Strengthening of Preloaded RC Beam Containing Square Opening Located At Shear Zone by GFRP and CFRP Sheets

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Abstract— This experiment work is carried out study of "strengthening of preloaded RC beam containing small square opening located at shear zone by Glass Fiber Reinforced Polymer (GFRP) and carbon Fiber Reinforced Polymer (CFRP) sheets" in order to investigate the efficiency of external strengthening with GFRP and CFRP sheets. In this experimental work total eight beams were cast. All beams have dimensions of 150mm width, 250mm depth and 2000mm length. The first beam is solid beam and second beam is cast with opening but not strengthened referred as control beam. The loading has been carried out in two stages. In the first stage the solid beam and control beam are tested up to the ultimate load. The ultimate load of control beam is 80kN. The next three beams B1, B2, B3 are preloaded up to 30%, 45%, and 60% of ultimate load (i.e. 80kN) respectively. The last three beams B4, B5, B6 are also preloaded up to 30%, 45%, and 60% of 80 KN respectively. In the second stage the preloaded beams B1, B2, and B3 are strengthened with GFRP sheets and the preloaded beams B4, B5, and B6 are strengthened with CFRP sheets. All beams were tested in loading frame with two point loading up to failure. The test results revealed that the beams B1 to B6 strengthened with CFRP and GFRP sheets have shown percentage increase in load carrying capacity as compared to control beam. The control beam has shown a decrease in the load carrying capacity by 24% as compared to the solid beam. The increase in load carrying capacity of preloaded beams B1, B2, and B3 strengthened with GFRP sheets is 22.5%, 17.5% and 15% respectively as compared to the control beam, whereas in case of preloaded beams B4, B5, and B6 strengthened with CFRP sheets the increase in load carrying capacity observed is 32.5%, 27.5% and 22.5% respectively as compared to the control beam. The beams B1 and B4 strengthened with GFRP and CFRP sheets respectively and both preloaded to 30% have shown a higher load carrying capacity as compared to beams with higher preloading's. In all the six beams, the percentage increase in load carrying capacity is more in case of beams strengthened with CFRP as compared to beams strengthened with GFRP. From the overall study it can be concluded that the application of CFRP and GFRP sheets reduces the excessive cracking and beam deflection and increases the ultimate load carrying capacity and stiffness of the beam. The use of CFRP and GFRP sheets wrapping with the designed strengthening configuration could significantly reduce excessive cracking, deflection and increases the ultimate capacity, stiffness of beam.

Keywords: GFRP and CFRP sheets, RC Beams, Strengthen, Flexural Behavior, Preload Level, Retrofitting. Compressive strength, deflection of RCC beams

I. INTRODUCTION

Utility pipes and ducts are necessary to accommodate essential services in a building. It has been practiced that pipes and ducts are usually hanged below the floor beams, and covered by a suspended ceiling for its aesthetic purpose. In order to reduce headroom and provide a more compact and economical design, it is now essential to pass these utility pipes and ducts through opening in a floor beam. Openings can be circular, square or rectangular in shape. It is found that circular opening is normally used for electricity cables, telephone lines and computer networks while square or rectangular openings are used for air- conditioning services. Providing an opening in the web of a reinforced concrete beams resulted to many problems in the beam behavior including reduction in beam stiffness, causes excessive cracking and deflection and reduction in beam capacity. Furthermore, inclusion of openings leads to high stress concentration at the opening corners. The reduction of area in the total cross sectional dimension of a beam changes the simple beam behavior to a more complex one. Strengthening of beams with openings primarily depends whether the building services are pre-planned or post-planned. In the case of pre-planned openings, the sizes and locations of openings are known in advance during the design stage. As in the case of post-planned, it involves drilling of openings in an existing structure in a newly constructed building. Problems may arise during the process of laying utility pipes and ducts. Engineers often request to provide or re-locate the position of opening to simplify the arrangement of pipes and ducts which has not been considered during the design stage. Simplifying the lengthy pipes and ducts cause a huge savings in terms of time, labor and cost especially in a multi-story building. Hence, structural engineers need to provide an opening without ignoring the safety and serviceability of the structure. In an existing beam, strengthening externally around the opening is crucial with the use of external reinforcing material, such as steel plates or by fiber reinforced polymer (FRP) materials. The most common type of FRP in the concrete industry is made with carbon, aramid or glass fibers. The FRPs are usually in the form of sheets, strips, wraps or laminates. These materials were applied by bonding it to the external surfaces of the beams with various configurations and layouts. Numerous experimental studies have shown that externally bonded FRP laminates could significantly increase a member's stiffness and load carrying capacity, enhance flexural and shear capacities, providing confinement and ductility to compression structural members and also controls the propagation of cracks.

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II. EXPERIMENTAL PROGRAMME

Eight beams of 2m length and cross-section 150mm x250mm were cast in a horizontal wooden mould. All beams were designed as under reinforced sections. Three cubes were cast of size 150mm x 150mm x150mm during casting of each beam.

A. Materials Used:

In present work various materials is used with their respective properties namely: OPC 53 Grade, Fine aggregates: Natural River sand, Coarse aggregate, Water.

1) Cement:

Ordinary Portland cement of 53 grades conforming to IS: 12269-1987 has been used. The physical properties of the cement obtained on conducting appropriate tests as per IS: 12269-1987.

2) Fine Aggregates:

Locally available clean river sand passing through IS-480 sieves have been used. The results of sieve analysis conducted as per the specification of IS: 383-1970. The fine aggregate was of Zone II, Fineness Modulus = 3.51 and Specific Gravity= 2.61.

3) Coarse Aggregates:

The coarse aggregate used is crushed (angular) aggregate conforming to IS 383: 1970. The maximum size of aggregate considered is 20mm IS sieve passing and minimum size of aggregate considered is 12.5mm IS sieve passing. The results of sieve analysis conducted as per the specification of IS: 383-1970. Fineness Modulus = 8.0, Specific Gravity= 2.71.

4) Water:

Clean potable water is used for casting and curing operation for the work. The water supplied in the campus is of the potable standard of pH value= 7.5 are used.

B. Mix Proportion:

Concrete mix design of M20 grade was designed conforming to IS: 10262-2009 is prepared and trial mixes were attempted to achieve workable concrete mix. Cubes of standard size 150x150x150mm, were casted and were tested at 7 and 28 days.

S L. N o	**Concrete**	**Designation**	**Cement**	**Sand**	**Coarse aggregate**	**Water**
1	M20 Grade	NC	358.18 kg	683.354kg	1153.390 kg	197
Mix Proportion			1	1.91	3.22	w/c=0.55

Table 1: Mix Proportions Of M20 Grade Concrete By Weight

C. Compressive Strength:

The accelerated curing of cube specimens will be using for determining the characteristic compressive strength. The cube is tested in a compression testing machine of capacity 2000KN. As per standard procedure explained in IS: 516-1959 to get the compressive strength of the concrete cube. The compressive strength was calculated by dividing the load by area of specimen.The compressive strength results are as shown in table.

Identification on cube	**Load in kN**	**Average (kN)**	**Compressive Strength at accelerated curing (Mpa)**	**Compressive strength equivalent to 28 days curing (Mpa)**
C1	407.2	409.86	18.21	30.87
C2	410.9			
C3	411.5			

Table 2: Compressive Strength Results

D. Preparation of Beam Specimens:

The surface preparation is the foremost step in the installation of CFRP and GFRP sheets on the concrete surface. The debondiy failure is occur in the strengthened beam due to improper surface preparation. The concrete surface is made free from any oil or greasy substance. The embedded dust particles shall be removed from the surface using wire brushing to expose the aggregate. The beam surface shall be made dry properly prior to application of CFRP and GFRP sheets. Initially the pores appearing on the prepared concrete surface filled with the preprocessed epoxy by using scrapper. On completion of the initial treatment, a layer of epoxy is applied at an appropriate thickness of about 1 mm with brush. The CFRP and GFRP sheets measured and cut to the strips of required width and then applied on the concrete surface and gently pressed onto the coated epoxy resin. Subsequently, the sheet rolled by using roller in both vertical and horizontal direction to squeeze out the excess of epoxy. Beam provided with CFRP is allowed to set for 24 hours and cured for 5 to 6 days.

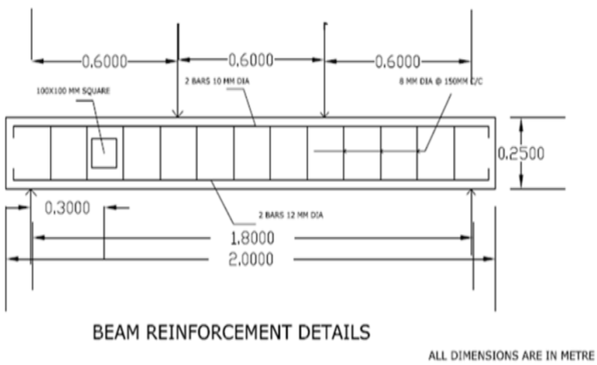

Fig. 1: Dimension of beam with square opening in shear zone

The steel consists of 2 main bar of 12mm diameter at the bottom and 2 holding bar of 10mm diameter at the top tied with the vertical stirrups of 8mm diameter at a spacing of 150mm.

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E. The procedures followed during testing:

Fig. 2: Beam Testing Method

All the beams were tested with two point loading applied at one third of the span, so as to have a pure bending or moment region in the middle of the beam and shear behavior at the support. The beam is placed such that the center of the beam and the center of the loading frame lie on the same line as per the required clear span of 1800mm. The load is distributed at two points by means of rigid distributing beam and rollers. The pressure jack is then placed over the center of distributing beam such that there was no eccentricity of the load. Load is indicated by pressure gauge provided in the loading jack. After the arrangement of loading system dial gauges were placed just below the mid span of the beam, one left side of the beam at 300mm from the support and one at the centre of the opening provided at shear zone. Before loading that is at zero load initial readings of all the gauges were noted. The load is applied at an increment of 2KN. At every load increment, dial gauges measurement were recorded and load corresponding to the first crack is noted down till the concrete fails. At every load increment the appearance of cracks were clearly observed and marked with marker.

III. Results and Discussions

A. General:

The results of the test conducted on eight RCC beams have been discussed in this chapter. The discussion is based on the load at failure, cracks pattern and load deflection curves of each beam.

B. Behaviours of Beams:

All beams have been loaded in two points loading symmetrical concentrated load applied at one-third of the span. The pre-loaded beams were initially loaded up to percentage of loading (30%, 45%, and 60%) of the control beam. Deflections were measured from dial gauge. At each increment, the crack was observed with the help of magnifying lens and the same were marked using a black pencil. The beams were loaded till failure, i.e. when the reading in the loading recorder starts coming back. The modes of failure of the specimen in this chapter a detailed discussion on the test results of non-strengthened beam and strengthened beam behavior of the beam, load deflection relationship and its mode of failure are presented.

Beam specimens	Preloading	Conditions
Solid beam (SB)	Nil	Without Strengthening
Control beam (CB)	Nil	Without Strengthening
B-1	30 percent	Strengthening with GFRP
B-2	45 percent	Strengthening with GFRP
B-3	60 percent	Strengthening with GFRP
B-4	30 percent	Strengthening with CFRP
B-5	45 percent	Strengthening with CFRP
B-6	60 percent	Strengthening with CFRP

Table 3: Behaviours of Beams:

Designation Beam	Type of Strengthened	Initial Cracking Load in KN	Ultimate Failure Load in KN	Increase load carrying capacity %	Maximum Deflection (mm)	Mode of Failure
Solid beam (SB)	Non Strengthened	28	106	-	10.60	Flexure
Control beam	Non Strengthened	22	80	-	9.98	Shear
B1	Strengthened by GFRP	20	98	22.5	12.30	Shear
B2	Strengthened by GFRP	18	94	17.5	13.03	Flexure
B3	Strengthened by GFRP	20	92	15.0	8.75	Flexure
B4	Strengthened by CFRP	22	106	32.5	13.7	Flexure
B5	Strengthened by CFRP	20	102	27.5	13	Flexure
B6	Strengthened by CFRP	20	98	22.5	10.6	Flexure

Table 4: Experimental Results

C. Load vs Deflection:

1) Comparisons of deflections:

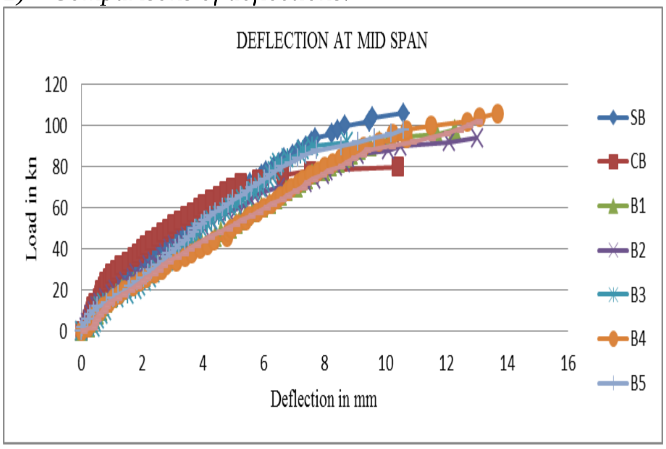

Fig. 3: Load-deflection relationship for all beams at mid span

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2) At Below Opening

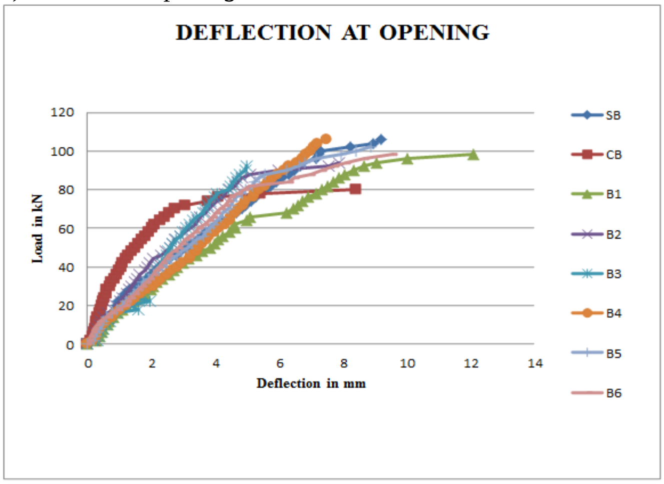

Fig. 4: Load-deflection relationship for all beams opening

3) At Right Side

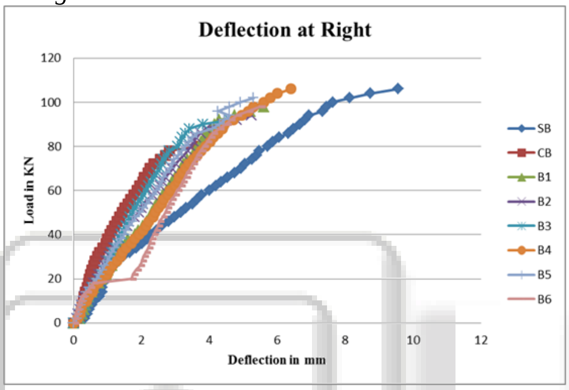

Fig. 5: Load-deflection relationship for all beams at below opening

D. Crack Mechanism:

The beam B1 strengthened around the opening with GFRP sheet as shown in figure5, the first crack is observed at the mid span of the beam at a load of P=20 kN. As the load is further increased at load of P=26kN, a small crack is observed bottom surface of the beam at the position of the opening. With an increase of the load more cracks were observed at the position between two concentrated loads. As the load increased a wide band of crack is observed inside of the opening of the beam. Finally, the beam failed in a shear mode at the opening at a load of 98 kN

Fig. 5: cracking pattern for the strengthened beam B1 with GFRP around the opening

Fig. 6: cracking pattern for the strengthened beam B2 with GFRP around the opening

The beams B5 strengthened around the opening with CFRP sheet as shown in figure 6, the first crack is observed at the mid span of the beams at a load of P=20KN. As the load is further increased at load of P=26KN respectively. a small crack is observed bottom surface of the beam at the position of the opening. With an increase of the load more cracks were observed at the position between two concentrated loads. As the load increased a wide band of crack is observed inside of the opening of the beam. Finally, the beams failed in a flexural mode at the opening at a load of 102KN respectively.

IV. Conclusion

- From the study it is concluded that, the inclusion of square opening significantly decreases load carrying capacity by 24% as compared to solid beam (SB).
- For preloaded beams B1, B2 and B3 strengthened with GFRP sheets the percentage increase in load carrying capacity observed is 22.5%, 17.5% and 15.0% respectively as compared to control beam.
- For preloaded beams B4, B5 and B6 strengthened with CFRP sheets the percentage increase in load carrying capacity observed is 32.5%, 27.5% and 22.5% respectively as compared to control beam.
- From the study it is observed that the beams strengthened at higher level of preloads have a lower load carrying capacity than those of beams strengthened at lower levels of preload.
- The percentage increase in load carrying capacity for preloaded beams strengthened with CFRP sheets is 8.18%, 8.55% and 4.55% in comparison to preloaded beams strengthened with GFRP sheets.
- For preloaded beams B1, B2 and B3 strengthened with GFRP sheets the percentage decrease in deflection is 23.25%, 30.56% and 14.05% respectively as compared to control beam.
- For preloaded beams B4, B5 and B6 strengthened with CFRP sheets the percentage decrease in deflection is 37.28%, 23.0% and 6.24% respectively as compared to control beam.
- Beams with opening in shear zone externally strengthened with CFRP and GFRP sheets the pattern of flexural cracks and mode of failure were similar to the solid beam.
- Modes of failure of strengthened beam with opening were observed in flexure zone.
- The application of GFRP and CFRP sheets thus reduces the excessive cracking and beam deflection and increases the ultimate load carrying capacity and stiffness of the beam.

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