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Experimental Investigation on the Study of Rectangular RC Beams with Opening Strengthened with CFRP

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Abstract:
Provision of web opening to accommodate service lines is necessary now-a-days to utilize the dead space below the soffit of the beam, this eliminates sufficient amount of dead space and results in more number of storeys for same intended height and often produces economical design. However, the introduction of web opening in the beam results in the reduction of stiffness thereby leading to decreased strength and increased deflection. In this paper the experimental study on the use of carbon fibre reinforced polymer (CFRP) fabric to strengthen the beam is presented. The experimental program included testing of thirteen RC beams, three were control beam, four beams with opening, four beams with opening strengthened by CFRP and two beams were retrofitted with CFRP. The experimental investigation was carried out under two point loading and results indicate the percentage decrease in strength due to web opening varies according to opening shape. It is observed there is an increase in strength of beams due to wrapping of CFRP in the shear zone. The effect of strengthening on deflection, ultimate load, strain and CFRP contribution is investigated.

Keywords: Beam with opening, circular opening, CFRP fabric, square opening, steel plate, ultimate load.

I. INTRODUCTION

In recent times there is a rapid increase in population, hence the need for tall structures is very much in need now-a-days. Providing service lines below the soffit of the beam reduces the headroom resulting in lesser number of storeys. Structural engineers are posed with problem to introduce the opening in web thereby utilizing the space below the soffit of the beam. Introduction of opening in web results in elimination of sufficient dead space and results in more number of storeys and often gives economical design. Providing opening in beams reduces the ultimate load, increases deflection due to decreased stiffness. Opening in shear span results in formation of shear crack from opening which is detrimental and results in brittle failure which is catastrophic. Strengthening the beam by using CFRP fabric in shear span can increase the load carrying capacity and stiffness of the beam. Providing opening to give provision for service lines in the beam causes decrease in strength. The improvement in strength and stiffness can be achieved by wrapping CFRP fabric in that zone.

II. RELATED WORKS

Javad Vaseghi Amiri et al [1] reported that the presence of diagonal reinforcement reduces the rapid propagation of shear cracks. Small stirrups at bottom and top of opening increased the load carrying capacity. J.Suresh et al [2] investigated the steel fibre reinforced beam with and without steel plate and concluded that there was an increase in load capacity and deflection. Steel fibre reinforced beam with opening with steel plate deflected more than the normal RC beam. Number of cracks appeared was less in beams with square opening strengthened with plate this is due to reduced stress concentration at the corners of the opening. Bengi Aykac et al [3] investigated flexural behavior of RC beam with square and circular opening and concluded that beam with square opening was effected by reinforcement ratio. Beams with square opening failed after plastic hinge formation and beams with circular opening failed due to crushing of concrete. K.H.Yang et al [4] investigated the behavior of continuous beam with web openings and concluded that the crack propagation was influenced by shear span to depth ratio. load capacity of beam with opening in exterior span was higher when compared to opening in interior shear span. H.A.Abdalla et al [5] reported that increasing the opening depth decreases the load capacity. Increasing the opening width had minor effect before cracking. Wrapping the FRP composites on web face was more efficient than pasting the FRP at top and bottom face of the beam. Weiwem Li et al [6] reported that for different shear span to depth ratio, rupture and failure sequence was not similar for strengthened beams contribution of CFRP to shear strength was higher when shear span to depth ratio was between 2 to 3 and was least for less than 2. Tamer El Maadawy et al [7] reported that beam behavior is dependent on the degree of interruption of the natural load path. Beam having interrupted load path, a non linear load versus deflection response is seen which suggest higher rate of formation of crack.

III. EXPERIMENTAL PROGRAM

In this experimental work thirteen beams were cast and tested less than two points loading. The dimension of beam was 150x200x1300mm. Shear span to depth ratio was 2.127 and opening size to depth ratio was 0.416. Out of thirteen beams, three beams are considered control beam, four beams are with openings with and without steel plate, and four beams are with openings with and without steel plate strengthened with CFRP fabric and two beams retrofitted with CFRP fabric. Beam reinforcement details are shown in Fig 1 which is designed as balanced sections. The beam details and designated are shown table I.

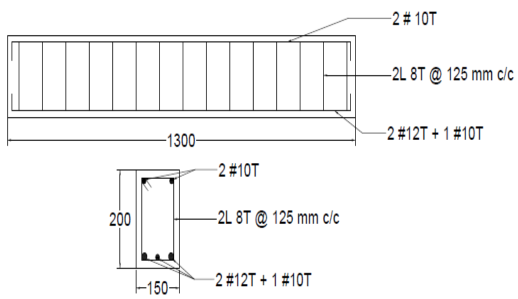


Figure.1. Beam reinforcement details

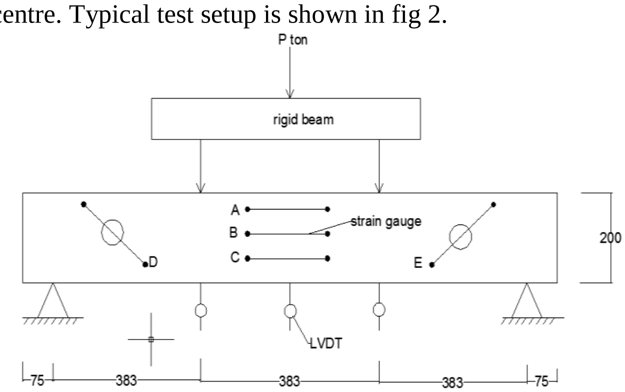
The grade of concrete used was of M30 having 28 day compressive strength of 35.11MPa, with water cement ratio of 0.437. Steel having yield strength of 500MPa was used for longitudinal reinforcement and for stirrups. CFRP fabric was used for strengthening and retrofitting of beams.

Table.1. Beam specimen details

Sl no	Group	Particular		designation	Pattern	No. of layers
1 2 3	–	Control beam		CB	–	–
4	Group A	Circular opening	Without steel plate	UC	U wrapped in shear span	One layer
5			With steel plate	UCS		
6		Square opening	Without steel plate	US		
7			With steel plate	USS		
8	Group B (Strengthened beams)	Circular opening	Without steel plate	SC		
9			With steel plate	SCS		
10		Square opening	Without steel plate	SS		
11			With steel plate	SSS		
12 13	Group C (Retrofitted beams)	Circular opening	Without steel plate	RC		

TEST SETUP

Loading frame of capacity 50tonne was used to test beams. Beams were subjected to two concentrated loads. The clear span between the supports was maintained at 1150mm. Shear span was maintained at 380mm for all beam specimens. The loading was applied at an increment of 10KN. LVDT were used to measure the deflection at the point below the loading and at the centre. Typical test setup is shown in fig 2.



Figur.2. Typical test setup

IV. RESULTS AND DISCUSSION

Ultimate load, deflection, mode of failure, crack pattern of beam specimens is observed. To investigate deflection and stiffness of beams with circular and square opening, load-deflection curves of the beams are studied. Table II gives deflection of various beams.

Table .2. Deflection of various beams

Beams	Deflection (mm)
CB	20.9
UC	13.9
UCS	12.8
US	11.1
USS	14.4
SC	15.6
SCS	17.5
SS	14.7
SSS	13.3
RC	14.05

A. LOAD-DEFLECTION BEHAVIOUR OF BEAM WITH CIRCULAR OPENINGS

The deflection at centre was found to be 20.9mm for beam CB, 13.9mm for beam UC, 12.8mm for beam UCS. The deflection of strengthened beam was found to be 15.6mm for beam SC, 17.5mm for beam SCS and 14.05mm for beam RC. Fig 3a to 3f gives load vs. deflection curve for various beams like control beams and beams with circular openings.

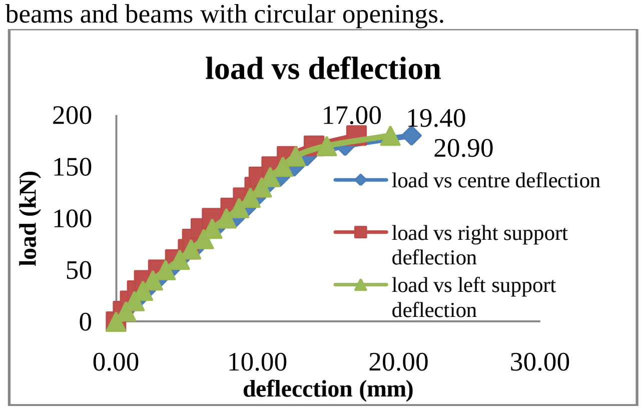


Fig ure.3.a: Load v/s deflection curve for control beam

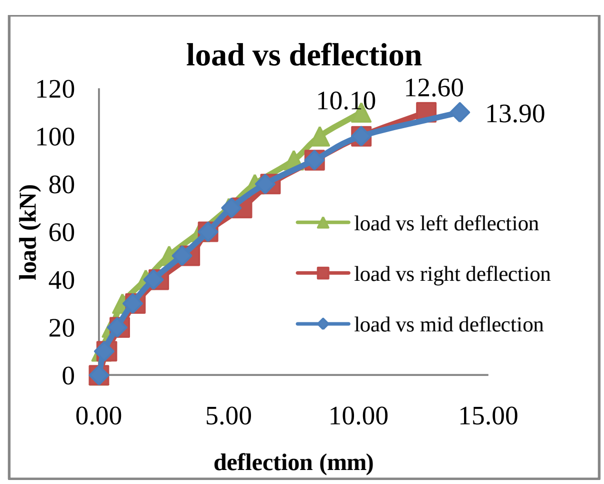


Figure.3.b: Load v/s deflection curve for beam UC

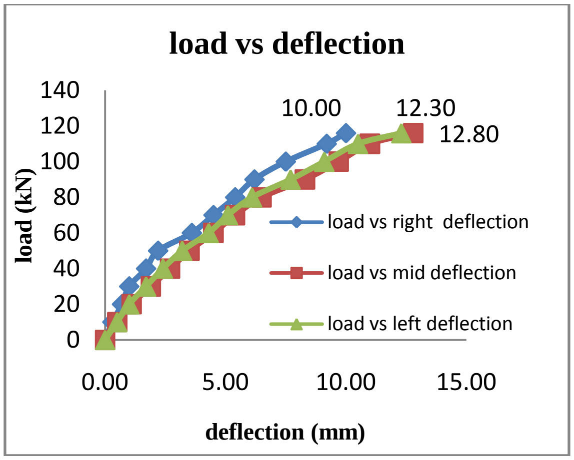


Fig 3c: Load v/s deflection curve for beam UCS

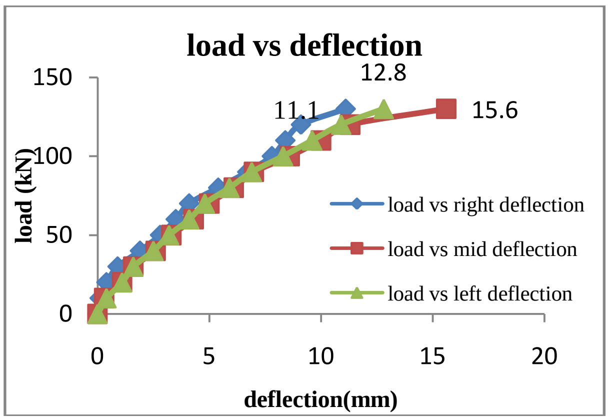


Figure.3. d: load v/s deflection curve for beam SC

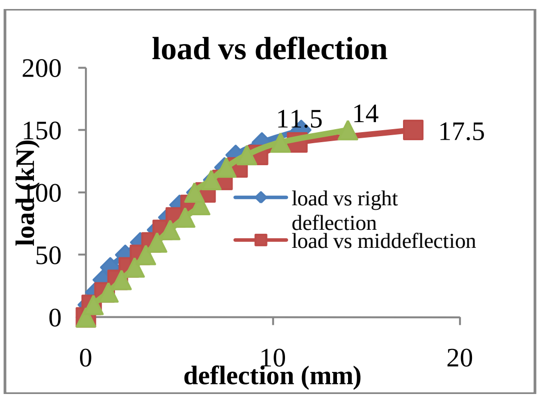


Figure.3.e: load v/s deflection curve for beam SCS

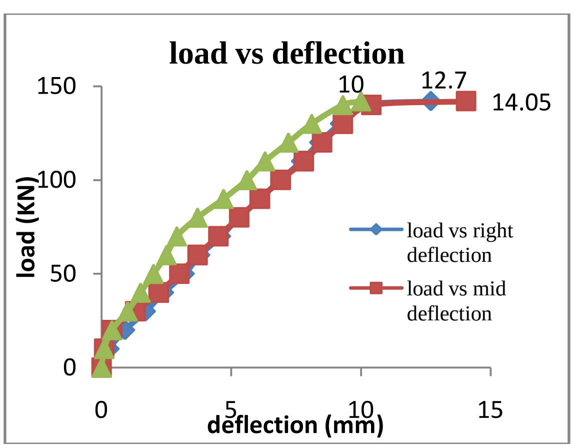


Figure.3. f: load v/s deflection curve for beam RC

It is evident from the graph (3a to 3f) that the deflection at centre is more than the deflection at point below the loading. It is observed that there is increase in deflection of beam UC is 51% with relation to beam CB. Decrease in stiffness of beam UC is 12.3% when related to beam CB. It is observed that there is increase in deflection of beam UCS is 29.3% with relation to beam CB. It is also observed that the decrease in deflection of beam UCS with relation to beam UC is 20.86%. Decrease in stiffness is found to be 6.25% in comparison to beam CB. Increase in deflection of beam SC is 48.57%, and decrease in stiffness is 9.92% with relation to beam CB. Decrease in deflection of beam SC is 28.06% when related to beam UC. Increase in deflection of beam SCS is 38.88%, and decrease in stiffness is 4.83% with relation to beam CB. Decrease in deflection of beam SCS is 41.03% with relation to beam SC. Decrease in deflection of beam SCS is 36.72% with relation to beam UCS.

B. LOAD-DEFLECTION BEHAVIOUR OF BEAM WITH SQUARE OPENINGS

The deflection at centre was found to be 12.8mm for beam US, 14.4mm for beam USS; 14.7mm for beam SS and 13.3mm for beam SSS. Fig 4a to 4d gives load vs. deflection curve for various beams like beam with square opening with and without opening and strengthened beams with square opening.

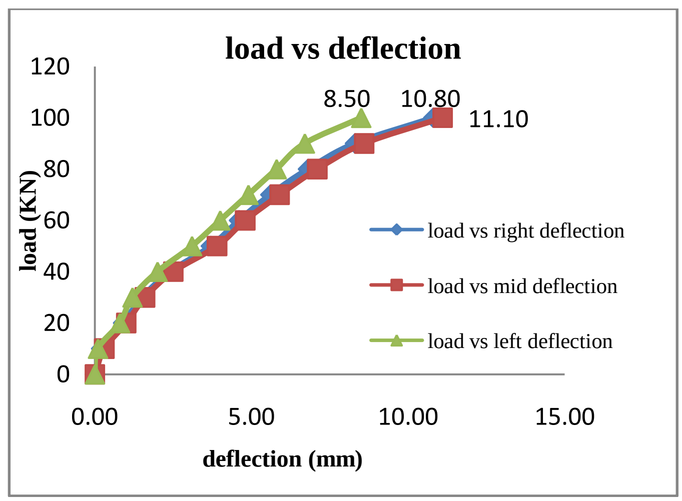


Figure.4. a: load v/s deflection for beam US

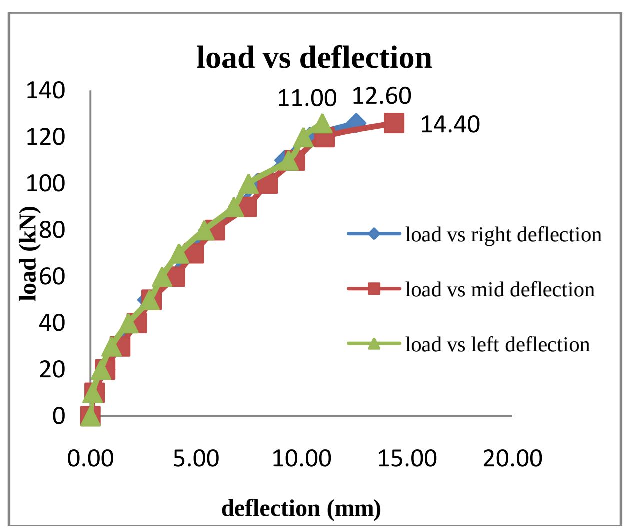


Fig ure.4.b: load v/s deflection for beam USS

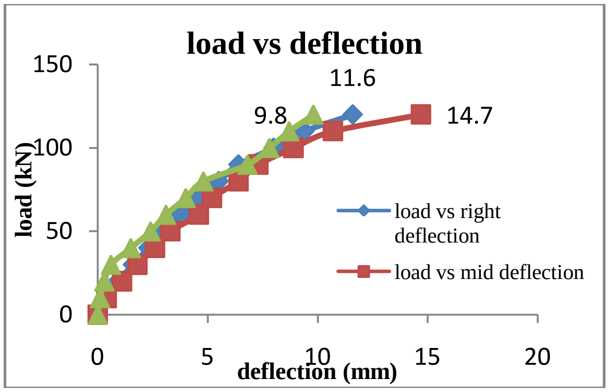


Figure.4. c: load v/s deflection for beam SS

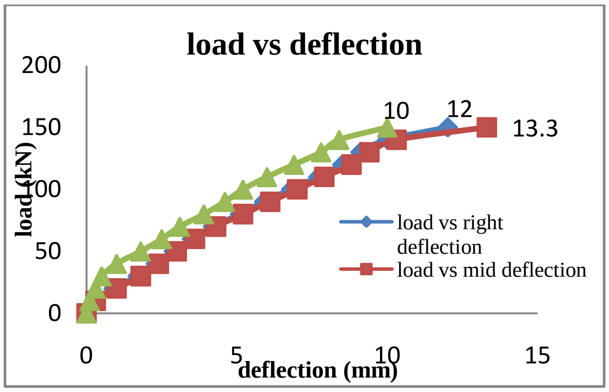


Figure.4. d: load v/s deflection for beam SSS

Increase in deflection of beam US is 32.14%, and decrease in stiffness is 27.58% with relation to beam CB. Increase in deflection of beam USS is 37.14% and decrease in stiffness is 7.17% when related to beam CB. Increase in deflection of beam SS is 48.48%, and decrease in stiffness is 26.5% with relation to beam CB. Decrease in deflection of beam SS is 19.8% with relation to beam US. Increase in deflection of beam SSS is 11.48%, and decrease in stiffness is 5.92% with relation to beam CB. Decrease in deflection of beam SSS is 40% with relation to beam SS. Decrease in deflection of beam SSS with relation to beam USS is 20.7%. Increase in deflection of beam RC is 34.46% with relation to beam CB. When correlated with the beam UC there was a decrease in deflection by 31.65% and 5% when correlated with beam SC.

C. ULTIMATE LOAD

Beams were loaded upto failure to find the ultimate load. Fig 5 gives comparison of ultimate load of various beams like control beam, beams with circular opening and beams with square openings. Table III gives ultimate load, increase or decrease in ultimate load of various beam specimens.

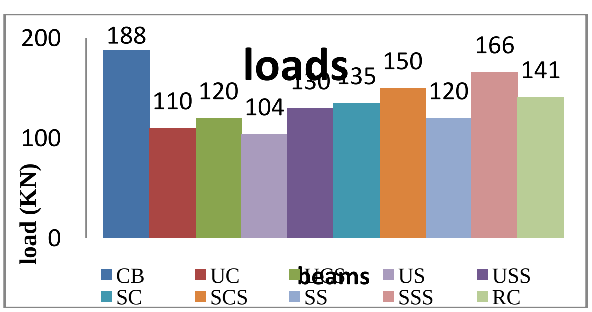


Figure. 5. Ultimate load of various beams

Table .3. Ultimate load

Beams	ultimate load	% decrease in ultimate load when compared to beam CB	% increase in strength due to wrapping
CB	188		
UC	110	41.40%	
UCS	120	36.20%	
US	104	44.70%	
USS	130	30.85%	
SC	135	28.19%	18.5%
SCS	150	20.20%	20%
SS	120	36.20%	13.33%
SSS	166	11.70%	21.68%
RC	141	25%	21.98%

We can see that there is a diminish in final load when openings are furnished, yet the rate of diminish in final load relies upon the shape of the opening. The rate of diminish in final load of beam UC is 41.4% when contrasted with beam CB. What's more, rate of diminish in final load of beam UCS is 36.2% when contrasted with beam CB. This might be because of presence of steel plate in the opening. The rate of diminish in ultimate load of beam US is 44.7% when contrasted with beam CB. An ultimate load of beam US is less because stress focuses at the edges of the opening which is not the case in circular opening which has no corners. The rate of diminish in ultimate load of beam USS is 30.85% as for beam CB. The rate of diminish in final load of beam SC is 28.19%, beam SCS is 20.2%, beam SS is 36.2%, beam SSS is 11.7% and beam RC is 25% when contrasted to beam CB.

D. SHEAR CONTRIBUTION BY CFRP

Since CFRP wrapping is being used to strengthened the beam shear span where opening is provided it is observed there is an increase in flexural load carrying capacity which is due to contribution of CFRP. Table IV gives shear contribution by CFRP.

Table.4. Shear contribution by CFRP

Sl no	Beams	Ultimate load (kN)	Shear force (kN)	Shear contribution by CFRP (kN)
1	UC	110	55	
2	UCS	120	60	
3	US	104	52	
4	USS	130	65	
5	SC	135	67.5	12.5
6	SCS	150	75	15
7	SS	120	60	8
8	SSS	166	83	18

The shear contribution by CFRP is found to be 12.5kN for strengthened beam with circular opening without steel plate, 15kN for strengthened beam with circular opening with steel plate, 8kN for strengthened beam with square opening without steel plate and 18kN for strengthened beam with square opening with steel plate. It can be noted the shear contribution is least for strengthened beam with square opening and more for strengthened beam with square opening with steel plate.

V. CONCLUSION

The following conclusions are drawn on the basis of the results obtained from the experimental study

- The improvement in ultimate load carrying capacity between unstrengthened beam with openings and strengthened beams with openings is seen and it varied from 13.33% to 21.68% for circular and square opening respectively.
- The use of steel plate within the opening additionally enhanced the ultimate load which varied from 8.33% to 27.7% for unstrengthened and strengthened beams with circular and square opening respectively.
- Contribution of CFRP wrapping in shear zone varied according to shape of the opening and is more for circular opening.
- Increase in deflection of unstrengthened beams with openings is found to be between 29.3% to 51% compared to control beam without opening, and between 11.48% to 48.57% for strengthened beams with openings when compared to control beam without opening.
- Decrease in stiffness of unstrengthened beams with openings is found to be between 6.25% to 27.58% and between 4.83% to 26.5% for strengthened beams with openings when related to control beam without openings.
- Observed some improvement in stiffness of CFRP strengthened beams with openings compared to unstrengthened beams with openings.
- Addition of steel plate in the opening, resulted in the increase in stiffness and reduction in the formation of cracks.
- Increase in ultimate load of strengthened beam is observed about 10% compared to unstrengthened beams with openings. And decrease in ultimate load for CFRP single layer strengthened beams with openings is 20% compared to control beams without openings and

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VII. ACKNOWLEDGEMENT

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