PUNCHING SHEAR STRENGTH OF FIBROUS SELF-COMPACTING CONCRETE FLAT SLABS

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Abstract

Punching shear causes failure around columns in reinforced concrete flat slab under applied load on the slab. Self compacting concrete is used widely because it does not need compaction and compact under its own weight and has the ability to spread and pass through narrow forms and congested steel reinforcement.

The aim of this research is to study the influence of steel fibres on the behaviour and punching shear strength or self compacting concrete flat slabs. The concrete mix was designed to get a nominal cylindrical compressive strength about 35 MPa. Seven square flat slabs were cast with a dimensions (900×900mm) and 70mm thickness. The dimensions of the column stub are (100×100mm) at the middle of the slab with 200mm height. Two reinforcement ratios were used for the flat slabs (1.4 and 1.8%) and different volume fraction of steel fibres (0,0.4,0.8,1.2) with 36.5 aspect ratio. The deflection at the middle of the flat slabs were measured. The test results show that as the volume of the steel fibres increase the punching shear strength increased and the presence of fibres delay the appearance of the first crack in the slab and gave less deflection than the slab without fibres. The shape of the failure surface is approximately circular around the column and the failure for slabs with steel fibre was ductile while those without steel fibre was brittle failure.

Keywords: Fibres, Punching shear, Self-Compacting Concrete, Slab.

1. Introduction

Reinforced concrete flat slabs system are widely used in structural systems. Its formwork is very simple as no beams or drop panels or capitals are used. However, the catastrophic nature of the shear failure exhibited at the connection between the slab and the column has concerned the design engineers. The critical area as far as the strength of flat slabs is concerned due to the concentration of high bending moments and shear forces. The failure load may be considerably lower than the unrestrained flexural capacity of the slab.

Generally the punching shear strength prdictions specified in different codes vary with concrete compressive strength f'_c and is usually expressed in terms of f_c^n. The ACI Code

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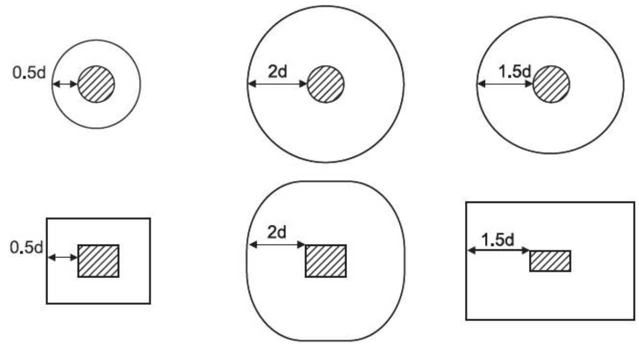
[1] and the Australian Code AS3600 [2] expresses the punching shear strength as proportional to $\sqrt{f_c^{'}}$. The critical failure section is specified in different code vary with the effective depth as shown in Figure (1).



(a) ACI[1] and AS3600 [2] (b) CEB- FIP MC – 90 [3] (c) BS 8110 [4]

Fig. 1: Critical perimeters specified in different codes

Most codes present formulae, where the design punching load is a product of a design nominal shear strength and the area of a chosen failure surface. Depending on the method used, the critical section for checking punching shear in slabs is usually situated between 0.5 to 2 times the effective depth from the edge of the load or the column face. Influences of reinforcement, slab depth and other parameters are customarily governed by the application of different modification factors.

To improve the punching shear of slab - column connections steel fibres can be used in concrete. It is well established that the presence of fibres in concrete increases its tensile strength, ductility and cracks propagation [5,6]. Tests on flat slabs showed that fibre reinforcement can effectively act as shear reinforcement, where conventional shear reinforcement is difficult especially for low slab depth, and increase their shear resistance [7]. The punching shear for high strength concrete was investigated by Ali [8] and he concluded that as the compressive strength increase from 40.1MPa to 62.0MPa the punching shear strength increased by 25.6%. Tan and Paramasivam and other rearchers [9,10] tested slabs with steel fibres and concluded that the steel fibre increase the punching shear strength, delay the appearance of the cracks and the failure is more ductile.

Self-compacting concrete is widely used in structural members due to its easiness of spreading, passing ability and environmental friendly [11,12]. In spite of its wide use, only a few research projects have been conducted on the punching shear resistance of self-compacting concrete slabs.

2. Experimental Programme

2.1 Materials

Seven square flat slabs were used with dimensions 900×900 mm and column size 100×100 mm in the middle of the slab. The slabs were reinforced with # 8 mm to give a reinforcement ratios of (1.4,1.8%) so that flexural failure will not initiate before shear failure, Figure (2). The column stub was reinforced with four #12 mm bars and three ties #8 mm. The properties of thes bars are shown in Table (1). The steel fibres used with 0.87mm equivalent diameter and 32 mm long with four volume percentage (0,0.4,0.8 and 1.2).

Tab. 1: Properties of the reinforcing bars

Bar Diameter (mm)	Yield Strength (MPa)	Tensile Strength (MPa)
8	614	710
12	591	691

Ordinary portland cement was used throughout this investigation, which was from Turkish factory. The fine aggregate used in this study was the local river sand, which is washed, dried and graded, which lies within the overall limit of the British-standard (B. S. 882/1992) [13]. The fineness modulus equals to 3.1. The coarse aggregate used throughout the investigation was natural gravel with 10 mm maximum size, which is mostly rounded in shape. The gravel was washed carefully and dried before grading. Thirty percent of cement was replaced by limestone powder.

The plasticizer type (Structuro 504E) was used in order to increase the workability of the fibrous concrete mixes. The mix proportions used was (0.7: 0.3:1.9: 2.4, cement: limestone:sand:gravel) with a water to (cement+limestine) ratio of 0.4.

Fig. 2: steel reinforcement

2.2 Mixing

The mixing procedure was as follows, the dry aggregates and cement, limestone powder were mixed in a horizontal pan type mixer for about one minute, the admixture dissolved in the mixing water and added to the mix then mixed for another one minute. The required amount of steel fibres was then added by hand in small quantities in random manner while the mixing pan is rotating. The mixing then continued until a good homogeneous mix was produced. The concrete was poured into the moulds then the specimens were covered by polythene sheets in the laboratory for 24 hours. After stripping the specimens from the moulds, they were covered with wet sheet for 28 days, For each mix six cylinders were cast for the compressive and splitting strength test. The mix was designed to produce a 28-day cylinder compressive strength of 35 MPa. All batches of self compacting concrete had a measured spread diameter of 650mm to 720mm and T500 of 2.8 to 3 sec which is within the ASTM limitation [14].

2.3 Testing arrangement

The slabs were simply supported on all four sides and loaded centrally through column stub using a hydraulic jack, the central deflection were recorded by using tranducer which are both connected to a data logger, Figure (3). In addition, the crack patterns and failure modes of the slabs were recorded carefully.

Fig. 3: Testing rig for the slabs

3. Results and Discussion

Table (2) shows the results of the compressive and splitting tensile strength. It shows a slight increase in the compressive compared to more increase in the splitting strength as the fibre content increase, this indicate that the fibrea are more effective in tension. The table shows also that the presence of fibre reinforcement increase the ultimate shear load of the slabs. The increases in the punching shear load range between (4-21.3%) for slabs with reinforcement ratio 1.4%, and (15-17%) for slabs with reinforcement ratio 1.8%. While the increase of shear load due to change in the steel reinforcement is about (5.6-7.4)% only this indicate that the fibres are more effective in enhancing the punching shear strength due to the crack arresting mechanism of the fibres.

Tab. 2: Reinforcement, materials and ultimate loads of the tested slabs

Slab No.	Reinforcement ratio %	Fibres volume %	Compressive strength f_c' MPa	Splitting strength f_{sp} MPa	Ultimate punching load kN
S1	1.4	0	33.8	2	111.4
S2	1.4	0.4	40.8	3.4	111.9
S3	1.4	0.8	39.4	3.5	136.8
S4	1.4	1.2	41.2	3.7	141.5
S5	1.8	0	37.6	1.7	120.3
S6	1.8	0.4	37.3	2.8	141.4
S7	1.8	0.8	40.7	3.6	144.9

The role of fibre reinforcement to act as a crack arresting mechanism will lead to an increase in stiffness and reduction in the deformation. Figures (4,5) show the load deflection curves for slabs with steel reinforcement 1.4% and 1.8% respectively. It is clear that fibre reinforcement increase the pre peak stiffness (which lead to a reduction in deflection) and a well defined post peak behaviour, besides the increase in the punching shear strength.

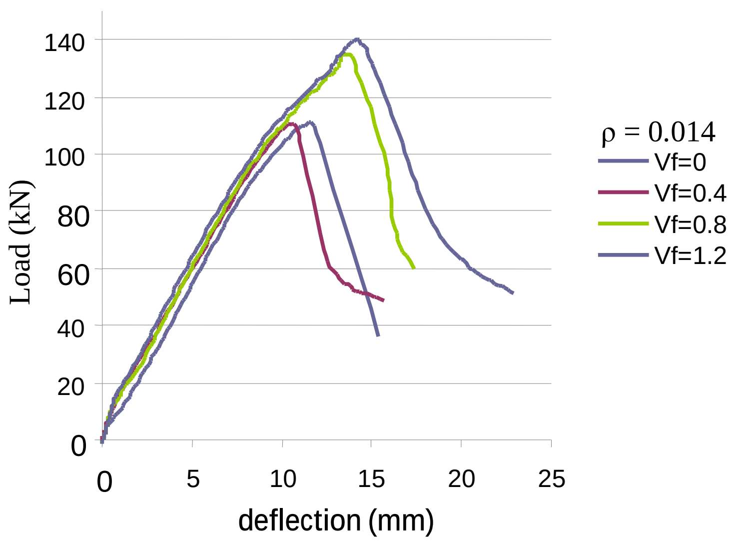


Fig. 4: Load – deflection curves for slabs with ρ =0.014

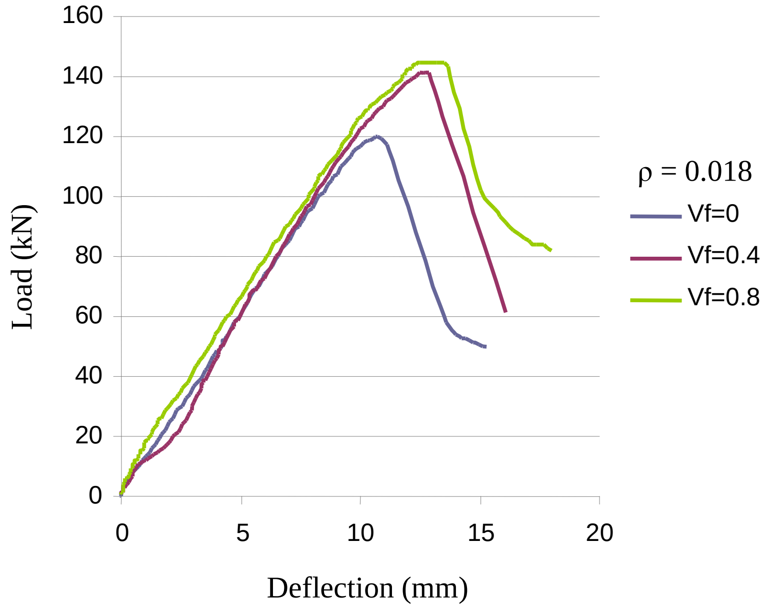


Fig. 5: Load – deflection curves for slabs with ρ = 0.018

Figures (6,7) show the results of the punching shear load obtained during testing of present SCC slabs and the results obtained from the work of other researches (15,16) for normal concrete slabs with fibre also ,which they have approximately the same depth, reinforcement ratio and compressive strength, which these parameters effect the capacity of the slabs shear punching shear .The results show that the punching shear load of SCC slabs were higher than the normal concrete slabs. This indicate that SCC can be used in slabs to resist punching shear and other structural element.

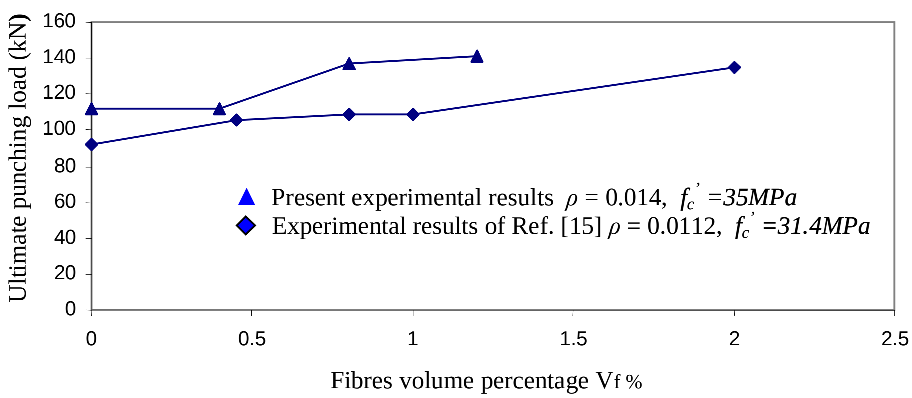


Fig. 6: Comparison of Experimental punching loads

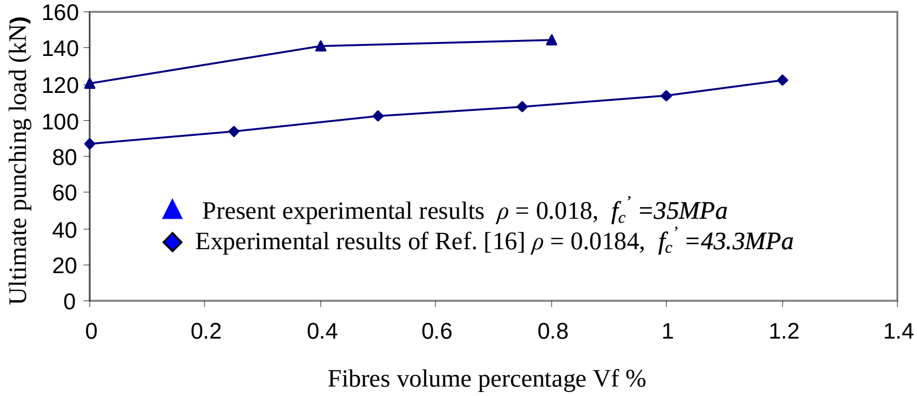


Fig. 7: Comparison of Experimental punching loads

3.1 Modes of Failure

In the slab without fibre the punching failure was complete and sudden, and the failure perimeter tend to be more square in plan, while in the fibre concrete slabs the punching shear failure was gradual and less cracks, the punching perimeter was larger and it is almost circular in shape.

4. Conclusions

The use of high percent of limestone powder and fibres for self-compacting mix gave good workability. The steel fibres increase the punching shear resistance of the slabs and fibres are more significant than steel reinforement due to their ability to arrest cracks.

The slabs without fibres fail suddenly and the failure perimeter was approximatly square while the slabs with fibre fail in a ductile type and the failure perimeter was circular in shape with the diameter increasing with the fibres volume.

The ability of SCC slabs to resist punching shear load is comparable to those of normal concrete slabs.

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