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Punching Shear Behavior of Voided Reinforced Concrete Flat Plate Panels

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ABSTRACT:

This investigation focuses experimentally the behavior of voided slab panels under punching shear stresses applied at the center of the panel. Six reinforced concrete flat plate panels were cast with different concrete types; normal strength concrete, high strength concrete and modified reactive powder concrete. The ultimate carrying capacity of voided panels were decreased about 18%, 10.2% and 8.8% in comparison with solid panels of normal strength concrete, high strength concrete and modified reactive powder concrete respectively. In addition, the first crack load of voided panels were decreased about 41.2%, 43.6% and 34.6% in comparison with solid panels of normal strength concrete, high strength concrete and modified reactive powder concrete respectively. Also, the deflection of voided panels through loading life were increased due to decrease its stiffness.

Keywords - bubbles, cracking load, deflection, flat plate slab, punching shear, stiffness, ultimate load, voided slab.

I. INTRODUCTION

Reducing the construction cost of concrete structures is considered one of important consideration that must be taken in to account. To achieve lightweight structures, several methods were adopted in the past; using lightweight aggregate concrete [1], using small concrete sections by using concrete with high mechanical properties [2] and using voids at the non-working concrete zone inside the section [3].

Flat plate floor system is considered one of the most commonly used slabs in multi-story buildings. The self-weight of flat plate slab is heavy because of large thickness to resist the punching shear stresses at slab-column connection. By introducing voids at the middle height of the section of slab, the own weight of the slab can be reduced and this lead to reduced the overall cost of the building . A decrease in the weight of the slab naturally leads to a decrease in its stiffness, which to some extent affects the slab carrying capacity [4].

The aim of this investigation is to removing the unused concrete from the middle height of the section by inserting a spherical balls, and studying the variation in the ultimate and cracking capacities of the slab in addition to evaluate the failure pattern and amount of reduction in stiffness resulting from a decrease in a second moment of inertia [5].

II. EXPERIMENTAL WORK

The material properties and specifications required for casting six reinforced concrete slabs of dimension (1000 mm of span, 1000 mm of breadth, and 70 mm of thickness) are illustrated below:

II.I FINE AGGREGATE

4.75 mm maximum size of natural sand is used as fine aggregate for normal concrete. The results showed that the grading of fine aggregate and the content of sulfate are within the requirements of the BS882:1992 [6]. Sand grading and physical properties are shown in Table 1 and Table 2 respectively.

Table 1: Physical specifications of sand

Physical properties	Test results
Specific gravity	2.49
Sulfate content	0.09%
Absorption	0.73%

Table 2: Sieve analysis of sand

No.	Sieve size (mm)	% Passing
1	10	100
2	5	91.41
3	2.36	71.47
4	1.18	56.26
5	0.6	44.49
6	0.3	38.53
7	0.15	10.52

II.II COARSE AGGREGATE

14 mm maximum size of natural gravel is used as coarse aggregate for concrete. The grading of the gravel is illustrated in Table 3. The obtained results indicate that the coarse aggregate grading is within the requirements of the BS882:1992 [6].

Table 3: Grading of coarse aggregate

No.	Sieve size (mm)	% Passing
1	20	100
2	14	95.36
3	10	66.2
4	5	8.1
5	2.36	0

II.III CEMENT

For all concrete mixes, Ordinary Portland Cement (OPC), (Type I) was used . The chemical composition and physical properties of cement are illustrated in Table 4 and Table 5 respectively. The results confirm to the American Standards ASTM-C150 [7].

Table 4: Chemical composition of cement

Chemical composition	Percentage (%)
Cao	62.33
SiO2	22.01
AL2O3	5.49
Fe2O3	3.93
MgO	2.54
SO3	1.92
L.O.I	0.83
Insoluble residue	1.2
L.S.F	0.86
C3S	35.66
C2S	36.2
C3A	7.91
C4AF	11.95

Table 5: Physical properties of the cement

Physical properties	Test result
Fineness using Blain air permeability apparatus(m/kg)	282.4
Soundness using autoclave method	0.4
Setting time using vicat's instrument initial setting time (minutes) Final setting time (hours)	 160 4
Compressive strength for cement cube (70.7mm) at 3 days (MPa) 7days (MPa) 28days (MPa)	 26 37 46

II.IV STEEL REINFORCEMENT

Three specimens with (500 mm length) prepared for each diameter of the reinforcing steel bars according to ASTM C370-16 [8]. The test results showed that the tested samples confirm to ASTM A615-09 (9), as mentioned in Table 6 and Table 7.

Table 6: Properties of steel bars

Nominal diameter (mm)	Measured diameter (mm)	Elastic Modulus (GPa)	Yield stress (MPa)	Ultimate strength (MPa)
6	9.53	200	484	719

Table 7: Properties of steel meshes

Property	Specifications
Relative density	7860 kg/m3
Yield strength	1130 MPa
Modulus of elasticity	200000 MPa
Strain at portion limit	$5650x10^{-6}$
Poisson's ratio	0.28
Average length	50mm
Nominal diameter	0.5 mm
Aspect ratio	100

II.V SILICA FUME

A grey colored identified silica fume was used as an admixture in MRPC mix to improve its properties. The fineness of the used silica fume was 20000 m2/kg. The chemical composition of this silica fume conforms to the ASTM C 1240-04 [10], as shown in Table 8.

Table 8: Properties of silica fume

Chemical composition	**Content (%)**
CaO	0.5
Fe2O3	1.4
Al2O3	0.5
SiO2	92.1
MgO	0.3
K2O	0.7
Na2O	0.3
So3	0.1
L.O.I	2.8

II.VI SUPERPLASTISIZER

In order to produce high strength concrete mixes, super-plasticizer based on poly carboxylic ether must be used. Also, it can be called (high range water reducing agent HRWRA). Glenium51 is one of the new generation of polymer which mainly used in designed super-plasticizer; the normal dosage for Glenium51 is 0.5-0.8 L/100kg of cement. Table 9 illustrates the typical properties of super-plasticizer.

Table 9: Properties of superplastisizer

Main action	Super-plastisizer
Color	Light brown
Ph Value	6.6
Form	Viscous liquid
Chlorides	Free of chloride
Relative density	1.08-1.15 gm/cm3 @25^{O}C
Viscosity	128±30 cps @20^{O}C
Transport	Not classified as dangerous
labeling	No hazard label required

II. IX COMPRESSIVE STRENGTH OF CONCRETE

For each mix, three cylinders were tested under compression load according to ASTM C-39 [11], the average compressive strength are listed in Table 10 below.

Table 10: Compressive strength of concrete

Concrete type	specimen No.	Cylinder compressive strength (MPa)	Average cylinder compressive ctrength (MPa)
Normal Strength Concrete	1	27.73	26.36
	2	25.99	
	3	25.36	
High Strength Concrete	1	62.87	64.2
	2	64.20	
	3	65.55	
Modifie Reactive Powder Concrete	1	73.35	73.13
	2	70.29	
	3	75.77	

II. X TENSILE STRENGTH OF CONCRETE

For each mix, three cylinders were tested under splitting load according to BS 1881-117 [12], the average tensile strength are listed in Table 11 below.

Table 11: Splitting tensile strength of concrete

Concrete type	Specimen No.	Splitting tensile strength (MPa)	Average splitting tensile strength (MPa)
Normal Strength Concrete	1	2.82	2.87
	2	3.11	
	3	2.69	
High Strength Concrete	1	3.87	3.85
	2	4.01	
	3	3.67	
Modified Reactive Powder Concrete	1	6.11	5.96
	2	5.83	
	3	5.94	

II. XI SPECIMENS DETAILS

It had been poured and tested six reinforced concrete slabs, two of them were poured with normal strength concrete (NSC), two of slabs were poured high strength concrete (HSC), and two were poured modified reactive powder concrete (MRPC). All specimens designed to fail by punching shear failure.

The dimensions of slab supporting were (1000 mm length x 1000 mm width x 70 mm thickness), the slabs reinforced with (ϕ 6@120 mm) smooth longitudinal bars in each direction of bottom reinforcement. The concentrated force was applied by steel column at the center of surface.

III. DISCUSSIONS AND RESULTS

III.I ULTIMATE CAPACITY

The ultimate loading capacity of tested panels are presented in Table 12. Generally, the results of ultimate load show that its decrease by inserting the voids in concrete panel.

The ultimate loads were decreased about (15.3%), (9.3%) and (8.1%) when the voids inserted in the normal strength concrete , high strength concrete, and reactive powder concrete respectively.

The use of the voids in concrete panels deteriorated the slab behavior and allowed lower forces to be transferred through the slab column connection. As a result of existing the voids in concrete panels, the voided slabs suffer from cracks extension faster than that of solid slabs.

Table 12: Cracking load of tested specimens

Specimen configuration	SN	SNB	SH	SHB	SM	SMB
Cracking load (kN)	26	17	39	22	80	47
Reduction in cracking load	R*	34.6	R*	43.6	R*	41.2
Ultimate load (kN)	85	72	130	118	185	170
Pcr. / Pult.	30.6	23.6	30	18.6	43.2	27.6

* R is the reference slab.

III.II FIRST CRACK LOAD

The first crack appeared on the tension face of the slab around the column. The first crack of normal strength concrete solid slab (SN) appeared at (30.6)% of the ultimate load. While , the first crack of normal strength concrete voided slab (SNB) appeared at (23.6)% of the ultimate load. Due to bubbles existence, the cracking load decreased in comparison with solid slab. The first crack load of solid and voided normal concrete slabs was appeared at 26 kN and 17 kN respectively.

The measured cracking load of high strength concrete slab was obtained its influence by bubbles existence; the first crack load of solid slab measured at (39) kN .while, the voided high strength concrete slab achieved first crack load about (22) kN. The first crack of high strength concrete solid slab (SH) appeared at (30)% of the ultimate load. While , the first crack of high strength concrete voided slab (SHB) appeared at (18.6)% of the ultimate load.

The first crack load of solid modified reactive powder concrete slab reached to (43.2)% of ultimate load. While the voided modified reactive powder concrete achieved first crack load at (27.6)% of the ultimate load. The first crack load of solid and voided modified reactive powder concrete slabs was appeared at 80 kN and 47 kN respectively, see Table 12.

III.III FAILURE MODE

All the tested slabs were failed in punching shear mode by propagation the cracks, these cracks propagated rapidly and extended from the column parameter toward the panel edges. At the same time, the cracks number and width were increased at the tension face of the panel. A failure occurred by crushing of the concrete especially for voided slabs see Fig. 1 to Fig. 6.

The cracking pattern depends on the type of slab which is solid or voided. So, the voided slabs have number of cracks more than that of the solid slab, in addition the crack width in voided slab was wider than that of solid slab. The voided slabs were failed in a brittle manner in comparison with solid slab.

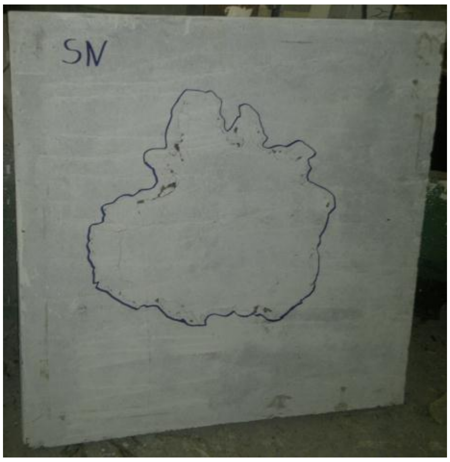

Fig.1 Failure pattern of solid normal concrete slab

Fig.2 Failure pattern of voided normal concrete slab

Fig.3 Failure pattern of solid HSC slab

Fig.4 Failure pattern of voided HSC slab

Fig.5 Failure pattern of solid MRPC slab

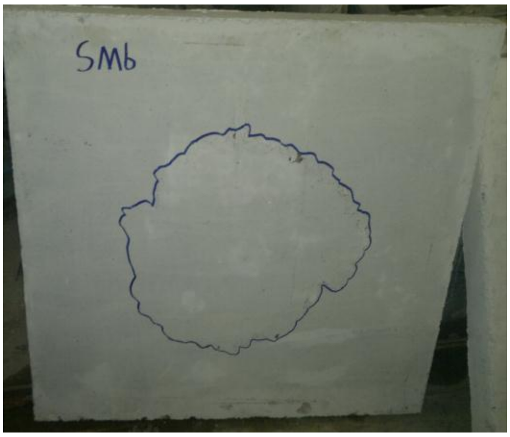

Fig.6 Failure pattern of voided MRPC slab

III.IV LOAD-DEFLECTION RESPONSE

In general, there are three main stages in load-deflection curves of tested specimens; first stage called elastic-uncracked stage, the deflection increases linearly with loading until appearance of the first crack, in this stage the materials still in elastic manner. Second stage called elastic-cracked stage, the deflection also increased linearly with loading but with a reduced slope, the stiffness of specimens was decreased gradually due to increasing the width and depth of cracks in addition to increasing the cracks numbers until yielding of reinforcing steel. After this stage, the deflection was decreased largely with small increase in load until failure of the specimens by punching shear.

At the initial loading levels, there is no significant difference in deflections as a results of loading, while the difference appeared clear in advanced loading levels; it seems the deflection in voided slabs larger than that of solid slabs for all concrete types, see Fig. 7 to Fig. 9.

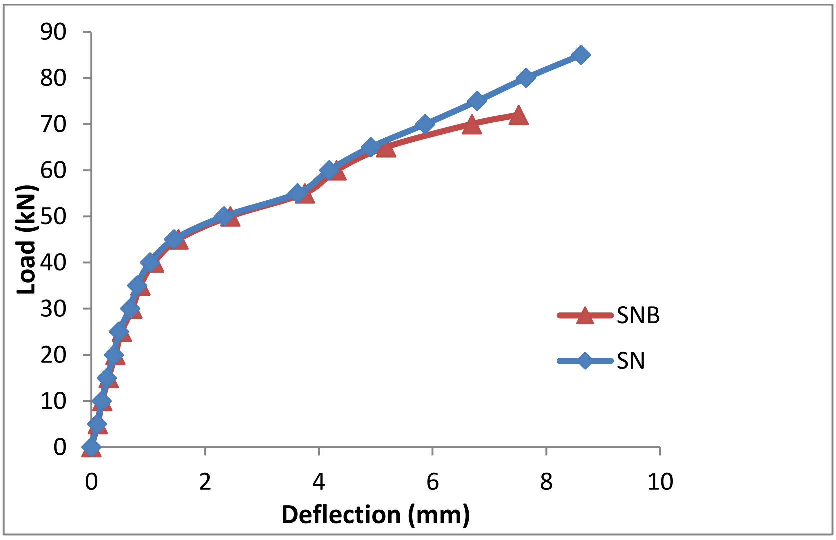

Fig.7 Load-deflection curve normal concrete slabs

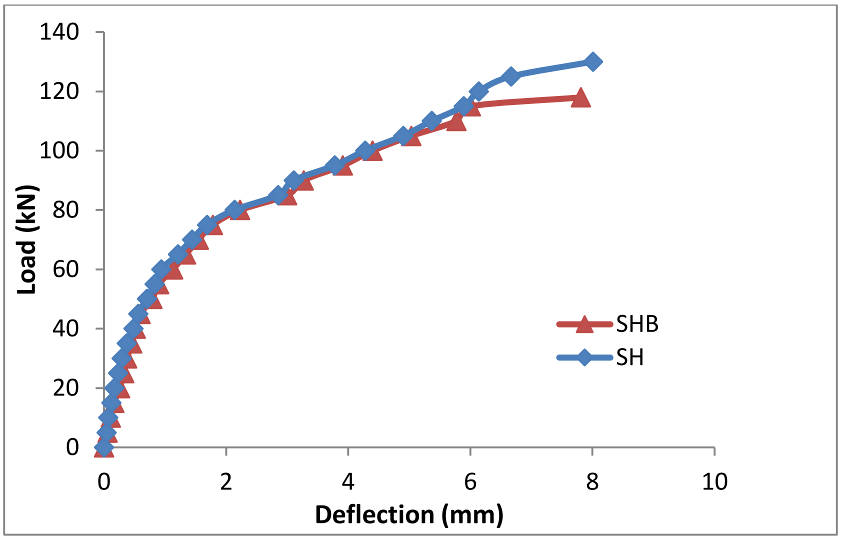

Fig.8 Load-deflection curve high strength concrete slabs

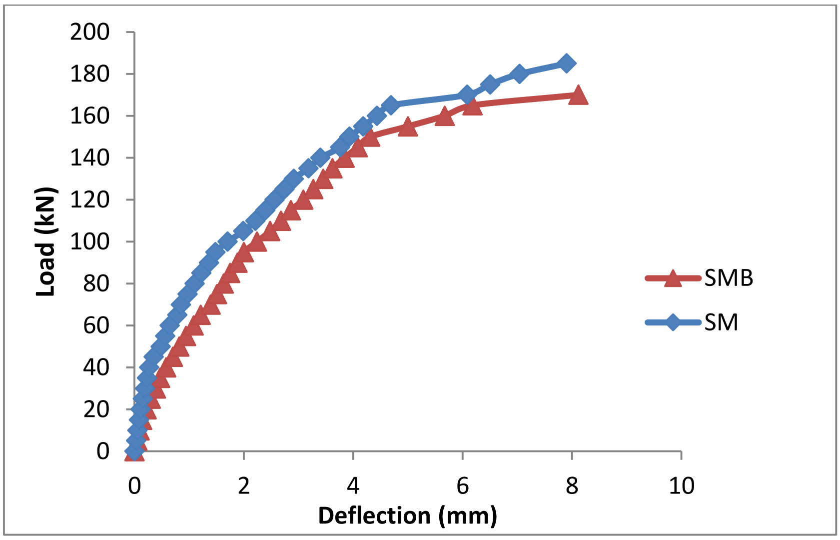

Fig.9 Load-deflection curve RPC slabs

III.V DUCTILITY OF TESTED SLABS

Ductility may be defined as the ability of the member to absorb energy before failure, it can be determined by calculating the ratio of deflection at failure to the deflection at yield. Table 13 shows the deflection at ultimate load, deflection at yield and ductility index of tested slabs. For normal strength concrete solid slab (SN), the ductility of the slab was 8.52, it is higher than the ductility of normal strength concrete voided slab (SNB) by about 20.67%. The ductility of high strength concrete voided slab (SHB) was decreased about 7.6% in comparison with high strength concrete solid slab (SH), slight decrease in ductility for voided high strength concrete slab when comparing with solid high strength concrete solid slab. The amount of the decrease in the ductility of voided modified reactive powder concrete slab seems obvious in comparison with high strength concrete voided slab, the modified reactive powder concrete voided slab (SMB) recorded about 18.96% reduction in ductility in comparison with modified reactive powder concrete solid slab.

Table 13: Ductility index of tested specimens

Specimen configuration	SN	SNB	SH	SHB	SM	SMB
Deflection at failure (mm)	8.61	7.51	8.01	7.81	7.9	8.12
Deflection at yielding (mm)	1.01	1.11	1.69	1.78	3.4	4.31
Ductility index	8.52	6.76	4.74	4.38	2.32	1.88
Reduction in ductility (%)	R*	20.67	R*	7.6	R*	18.96

R* : reference slab.

III.VI STIFFNESS OF TESTED SLABS

From Table 14, the amount of reduction in stiffness due to existing the voids didn't seems great for three types of concrete because the voids are located in a minimum stress zone inside the section (at the mid-thickness of slab section). From this table, the voided specimens recorded 2.94%, 6.97% and 10.68% reduction in stiffness if compared with solid specimens of normal strength concrete, high strength concrete and modified reactive powder concrete respectively.

Table 14: Stiffness of tested specimens

Specimen configuration	SN	SNB	SH	SHB	SM	SMB
Deflection at failure (mm)	8.61	7.51	8.01	7.81	7.9	8.12
Failure load (kN)	85	72	130	118	185	170
Stiffness (kN/mm)	9.87	9.58	16.23	15.1	23.4	20.9
Reduction in stiffness (%)	R*	2.94	R*	6.97	R*	10.68

R* : reference slab.

IV. CONCLUSION

From the results, due to reduced self-weight of the flat plate slab by inserting the voids, it may conclude that:

1. There is a decrease in ultimate strength and first crack load due to inserting the voids in all types of concrete panels.

2. The deflection in voided slabs larger than that of solid slabs for all concrete panels.
3. The ductility of tested voided slabs decreases as compared to solid slabs.
4. It is observed that there is a decrease in stiffness of slabs due to inserting the voids in all types of concrete.
5. At failure, the voided slabs have number and width of cracks larger than that of the solid slab.
6. For voided slabs , a failure occurred by crushing of the concrete.

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