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Punching Shear Behavior of Fibre Reinforced Flat Slab under Different Support Conditions

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Abstract: ***The flat slab has gained popularity for many years in the construction industry because of its advantages over the conventional slab. Punching shear failure is the major issue in the flat slab system. The most affected portion in the flat slab system is the slab column joint. The test specimen was modelled by using a finite element software known as ABAQUS. This software has good performance quality and ability to solve the complex problems in different fields of engineering. In order to conduct the study, nine slab-column specimens of the flat slab were casted and subjected to test with four, three and two sides rigidly supported. Three flat slabs with control mix and six flat slabs with hooked end steel fibres were used. The tests were conducted to study the capacity of the test specimen to withstand the punching shear. The crack patterns developed on the test specimens was studied. It was observed that the four side supported slab-column connection of the flat slab enhance more punching shear strength capacity than three and two sides supported. Also, it was found that the usage of the steel fibre can improve the stiffness and the load bearing capacity of the test specimens.***

Index Terms: ***Crack pattern, Flat slab, Punching shear, Steel fiber reinforced concrete***

I. INTRODUCTION

The slab which supports directly on the column without any beam is known as the flat slab. Nowadays in the construction industry, the flat slabs are gaining more popularity than the other various types of reinforced structures. There are many advantages of flat slab system over the conventional slab. The advantages of the flat slab are simp
le form work, reduced storey height, architectural flexibility, ease of construction, takes less time for the completion of structure and economy. Some major problems are there in the design of the flat slab system. The main disadvantage in this system is the failure due to the presence of punching shear. In flat slab system, the slab gets separated from the column because of the influence of punching shear. The portion near the slab-column bond is the most critical area where the punching shear occurs by the transfer of the shear force and the unbalanced moments. In the failure, the stability of the structure is considerably decreased and the slab gets separated from the column. In the flat slab structural system, the punching shear failure happens unexpectedly without any notice before the collapse of structure. This is one of the dangerous failures and creates serious problems because of its brittle failure. Many researchers are investigating the different methods to improve the punching shear performance of flat slab. A study was conducted by Micael et al [1] on high strength concrete to strengthen the punching shear behaviour. From the study, author concluded that the high strength concrete provides more load carrying capacity than normal load and the punching shear behaviour can improved by increasing the longitudinal reinforcement. Min – Yaun Cheng, Gustavo J Parra-Montesinosv [2] focused on the steel fibre reinforced concrete to improve the punching shear strength and ductility of the slab. Pilakoutas, K., Li, X [3] carried out a research to introduce a new method to improve punching shear capacity called shear band. He concluded that the shear bands can increase the behaviour of slab against punching shear. A model on the basis of critical shear crack theory was introduced by Aurelio Muttoni [4]. L. Nguyen-Minh [5] focused on the study of the performance of steel fiber reinforced concrete (SFRC) slabs under punching shear force. From the results, concluded that the strength of the slab against punching shear can improve by using steel fibers. Also, he concluded that the stiffness and concrete ductility can be increased with steel fibers. Tamara Adnan Qasim Al-Shaikhli [6] conducted a study on non-rectangular reactive powder concrete slabs to find the influence of steel fibre on the behaviour of slab against punching shear failure. T S Viswanathan [7] presented a linear analysis on the shear stress distribution of flat slab with or without shear stud using ABAQUS. Viswanathan [8] also conducted a non-linear analysis of flat plate system with shear studs arranged in orthogonal, radial and critical perimeter using ABAQUS. He concluded that the critical perimeter pattern shows good performance against the punching shear strength and the ductility characteristics can improve with the critical perimeter and radial pattern.

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II. EXPERIMENTAL PROGRAM

A. Material and its Mix Proportion

The materials used for test specimens are ordinary Portland cement, natural sand, coarse aggregate, water, and superplasticizer. All the slabs had the same composition of materials. The mix proportion of concrete for 1m3 is furnished below in Table I. For the fibre reinforced concrete, hooked end steel fibres with 30 mm long, 0.5 mm of diameter. The aspect ratio of hooked end steel fibre used was 60. Different types of concrete mix proportion were considered for conducting the experiment.

They are control mix without steel fibre (CF1) and other mix proportions with steel fibres of volume 0.3% (CF2) and 0.4% (CF3).

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Table I: Proportion of Concrete

Materials	Quantity per m^3
Cement (53 grade OPC)	350 kg
Fine aggregate	896 kg
Coarse aggregate	1140 kg
Water	140 l
Superplasticizer	7 kg

B. Slab Specimen

A total of nine slab specimens with the same dimension and mix proportion were casted. All the slabs were casted and cured under the same condition. Table vibrator were used for compacting the slabs and levelled for finishing. The slabs were removed from the mould and kept for curing for 28 days under similar condition. The area of the test specimen was 300 mm x 300 mm with 50 mm thickness. The column part of the specimen was 100 mm x 100 mm with 200 mm depth. The reinforcement for the slab and column were provided with 6 mm diameter bars. The slab was provided with the bottom reinforcement spaced at 50 mm. The stirrups were provided with 50 mm spacing. The column reinforcement was provided with a cover of 20 mm from the top and the sides of the column. The details of reinforcement provided are as shown in figure 1.

Figure 1 Reinforcement of the test specimen

C. Test procedure and Instrumentation

The universal testing machine was used for testing the test specimens. The load was applied on the column part of the flat slab having cross section 100 mm x 100 mm. Punching shear failure is one of the major issues in the flat slab design. The study was carried out to find the behavior of flat slab under punching shear with different support conditions. The slabs were tested with four sides rigidly supported, three sides supported and two sides supported. Deflectometer was used to determine the deflection and placed near slab-column connection. The application of load was continued in equal increments till failure of specimens to determine the ultimate load. At each load level, the deflection values were recorded. Figure 2 shows the experimental setup for the test specimens.

Figure 2 Test setup for slab specimen

III. MODELLING OF FLAT SLAB

For the analytical study, the flat slabs were modelling using a finite element software known as ABAQUS. In various engineering field such as aerospace engineering, mechanical engineering, civil engineering etc., the finite element analysis are widely using for solving the complex problems. ABAQUS is a well-established finite element tool with high performance quality. The dimension of slab with 300 mm x 300 mm and slab thickness 50 mm was modelled. The slab was supported with a column at the centre. The cross sectional area of column was 100 mm x 100 mm with depth of 200 mm. The slab consists of only flexural reinforcement which is considered as the bottom reinforcement. The 6 mm diameter bars of bottom reinforcements are provided in both orthogonal directions spaced at 50 mm. The longitudinal reinforcements of column were provided with 6 mm diameter bars with the development length of 50 mm. The stirrups were provided with 6mm diameter bars at 50 mm spacing. The modelling of slab-column connection of flat slab in ABAQUS is as shown in figure 3. After placing the reinforcement in slab and column, the two parts are merged by using merge option in assembly to make them monolithic structure. Figure 4 shows the wireframe model of the test specimen modelled using ABAQUS software. The next important procedure in the finite element analysis is meshing. Figure 5 illustrates the meshing of specimen. After meshing, the next step is creating a job for the analysis. The details of deflected shape of the specimen obtained from the ABAQUS is in figure 6.

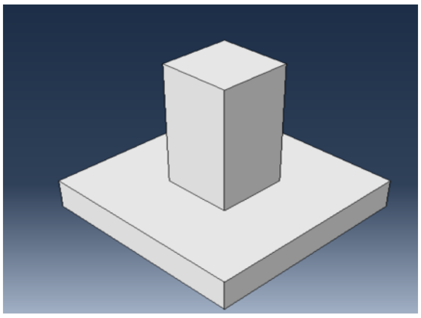

Figure 3 ABAQUS model of flat slab

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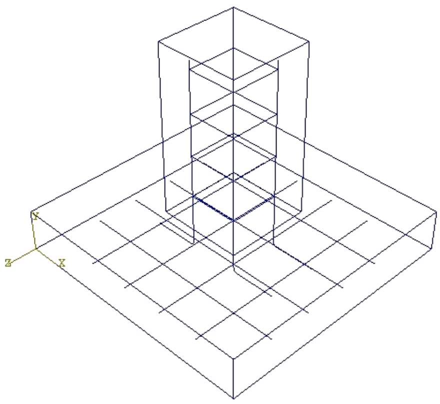

Figure 4 Wireframe model of test specimen

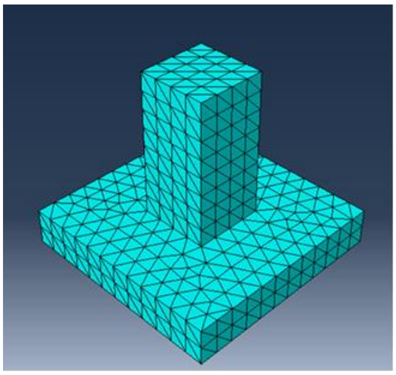

Figure 5 Meshing of flat slab using ABAQUS

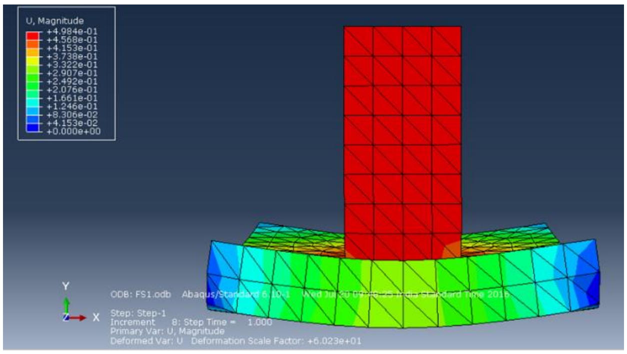

Figure 6 Deflected shape after analysis

IV. TEST RESULTS AND DISCUSSIONS

A. Failure of Specimens

All slabs were loaded under the same loading with equal increments of load upto the failure and failed in punching shear. The slab specimens were tested under different support conditions and the crack pattern for all the slabs was studied and illustrated in figures 7,8,9,10,11,12,13,14 and 15. The Deflectometer was bonded to the surface of the slab near slab-column connection and the readings were taken only till the first crack formed because the punching shear failure is in brittle nature. The table II, III and IV gives the details of the load at which the initial crack and ultimate crack observed for different test specimens under different support conditions.

Table II First crack load and ultimate load details for control mix

Sl. No.	Name of slab	Support Condition	First Crack Load	Ultimate Load
1.	C F 1.1	4 sides supported	24 kN	31.4 kN
2.	C F 1.6	3 sides supported	25 kN	31 kN
3.	C F 1.5	2 sides supported	8 kN	13.3 kN

Table III First crack load and ultimate load details for mix with 0.3% steel fibre

Sl. No.	Name of slab	Support Condition	First Crack Load	Ultimate Load
1.	C F 2.2	4 sides supported	50 kN	53kN
2.	C F 2.4	3 sides supported	38 kN	40 kN
3.	C F 2.5	2 sides supported	18 kN	28 kN

Table IV First crack load and ultimate load details for mix with 0.4% steel fibre

Sl. No.	Name of slab	Support Condition	First Crack Load	Ultimate Load
1.	C F 3.4	4 sides supported	31 kN	45 kN
2.	C F 3.2	3 sides supported	30 kN	34.4 kN
3.	C F 3.1	2 sides supported	30 kN	44 kN

Figure 7 crack observed on four sides supported slab specimen without steel fibre

Figure 8 crack observed on three sides supported slab specimen without steel fibre

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Figure 9 crack observed on two sides supported slab specimen without steel fibre

Figure 10 crack observed on four sides supported slab specimen with 0.3% of steel fibre

Figure 11 crack observed on three sides supported slab specimen with 0.3% of steel fibre

Figure 12 crack observed on two sides supported slab specimen with 0.3% of steel fibre

Figure 13 crack observed on four sides supported slab specimen with 0.4% of steel fibre

Figure 14 crack observed on three sides supported slab specimen with 0.4% of steel fibre

Figure 15 crack observed on two sides supported slab specimen with 0.4% of steel fibre

B. Load – displacement responses

In general, the cracks generated during testing can be grouped in two categories. The first category is termed as first cracking stage and next stage is an ultimate cracking stage. The below figure 16, 17, 18, 19, 20, 21, 22, 23 and 24 shows the load-deflection graph plotted for tested specimens with different mix and support conditions. From the load-deflection graph, displacement of the four side supported slab is lower than the other slabs supported at three and two sides. It was observed that the stiffness increases and the cracks developed away from the column for the test specimens without steel fibres. In steel fibre reinforced concrete, the stiffness increases by improving load carrying capacity.

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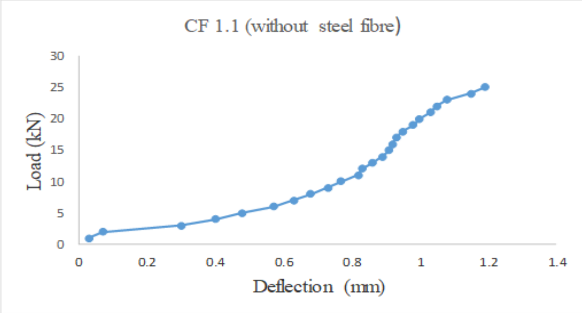

Figure 16 Load displacement graph for four sides supported slab specimen

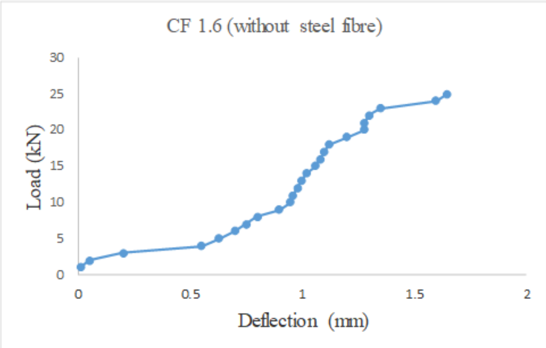

Figure 17 Load displacement graph for three sides supported slab specimen

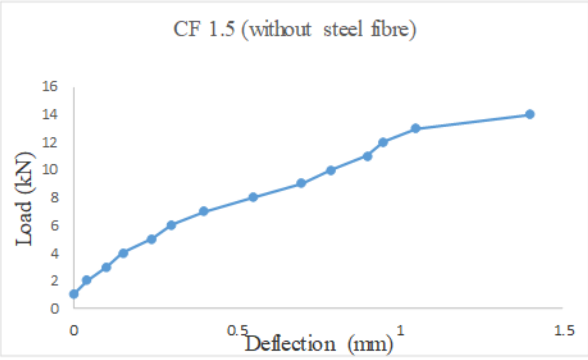

Figure 18 Load displacement graph for two sides supported slab specimen

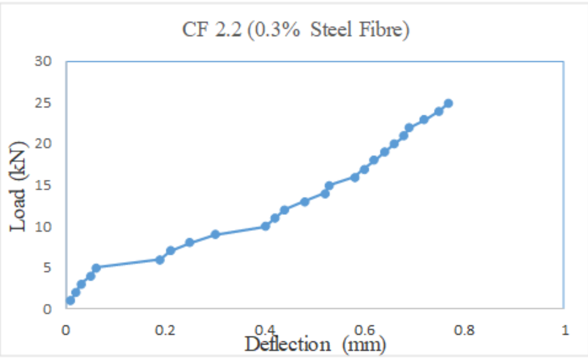

Figure 19 Load displacement graph for four sides supported slab specimen with 0.3% steel fibre

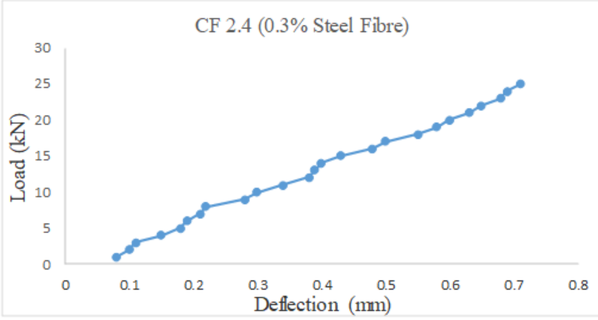

Figure 20 Load displacement graph for three sides supported slab specimen with 0.3% steel fibre

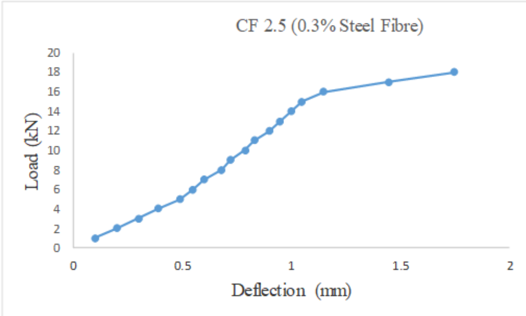

Figure 21 Load displacement graph for two sides supported slab specimen with 0.3% steel fibre

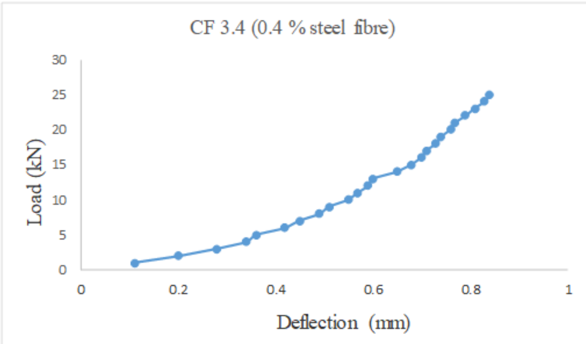

Figure 22 Load displacement graph for four sides supported slab specimen with 0.4% steel fibre

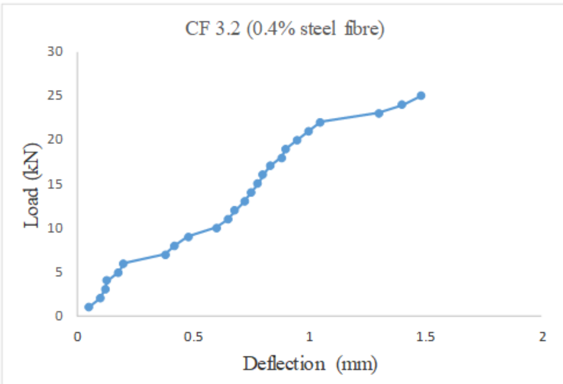

Figure 23 Load displacement graph for three sides supported slab specimen with 0.4% steel fibre

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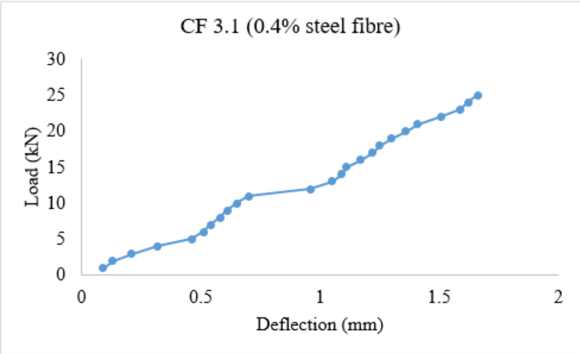

Figure 24 Load displacement graph for two sides supported slab specimen with 0.4% steel fibre

V. COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

The results obtained from the experimental analysis of flat slab under punching shear were compared with analytical results. The deflection for the test specimens under different support conditions were compared and details were shown in below tables V, VI and VII. From the comparison, it is seen that results of experimental study are in line with the analytical study.

Table V FEM results versus experimental results for test specimen without steel fibre

Name of the specimen	Support condition	Load	Deflection from finite element analysis (in mm)	Deflection from experimental study (in mm)
CF 1.1	Four sides supported	25 kN	1.13	1.15
CF 1.6	Three sides supported	25 kN	1.66	1.65
CF 1.5	Two sides supported	14 kN	1.7	1.4

Table VI FEM results versus experimental results for test specimen with 0.3% steel fibre

Name of specimen	Support condition	Load	Deflection from finite element analysis (in mm)	Deflection from experimental study (in mm)
CF 2.2	Four sides supported	25 kN	0.732	0.77
CF 2.4	Three sides supported	25 kN	1.01	0.71
CF 2.5	Two sides supported	18 kN	1.63	1.75

Table VII FEM results versus experimental results for test specimen with 0.4% steel fibre

Name of the specimen	Support condition	Load	Deflection from finite element analysis (in mm)	Deflection from experimental study (in mm)
CF 3.4	Four sides supported	25 kN	0.84	0.84
CF 3.2	Three sides supported	25 kN	1.48	1.48
CF 3.1	Two sides supported	25 kN	1.42	1.66

VI. CONCLUSION

On the basis of outcomes from the study, the following conclusions can be obtained:

1) By supporting the four sides of slab, the stiffness and punching shear behaviour can be improved and helps to withstand more loads.
2) The addition of the steel fibre can increase the strength, load carrying capacity, ductility and bonding of slab and column.
3) For fibre reinforced slab, it is observed that the crack formed away from the column and provides more stability when compare with the slab without steel fibre.
4) From the study, it is observed that the concrete with steel fibres improves the strength to withstand punching shear of the flat slab than the plain reinforced concrete. It was seen that four side support conditions provide more stability than other support conditions.
5) From the test results, it is seen that there was a variance of 0 to 17% in deflection. This is due to random distribution of steel fibres during mixing.
6) From the comparative study, it is seen that the deflection obtained from the experiment and ABAQUS software are almost similar values. Therefore based on the outcomes, it is concluded that the analytical study by using finite element software agrees well with the experimental study.

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