Experimental Investigation on the flexural behaviour of RC beams with circular opening strengthened by GFRP and AFRP sheets

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ABSTRACT - *Utilty pipes are necessary in the building constructions. But the provisions of utility pipes below the floor beams increases the head room height. So provision of a hole inside the floor beam will decrease the head room height. But it will decrease the strength capacity of the beam. Strengthening should be done in this situation. So many strengthening methods are available in the construction industry. In this paper, light weight FRP sheets are used for the retrofitting purpose. AFRP(Aramid fibre) and GFRP(Glass fibre) sheets are selected for the concrete strengthening. It offers high strength and high fatigue resistance. There are sixteen beams are used for the experimental study. Out of sixteen, twelve were strengthened by AFRP and GFRP. Then flexural behaviour, ductility index,energy absorption capacity of the casted beams were studied.*

***Key Words*: flexural behaviour, RC beams, circular opening, GFRP , AFRP**

INTRODUCTION

The deterioration can be mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals and saline water and exposure to ultra-violet radiations. As complete replacement or reconstruction of the structure will not be cost effective, strengthening or retrofitting is an effective way to strengthen the same. Common strengthening technique involves construction of steel jackets. However, it increases overall cross-sectional dimensions, leading to increase in self-weight of structures and is labour intensive. To eliminate these problems, steel plate was replaced by corrosion resistant and light-weight FRP composite plates. By wrapping FRP sheets, retrofitting of concrete structures provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance.

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 increase 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.More common methods of strengthening the beams with openings are strengthening by Carbon Fibre Reinforced Polymer Sheets (CFRP Sheets), Glass Fibre Reinforced Polymer Sheets (GFRP Sheets), Aramid Fibre Reinforced Polymer Sheets (AFRP).

Glass Fibre Reinforced Polymer materials are being used worldwide for the retrofitting and repair of deficient and old infrastructures such as bridges and buildings. In the case of Reinforced Concrete beams, externally strengthened with GFRP plates and fabrics and exposed to aggressive environmental conditions, however the bond between the GFRP plate and surface of the RC beam significantly affects the strength of externally reinforced RC beams. Thus it is essential to investigate the overall response of the RC beams externally strengthened with GFRP plates and fabrics and exposed to different environmental conditions.

Aramid fibre reinforced polymers are composite materials. In this case the composite consists of two parts: a matrix and a reinforcement. In AFRP the reinforcement is aramid fibre, which provides the strength. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. The reinforcement will give the AFRP its strength and rigidity; which are measured by stress and elastic modulus respectively. Unlike isotropic materials like steel and aluminium, AFRP has directional strength properties. The properties of AFRP depend on the layouts of the carbon fibre and the proportion of the carbon fibres relative to the polymer.

2 EXPERIMENTAL DETAILS

2.1 Specimen details

The experimental program consisted of strengthening using glass fibre reinforced polymer and aramid fibre reinforced polymer sheets. The test program consisted of fourteen R.C.C. beams with opening categorized into three groups. The beam has a cross section of 150 mm x 250 mm with an overall length of 1000mm. The first and second groups of beams with and without hole were tested without strengthening were considered as control specimens. The third and fourth group of beams with hole of 10 cm diameter at centre were strengthened with GFRP sheet and AFRP sheet inside the hole. Fifth and sixth group of beams were strengthened with GFRP sheet and AFRP sheet of 500mm width in single layer. GFRP and AFRP sheets were used in seventh and eighth group on both inside and surface in single layer. The Fig.3.11 shows reinforcement cage of the beam along with the specimen mould.

2.1.1 Reinforcement details

All beams were reinforced with two numbers of 12 mm diameter steel bars in tension side (bottom) and two numbers of 10 mm diameter steel bars in compression side (top). All beams were provided with 10 numbers of 8 mm diameter steel stirrups. Beams were tested simply supported and were subjected to two point loads symmetrically placed at equal distance from the center line of the beam. Further details of the cross section of the beams are shown in Fig.2.1.

Fig.2.1Reinforcement cage of the beam along with the specimen mould

2.1.2Casting and curing

The concrete was placed into the mould immediately after mixing and well compacted. The test specimens were remolded at the end of 24 hours of casting. They were cured in water for 28 days. After 28 days of curing the specimen were dried in air and white washed. Then all the beams were loaded up to the first crack and control beams were loaded up to the ultimate load. Fig.2.1 shows the cast specimen, Fig.2.2 shows the curing of specimens.

Fig.2.1 Cast specimen

Fig.2.2 Curing of specimen

Fig.2.3 Whitewashed specimens

2.2.3 Beam designation details

Sixteen beam specimens were cast to study the flexural behavior. Table 2.1 shows the beam designation details of the test specimens.

Table 2.1 Beam designation details

Sl.No.	Beam Designation	Wrapping Style
1	CB1	Control beam without opening
2	CB2	Control beam with opening
3	HB1	Beam with GFRP wrapped inside the hole
4	HB2	Beam with AFRP wrapped inside the hole
5	HB3	Beam with GFRP wrapped on the surface
6	HB4	Beam with AFRP wrapped on the surface
7	HB5	Beam with GFRP wrapped inside the hole and on the surface
8	HB6	Beam with AFRP wrapped inside the hole and on the surface

2.2.4 Test procedure

The specimens were tested in a loading frame of 2000kN (200t) capacity with an effective span of 1100mm by keeping the beam in horizontal position with two point loading system of 36.67cm internal loading distance and hinge at a distance of 5cm from the end support. Load cell of 200kN capacity with a least count of 1kN was usedto measure the applied load. The load was applied on top of the beams until the hair line cracks were identified and first crack load was noted for each beam. Further the loading was continued until the ultimate load was obtained. At each stage of loading deflection at mid span was found out using a LVDT. Fig.3.16 shows the schematic diagram of test set up.

3.RESULT AND DISCUSSIONS

3.1 BEHAVIOUR OF FLEXURAL BEAMS

All beams were tested under two point loading condition in the loading frame of 200 tonne capacity. Load was applied by hydraulic jack, then these beams were loaded up to the first flexural cracking and it was observed at an average load of 69kN. All the beams were loaded up to the ultimate load.

The FRP wrapped specimens showed improvement in the properties compared to control beam.

Table 4.1 First crack load and ultimate load for various beam specimens

Sl.No.	Beam designation	First crack load (kN)	Ultimate load (kN)
1	CB1	80	130
2	CB2	65	96
3	HB1	61	105
4	HB2	61	110
5	HB3	63	113
6	HB4	69	119
7	HB5	72	120
8	HB6	75	125

3.2 CRACK BEHAVIOUR AND FAILURE MODES

The crack behavior and failure modes of different beams tested in the experimental program are discussed below.

3.2.1 Control beam without opening (CB1)

Fig Control beam without opening (CB1)

The first hair crack was visible in the shear span at a load of 80 kN. As the load increased beyond the first crack load, many inclined cracks were also developed and the first visible crack started widening. With further increase in load, the beam finally failed at a load of 130 kN exhibiting a wider crack.

3.2.2Control beam with opening (CB2)

Fig Control beam with opening (CB2)

The first hair crack was visible at a load of 65 kN. As the load increased beyond the first crack load, many inclined cracks were also developed and the first visible crack started widening. With further increase in load, the beam finally failed at a load of 96 kN exhibiting a wider crack. It was found that the ultimate load carrying capacity was decreased by 26.15 % when compared to the solid control beam (CB1).

3.2.3Strengthened beam (HB)

The crack pattern of strengthened beam was found to be similar to that of control beam without opening. Crack patterns were visible on the shear zone. Due to wrapping of GFRP and AFRP sheets under each schemes, the crack pattern on the wrapped area was not visible.

Strengthened beam 1(HB1)
The beam HB1 was strengthened with GFRP sheet wrapped inside the opening. The same two-point loading was applied. The initial crack in the specimen appeared at 61 kN. As the load was enhanced, the failure was followed by an ultimate load of 105 kN. The ultimate load carrying capacity of strengthened beam HB1 showed an increase of 9.3% when compared to control beam CB2.

Strengthened beam 2 (HB2)
The beam HB2 was strengthened with AFRP sheet wrapped inside the opening. The same two-point loading was applied. The initial crack in concrete was appeared at 61 kN. As the load was increased, the failure was followed by an ultimate load of 110 kN. However, there is a 14.5% increase in ultimate load carrying capacity over the control beam CB2.

Strengthened beam 3(HB3)
The beam HB3 was strengthened by wrapping of GFRP sheet on the surface of the opening of width 20mm on either side from the edge of the opening. The failure was initiated by the debonding of GFRP sheets. The crack patterns were more visible after the debonding of GFRP sheets. The initial crack started at a load of 63kN. Failure of beam HB3 occurred at an ultimate load of 113 kN. The rupture of GFRP sheet was sudden and accompanied by a loud noise indicating a total loss of load capacity. The strengthening of beam HB3 resulted in a 17.7% increase in the ultimate load carrying capacity over the control beam CB2.

Strengthened beam 4(HB4)
The beam HB4 was strengthened by wrapping of AFRP sheet on the surface of the opening of width 20mm on either side from the edge of the opening. The initial crack started at a load of 69kN. Failure of the beam occurred at an ultimate load of 119kN. The strengthening of beam resulted in a 24 % increase in the ultimate load carrying capacity over the control beam CB2.

Strengthened beam 5(HB5)
The beam HB5 was strengthened with a layer of GFRP sheet inside and on the surface of the openings. The same two-point loading was applied. The failure was initiated by the debonding of GFRP sheets. As the load was enhanced, the debonding failure was followed by an ultimate load of 120 kN. The rupture of GFRP sheet was sudden and accompanied by a loud noise indicating a total loss of load capacity. The strengthening of beam HB5 resulted in a 25% increase in the ultimate load carrying capacity over the control beam.

Fig Beam with GFRP wrapped inside the hole and on the surface

Strengthened beam 6(HB6)
The beam HB6 was strengthened with a layer of AFRP sheet inside and on the surface of the openings. The same two-point loading was applied. The failure was initiated by the debonding of AFRP sheets. As the load was increased, the debonding failure was followed by an

ultimate load of 125 kN.The rupture of AFRP sheet was sudden and accompanied by a loud noise indicating a total loss of load capacity. The strengthening of beam HB6 resulted in a 30.2% increase in the ultimate load carrying capacity over the control beam CB2.

Fig Beam with AFRP wrapped inside the hole and on the surface

3.3 LOAD DEFLECTION BEHAVIOUR OF BEAMS

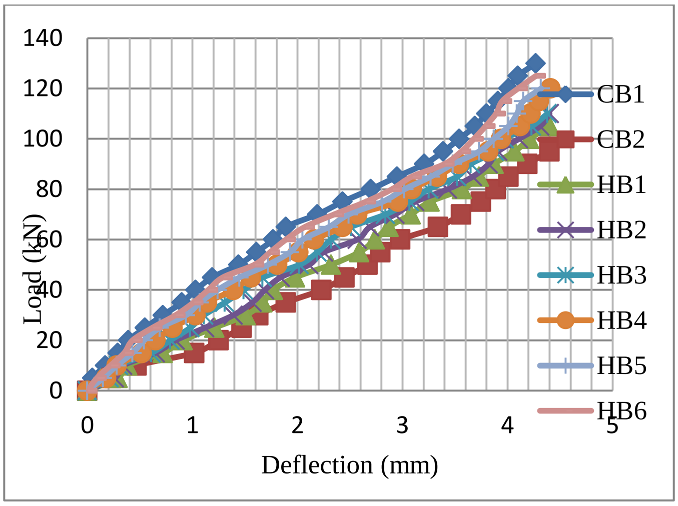
The specimens were tested under monotonically increasing load until failure. As the load increased, beam started to deflect and flexural cracks developed along the span of the beams. Eventually, all beams failed in a typical flexure mode.

Fig. 4.7 Load-deflection curve for wrapped specimens

Examining the results presented in the Table 4.1, it is clear that the presence of an opening not only reduces the load carrying capacity of the beam but also reduce the stiffness of the beam. The reduction in the load carrying capacity of the beam was about 26.15 % due to presence of a 100 mm diameter circular opening within the flexural zone. The percentage of increase in load carrying capacity for the beams HB5 and HB6 strengthened with GFRP and CFRP sheets around and inside the opening was 25 % and 30.2 % respectively as compared to non-strengthened beam CB2 (control beam with circular opening). It can be seen that external strengthening around and inside the opening significantly increases the beam stiffness at the opening, increase in the load carrying capacity and decrease in deflection as compared to non strengthened beam CB2. It has been observed that within the elastic range of loading, the behaviour of all strengthened beams with opening were similar to that of the solid beam CB1.

4. CONCLUSIONS

- From the load defection graph of each beam specimens obtained, it was clear that the load deflection graph for wrapped specimens was found to be in between of that of control solid beam and control beam with opening. The load deflection graph of HB6 was found near to the control solid beam. The energy absorption and ductility index values of HB6 were also found to be near to the control solid beam. Hence AFRP wrapped around the opening and on the surface can be adopted as the better scheme among the other wrapping styles.
- Wrapping of beams with FRP was found to be an effective method for strengthening of beams.



Strengthening of the beam opening with AFRP and GFRP sheets around the opening is more efficient than strengthening of the beam opening with AFRP and GFRP sheets inside the opening.

- Strengthening of the beam opening by using AFRP and GFRP sheets both around and inside the opening increases the load carrying capacity significantly and in case of AFRP sheets percentage of increase in load carrying capacity is 30.2% where in the case of GFRP sheets percentage of increase in load carrying capacity is 25%.

From the study, it can be concluded that the strengthening with AFRP around and inside the opening increases ultimate load carrying capacity and was found the best strengthening technique among all the strengthening process.

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