Punching Shear in Voided Slab

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Abstract
The revolutionary technology of flat slab construction by using hollow sphere to replace the ineffective concrete in the center of the slab (Bubble Beck) has many advantages, beside it is reduce the material, the load, lower the coast and increasing the span length it is also a green technology, And Since the punching shear capacity is one of the most interesting properties of flat slab, the influence of the cavities due to using the plastic balls on the punching behavior of self compacted concrete was study in this paper. also the effect of strengthening the punching zone by using different percentage of steel fiber (0.8%, 1%) on the maximum punching load and deflection were included.

1.Introduction

In building, the slab is very important structural member to make a space and it is one of the largest member consuming concrete. As the people getting interest of long span buildings the slab thickness is on the increase. The increasing of slab thickness makes slab heavier, and it leads to increase column and base size. Thus, it makes building consume more materials such as concrete and steel.

For decades, several attempts have been made to create biaxial slabs with hollow cavities in order to reduce the weight. Most attempts have consisted of laying blocks of a less heavy material like expanded polystyrene between the bottom and top reinforcement, while other types including waffle slabs / grid slabs. Of these types, only waffle slabs can be regarded to have a certain use in the market. But the use will always be very limited due to reduced resistances towards shear, local punching and fire.

In the 1990ies, a new system was invented by Jorgen Breuing, eliminating the above problems, the so called BubbleDeck technology. The Bubble Deck technology uses spheres made of recycled industrial plastic to create air voids while providing strength through arch action. As a result, this allows the hollow slab to act as a normal monolithic two-way spanning concrete slab. These bubbles can decrease the dead weight up to 35% and can increase the capacity by almost 100% with the same thickness. As a result, bubble deck slabs can be lighter, stronger, and thinner than regular reinforced concrete slabs (3).

Through the tests, models and analysis from variety of institution, bubble deck was proven to be superior to the traditional solid concrete slab. The reduced dead load makes the long-term response more economical for the building while offsetting the slightly increased deflection of the slab. However, the shear and punching shear resistance of the bubble deck floor is significantly less than a solid deck since resistance is directly related to the depth of concrete. Design reduction factors have been suggested to compensate for these differences in strength. This system is certified in the Netherlands, the United Kingdom, Denmark and Germany(4).

The main objective of this study is to investigate experimentally punching shear strengths of voided slab with self compacted concrete, and the effect of strengthening zone with using two different values of steel fiber (1% , 0.8%) by volume friction at distance d from the face of the column.

2.Experimental work

To investigate the punching shear capacity of the SCC voided slabs five slabs of dimension (1000mm* 1000mm *80mm) were produced and tested. one of normal strength concrete and the rest are of SCC. Three of the slabs had plastic spheres of 40mm in diameter with 169 balls in each slab. Two of these slabs were strengthened using two different values of steel fiber (1%, 0.8%) by volume friction at distance d from the face of the column. The dimensions and the details of the tested slabs shown in table (1) and Fig (1) respectively. Three cubes of 150*150*150 mm were casting with each group; the mix proportions and the compressive strength are shown in Table (2).

Table (1) : Details of slabs

Slab NO.	Concrete type	Plastic balls No.	Ratio of steel fiber % by volume friction at b*+2d
S_N	NC	-	-
S_S	SCC	-	-
S_3	SCC	169	-
S_2	SCC	169	1
S_1	SCC	169	0.8

** b = column width = 100mm*

Table (2): Mix proportion

Mix Notation	Cement Kg/m^3	Sand	Gravel	water	LSP Kg/m^3	Superplasti-cizer L/m^3	Steel fiber (% by the total volume)	Compressive Strength MPa	Density of Concrete Kg/ m^3
NSC	367	841	791	183	0	0	0	30.5	2324
SCC	367	841	791	183	195	4	0	31	2465

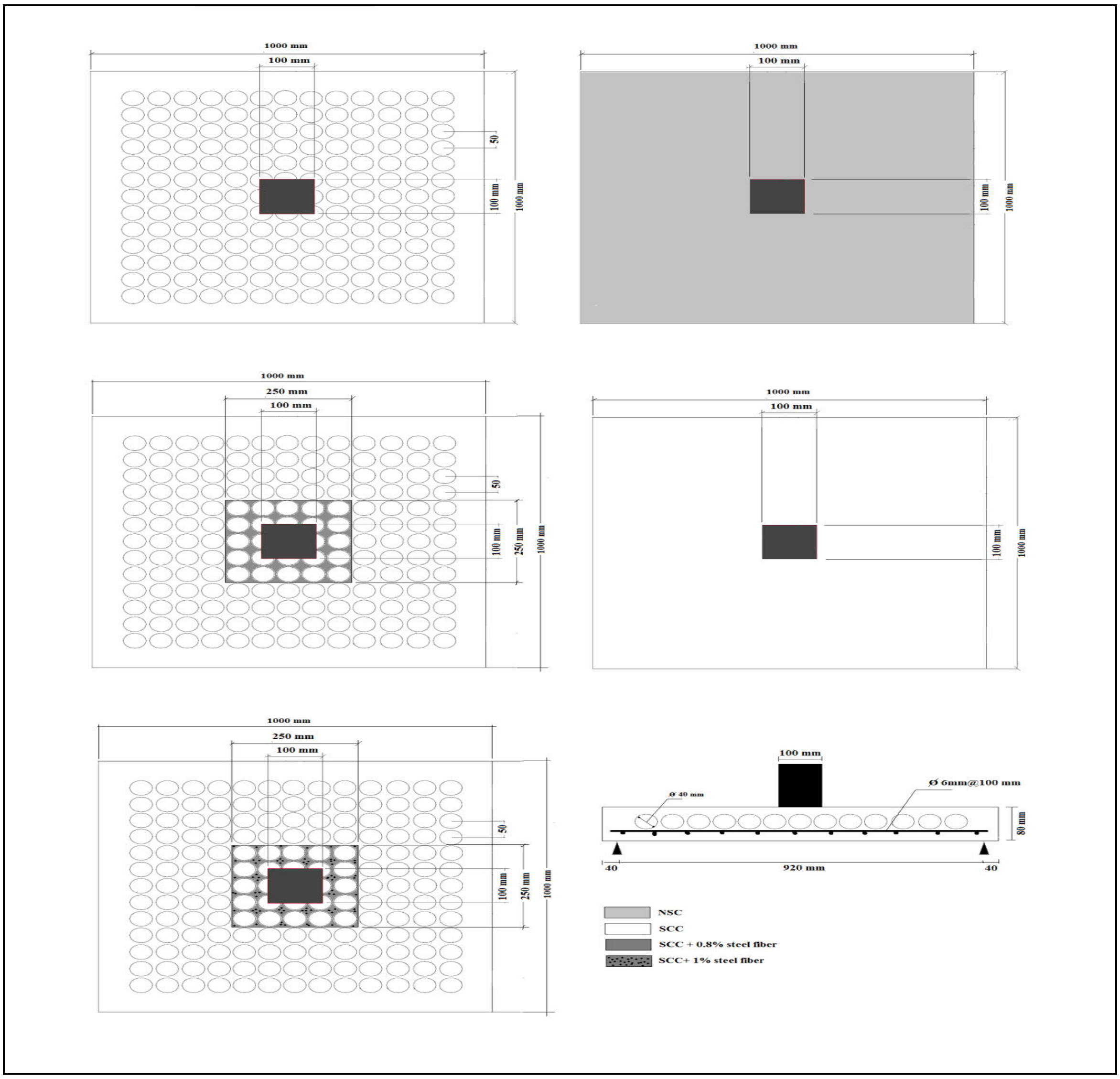

Figure (1): The Slabs Details and Dimension welded wire fabric mesh was used as flexural reinforcement placed in the tension face of the slab. The wires were 6 mm in diameter at 100 mm c/c spacing each way. A clear cover of 20 mm was provided below the mesh. A steel mesh was used to fix the balls in their place during the poring of concrete. The reinforcement details of slabs and steel mish are shown in table (3) and Figure (2) respectively.

Table (3): steel reinforcement and steel mesh properties

	Steel Reinforcement	Steel mesh
fy	495	595
fu	677	487.5
E	10%	11%

Figure (2): The Steel Reinforcement Details

The commercially available high strength steel, end hooked, steel fibers (1000 MPa) are added in the desired volume percentage. Dramix® ZC 50/50 type end hooked steel fibers manufactured by Bekaert Corporation which is of Belgium origin are used in this study, as shown in Figure (3). The steel fibers have a length of 50 mm and a diameter of 0.5 mm with aspect ratio of 100 and density of 7850 kg/m3. The fiber details and dimensions are presented in Figure (4).

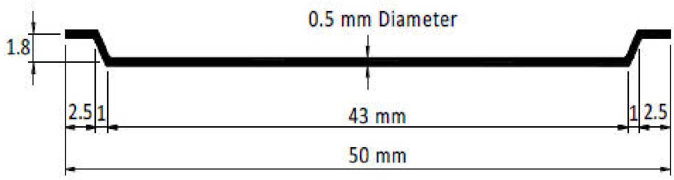

Figure (3): Hooked Steel Fiber

Figure (4): Steel Fiber Dimension

For the production of the self-compacting concrete and high strength conventional concrete, superplasticizer (high water reducing agent HWRA) based on polycarboxylic ether is used. One of a new generation of copolymer-based superplasticizer designed for the production of self-compacting concrete is the Glenium 51. Glenium 51 is free of chlorides and complies with ASTM C494, type A and type F. It is compatible with all Portland cements that meet the recognized international standards. The typical properties of Glenium 51 are shown in table (4).

Table (4): Typical Properties of Glenium 51

Form	**Viscous Liquid**
Colour	Light Brown
Relative Density	1.1 @ 20 0C
PH	6.6
viscosity	128+/-30 cps @ 20 0C
Transport	Not Classified as Dangerous
Labeling	No Hazard Label Required

In this work, crushed limestone brought from local market is used and the fineness of the gained material is (3100 cm2/gm). The limestone powder passing sieve No. 0.075mm is used in this work. The chemical composition of the limestone powder is shown in Table (5).

Table (5): Chemical Analysis of the Limestone Powder.

Oxide	**Content %**
CaO	56.10
SiO2	1.38
Fe2O3	0.12
Al_2O_3	0.72
MgO	0.13
SO_3	0.21
L.O.I	4.56

3.Test Procedure

Setup of tested specimens is shown in Figure (5). All slab specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested slabs were simply supported and loaded with a single-point load. The slabs have been tested at ages of (28) days. The slab specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations.

Figure(5): Test Setup

Loading was applied slowly in successive increments; the applied load is transformed from testing machine through a central column of dimensions (100x100mm). At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the slab surface. When the slab reached advanced stage of loading, smaller increments were applied until failure, where the load indicator stopped recording anymore and the deflections increased very fast without any increase in applied load.

4.Results and discussions

4.1Load_ deflection relationships

Deflection was measured at the center of tested specimens by means of (0.01 mm) dial gauge, and readings from this gauge were recorded for each load increment.

There are three main stages can be seen in load-deflection curve, first linear zone shows that there is a linear relationship between load and deflection up to appearing first crack at the tension face of tested specimens, second linear zone can be seen after appearing first crack, at the advanced stages of loading application there are rapid increase in deflection with small increments in load, at the failure the deflection increase rapidly without any increment in load.

Figure (6) show the load-deflection relationships for normal concrete slab (SN) and (SS) slab. in these figure there is a clear difference between two types of slab, there are difference in stiffness and the deflection values during the stages of load applications. In general, the self-compacted concrete slab seems more stiffness than the slab with normal concrete this leads that the deflection of self-compacted concrete is less than the deflection of normal concrete slab. This behavior belong to good bond characteristics between concrete and steel in self-compacted concrete make the concrete and steel behave to some extent as homogeneous mass in comparison with the normal strength slab there is a less bond.

The load-deflection curves of the voided and solid slab is approximately same at the first stages of loading application, then after reach the yielding of steel reinforcement the deflection of solid slab seems more than the voided slab because the main variable which control the deflection is the stiffness of slab and the stiffness of solid slab is more than the stiffness of voided slab. See Figure (7).

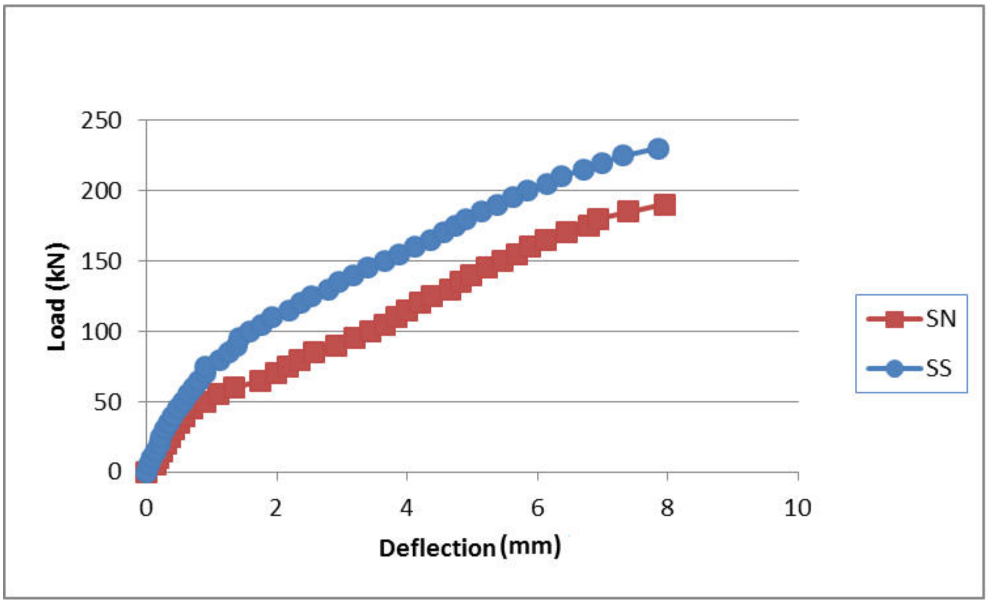

Figure (6): load-deflection relationships for normal concrete slab and self-compacted slab

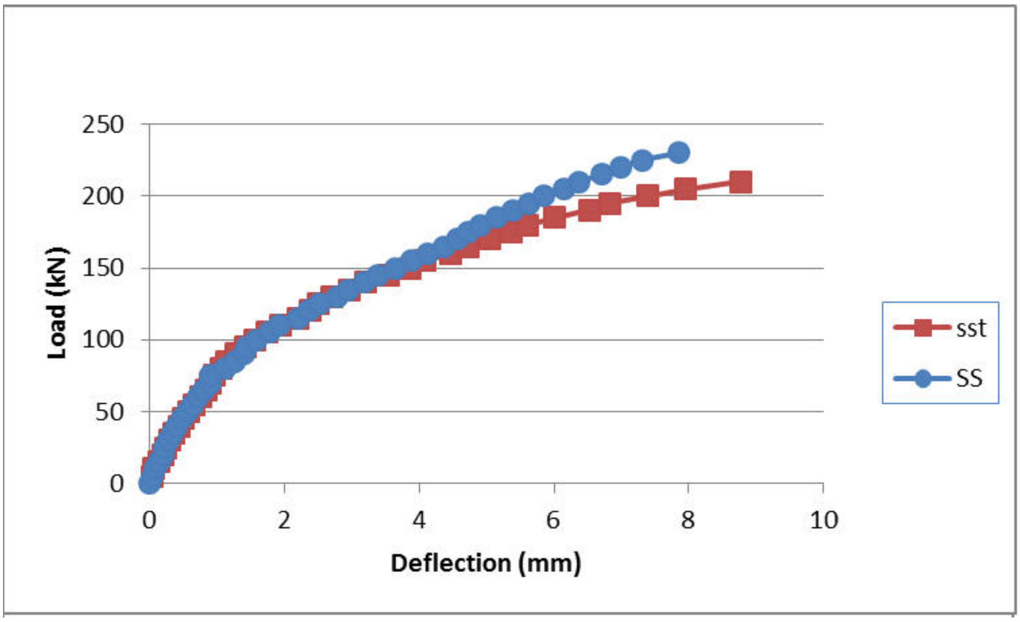

Figure (7): load-deflection relationships for self compacted concrete slab and voided slab

For figure (8) the relationships between voided self compacting concrete slabs SST without steel fiber, SST+1% with adding steel fiber by 1% by volume fraction at the zone (250*250 mm) in the middle of slab and SST+0.8% with adding steel fiber by 0.8% by volume fraction at the same zone ,the figure shows that all the three curves have the similar behavior especially at the first stage of loading and the little different appeared at the final stage of loading at punching strength between them, the punching strength of voided SCC slab with steel fiber 0.8% increased by 2.56% and for voided SCC slab with steel fiber 1% the punching strength increased by 7.7% compared by voided SCC slab without steel fiber ,also the deflection increased by 3.153% and 15.243% respectively. These percentages occurred because of the effect of adding the steel fiber especially for slab with 1% by volume fraction .The punching strength depending on the concrete compressive strength mainly and the fy of steel reinforcement ,the steel fiber was more effect at the tensile strength and little increasing of compressive strength.

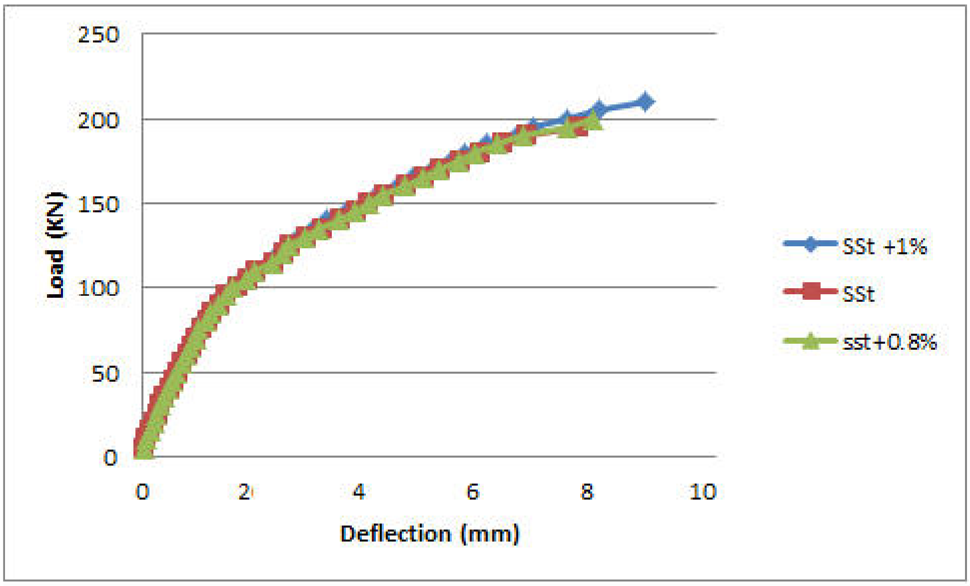

Figure (8): load-deflection relationships for self-compacted concrete vided slab and sables with different percent of steel fiber

4.2Ultimate load capacity

The observed failure load of the tested slabs is shown in Table (6). Test results show that the slab with self-compacted concrete has punching strength capacity more than the slab with normal strength concrete, compressive strength is more control parameter effect on punching shear.

There is a little difference in ultimate strength between the solid and voided slabs because the voids lay at the mid depth of section in which the minimum stress at this position. This is a good benefit to decreasing the weight of slab in same time maintain the ultimate strength.

Table (6): the max. load and max deflection of the slabs

Slab NO.	Max. Load Kn	Max. deflection $*10^{-2}$ mm
S_N	190	795
S_S	230	785
S_3	195	761
S_2	210	877
S_1	200	785

4.3Crack pattern and failure mode

The initial cracking of all the tested slabs was first observed in the tension zone of the slab near one or more of the corners of the column. In general, the initial crack was observed in the corners of the column stub along the line of the tension reinforcement on the tension surface in the form of flexural cracks. The first cracks opened parallel to the line of tension reinforcement after which new cracks appeared parallel to the diagonal axis and extended towards the slab edge. See figures below.

The first flexural crack initiated at (40 kN) in normal and self-compacted concrete slabs. as shown in Table (7), and at this stage of loading the tensile stress in concrete reached the modulus of rupture value and cracking started in the zone of maximum tensile stress.

In case of steel fiber self-compacted slab there is an improvement in appearing the first cracking load (70 kN for 0.8% steel fiber and 80kN for 1% steel fiber ratio). This increasing because of that the steel fiber work as a bridge connects the two sides of crack together and delay opening of cracks towards the upper fiber of slab section.

Also ,use the SCC slab decrease the critical zone more than that at the normal concrete slab, and the use of the SCC voided slab appeared the same case of the SCC slab ,but the voided SCC slab with steel fiber at the critical zone increased the critical crack especially for voided SCC slab with steel ratio 1%by volume fraction .

Table (7): the first and the max deflections and loads of the slabs

Slab NO.	**first crack Load at**	**first crack Deflection**	**Max. Load Kn**	**Max. deflection mm**
S_N	40	58	190	795
S_S	40	39	230	785
S_3	40	47	195	761
S_2	80	106	210	877
S_1	70	93	200	785





5.Conclusions

1.Voided slabs eliminate concrete where it isn't needed , the reduced weight of the slab allows for longer slabs between columns without beams and a reduction in concrete and steel in floors, columns, and footings, saving money and reducing the total building weight, allowing lighter foundation also using recycled material.

2.The use of SCC increase the punching shear strength and reduce the mid span deflection.

3.At voided SCC slab the punching shear strength increased and the mid deflection decreased also reduced the slab weight.
4.Adding steel fiber at the critical zone increased the punching strength and reduced the angle of punching failure.
5.The steel fiber ratio 1% by volume fraction was more effect than ratio 0.8% by volume fraction .
6.The crack pattern of punching shear reduced by use the SCC and voided SCC ,but increased by used the voided SCC strengthened by steel fiber especially 1% by volume fraction.

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