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Investigation on EBROB Method to Postpone Debonding Of CFRP Sheet Composite in Pre-Cracked RC Beams

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Abstract - *One of the key issues associated with bonding of carbon fibre reinforced polymer (CFRP) sheets to the tension side of reinforced concrete (RC) beams is the debonding of CFRP sheets that leads to premature and brittle failure of the structural member. When the beam is loaded the CFRP sheet get peeled off from the beam with a piece of substrate concrete before reaching the ultimate load capacity. In this project boring EBROB (externally bonded reinforcement on bores) is proposed as an alternative method for bond strengthening in pre-cracked beam. The bonding strength is studied with the diameter of holes, depth of holes, spacing or number of holes. This project deals with the experimental Investigation on EBROB Method to Postpone Debonding of CFRP Sheet Composite in Pre-Cracked RC Beams. Results shows that performance of EBROB method can be improved by increasing holes diameter and by decreasing spacing between holes. There is an optimum hole depth beyond which ultimate load capacity of specimen is reduced. The EBROB strengthened specimens shows higher load capacity up to 23.75 %.*

Key Words: Flexural strengthening, EBROB, Pre cracked RC Beam, Debonding, Carbon Fiber Reinforced Polymer (CFRP)

1. INTRODUCTION

The use of Fibre Reinforced Polymers (FRP) in the last few years in various engineering applications, forums, and configurations offers an alternative design approach for the construction of new concrete structures and rehabilitation of existing ones. Strengthening of existing structures may be required due to design and execution problems, emergent needs for higher load capacities and better condition or changes in construction codes and regulation.

The key properties that make FRP materials suitable for structural strengthening are their non-corrodible nature and high strength-to-weight ratio. One of the key issues associated with bonding of Carbon Fibre Reinforced Polymer (CFRP) sheets to the tension side of Reinforced Concrete (RC) beams is the deboning of CFRP sheets that leads to premature and brittle failure of the structural member. When the beam is loaded the CFRP sheet get peeled off from the beam with a piece of substrate concrete before reaching the ultimate load capacity. Debonding of FRP sheets from concrete surface is the most challenging type of failure observed in RC strengthened members. Externally bonded reinforcement (EBR) is a common method for mounting the sheet that causes conventional surface preparation

Debonding failures are often brittle and occur with little warning, therefore making them an undesirable failure mode. Numerous experimental studies have been conducted to investigate the flexural and shear performance of uncracked reinforced concrete (RC) members externally strengthened with CFRP laminates or strips. However, the most practical usage of CFRP is to retrofit sections that had already been cracked and in need of maintenance. The fact that there have been limited studies to investigate the behaviour and performance of pre cracked beams strengthened with CFRP systems necessitated new and further investigations. EBROB (Externally Bonded Reinforcement on Bores) method is a special form of externally bonded reinforcement on bores which is proposed as an alternative to conventional method of surface preparation in EBR method.

2. EXPERIMENTAL INVESTIGATION

This section consists of the experimental investigation on the EBROB method to postpone debonding of CFRP composite in pre cracked reinforced concrete (RC) beams. In this chapter details of specimen, material properties, loading setup and strengthening techniques of this experimental program is described.

2.1 MATERIALS

Table 1 gives the details of material testing

Table -1: Material test

Tests	Materials	Equipment used	Value obtained
Specific gravity	Cement(PPC)	Le chatelier flask	3.125

Consistency limit	Cement(PPC)	Vicat apparatus	33%
Fineness	Cement(PPC)	Sieve shaker	5%
Initial setting time	Cement(PPC)	Vicat apparatus	45 min
Specific gravity	Course aggregate	Wire basket	2.72
Specific gravity	Fine aggregate	Pycnometer	2.65

2.2 MIX PROPORTION

Mix design for M25 concrete have been worked out as per IS 10262:2009. The same mix proportions were used for all the specimens. In table 2 gives the details of mix proportion.

Table-2: Mix proportion for M25 grade,Kg/m³

Cement	Fine aggregate	Course aggregate	Water
394.32Kg/m³	721.94Kg/m³	1195.4Kg/m³	157.7Kg/m³

2.3 BEAM SPECIMEN CONFIGURATIONS

The RC beam having rectangular cross section of 120 mm width and 140 mm depth and 1000 mm length. The clear span length is 750 mm and the beams were reinforced with two 8 mm diameter top and two 6 mm diameter flexural reinforcement bars. The shear reinforcements comprised of 6 mm diameter stirrups at 80 mm Centre to Centre (c/c). The design of reinforcements for beam was done according to IS 456:2000 codes. The ultimate load capacity for the specimen is determined by using three point bending test in Universal Testing Machine (UTM).

In this investigation two control beams are there one is for finding the pre-cracking load i.e., 60% of ultimate load of first control beam is taken as pre cracking load. Second control beam is for finding the debonding of CFRP composite without EBROB method.

There are fifteen configurations with parameters being borehole depth, borehole diameters, and borehole spacing. For this work, the diameter of boreholes used are 10mm, 12mm, 16mm, and 25mm. Centre to centre spacing of boreholes used are 100mm,115mm, 125 mm and 150 mm respectively. Depth of holes studied are 20mm, 30mm, 40mm, 50mm, and 60mm.

The various EBROB strengthened beam specimens and their configuration characteristic are shown in Table 3

Table-3: Details of specimen

Specimen ID	Diameter (mm)	c/c Spacing (mm)	Depth (mm)	precracking
CB 1	-	-	-	No
CB2	-	-	-	Yes
B1	12	125	20	Yes
B2	12	125	30	Yes
B3	12	125	40	Yes
B4	12	125	50	Yes
B5	12	125	60	Yes
B6	10	125	50	Yes
B7	12	125	50	Yes
B8	16	125	50	Yes
B9	25	125	50	Yes
B10	12	100	50	Yes
B11	12	115	50	Yes
B12	12	125	50	Yes
B13	12	150	50	Yes

A schematic diagram consisting of cross section and longitudinal section of the control beam is shown in Fig 1.

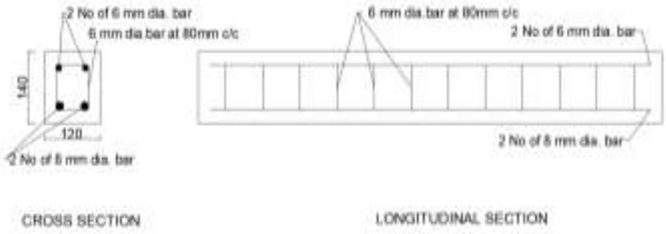

Fig -1: Reinforcement details of control beam

The different EBROB strengthened beams configurations as mentioned in Table 3 are diagrammatically represented in Fig 2 to Fig 10.

a) To study the effect of depth

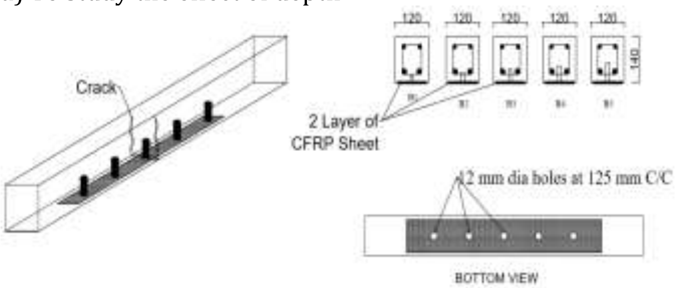

Fig -2: Beam with holes of 12 mm dia and varying depth (20mm to 60 mm)

b) To study the effect of diameter

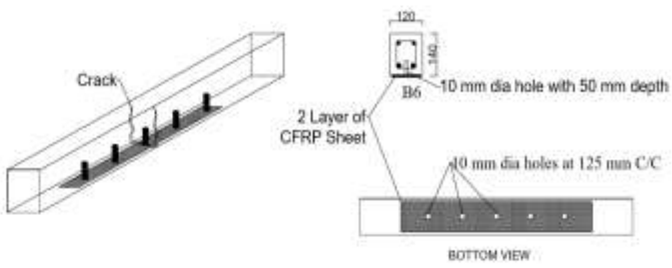

Fig -3: Beam with holes of 10 mm diameter

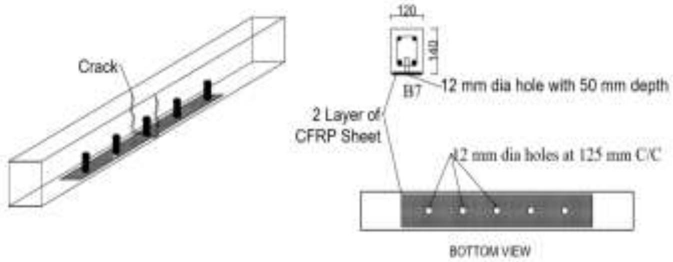

Fig -4: Beam with holes of 12 mm diameter

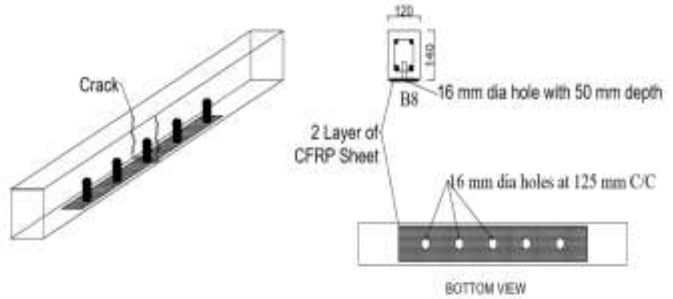

Fig -5: Beam with holes of 16 mm diameter

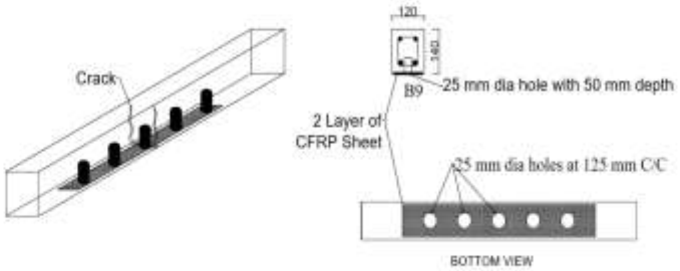

Fig -6: Beam with holes of 25 mm diameter

c) To study the effect of Spacing

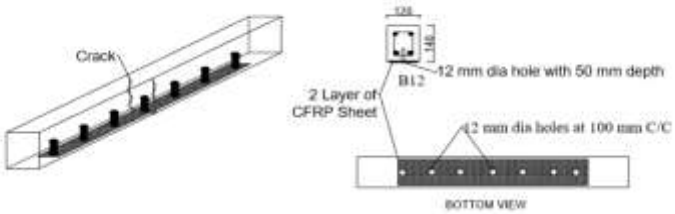

Fig -7: Beam with holes of 12 mm diameter and at 125 mm c/c spacing

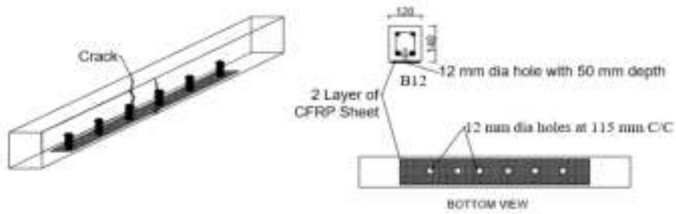

Fig -8: Beam with holes of 12 mm diameter and at 115 mm c/c spacing

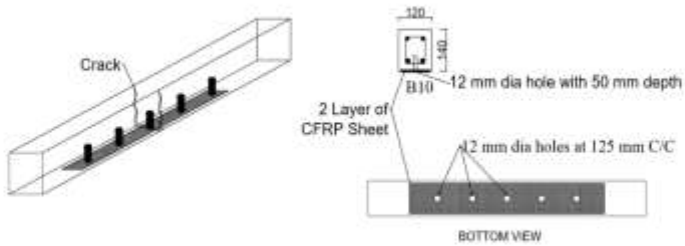

Fig -9: Beam with holes of 12 mm diameter and at 125 mm c/c spacing

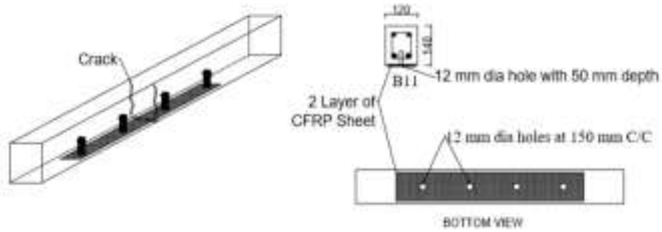

Fig -10: Beam with holes of 12 mm diameter and at 150mm c/c spacing.

Fig -11: Stages of beam casting

2.4 BEAM CRACKING

The precracking strengthening technique was prepared by loading the specimen to 25 KN (which is 60 % of the ultimate load capacity of 1st control beam) until flexural cracks were developed. After that the load is removed and study the effect of EBROB method in the debonding of CFRP sheets from the concrete.

Fig -12: Testing Of Control Beam 1

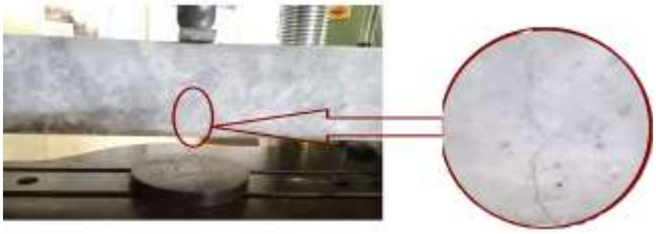

Fig -13: Beam Cracking

Fig -14: Beams with holes

Fig -15: Installation of CFRP sheets after making holes

2.5 TEST SETUP AND INSTRUMENTATION

The beams are tested in Universal Testing Machine (UTM) with a load range of (0 – 500) KN. The three point testing is used to study the variations in the results. The beams were simply supported with an effective span of 740 mm. Dial gauge with least count 0.01mm and the main scale in the UTM with least count 1mmwere used to measure the deflection on the beams.

Fig -16: Testing of strengthened beam in UTM

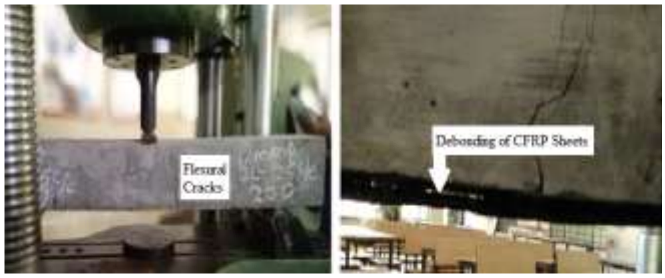

Fig -17: Failure pattern and debonding of beam with 20 mm depth after testing

3. RESULT AND DISCUSSIONS

This chapter presents the results of the effect of EBROB method to postpone the debonding of CFRP Laminates in RC beams. Three point bending tests are conducted on two control beams (CB 1- Without cracking and bore holes, CB 2- with crack and without boring) and strengthened beams with EBROB method. The test results are tabulated in table 4.

Table-4: Beam Test Results

Specimen ID	Ultimate load (kN)	% Increase in ultimate load (kN)	Ultimate defection (mm)
CB 1	40	-	8
CB2	42.6	6.5	6
B-12d-125 s-20D	43.4	8.5	7
B-12d-125 s-30D	45.0	12.5	7
B-12d-125 s-40D	47.2	18	6
B-12d-125 s-50D	48.6	21.5	5
B-12d-125 s-60D	42.6	6.5	4.5
B-10d-125 s-50D	46.8	17	8
B-16d-125 s-50D	48.9	22.2	6
B-25d-125 s-50D	49.5	23.75	8
B-12d-100 s-20D	49.3	23.25	5
B-12d-115 s-20D	49.0	22.5	7
B-12d-150 s-20D	43.8	9.5	5

The control beams and all EBROB strengthened beam specimens all are failed in flexure as designed. The strengthened beams shows good performance in load carrying capacity. They show at least 6.5% and maximum of 23.75 % increase in ultimate load for the EBROB strengthened beams. This shows that EBROB method helps the CFRP sheets in improving load carrying capacity of beams by delaying the debonding of CFRP sheets. Fig4.1 shows the ultimate loads of all the specimens. The specimen with 25 mm diameter hole at 125 mm centre to centre distance with 50 mm depth shows maximum ultimate load of 49.5 kN as shown in **chart: 1.**

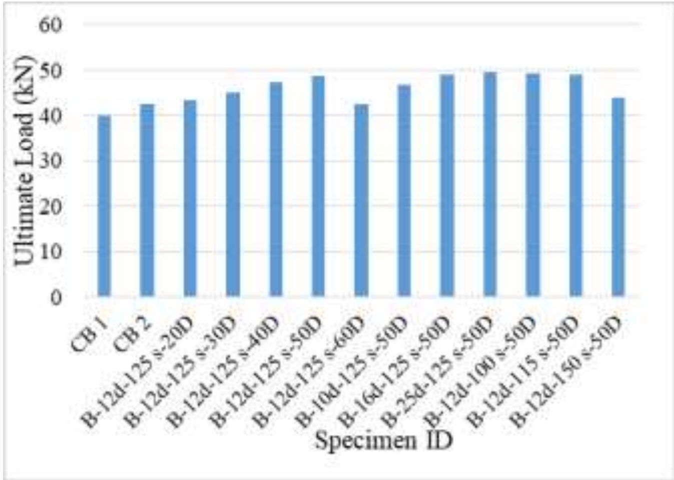

Chart -1: Ultimate Load for Beams.

3.1 PARAMETRIC STUDY

This section compares the influence of parameters such as depth of hole, diameter of hole and spacing between holes in EBROB method. The results of strengthened beam is compared with control beam 1 (without crack and holes) and control beam 2 (with crack and without holes).

3.1.1 EFFECT OF HOLE DEPTH

The effect of holes depth in EBROB method is one of the most important parameters. The total depth of the specimen is 140mm and the chosen depths for studying the effect are 20mm, 30mm, 40mm, 50mm, and 60mm.The specimen is tested for studying the effect of depth by fixing the diameter as 12 mm and spacing between the holes are 125 mm c/c. The load deflection curve of all the specimens tested follows a uniform straight pattern till its yield point and shows an abrupt increase in the deflection followed by flexural crack. On studying the holes depth in EBROB method it is found that load carrying capacity increases up to a depth of 50 mm and when the depth is approaches the neutral axis, it reduces. From the Chart 2, it can be see that the failure load increases with increase in holes depth and deflection of beams decreases with increase in depth of hole. From the beam results, it is clear that beam with 20 mm hole depth has a percentage increase of 6 % from the control beam without strengthening and 1.87 % increase from control beam with normal EBR strengthening. Whereas the beam with 50 mm hole depth has maximum percentage of 21.5 % from control beam. This is found to be the optimum hole depth since load carrying capacity of beam with 60 mm depth decreases.

In this method not only the contact area between epoxy and concrete surface increased but cylindrical anchors are also created at the interface between CFRP and concrete surface. This helps to transfer the stress to greatest depth of the beam. The beam with 50mm depth shows 15 % increase in strength compared to the specimen strengthen without holes.

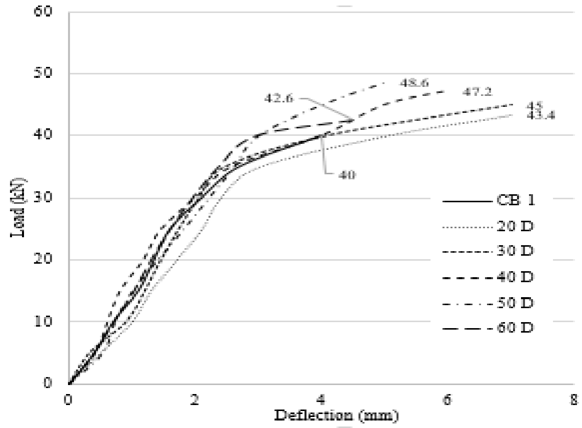

Chart -2: Load Deflection Curve of Beams with Varying Depth

Chart 3 shows the variation in ultimate loads with depth of holes. From this we can see that 50 mm depth gives the maximum strength. The reduction in strength occurs for 60 mm depth hole since the depth of hole approaches neutral axis of the beam. Thus the optimum hole depth for 140 mm depth of beam is fixed as 50 mm which gives maximum load carrying capacity.ie, for D/dh ratio of 0.28 shows high performance.

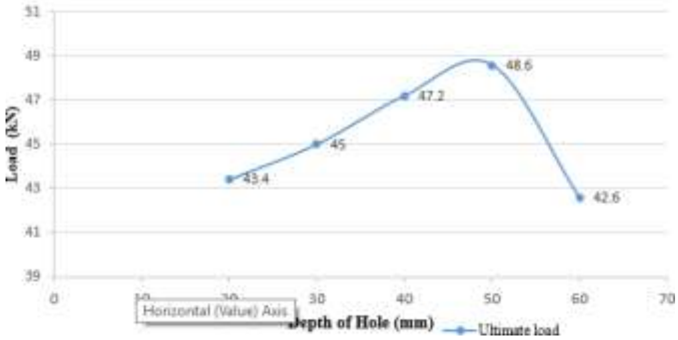

Chart -3: Load Deflection Curve of Beams with Varying Depth

3.1.2 EFFECT OF HOLE DIAMETER

The effect of holes diameter in EBROB method is one of the most important parameters. The total width of the specimen is 120 mm and the chosen diameters for studying the effect are 10mm, 12mm, 16mm, and 25 mm. The hole depth is fixed as 50 mm and spacing between the holes are 125 mm c/c.

Chart 4 shows the load deflection curve for EBROB strengthened beams with varying hole dimeter. From the graphs it is found that the load carrying capacity of strengthened beams are more than the control beams. The specimens with 10 mm, 12 mm, 16 mm, and 25 mm hole diameter shows an increase in ultimate load of 17 %, 21.5%, 22.22 %, and 23.75% than the control beam without strengthening and 16%, 20.18%, 20.89% and 22.3%

increase in ultimate load than the control beam strengthen with normal ERB method.

The Chart 5 shows that the load carrying capacity of EBROB strengthened specimens increases with increase in hole diameter. The load carrying capacity of specimen with 10 mm diameter is 46.8 kN. When the diameter increase to 12 mm the load carrying capacity is increase 3%.and for 16 mm and 25 mm ultimate load carrying capacity is increases 4.5% and 5.7% than the 10 mm hole diameter. The increase in hole diameter creates more contact area between concrete and CFRP sheets and increase the bonding between the CFRP sheet and concrete surface.

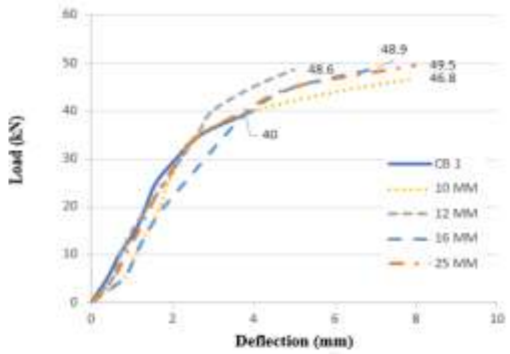

Chart -4: Load Deflection Curve of Beams with Varying Diameter.

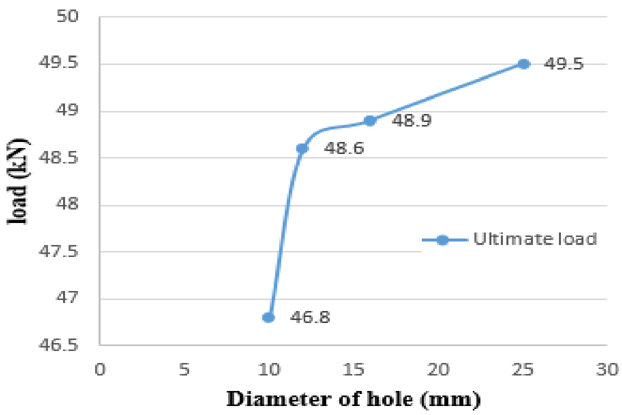

Chart -5: Load Curve of Beams with Varying Diameter.

3.1.3 EFFECT OF HOLE DIAMETER

Effect of spacing is also an important parameters in EBROB method. Here we use spacing from 1/7 th to 1/4 th of bond length.ie, the spacing used are 100 mm c/c, 115 mmc/c, 125 mm c/c, and 150 mm c/c. Total bond length is 700mm. The effect of spacing is studied by fixing holes diameter as 12 mm and holes depth as 50 mm

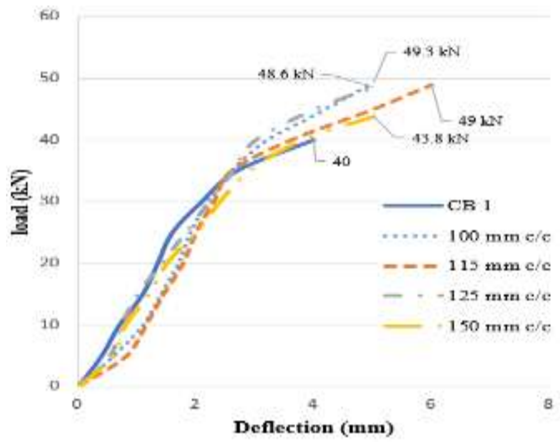

Chart -6: Load Deflection Curve of Beams with Varying Spacing

Chart 6 shows the load deflection graph of specimens with varying spacing between holes. All the EBROB strengthened specimen shows about 9.5% to 23.25% increase in load carrying capacity than the control beam. The specimen with 100 mm c/c spacing shows maximum load carrying capacity of 49.3 kN. On studying the graph it can be see that the load carrying capacity of EBROB strengthened specimen decrease with increase in spacing. The specimens with 115 mm c/c, 125 mm c/c, and 150 mm c/c shows 0.75%, 1.45% and 11.1% decrease in ultimate load carrying capacity than the strengthened specimen with 100 mm c/c. From Chart7 shows the graphical variation of ultimate load carrying capacity of EBROB strengthened specimens with spacing.

When the spacing between holes is increase number of holes is decrease and vice versa. When the number of holes increase the contact area between concrete and CFRP sheet is increase. More contact area gives more bonding strength to the CFRP sheets this helps to increase the ultimate load capacity.

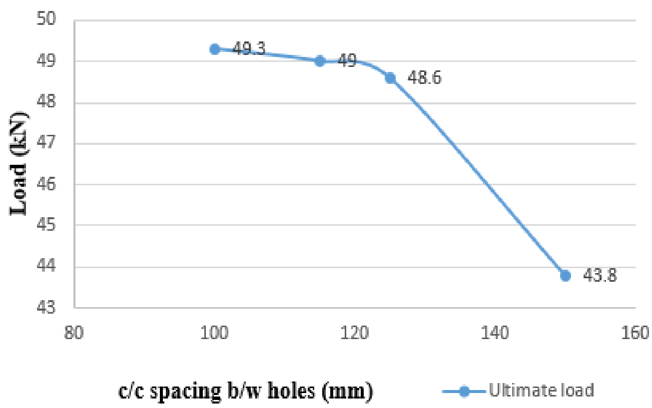

Chart -7: Load Curve of Beams with Varying Holes Spacing.

4. CONCLUSIONS

Based on investigation on EBROB method to postpone the debonding of CFRP sheet composites in pre cracked RC beams, the following conclusions are drawn,

1. Flexural strengthening of RC beams by increasing bonding strength between CFRP sheet and concrete substrate through EBROB method is very efficient and shows improvement in load carrying capacity. This method gives 6.5 % to 23.75 % increase in ultimate load compared to control beams.

2. The load carrying capacity of EBROB strengthened beams increases by increasing the depth of hole and when the depth is reach to the neutral axis the load carrying capacity is reduced.

3. The increase in diameter of holes increase the load carrying capacity of EBROB strengthened beams. This increase the contact area between epoxy and concrete and create cylindrical anchors in concrete substrate below the CFRP sheet.

4. The load carrying capacity of EBROB strengthened beams shows higher performance at lesser spacing and strength is decreases with increase in spacing. The number of holes is more at smaller spacing and it gives more strength to the beam

5. The EBROB method provides a good bonding mechanism between the concrete and CFRP composites than the normal EBR application.

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