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Research Paper

STRENGTHENING OF PRELOADED RC BEAMS CONTAINING CIRCULAR OPENING AT SHEAR BY USING CFRP AND GFRP SHEETS

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In modern buildings construction opening in beams are more often used to provide passage for utility duct and pipes. As a result storey height and material cost can be reduced. However providing an opening in the beam causes cracks around opening reduces load carrying capacity of the beam. In this experiment total eight beams were casted. The first beam is solid beam and second beam is casted 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 was 80 KN. The next three beams B1, B2, B3 are subjected to preloading up to 30%, 45%, 60%, respectively of 80 KN. The last three beams B4, B5, B6 are also subjected to preloading up to 30%, 45%, 60% respectively of 80 KN. In the second stage the preloaded beams B1, B2, B3 are strengthened with GFRP sheets and the preloaded beams B4, B5, B6 are strengthened with CFRP sheets. The test results revealed that the load carrying capacity of the control beam has shown a decrease in strength by 24.5% as compared to the solid beam. The increase in load carrying capacity of the beams strengthened with GFRP and CFRP observed was 17.5% and 32.5%, respectively as compared to the control beam. The beams B1 and B4 strengthened with GFRP and CFRP respectively and both preloaded to 30% have given a higher strength as compared to beams with higher preloading's. In all the six beams, the percentage increase in strength is more in case of beams strengthened with CFRP as compared to beams strengthened with GFRP.

Keywords: Reinforced concrete beams, Circular opening, Glass Fiber Reinforced Polymer (GFRP) sheets, Carbon Fiber Reinforced Polymer (CFRP) sheets, Preloading, strengthening

INTRODUCTION

Utility pipes and ducts are necessary to accommodate essential services in a building. The types of services include air-conditioning, power supply, telephone line, computer network, sewerage and water supply. It has been practiced that pipes and ducts are usually hanged below the floor beams, and covered

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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.

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. Thus sufficient strength and serviceability of beams with opening can ensured before construction. 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.

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 Fiber Reinforced Polymer (FRP) materials.

TYPES OF OPENINGS

Openings that are circular or square in shape are considered as small openings provided that the depth (or diameter) of the opening is less than or equal to 40% of the overall beam depth. Then the opening is said to be small opening. In such a case, beam action may be assumed to prevail. Therefore, analysis and design of a beam with small openings may follow the similar course of action as that of a solid beam.

When the depth of opening is greater than 40% of overall depth of beam then it is said to be large opening.

FIBER REINFORCED POLYMER

An FRP composite is defined as a polymer that is reinforced with a fiber. The primary function of fiber reinforcement is to carry load along the length of the fiber and to provide strength and stiffness in one direction. FRP represents a class of materials that falls into a category referred to as Composite materials. The composite properties are mainly influenced by the choice of fibers. In Civil Engineering three types of fibers dominate. These are carbon fibers, glass fibers and aramid fibers and the composite is often named by reinforcing fiber. For example Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP).

CFRP: It is an extremely strong and light fiber reinforced polymer which contains carbon fibers. In CFRP the reinforcement is carbon fiber which provides the strength and the matrix is polymer resin such as epoxy, to bind the CFRP Sheets on the concrete surface.

Advantages: CFRP sheets have excellent high strength to weight ratio, ease of construction, free maintenance properties, cost effectiveness and less impact on environment.

MATERIALS

Ordinary Portland cement 43 grade conforming to IS:8112-1989 was used. The locally available sand was used as fine aggregates. The sample satisfies the requirement of grading of zone II as per IS 383-1970. The size of coarse aggregates used was 20 mm down and 12.5 mm down which were mixed in equal in proportion.

Concrete mix proportion of M20 grade is obtained referring to IS: 10262-2007 as recommended. The proportion of cement, fine aggregate and coarse aggregate (20 and 12.5 mm) were 1:1.91:3.22 by weight and water cement ratio of 0.55 is maintained throughout the investigation.

Table 1: Quantity of Materials per Qubic Meter of Concrete

Ingredients	Quantity
Cement	358.18kg
Fine aggregates	683.35kg
Coarse aggregates	1153.39kg
water	197kg

High Yield Strength Deformed bars (HYSD) Fe 415 has been used as main reinforcement.

EXPERIMENTAL WORK

In the present experimental work 8 reinforced concrete beams were tested. All beams have a rectangular cross section of 150 mm width, 250 mm depth and length of 2000 mm and a effective span of 1800 mm. The first beam is casted solid without any openings, beam is designated as SB and second beam is casted with opening and not strengthened, it is referred as control beam and designated as CB. 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 next three beams B1, B2, B3 are subjected to preloading up to 30%, 45%, 60%, respectively of ultimate load of the control beam. The last three beams B4, B5, B6 are also subjected to preloading up to 30%, 45%, 60%, respectively of ultimate load of the control beam.

In the second stage the preloaded beams B1, B2, B3 are strengthened with GFRP sheets and the preloaded beams B4, B5, B6 are strengthened with CFRP sheets.

The circular opening will be provided by inserting a polyvinyl chloride (PVC) pipe. All openings will be preplanned circular openings of 100 mm diameter provided at a distance of 300 mm from the support of the beam.

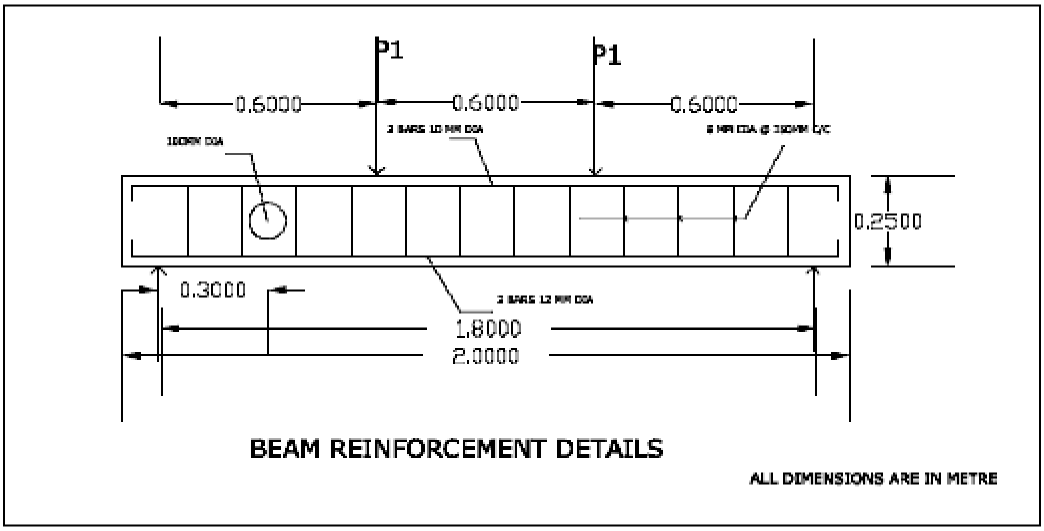
Table 2: Details of Beam Specimens Casted

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

Figure 1 shows the dimensions of the beam with opening.

All the beam consist of 2 bars of 12 mm as bottom reinforcement and 2 bars of 10 mm as top reinforcement and 8 mm diameter stirrups are provided at 150 mm center to center.

Figure 1: Dimensions of Beam



Strengthening Process

All the beams except the solid beam and control beam are strengthened by using CFRP and GFRP sheets. The sheets are applied on both the sides of opening up to 10 cm from the edge of the opening and sheets are also applied inside the opening. The beams B1, B2, B3 are strengthened by applying the GFRP sheets and the beams B4, B5, B6 are strengthened by applying the CFRP sheets.

Application of CFRP and GFRP Sheets

The surface preparation is the first step in application of the sheets on the concrete surface. The concrete surface is made free from dust, oil or greasy substances. The embedded dust particles were removed from the surface with metal wire brush. The beam surface must be dried prior to application of the sheets.

Lapox epoxy resin L-12(3202) and Lapox hardener K-6 their mixture was used as a matrix for binding the sheets to the concrete surface. Epoxy resin and hardener mixed in a proportion of 10:1. The mixture is mixed thoroughly in a metal plate. The mixture is applied using brush over the concrete surface. The carbon and glass fiber sheets were cut to required size and then gently pressed over the surface by gloved hand. The mixture is once again applied over the sheets. After application of sheets. The beams left for 6 days for cuing. After 6 days the beams were tested in the loading frame until the failure.

Figure 2: Application of Epoxy Resin to the Concrete Surface

Experimental Set up

Loading frame: All the beams were tested under loading frame of 1000 KN capacity. A solid MS rollers of 15 mm diameter and 150 mm long were used at each of the point load for transfer of loads. An ISMB 100 is placed on the MS rollers to distribute the applied load as the two point loads on the test beam. The proving ring and hydraulic jack arrangement are as shown in Figure 3.

Figure 3: Experimental Set up

Specimen Testing Procedure

All the beams were tested with two point loading applied at one third of the span, so as to have a pure 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 center of the loading frame lie on the same line.

The load is distributed at two points by means of rigid distributing beam and rollers. The hydraulic jack is placed over the center of distributing beam such that there was no eccentricity of the load.

Load is indicated by the pressure gauge provided in the loading jack. After arrangement of the loading system, dial gauges were placed just below the mid span of the beam, one at centre of the opening and one at other end of the beam at 300 mm from support.

Before loading the jack reading is set to zero and also dial gauges reading are set to zero. The load is applied at an increment of 2 KN.

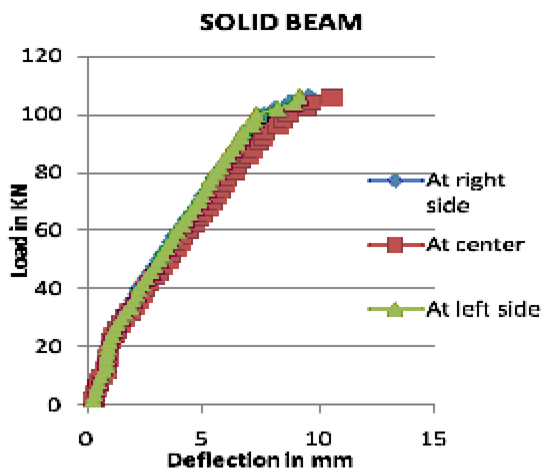
At every load increment dial gauges reading are recorded up to beam fails and load corresponding first crack load is noted down. At every load increment the appearance of cracks were clearly observed and marked with pencil.

TEST RESULTS AND DISCUSSION

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, crack patterns and load deflection curves of each beam.

The load defection behavior of all the tested beams has been presented in the following sections.

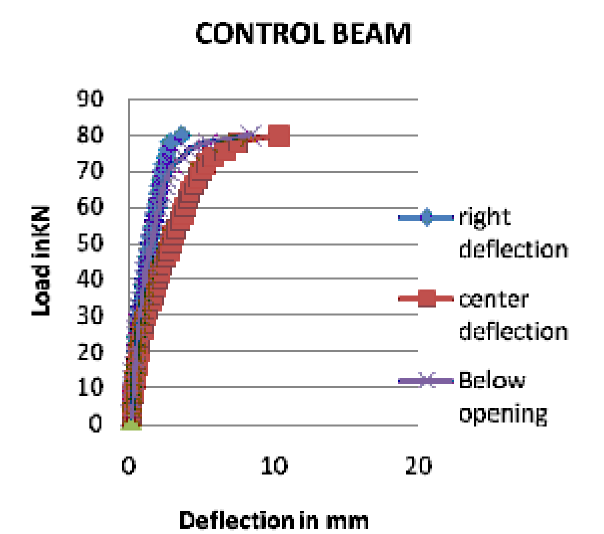
Figure 4: Load Deflection Relationship for Solid Beam



From the Figure 4, it is observed that the deflection at the center, at left side and at right side showing a equal increase up to a load of 46 KN and thereafter deflection at left side and at right side showing a equal increase and at the end, deflection at center has shown a maximum value. The maximum deflection observed at mid span is 10.6 mm.

From the Figure 5, it is observed that the deflection at the center of the beam showing a significant increase as compared to deflection below opening and at right side. The beam fails at a load of 80 KN in shear mode. The maximum deflection observed at mid span is 10.42 mm.

Figure 5: Load Deflection Relationship for Control Beam



Load Deflection Relationship of Beams After Preloading

The beam 1 shown in Figure 6 is pre-loaded up to 30% of the ultimate load of control beam (24 kN).

The beam 2 shown in Figure 7 is pre-loaded up to 45% of the ultimate load of control beam (36 kN).

Figure 6: Load Deflection Relationship for Beam 1

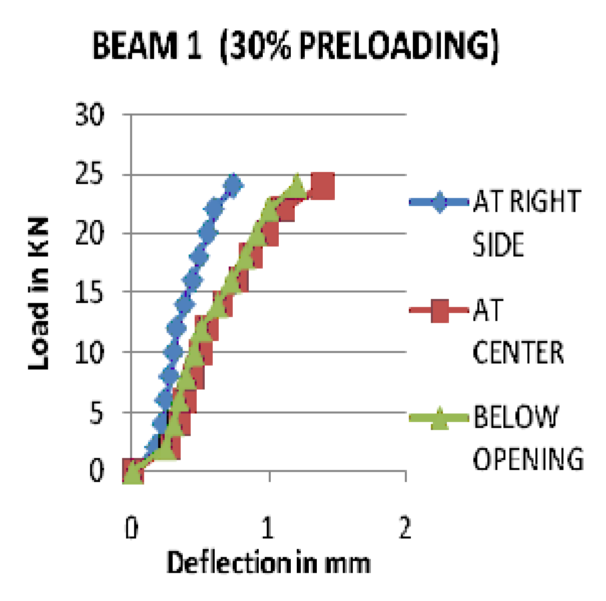
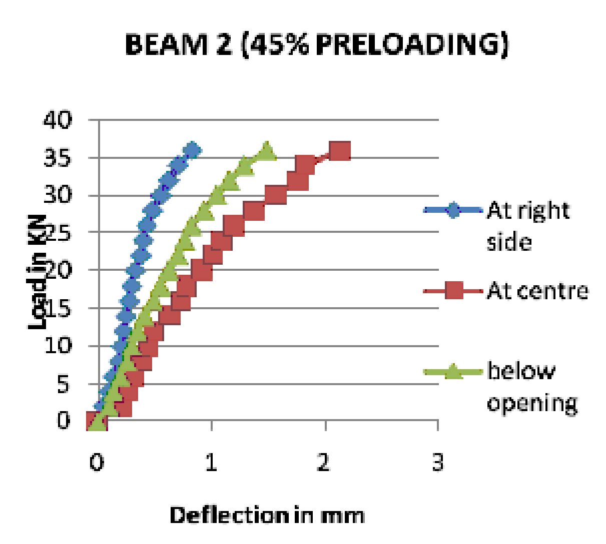


Figure 7: Load Deflection Relationship for Beam 2



The beam 3 shown in Figure 8 is pre-loaded up to 60% of the ultimate load of control beam (48 kN).

The beam 4 shown in Figure 9 is pre-loaded up to 30% of the ultimate load of control beam (24 kN).

Figure 8: Load Deflection Relationship for Beam 3

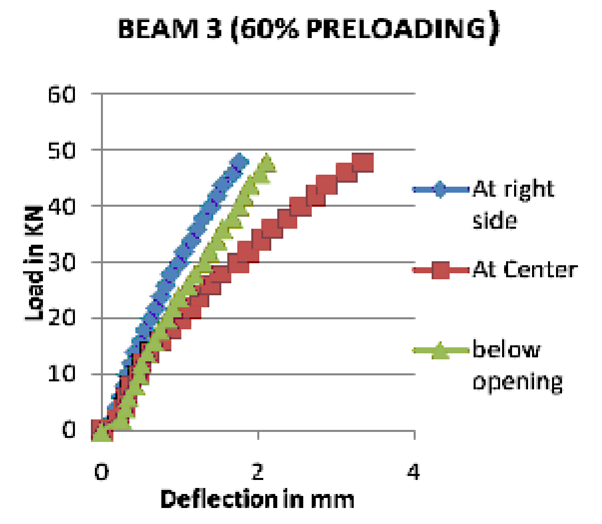
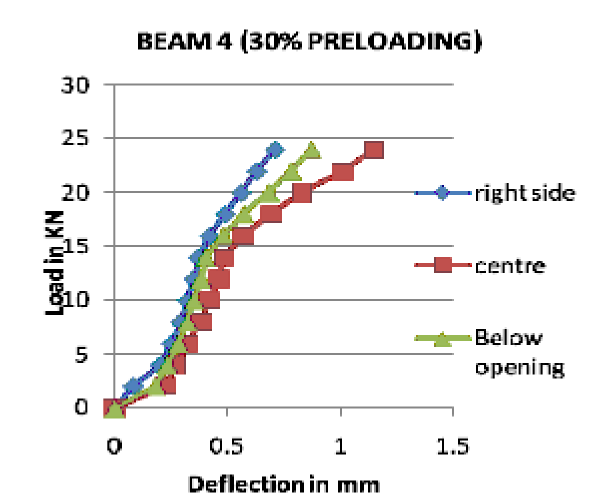


Figure 9: Load Deflection Relationship for Beam 4



The beam 5 shown in Figure 10 is pre-loaded up to 45% of the ultimate load of control beam (36 kN).

The beam 6 shown in Figure 11 is pre-loaded up to 60% of the ultimate load of control beam (48 kN).

In all the preloaded beams deflection at the center has shown a significant increase as compared to below opening and at right side.

Figure 10: Load Deflection Relationship for Beam 5

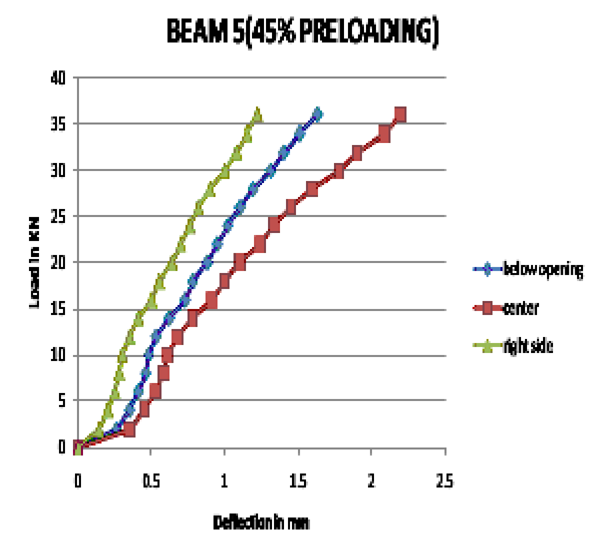
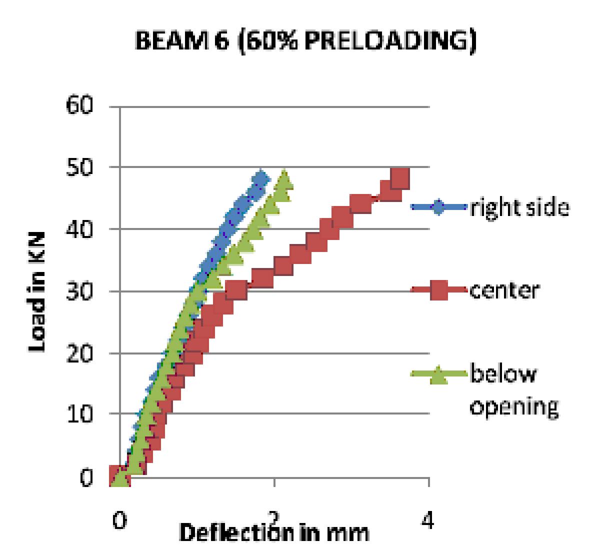


Figure 11: Load Deflection Relationship for Beam 6



Load Deflection Relationship of Beams After Strengthening

From Figure 12, it is observed that the deflection at center, below opening and at right side are increasing equally up to a load of 20 kN and there after the deflection at center shown a significant increase as compared to

Figure 12: Load Deflection Relationship for Beam 1

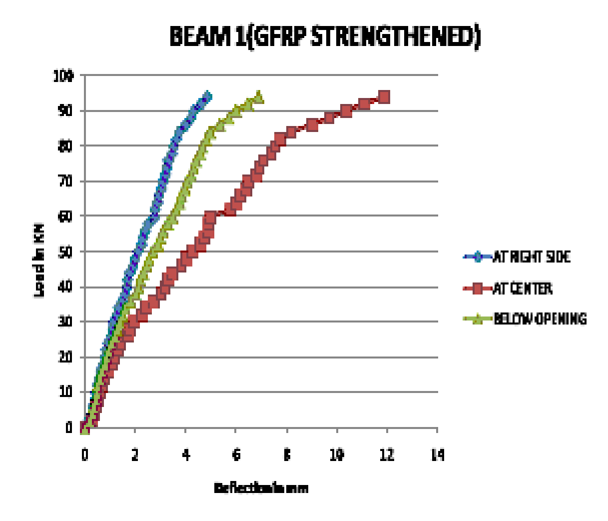
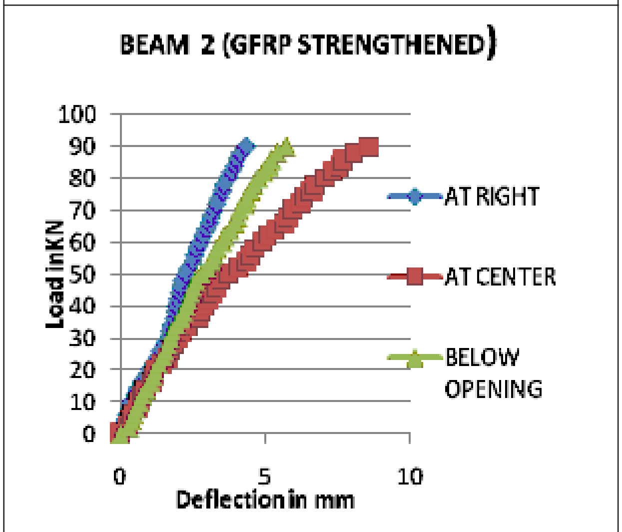


Figure 13: Load Deflection Relationship for Beam 2



below opening and at right side. The maximum deflection observed at midspan is 11.9 mm.

From the Figure 13, it was observed that the deflection at center, and below opening shown a equal increase up to a load of 22 kN and thereafter deflection at center shown a significant increase compared to below opening and at right side. The maximum deflection observed at mid span is 8.55 mm.

Figure 14: Load Deflection Relationship for Beam 3

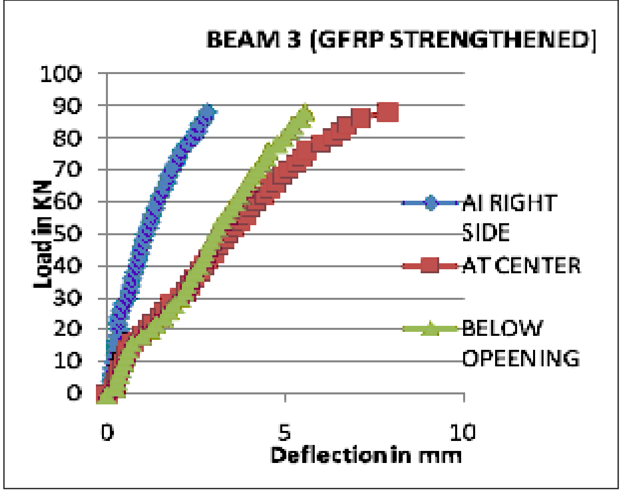
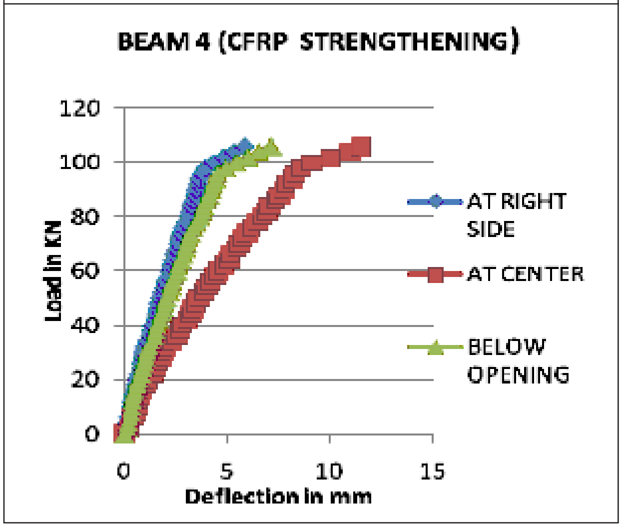


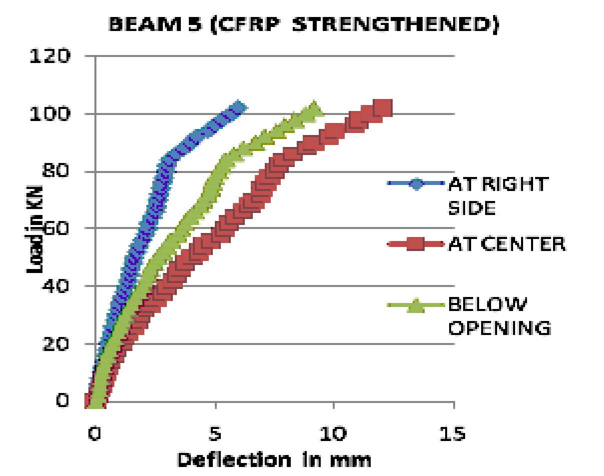
Figure 15: Load Deflection Relationship for Beam 4



From the Figure 14, it was observed that the deflection at center, and below opening shown a equal increase up to a load of 40 kN and thereafter deflection at center shown a increase compared to below opening and at right side. The maximum deflection observed at mid span is 7.9 mm.

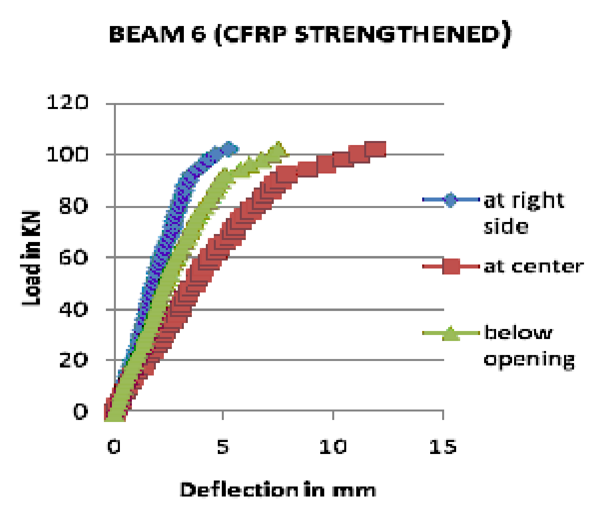
From the Figure 15, it was observed that the deflection at center, below opening and at right side is increasing equally up to a load of 16 kN and there after the deflection at center shown a significant increase as compared to below opening and at right side. The maximum deflection observed at mid span is 11.48 mm.

Figure 16: Load Deflection Relationship for Beam 5



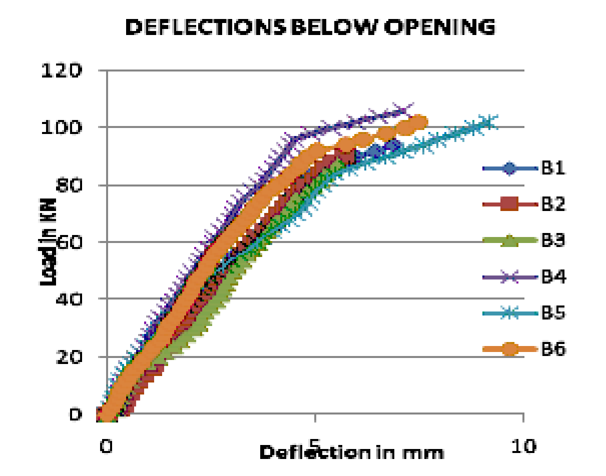
From the Figure 16, it was observed that the deflection at center, below opening and at right side are increasing equally up to a load of 18 kN and there after the deflection at center shown a significant increase as compared to below opening and at right side. The maximum deflection observed at mid span is 12.08 mm.

Figure 17: Load Deflection Relationship for Beam 6



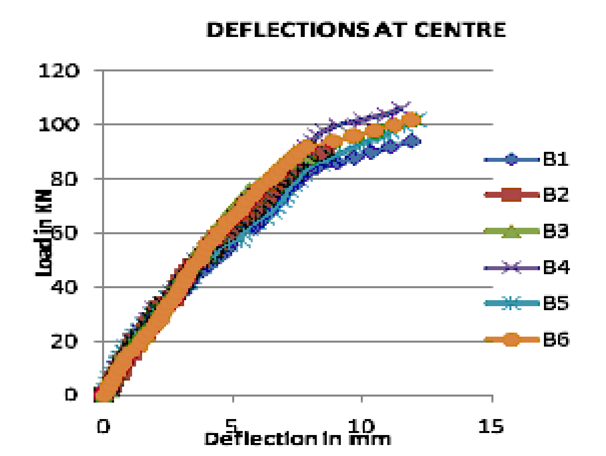
From the Figure 17, it was observed that the deflection at center, below opening and at right side are increasing equally up to a load of 16 kN and there after the deflection at center shown a significant increase as compared to below opening and at right side. The maximum deflection observed at mid span is 11.89 mm.

Figure 18: Load Deflection Relationship Below Opening for all the Beams



From the Figure 18, it was observed that the beam 5 strengthened with CFRP revealed a significant increase in the deflection compared all other preloaded beams. The beams B4, B5, B6 strengthened with CFRP

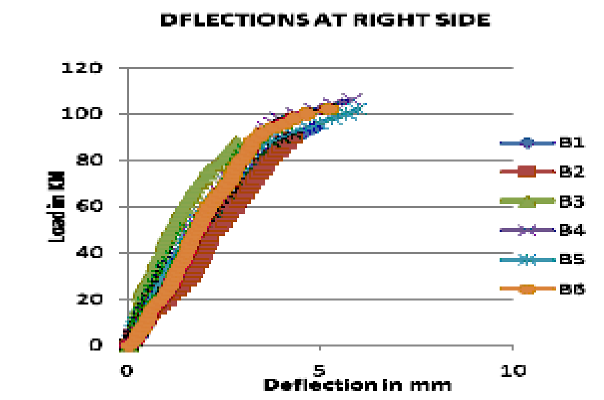
Figure 19: Load Deflection Relationship at Center for all the Beams



have shown increase in deflection compared to the beams B1, B2, B3 strengthened with GFRP.

From the Figure 19, it was observed that the beams B1, B4, B5, B6 revealed a significant increase in the deflection compared B2, B3 beams.

Figure 20: Load Deflection Relationship at Center for all the Beams



From the Figure 20, it was observed that the beam B4, B5 strengthened with CFRP revealed a significant increase in the deflection compared all other preloaded beams. The beam B3 strengthened with GFRP has shown a decrease in deflection compared to all other beams.

Cracking Patterns and Failure Modes

The solid beam was shown in Figure 21. The first crack was observed at mid span of the beam at a load of 32 kN, most of the cracks

Figure 21: Cracking Pattern for Solid Beam

Figure 22: Cracking Pattern for Control Beam

are observed in the flexure zone and finally beam failed in flexure zone at a load of 106 kN.

The first crack is observed in shear zone that is around the opening at a load of 28 kN, most of the cracks are observed around the opening.

Figure 23: Cracking Pattern for Beam 1

Finally, the beam failed in shear zone with a major diagonal crack at a load of 80 kN.

The control beam was shown in Figure 22. The beam 1 shown in Figure 23 was strengthened with GFRP sheets. The first crack is observed in the beam at a load of 26 kN. The major cracks are observed in between the center and the opening of the beam and the beam failed in flexure zone at a ultimate load of 94 kN.

Figure 24: Cracking Pattern for Beam 2

The beam 2 shown in Figure 24 is strengthened with GFRP sheets. The major cracks are observed below the point load and the beam failed in flexure zone at a ultimate load of 90 kN.

Figure 25: Cracking Pattern for Beam 3

The beam 3 shown in Figure 25 is strengthened with GFRP sheets. The major cracks are observed in region between mid span and edge of the GFRP sheets. The beam failed in flexure zone at an ultimate load of 88 kN.

Figure 26: Cracking Pattern for Beam 4

Figure 27: Cracking Pattern for Beam 5

The beam 4 shown in Figure 26 is strengthened with CFRP sheets. The first crack is observed in the beam at a load of 26 kN. The beam failed in shear zone by forming a major diagonal crack from support to the point load. The beam failed at an ultimate load of 106 kN.

Figure 28: Cracking Pattern for Beam 6

The beam 5 and 6 shown in figure 27 and 28, are strengthened with CFRP sheets. The major cracks are observed in region between mid span and edge of the CFRP sheets. Both the beams failed in flexure zone at an ultimate load of 102 KN.

TEST RESULTS AND DISCUSSION

Table 3: Test Results

Beam specimen	Crack Load in kN	Ultimate Load in KN	Deflection in mm
SB	32	106	10.6
CB	28	80	10.42
B1	26	94	11.9
B2	24	90	8.55
B3	26	88	7.9
B4	26	106	11.48
B5	28	102	12.08
B6	28	102	11.89

Beam specimen	Increase in Strength in%	Deflection in %	Failure Mode
SB			Flexure
CB			Shear
B1	17.5	14.2	Flexure
B2	12.5	-17.94	Flexure
B3	10	-24.18	Flexure
B4	32.5	10.17	Shear
B5	27.5	15.93	Flexure
B6	27.5	14	Flexure

DISCUSSION

The load carrying capacity, crack load , percentage increase in strength, percentage increase in deflection and modes of failure have been presented in the Table 3 for all the tested beams.

Examining the results presented in the Table 3, it is clear that the presence of an opening within the shear zone reduces the load carrying capacity and increases deflection. For the beams B1, B2, B3 which are preloaded upto 30%, 45% and 60% the percentage increase in strength observed was 17.5%, 12.5%, and 10%, respectively. For the beams strengthened with GFRP sheets for every increase in 15% in preloading the percentage in strength will reduce by 5%. The percentage decrease in strength in case of beams B1, B2, B3 strengthened with GFRP sheets are 11.3%, 15.09%, and 17%, respectively as compared to the solid beam. The percentage decrease in strength in case of beams B4, B5 strengthened with CFRP sheets are 3.77%, and 3.77% respectively as compared to the solid beam.

CONCLUSION

From the test results table the following conclusion are made:

Providing an opening within the shear zone in a beam decreases the load carrying capacity by 24.5% as compared to the solid beam.

The beams B1 and B4 strengthened with GFRP and CFRP, respectively and both preloaded to 30% have given a higher strength as compared to beams with higher preloading’s.

By comparing the beams B1, B2, B3 strengthened with GFRP it is observed that, as the percentage of preloading is increased, the percentage increase in strength has reduced. Thus if the percentage of preloading is less then increase in strength is more.

For the beams strengthened with CFRP with preloading 45% and above the percentage increase in strength observed was constant.

For the beams B4, B5, B6 percentage increase in deflection observed was 10.17% 15.93%, 14% as compared to the control beam. Thus CFRP sheets increases the ductility of the beams.

The control beam CB failed in shear because the opening is the weaker zone which is not strengthened and beam B4 failed in shear either due to the improper bonding of the sheet with the surface or due to the air gap which is created while applying the sheet on the surface.

In all the six beams, the percentage increase in strength is more in case of beams strengthened with CFRP as compared to beams strengthened with GFRP.

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