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STRUCTURAL BEHAVIOR OF VOIDED NORMAL AND HIGH STRENGTH REINFORCED CONCRETE SLABS

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ABSTRACT

The intent of this paper is to study the structural behavior of voided normal and high strength reinforced concrete two-way slabs. Voided slab is a hollow core slab which has an advantage of reducing self-weight by reducing concrete mass within the center zone of the slab section. The experimental program included testing of twelve simply supported slab specimens with dimensions of (1100 x 1100 x 100) mm, and they were subjected to vertical four patch loads. Many parameters were included, such as shape of voids (spherical and cubic), type of concrete strength (normal of 30 MPa strength and high of 60 MPa strength), and ratio of steel reinforcement (0.002, 0.0026). In addition, they have different values of dimension of void to slab thickness (D/H) ratio (0.5, 0.6 and 0.65). The experimental results showed that the use of voided slabs tends to save in self-weight up to 21.6%. The use of spherical voids in voided slabs is more effective than cubic voids due to cracking and ultimate loads capacity and the structural behavior. The use of voided slabs led to reducing the first cracking load in a range of 15%-62% and 5%-40% for high and normal strength, respectively. Also, using voided slabs tended to reduce the ultimate load capacity in a range of 8%-26% for balls and 9%-48% for cubes. Using high strength concrete in voided slabs led to reducing the crack width in a range of 18.2%-27.8% for voided slabs (65 mm ball shapes). Decreasing the size of voids led to reducing the deflection for the same stages of load in a range of 20%-35.7% for high strength voided slab (ρ= 0.20% ball shapes) specimens. Increasing the reinforcement ratio from 0.2% to 0.26% led to reducing the deflection in a range of 1.6%-35.9% for high strength voided slab (ball shapes D=60mm) specimens.

KEYWORDS: Voided slab; Flat slab; High strength; Reinforced concrete; Structural behavior

1. INTRODUCTION

Reinforced concrete structures are largely used in many applications. The most general types of constructional elements are reinforced concrete slabs. Voided slab is a hollow core slab which has an advantage of reducing self-weight (Lai, 2010; Chung et al., 2010; Călin et al., 2010). Badkubi, (2016) studied the behavior and ultimate load carrying capacity of Reactive Powder Concrete (RPC) continuous bubbled slabs. It was found that using RPC instead of NC increases the ultimate load capacity (Badkubi, 2016). Many studies included the use of different void shapes, such as balls and elliptical voids, different strength, and load conditions (Amer et al., 2013). The intent of this paper is to assist regulatory authorities, engineers, developers, and other interested parties in understanding the structural behavior of simply supported voided normal and high strength reinforced concrete slabs by studying many parameters, such as shape of voids (spherical and cubic), type of concrete strength (normal of 30 MPa strength and high of 60 MPa strength), ratio of steel reinforcement (0.002, 0.0026), and dimension of void to slab thickness ratio (D/H) (0.5, 0.6 and 0.65) and comparing them with solid slab.

2. EXPERIMENTAL PROGRAM

The experimental program includes performance tests twelve slabs. All of the slabs are simply supported slabs with single span and dimensions of (1100 x 1100 x 100) mm. The slabs are made from different types of concrete, seven of them with high strength concrete, whilst the others are made from normal strength concrete. Ten of the slabs are voided, and the other two slabs are solid. Two shapes of voids are used in this research, i.e. spherical and cubic shapes. All slabs were tested under vertical four patch loads at the structural laboratory in the Department of Civil Engineering /Faculty of Engineering / University of Kufa.

3. MATERIALS PROPERTIES

The properties of all materials, which are used to produce the slab specimens, are presented in this section. These materials are: cement, fine aggregate, course aggregate, super plasticizer, mixing water, steel bars, and voids (plastic balls & styropor cubes).

In this study Ordinary Portland cement (Type I) was used. The ordinary Portland cement has been manufactured by (KAR) company for cement production (Najaf- Iraq), and complies with the Iraqi Specifications (IQ.S. 5/1984).

Normal sand imparted from Al-Najaf zone in Iraq was used as fine aggregate for concrete mixes in this paper. The maximum size of sand has (4.75mm) with soft structure and rounded particle form with fineness modulus of (2.54). The fine aggregate grading and the sulfate content indicate results that were within the Iraqi Specification according to (IQ.S. 45/1984).

Gravel (Crushed coarse aggregate) having maximum size of (10mm) with absorption and specific gravity of (0.67%) and (2.66), respectively, was used for casting all concrete samples. Sieve analysis test showed that the coarse aggregate grading is with the requirements of the Iraqi specifications (IQ.S.45/1984).

Super Plasticizer known commercially GLENIUM®54 is used in this study to achieve high strength concrete. It is produced by BASF Company and conforms to ASTM C 494 Type F.

In this study, ordinary clean tap water was used for concrete mixture as well as washing sand and gravel particles, and curing for all slab specimens.

Two types of steel reinforcement are used in the present work. For solid slabs, deformed steel bars are used as bottom steel reinforcement of the slabs, in long and short directions. All deformed steel bars have the size of (Ø 4mm) in diameter and conform to the ASTM A615M specification. For voided slabs, two layers of smooth steel mesh (Ø 2mm) in diameter are used to fix the voids within the slabs in addition to deformed steel bars.

In the present study, plastic balls with different diameters of (65 mm & 60 mm) and cubic styropor with dimensions of (60 mm & 50 mm) are used inside the concrete slab to made voids as shown in Fig. 1.

Fig. 1. Photographs show plastic balls and styropor cubes voids.

4. CONCRETE MIXTURE DESIGN

According to ACI 211.1-91 mix design method, the normal strength concrete slab was designed with compressive strength of (30MPa) at 28 days. According to P.C. Aitcin method the high strength concrete slab was designed with compressive strength of (60 MPa) at 28 days. Low water/cement ratio, high cement content, and using super plasticizer are necessary to achieve High Strength Concrete (HSC). Through the earlier stage of the study, several trial mixes have been made. At ages of (7 and 28 days), the trial mixes were tested until the proper mix was achieved which gave a good workability and an adequate strength.

5. SPECIMENS PREPRATION

In this section, descriptions of all specimens of voided and solid slabs which are used in this research are given in Table 1. In addition, five parametric studies are done during the laboratory work as given in and Table 2. The slabs were designed in accordance with ACI318M-14. The main steel reinforcement in each direction was consisted of (21Ø 4mm) of steel ratio (ρ=0.26%) and (16 Ø 4mm) of steel ratio (ρ=0.20%) in two directions as shown in Figs. 2 and 3. For voided slab specimens the voids (balls or cubes) were placed at their locations for all area. Voids fixed in their locations by two layers of steel mesh (Ø 2mm) at top and bottom of voids to prevent plastic balls or styropor cubes from moving during the casting of concrete as shown in Figs. 4 and 5.

Table 1. Descriptions of voided and solid slabs

No.	Symbol of Slab	Type of Strength	Type of Voids	Dia. of Voids (cm)	(D/H) Ratio	Reinforcement Ratio r=As/(bd)
1	B1R1H	High	Ball	6.5	0.65	0.0026
2	B1R2H	High	Ball	6.5	0.65	0.0020
3	B1R2N	Normal	Ball	6.5	0.65	0.0020
4	B2R2H	High	Ball	6	0.6	0.0020
5	B2R1H	High	Ball	6	0.6	0.0026
6	B2R2N	Normal	Ball	6	0.6	0.0020
7	C1R1H	High	Cubic	6	0.6	0.0026
8	C1R2N	Normal	Cubic	6	0.6	0.0020
9	C2R2N	Normal	Cubic	5	0.5	0.0020
10	C2R2H	High	Cubic	5	0.5	0.0020
11	SR2H	High	❖	0	0	0.0020
12	SR2N	Normal	❖	0	0	0.0020

❖ Solid

Table 2. Present Parametric Studies

No.	Parameter	The Description
1	Type of voided	Spherical void
		Cubic void
2	Volume of voided (D/H) ratio	0.65
		0.6
		0.5
3	Reinforcement ratio	0.20%
		0.26%
4	Strength of concrete	High
		Normal
5	Type of slab	Solid
		Voided

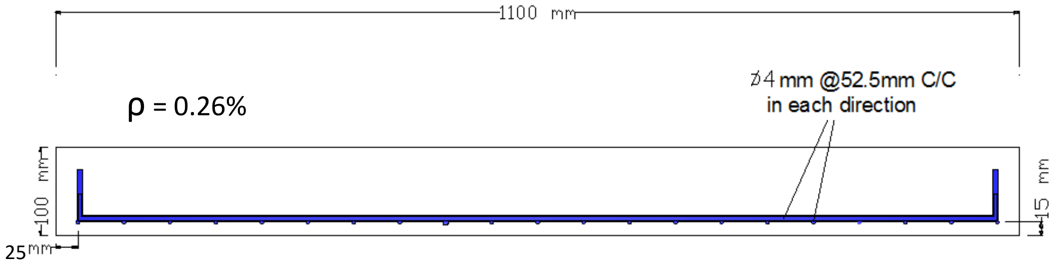

Fig. 2. Main Reinforcement details for slabs of steel ratio (0.26%).

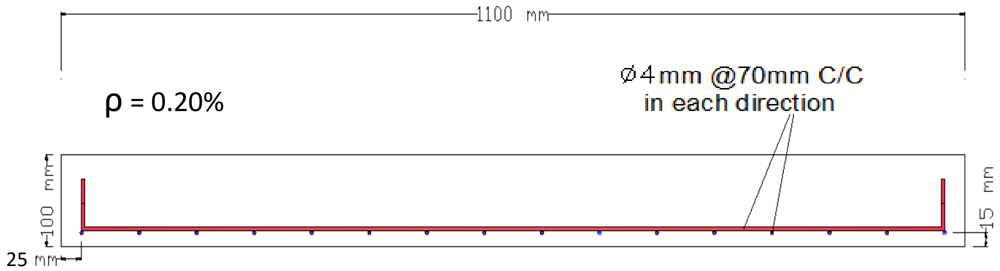

Fig. 3. Main Reinforcement details for slabs of steel ratio (0.20%).

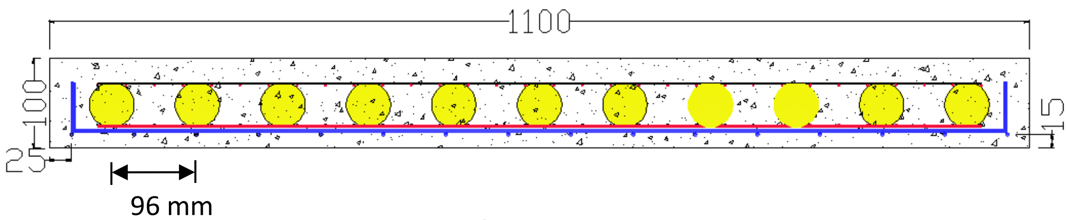

Fig. 4. Section of voided slabs using balls.

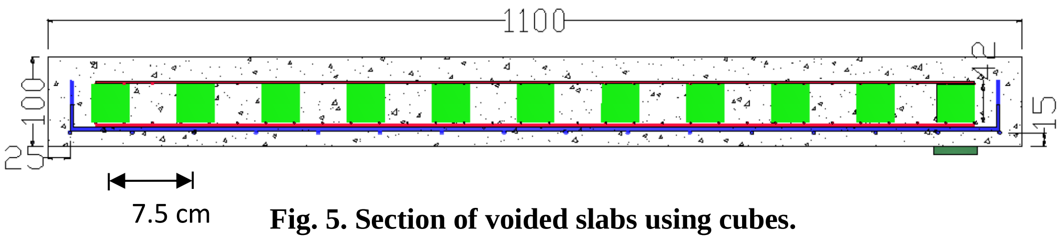

Fig. 5. Section of voided slabs using cubes.

6. TEST SETUP

After curing, all slabs were supported by a stiff steel framework using C-sections (100 mm). On the upper of the square steel basis, three plain bars (10mm) in diameter in each side were welded to get a simply supported with a dimension of (950mm) square slab as shown in the Figs. 6 and 7. A hydraulic machine of (2000) kN capacity is used to apply the load which inherited to four static points using a loading base which is consisted of three steel members using I-sections of (100×70) mm. All slabs were loaded up to ultimate loads.

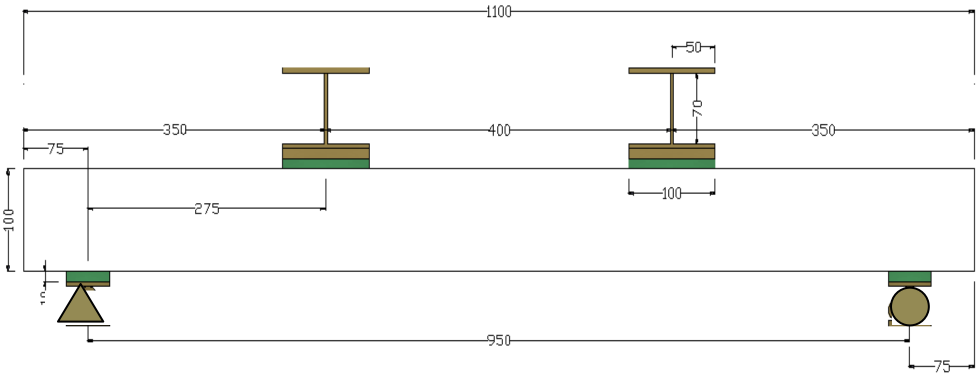

Fig. 6. Test setup and supporting details.

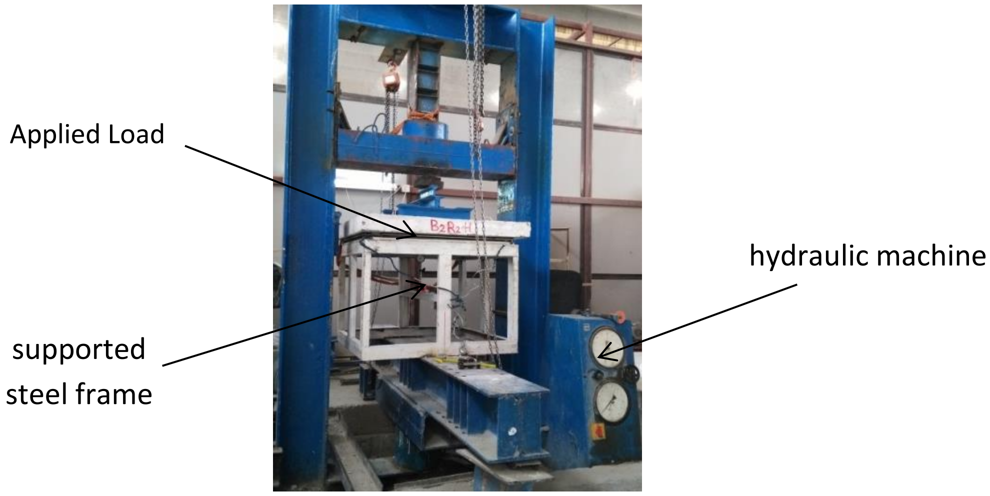

Fig. 7. Test slabs by hydraulic machine.

7. EXPERIMENTAL RESULTS

In this section, analyzing and discussing the results of experimental work are presented to assess the structural behavior of voided reinforced concrete slabs and compare the results with the solid slabs. The structural behavior based on cracking and ultimate loads, behavior of load deflection and failure mode.

8. BEHAVIOR OF LOAD DEFLECTION

The load central deflections of slabs were measured by using a dial gage at the center of slabs. In general, at initial stages the tested slabs exhibited linear behavior for all load deflection curves. At first crack loads a change in the slope. The nonlinear behavior will begin after the first crack loading near yielding stage. At previously stages, the load deflection curves are near to each another for voided slabs. The use of high strength concrete is more effective for solid slabs rather than for voided slabs as shown in Fig. 8. The flexural rigidity of the voided slabs is smaller than the solid reference slabs by 43% and 37% for high and normal strength (60 and 30 MPa), respectively. Figs. 9 represents a comparison of load-deflection curve for all high and normal strength slabs, respectively. Due to the load-deflection behavior and minimum reduction in the ultimate load capacity, the slabs B2R1H and B2R2N are the best of all high and normal strength slabs, respectively, when they are compared with the solid slabs.

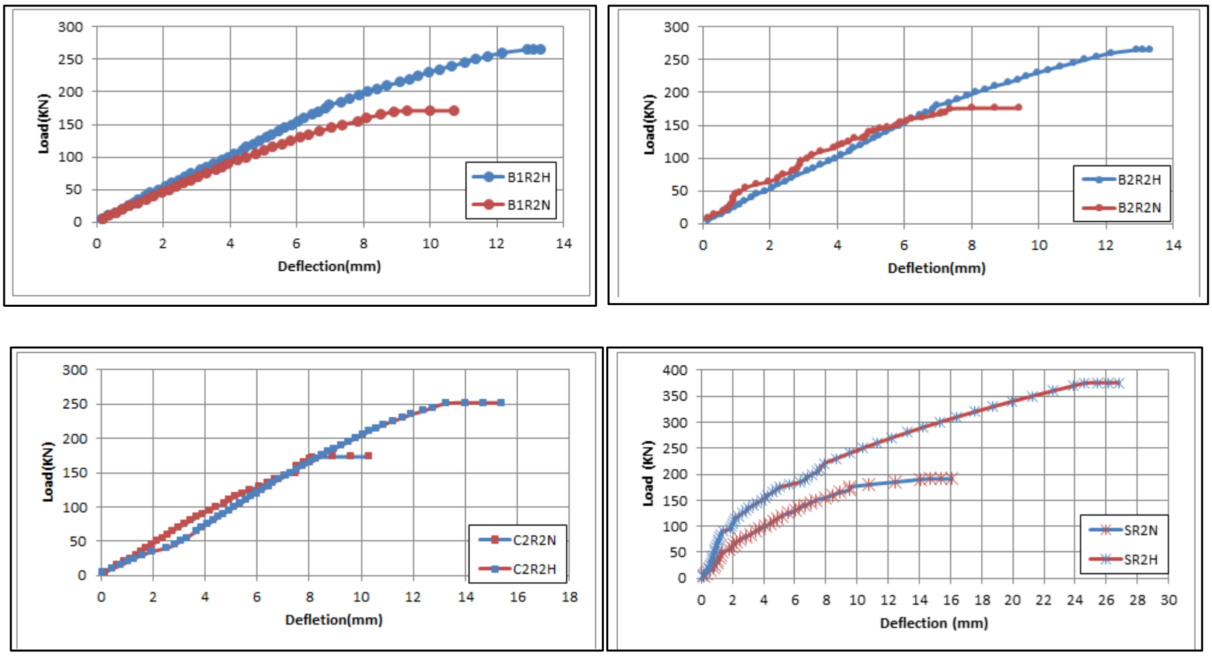

Fig. 8. Effect of using HSC on the load–deflection relationships.

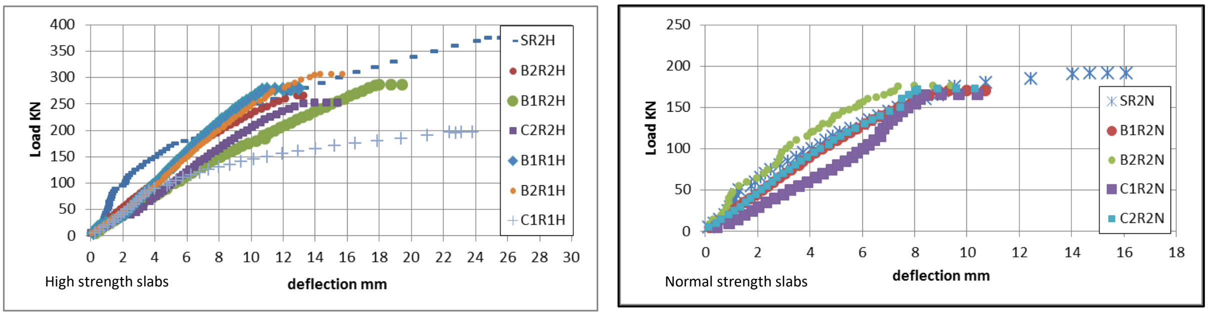

Fig. 9. Load–deflection relationships for high and normal strength slabs.

9. ULTIMATE LOAD CAPACITY OF VOIDED SLABS

The results of ultimate load capacity and the percentage of weight reduction and ultimate load reduction ratios are tabulated in Table 3. Fig. 10 shows the ultimate load values for specimens that are sorted from the highest value to the lowest value. Fig. 11 shows the ratio of weight reduction to ultimate load reduction (R2/R1) for all specimens. It may be seen from the experimental results that the maximum ratio of (R2/R1) is obtained for B2R1H and C1R2N for high and normal strength slabs, respectively. Using voided slabs tended to save in self-weight up to 21.57%.

Table 3. Ultimate load capacity and weight reduction results.

Slab name	Ultimate Load Pu (kN)	Reduction in Ultimate Load% (R1)	Weight (kg)	Reduction in Weight % (R2)	R2/R1
SR2H	375	---	283	0	0
SR2N	190	---	270	0	0
B1R1H	276	26.4	249	13.64	0.516
B1R2H	265	29.33	245	13.64	0.465
B1R2N	170	10.53	233	13.63	1.295
B2R1H	305	18.67	255	11.24	0.602
B2R2H	285	24	251	11.24	0.468
B2R2N	175	7.89	239	11.24	1.42
C1R1H	195	48	226	21.57	0.449
C1R2N	165	13.16	211	21.56	1.638
C2R2H	251	33.07	248	12.48	0.377
C2R2N	172	9.47	236	12.47	1.312

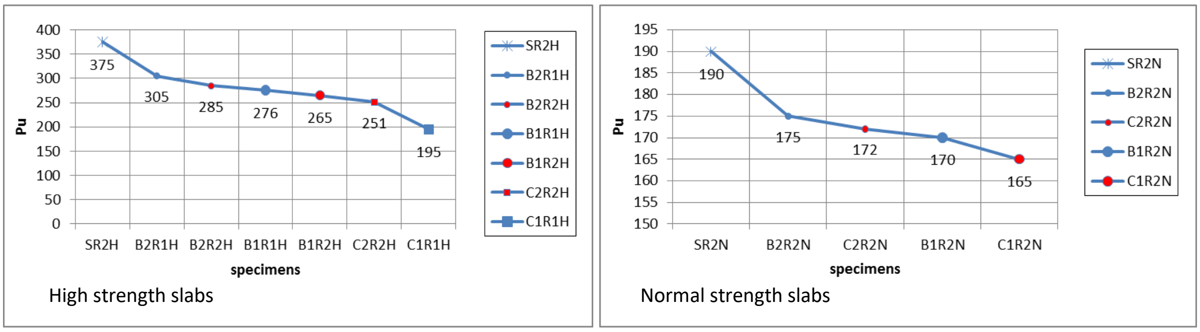

Fig. 10. Ultimate load capacity for high and normal strength specimens.

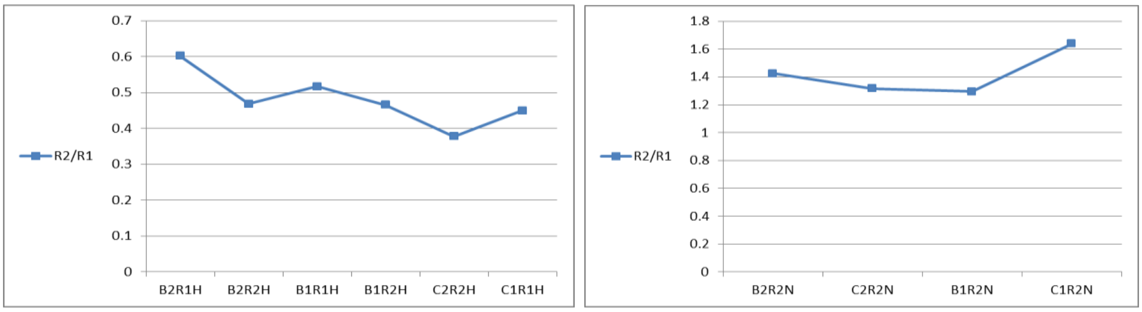

Fig. 11. Reduction in weight to ultimate load reduction ratio (R2/R1) for high and normal strength slabs.

10. CRACKING BEHAVIOR

To assess the behavior of the voided concrete slabs, crack formation was monitored throughout testing in comparison with the action of control solid slab. The first cracking loads (Pcr), cracking patterns, and width of all slabs are given in the following sections.

The first cracking load results are presented in Table 4. From Fig. 12, it may be seen the ratio of first cracking load for voided slabs in relation to the control slabs (SR2H, SR2N) decreased in a range of 15%-62% and 5%-40% for high and normal strength, respectively. Fig. 13 displays ultimate load capacity and load at the first crack for all specimens.

Table 4. First Cracking Load for Slabs.

Slab name	First crack load Pcr (kN)	Ultimate load Pu (kN)	Pcr/Pu %
SR2H	65	375	17
SR2N	40	190	21
B1R1H	55	276	20
B1R2H	48	265	18
B1R2N	30	170	18
B2R1H	43	305	14
B2R2H	35	285	12
B2R2N	38	175	22
C1R1H	35	195	18
C1R2N	35	165	21
C2R2H	25	251	10
C2R2N	24	172	14

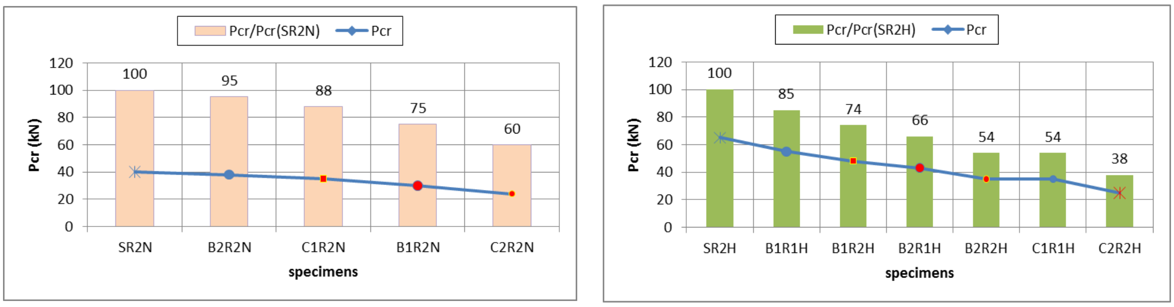

Fig. 12. The ratio of first cracking load of voided slab to reference of solid slab.

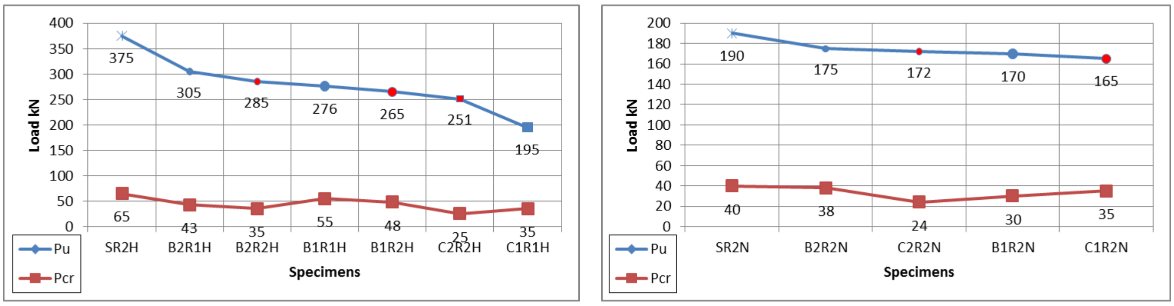

Fig. 13. First crack and ultimate loads for high and normal strength slabs.

In general, the specimens showed flexural failure mode as shown in Fig. 14. Cracks were increased for voided slabs compared to the solid slabs.

Fig. 14. Cracks patterns for all specimens.

The control slabs (SR2H, SR2N) gave less crack width for the same loading stage compared to voided slab specimens. The specimens that contained a small ball (B2) voids (B2R2H, B2R1H) gave the least crack width compared to the other of the specimens, while the specimens that contained a big cube (C1) voids (C1R2H, C1R2N) gave the highest crack width as shown in Fig. 15.

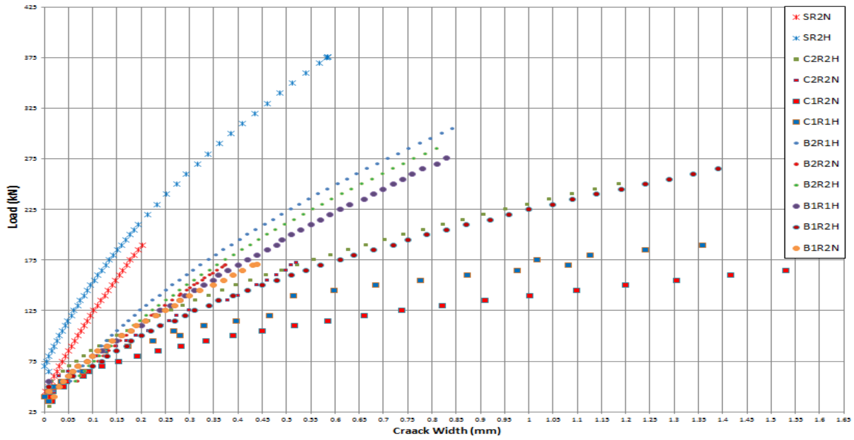

Fig. 15. Crack width for all slabs.

11. CONCLUSIONS

- Using voided slabs tends to save in self-weight up to 21.6%.
- The use of ball voids for voided slab is better than cubic voids.
- The use of voided slabs leads to reduce the first cracking load in a range of 15%-62% and 5%-40% for high and normal strength, respectively. Also, using voided slabs tend to reduce the ultimate load capacity in a range of 8%-26% for balls and 9%-48% for cubes.
- Using high strength concrete in voided slabs leads to reduce the crack width in a range (18.2%-27.8%) for voided slabs (65 mm ball shapes).
- Decreasing the size of voids leads to reduce the deflection for the same stages of load in a range of (20%-35.7%) for high strength voided slab (ρ = 0.20% ball shapes) specimens.
- Increasing the reinforcement ratio from (0.2%) to (0.26%) leads to reduce the deflection in a range (11.6%-35.9%) for high strength voided slab (ball shapes D=60mm) specimens.

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