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Finite Element Analysis of Flat Slab with Punching Shear Reinforcement

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Abstract— Punching shear failure is a major problem encountered in the design of reinforced concrete flat slabs. The utilization of shear reinforcement via shear bolts, shear studs or other means has becomes a choice for improving punching shear capacity. In this paper Finite-element analyses (FEA) of flat slab with shear reinforcement are presented and discussed. The punching shear strengthening is done using carbon fiber reinforced polymer (CFRP) strips which is externally bonded to the tension face of the slab. The effect of varying CFRP strengthening amount and configuration on the punching shear capacity of the slab specimens was investigated. The results clearly showed that CFRP strengthening leads to significant improvements in the structural behaviour of slab-column connections. The general finite element software ANSYS 18 can be used successfully to simulate the punching shear behaviour of reinforced concrete flat plates.

Key words: CFRP, FRP

I. INTRODUCTION

Punching failure can be classified as a shear dominant brittle type of failure. Because of its brittle nature, it becomes almost impossible to inspect typical warnings on the structural components prior to failure. When the flat slab-column connections are subjected to heavy vertical loading, cracks will occur inside the slab in the vicinity of the column. These cracks then propagate through the slab thickness at an angle of 20 to 45 degree to the bottom of the slab. This can lead to punching shear failure of the slab along the cracks. The critical element of this system is the slab to column connection because of the concentration of shear stress that is generated in the connection zone, and due to the slab punching risk. The term punching shear denotes slab failure in the zone where the concentrated load is applied, or in the support zone (column) due to shear stress. At the moment when the punching occurs, the column and slab physically separate from one another, which significantly disturbs the balance of the system formed by these elements. Very often, such disturbance may cause collapse of great proportions due to redistribution of load to other elements that are not designed to transfer such forces. In such cases, slabs must be replaced or strengthened. Strengthening can be a cost effective alternative to replacement and is often the best solution. The choice of strengthening techniques applied to any particular situations depends on technical and economic factors.

II. PREVIOUS STUDIES

Many researchers conducted tests examining shear reinforced concrete slabs by using and proposing different type of shear reinforcements, for example: bent-up bars, closed stirrups, shear head, shear stud and shear bolt. The use of a more uniform distribution of shear studs seemed to have helped delay concrete degradation in the connection, which was the likely reason for the increased drift capacity (M.Y.Cheng, 2014). The effect of adding steel fibers has been discovered through studying its impact on the load-deflection behavior, ultimate capacity, cracking capacity, failure mode, ductility and energy absorption of tested specimens. The adopting of steel fibers in strengthening the slab against punching shear stresses gives a good improvement (Aamer Najim et al. 2016). The FRP shear bolts system is used to protect previously built reinforced concrete (RC) slabs against brittle punching shear failure (Nicholas et al. 2014). Using the FRP shear reinforcement in the tested slabs showed a significant increase in the deformation capacity even with low flexural reinforcement ratios. The use of FRP stirrups not only enhanced the punching shear strength but also the slab deformation capacity, particularly when the flexural reinforcement ratio was high (Hassan and Ahmed 2014).

A new alternative of reinforcement, the introduction of rebar mesh at the middle of flat plate thickness covering the punching zone and anchored outside this zone, is proposed. The obtained results indicate that, the proposed shear reinforcement system has a positive effect in the enhancement of both the punching shear capacity and the strain energy of interior slab–column connection of both normal and high strength concrete (Ahmed Ibrahim et al. 2015). The CFRP sheets inhibit the growth of large cracks by helping distribute a large number of small cracks. (R Al.Rousan et al. 2012). He found that externally bonded CFRP are very effective in enhancing the ultimate carrying capacity of RC slabs.

Durate M.V Faria et al. (2014), they applied FRPs on top of slab column connections, this technique allows increasing the flexural stiffness and strength of the slab as well as its punching shear strength. They found that the increase on punching strength due to strengthening is not linearly proportional to the amount of FRP laminates and depends on its location, with which higher efficiencies for laminates glued near the slab column connection. M.A.Eder et al. (2010), presents a nonlinear finite element procedure for simulating punching shear failure in RC slabs with and without shear heads. Sensitivity analyses are presented to show the influence of the concrete tensile strength, shear retension factor and mesh density on the predicted failure load. A parametric analysis carried out to determine the influence of the key parameters which govern the performance.

III. FINITE ELEMENT MODELLING

ANSYS is general-purpose finite element software for numerically solving a wide variety of structural engineering problems. The dimensions of square slab were 1,800 × 1,800 × 120 mm, in which simple supports at its ends. All slabs were reinforced in the same way, using 10M bars at 100 mm and 90 mm for the tension mat and 10M bars at 200 mm for the compression mat. The spacing of the tension reinforcement is different in the two directions to achieve the same moment capacity in both orthogonal directions. The yield strength of the flexural reinforcement was 455 MPa. The concrete cover was 20 mm, and the dimensions of the cross section of the square columns were 150 × 150 mm. The columns extended 150 mm beyond the top and the bottom surfaces of the slabs, and they were reinforced with four 20M bars and 8M ties. The thickness of the slabs was 120 mm, and the effective depth was equal to 90 mm. The specimen is designed to experience punching shear mode of failure. The quarter span of the flat slab is analyzed by providing symmetry boundary condition.

The CFRP strips apply on the tension surface of the flat slab as externally bonded reinforcement. 1 mm thick CFRP strips are used in this study we are using rectangular patterns of CFRP strips which is shown in figure 1. The CFRP strips of varying width 25mm, 50mm, 75mm are used. 3 different spacing arrangement 25mm, 50mm, 75mm are used and they are placed upto 4 rings. In all specimens the first strip is located at a distance from the column which is same as spacing between the strips.

For the numerical simulation of any RC structure, three dimensional solid element SOLID65 has been used for modeling the nonlinear behaviour of concrete, three dimensional spar elements LINK180 has been used for modeling the reinforcement. SHELL181 is used for CFRP strip. To model the contact, contact elements CONTA174 and TARGE170 are used.

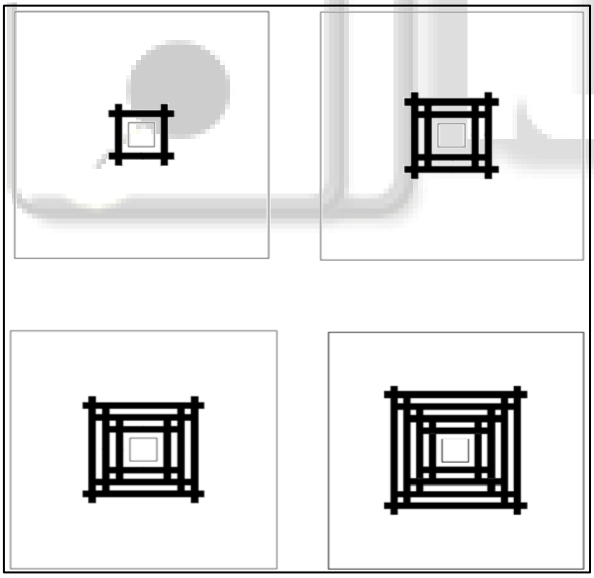

Fig. 1: CFRP Patterns

The specimen designations of CFRP strengthened models are listed in table 1. One model is kept control specimen which is unreinforced.

Specimen designation		
R_S0_W0_N1	R_S0_W1_N1	R_S0_W2_N1
R_S0_W0_N2	R_S0_W1_N2	R_S0_W2_N2
R_S0_W0_N3	R_S0_W1_N3	R_S0_W2_N3
R_S0_W0_N4	R_S0_W1_N4	R_S0_W2_N4
R_S1_W0_N1	R_S1_W1_N1	R_S1_W2_N1
R_S1_W0_N2	R_S1_W1_N2	R_S1_W2_N2
R_S1_W0_N3	R_S1_W1_N3	R_S1_W2_N3
R_S1_W0_N4	R_S1_W1_N4	R_S1_W2_N4
R_S2_W0_N1	R_S2_W1_N1	R_S2_W2_N1
R_S2_W0_N2	R_S2_W1_N2	R_S2_W2_N2
R_S2_W0_N3	R_S2_W1_N3	R_S2_W2_N3
R_S2_W0_N4	R_S2_W1_N4	R_S2_W2_N4

Table 1: Specimen Designation

Where ‘R’ is rectangular strip, ‘S’ is spacing between strips, ‘W’ is width of strip, ‘N’ is number of rings
S0 = 25 mm, S1=50 mm, S2=75 mm
W0= 25 mm, W1= 50 mm, W2=75 mm
N1= 1 ring, N2= 2 ring, N3= 3 ring, N4= 4 ring

Some examples of models are shown in figure 2 and 3.

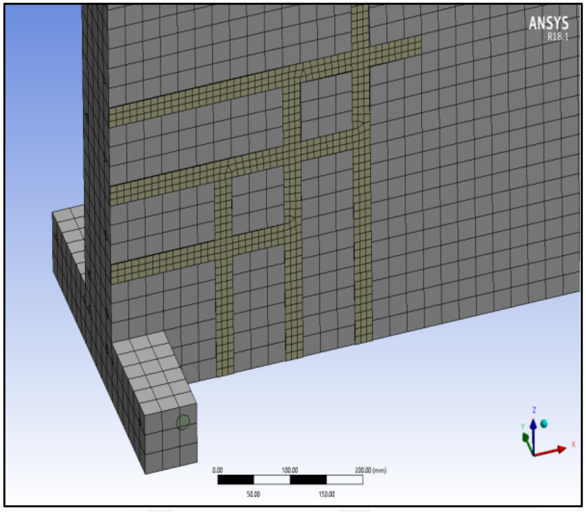

Fig. 2: Meshed Model of R_S2_W0_N3

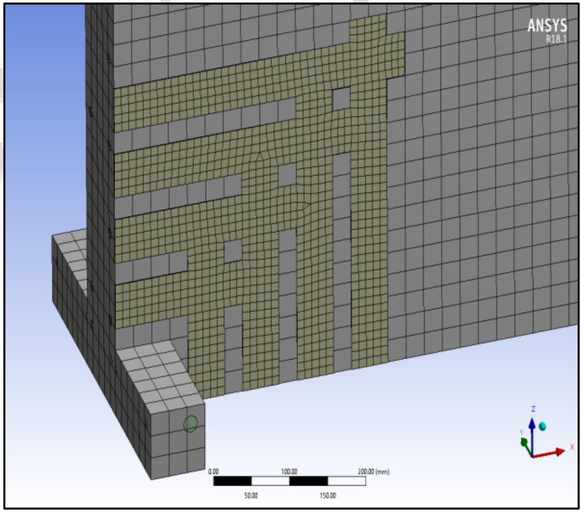

Fig. 3: Meshed Model of R_S0_W2_N4

IV. FINITE ELEMENT ANALYSIS RESULTS

A. Crack Patterns & Failure Modes

Strain diagrams give better representation of cracks. The cracking propagates inside the slab adjacent to the column. It starts tangentially near the column and then extends radially as the load increases. At the ultimate load the punching shear cone is visible due to sudden opening of the cracks. All specimens failed in punching shear. Figure 3 and 4 shows crack propagation of some model

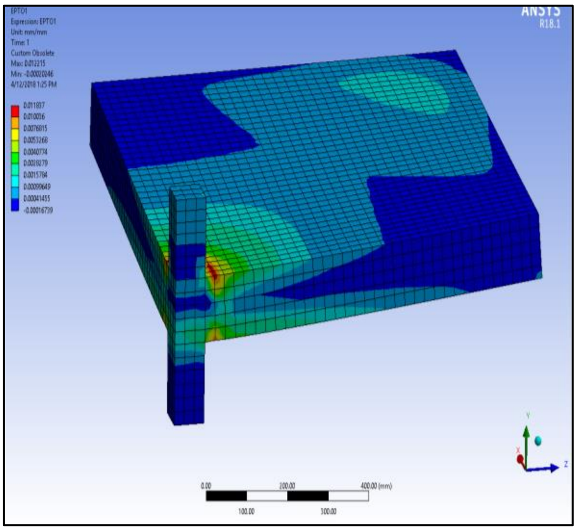

Fig. 4: Crack ropagation of R_S2_W0_N3

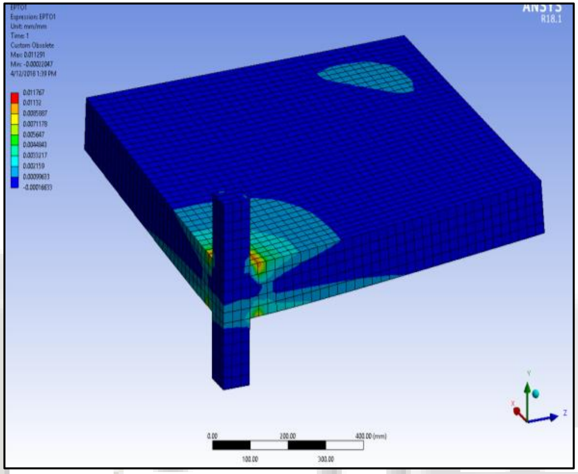

Fig. 5: Crack Propagation of R_S0_W2_N4

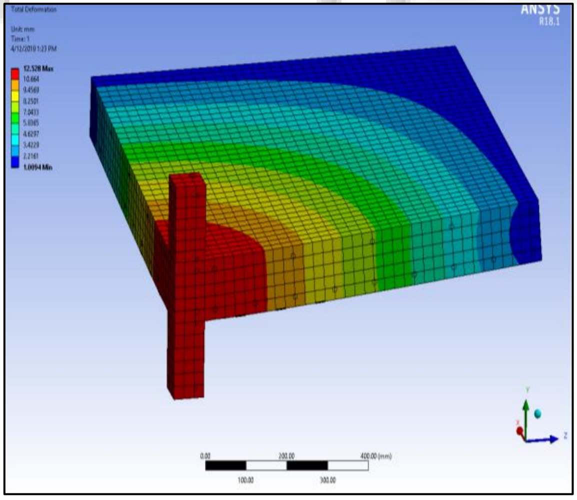

Fig. 6: Total deformation of R_S2_W0_N3

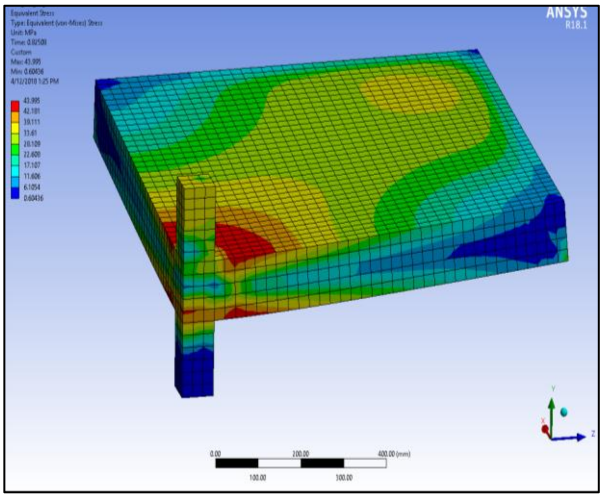

Fig. 7: Equivalent stress of R_S2_W0_N3

B. *Load Deflection Response*

The ultimate load and deflection values obtained from ANSYS are listed in table 2.The punching load and deflection is increased due to CFRP reinforcement. The increased deflection is due to the stiffening effect of CFRP. The control specimen experienced lowest punching load (253 kN) and deflection (12.1 mm). All strengthened specimens had higher punching load than control specimen.

Specimen	Deflection (mm)	Load (kN)
Control specimen	12.1	253
R_S0_W0_N1	16.46	301.48
R_S0_W0_N2	17.62	325.816
R_S0_W0_N3	16.23	346.588
R_S0_W0_N4	17.10	362.018
R_S0_W1_N1	18.25	354.896
R_S0_W1_N2	18.9	379.228
R_S0_W1_N3	19.65	394.065
R_S0_W1_N4	19.13	399.407
R_S0_W2_N1	17.71	334.125
R_S0_W2_N2	19.0	344.214
R_S0_W2_N3	19.32	364.985
R_S0_W2_N4	19.58	377.448
R_S0_W2_N1	15.23	283.68
R_S0_W2_N2	15.304	300.89
R_S0_W2_N3	16.81	324.629
R_S0_W2_N4	16.17	337.685
R_S1_W0_N1	16.94	318.101
R_S1_W0_N2	18.33	333.531
R_S1_W0_N3	19.5	352.522
R_S1_W0_N4	18.78	372.7
R_S1_W2_N1	16.43	316.914
R_S1_W2_N2	17.13	330.564
R_S1_W2_N3	17.23	339.466
R_S1_W2_N4	15.91	351.929
R_S2_W0_N1	13.96	263.905
R_S2_W0_N2	14.47	276.92
R_S2_W0_N3	14.99	288.16
R_S2_W0_N4	14.02	298.817
R_S2_W1_N1	14.63	271.006
R_S2_W1_N2	15.25	292.308
R_S2_W1_N3	15.73	316.568

R_S2_W1_N4	16.50	320.71
R_S2_W2_N1	15.18	286.391
R_S2_W2_N2	16.24	298.225
R_S2_W2_N3	16.63	326.036
R_S2_W2_N4	16.98	334.32

Table 2. Ansys Results

C. Influence of Number of Rings of CFRP Strips

For the current study spacing between the strips is kept constant. The width and number of rings of CFRP strips are varied. In this study as number of ring increases, punching load is increased .the maximum load is occurred in 4th ring. For a specified spacing, maximum load is achieved by W1 strips. The highest load is achieved by S0 spacing. Figure 8 and 9 shows load deflection response of some combination.

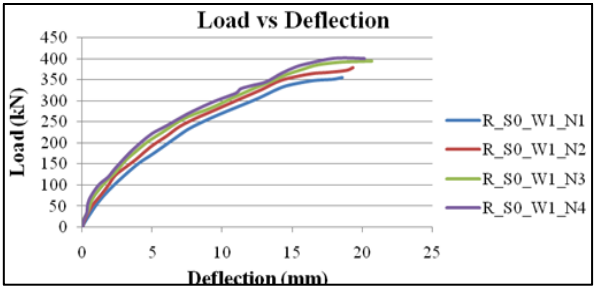

Fig. 8: Load-Deflection Response of S0_W1

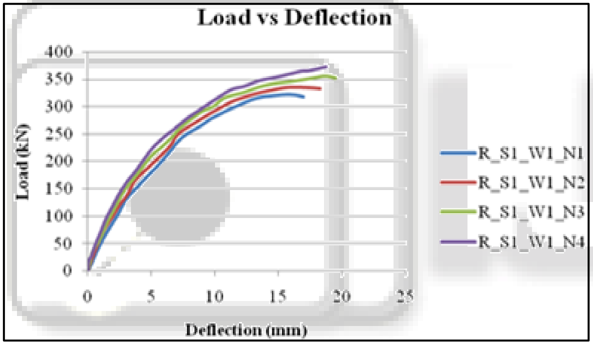

Fig. 9: Load-Deflection Response of S1_W1

D. Influence of Spacing between the CFRP Strips

In this study width of strip is kept constant. The spacing and number of rings of strips are varied. Figure 10 and 11 shows load deflection response of some combination. We can see that as spacing is increases, punching load is decreased. The highest load is achieved by S0 spaced strips. For a specified width as number of rings increases, load is increased. The highest load is achieved by W1 strips.

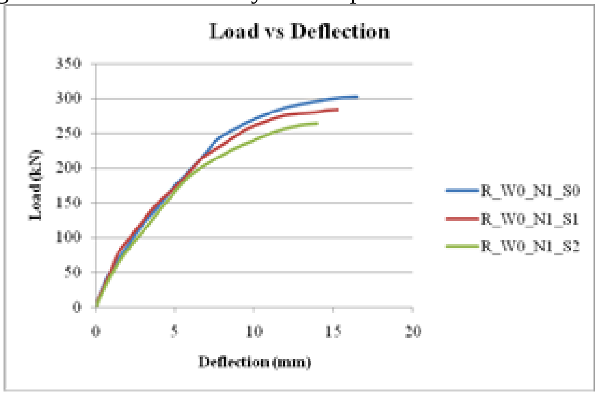

Fig. 10: Load-Deflection Response of W0_N1

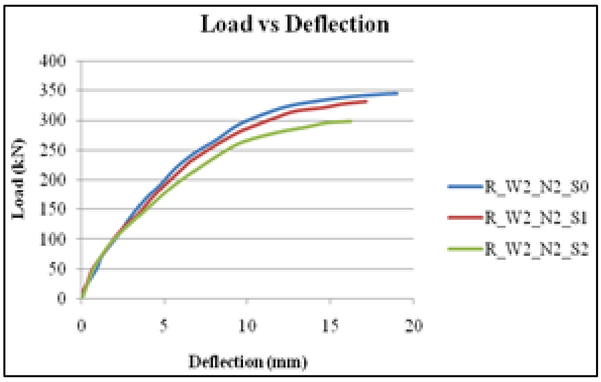

Fig. 11: Load-Deflection Response of W2_N2

E. Influence of Width of Strip

In this study number of ring is kept constant. The spacing and width of strips are varied. Figure 12 and 13 shows load deflection response of some combination. In this study maximum punching shear load is occur at 50 mm strip width and it has high deformation capacity.

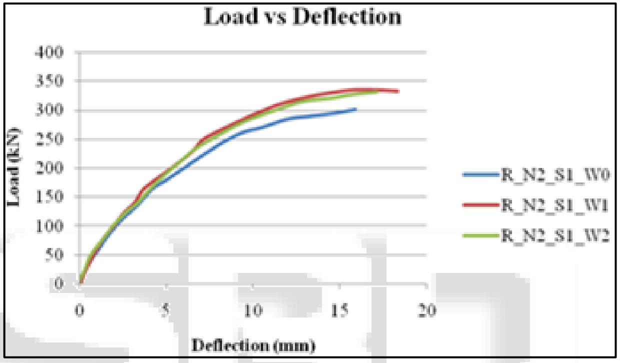

Fig. 12: Load-Deflection Response of N2_S1

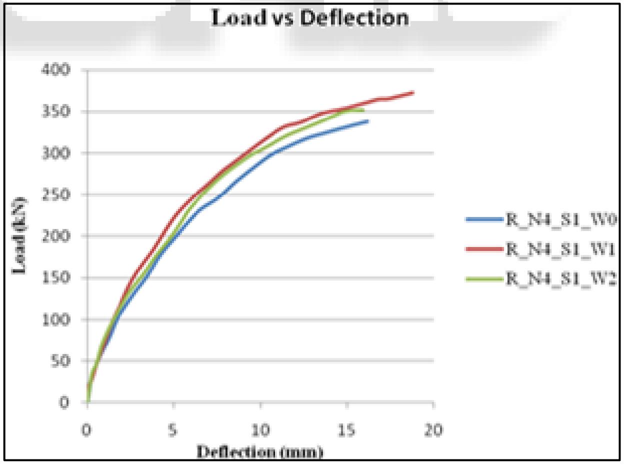

Fig. 13: Load-Deflection Response of N4_S1

F. Comparison of CFRP Reinforcement

The highest punching load occurs at R_S0_W1_N4. A comparison of without shear reinforcement and with shear reinforcement is plotted in figure 14. The specimen has 399 kN punching shear load and 19 mm deflection capacity.

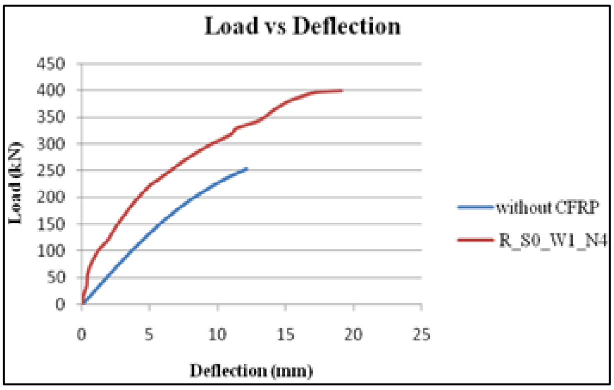

Fig. 14: Load-Deflection Response

V. CONCLUSIONS

- The proposed shear reinforcement system has a significant effect in increasing punching shear strength.
- The use of CFRP strips in the tension side of slab delay the formation and growth of cracks by increasing the flexural strength of the slab in the vicinity of column.
- The use of CFRP strips increased deformation capacity.
- As spacing between the strip increases the punching shear load is decreased.
- As number of rings increases the punching shear load is increased.
- The most efficient configuration for CFRP strip is R_S0_W1_N4. Which increases punching load upto 57.7%.

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