) is shown in Figs. 21 and 22.

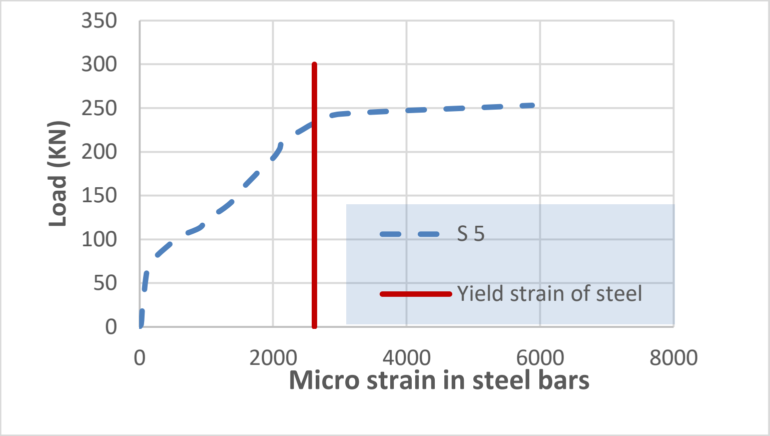

Fig. 22 Load strain curves for slab (S5)

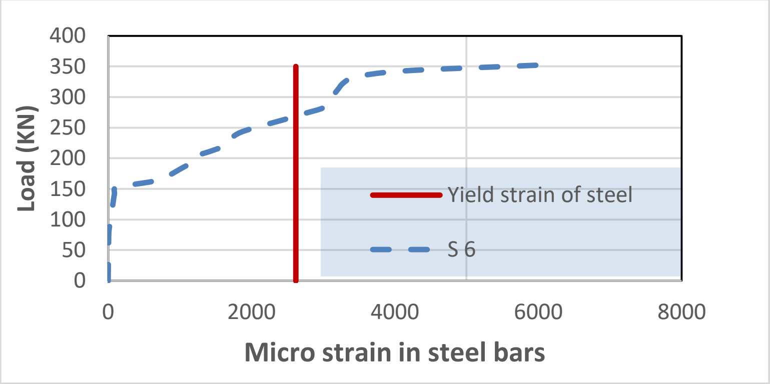

Fig. 23 Load strain curves for solid slab (S6)

For comparison between circular hollow-core slab with S.F (slab-6 and slab-12) showed that the specimen that subjected to repeated loading, decreased in yielding load and ultimate load at about (13.5%) and (30%), respectively. Ductility in (slab-6 and slab-12) is about (1.93) and (1.77) respectively. Load -strain curve of slab 6 is shown in Fig. 23.

4.3 Load-deflection curves

The specimens' behaviors were evaluated in terms of load deflection performance. During the monotonic tests, it was noticed that the load increased linearly with mid span deflection until bottom steel bars yielded. After that, the load deflection curve exhibited nearly horizontal with an increase in the deflection until the failure of specimens occurred. On the other hand, the results got from these repeated tests were compared to the monotonic tests results.

Fig. 24 to Fig. 29 shows the load versus the monotonic and the repeated deflection curves for the twelve tested slabs. Both solid slabs (slab1 & slab7) and circular hollow-core slab with S.F (slab6 & slab12) showed relatively large deflection values before failing the specimens in monotonic and repeated cases. The square hollow-core slabs showed lower load carrying capacity as well as deflection at failure than other specimens. The ultimate load of slab 5 and slab 11 was 226.9 kN and 220.69 kN, respectively. This is because the main cracks occurs generally bellowing the neutral axis at corners of the square hollow core. Thus, the slab response is dependent mainly on the concrete strength. Also, a reduction in weight in (slab-5 and slab-11) is (5.4%). The shear failure mode was happened for both slabs.

For comparison between solid (slab-1 and slab-7) and 50 mm circular hollow core (Slab-2 and slab-8), ultimate load and deflection decreases in (slab-2) by about (13.46%) and (23.14%), respectively. Also, ultimate load and deflection decreases in (slab-8) at about (3.76%) and (26.74%), respectively. Reduction in weight is about (3.27%). Shear failure mode is observed for both (slab-2 and slab-8).

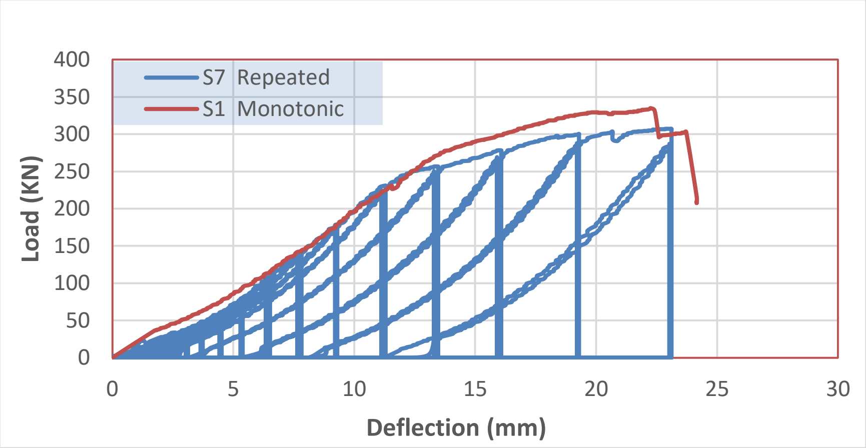

Fig. 24 Load deflection curves for solid slab with Different Loading

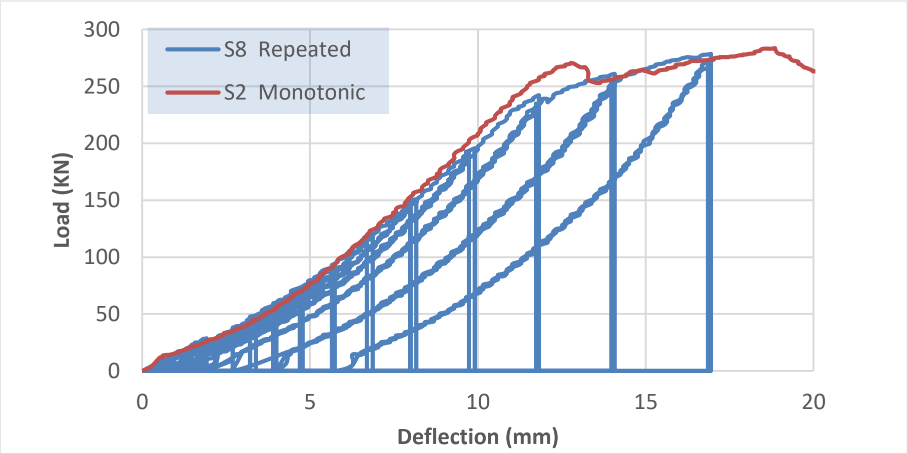

Fig. 25 Load deflection curves for one core size 50 mm (HCS) with Different Loading

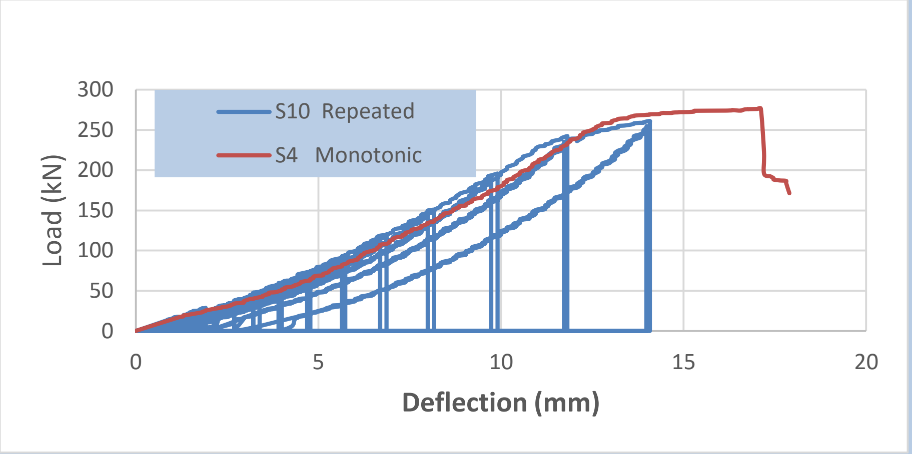

Fig. 26 Load deflection curves for Two core size 50 mm (HCS) with Different Loading

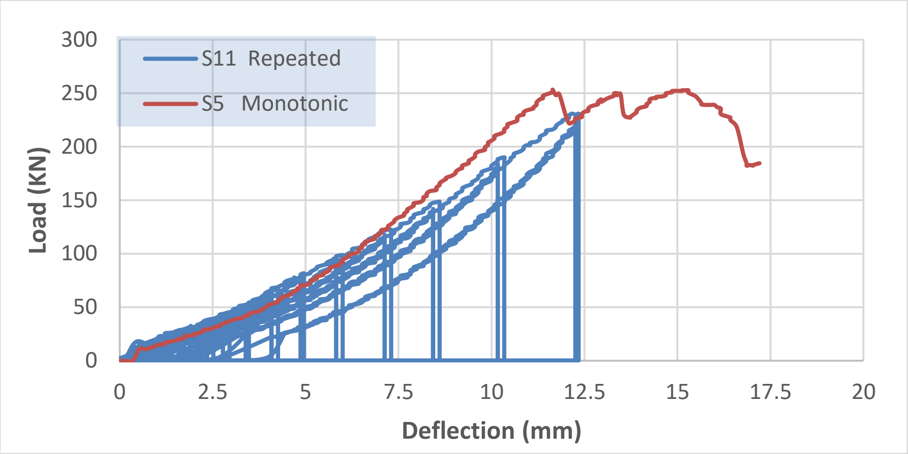

Fig. 27 Load deflection curves for Square core dimensions (57 x 57) mm (HCS) with Different Loading

For slab3, slab9, slab4, and slab10, these specimens have same voided area but different in the number and size of hollow core. The ultimate load carrying capacities of slab3, slab9, slab4, and slab10with respect to control slabs (slab1 & slab7) decreased by 24.6%, 14.2%, 16.8%, and 21.3%, respectively. The ultimate load obtained for slab3, slab9, slab4, and slab10 is 250.79 kN, 285.2kN, 276.57kN, and 261kN, respectively. The reduction in weight in four specimens is about (6.54%).

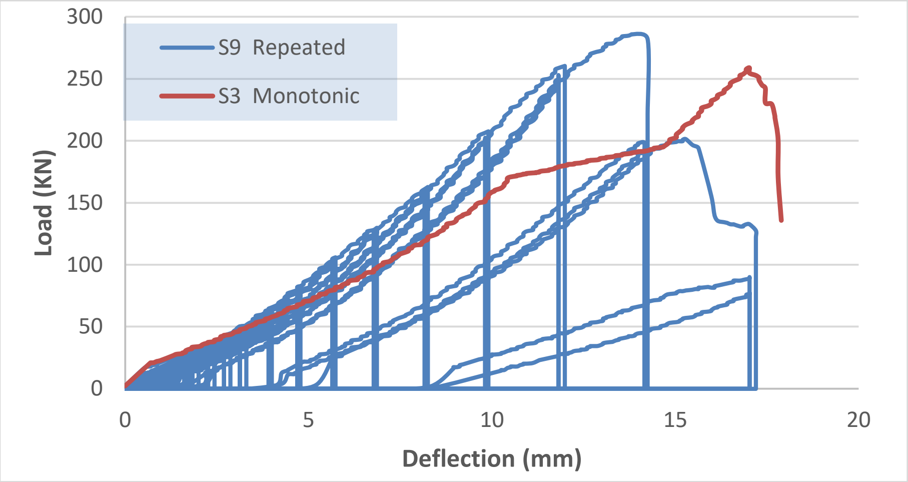

Fig. 28 Load deflection curves for one core size 100 mm (HCS) with Different Loading

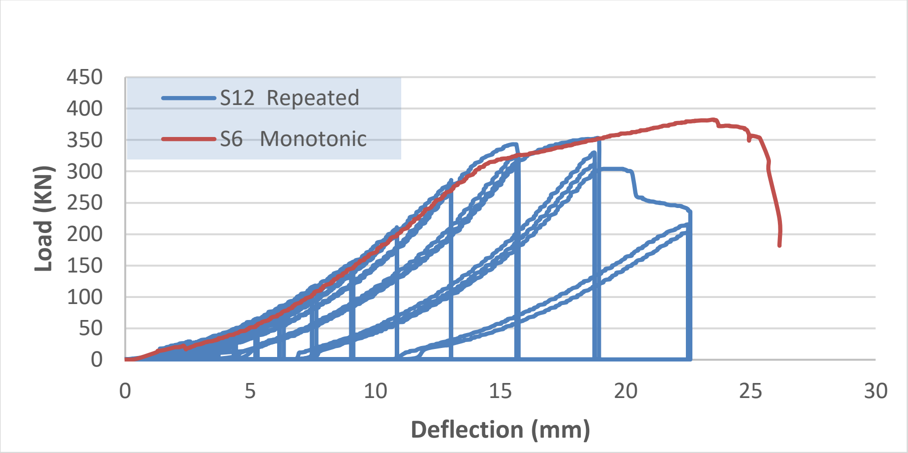

Fig. 29 Load deflection curves for one core size 100 mm S.F (HCS) with Different Loading

5. Conclusions

The main task of this research was to investigate experimentally the response of reinforced concrete solid and hollow-core slabs under monotonic and repeated loading. The test program is carried out to study the effects of load type, core diameters, core shape, number of cores, and steel fiber existence on slab behavior. Based on this study, the main conclusions emerged from laboratory testing is given in the followings.

- Reducing in stiffness resulting from repeated loading causing reduction of ultimate loads in contrast, the crack loads do not influence.

- The loading and reloading at stress level above the steel yielding strength of the specimen does not produce a considerable reduction in the slab stiffness.
- Increasing the voids diameter leads to decreasing in crack loads and also ultimate loads capacity of moderately thick hollow core slab.
- The circular hollow core slab that contain steel fibers more ductile from the circular hollow core slab without steel fibers. Existence the steel fiber leads to increasing in ultimate strength and deflection resulting from monotonic and repeated loading.
- The hollow core shape has remarkable influence on overall performance of the specimens. On the other word, the square hollow-core slabs showed lower load carrying capacity as well as deflection at failure than other specimens
- Reducing in ductility when applied the specimens under repeated loading effects.

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