

EBR and GM Methods for External Flexural Strengthening of RC Beams

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Abstract - In recent years, using FRP sheets for strengthening and rehabilitation of reinforced concrete (RC) beams has been considered as an effective, convenient and practical method. Externally Bonded Reinforcement (EBR) is a common method for mounting the sheet that uses conventional surface preparation. Premature debonding is one of the issue facing the use of FRP sheets as external flexural and shear reinforcement of concrete beams. It is caused by the lack of appropriate bonding between concrete surface and composite sheet. Grooving method (GM) is a special form of Externally Bonded Reinforcement on Grooves which is proposed as an alternative to conventional method of surface preparation. In this experimental investigation, reinforced concrete beams with dimension of 120x140x1000 mm were strengthened with CFRP sheets by EBR and GM methods. Specimens with different groove pattern, bond length and FRP plies were designed in a way under which the efficiency of GM method was evaluated. This study focused on load carrying capacity and deflection of strengthened RC beams.

benefits such as simple and rapid installation. But the major difficulty with RC beam strengthened with EBR method is their premature failure which is due to the sudden debonding of the FRP sheet before its ultimate capacity can be exploited. Debonding of FRP sheet is mainly due to the development of high interfacial shear stresses at plate or FRP sheet ends while loading. Many studies have been conducted to find solutions to this premature debonding and to reduce the interfacial stresses between the RC substrate and the FRP sheet.

Davood Mostofinejad introduced an effective alternative method for EBR to postpone debonding of FRP laminates in concrete beam [1, 3, 4]. In this method, grooves on the concrete surface of the elements were cut and filled with suitable epoxy, and FRP sheets were installed on the concrete surface. This method is called Externally Bonded Reinforcement on Grooves (EBROG) or Grooving Method (GM). This method has shown great promises in dealing with debonding problems. Previous investigations have revealed that in this technique, debonding is postponed and in some cases is completely eliminated.

The present study illustrates an experimental investigation on the external flexural strengthening of RC beam specimens with Carbon Fiber Reinforced Polymer (CFRP) composite by EBR and GM methods. A number of RC beam specimens were strengthened using CFRP woven fabric sheets, which are then subjected to static loading. The efficiency of grooving method is evaluated by studying the parameters like CFRP layer, grooving pattern and bond length.

Key Words: FRP, Strengthening, EBR, Debonding, GM.

1. INTRODUCTION

Demolishing and rebuilding new structures is often not economically cost effective, therefore finding an appropriate solution for repairing and strengthening the existing structures has a great importance. Rehabilitation and strengthening of structures provides upgrading of its resistance to withstand underestimated loads, increase in the load carrying capacity for higher permit loads, eliminating premature failure due to inadequate detailing, restoration of lost load carrying capacity due to corrosion or other types of degradation caused by aging, etc. An array of methods are available for this purpose, the selection of which depends on a great number of variables. The improper choice of an inappropriate repair or strengthening method can even worsen structure's function.

One of the most common technique for the external flexural strengthening of RC beams with FRP composite is the Externally Bonded Reinforcement (EBR), where the FRP composites are adhesively bonded to the tension face of the structure. Although EBR technique has been widely utilized in strengthening projects all around the world due to certain

2. EXPERIMENTAL PROGRAMME

2.1 Characteristics of Concrete Specimens

In order to carry out the test, fourteen reinforced concrete specimens with dimension of 120 x 140 x 1000 mm were casted. The beams were designed as under reinforced beams to initiate failure in flexure. M25 grade concrete was selected for all concrete specimens. Two numbers of 8mm diameter bars (Fe 500 grade) were provided at the bottom of the beam as tension reinforcement and two numbers of 6 mm diameter bars (Fe 415 grade) were provided at the top

of the beam as compression reinforcement. For the shear strengthening of beam, 6mm diameter bars were provided as stirrups at 80 mm center to center distance. Concrete cover of 25 mm was used. Fig-1 shows the detailing of RC control specimen.

Out of the fourteen RC beams, five beams were strengthened in flexure with EBR method, eight beams were strengthened in flexure with GM method and the remaining one is considered as control beam. Table-1 shows the details of specimens. The designation CB stands for control beam. UCB stands for EBR strengthened beams. L stands for number of CFRP sheet layers (1L, 2L, 3L), BL stands for bond length of CFRP sheet (700BL, 650BL, 600BL). And beam strengthened by Grooving Method was designated with the type of groove as initial component, where G stands for the number of groove (1G, 2G). LEG stands for the longitudinal end grooves and TEG stands for the transverse end grooves. CFRP width for all strengthened specimens were kept constant as 100 mm.

All beams were tested under three-point bending test. The tests were conducted with Universal Testing Machine (UTM). The midspan deflection of the beam was taken using dial gauge. Fig-2 shows the test setup. Clear distance between the two supports is 750mm.

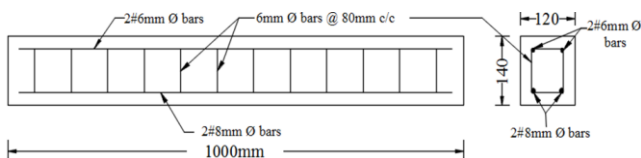


Fig -1: Detailing of Control Beam

Table -1: Beam Designation

Sl. No	Beam ID	Specification	CFRP	
			L mm	N
1	CB	—	—	—
2	UCB1L700BL	EBR	700	1
3	UCB2L700BL	EBR	700	2
4	UCB3L700BL	EBR	700	3
5	UCB2L650BL	EBR	650	2
6	UCB2L600BL	EBR	600	2
7	1G1L700BL	Longitudinal Groove	700	1
8	1G2L700BL	Longitudinal Groove	700	2
9	1G3L700BL	Longitudinal Groove	700	3
10	1G2L650BL	Longitudinal Groove	650	2
11	1G2L600BL	Longitudinal Groove	600	2
12	2G2L700BL	Longitudinal Groove	700	2
13	LEG2L700BL	Longitudinal End Groove	700	2
14	TEG2L700BL	Transverse End Groove	700	2

L- Length of CFRP sheet, N- Number of layers of CFRP sheet

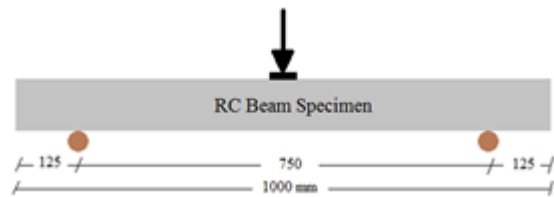


Fig -2: Three-Point Loading Set-up

2.2 Material Characteristics

In order to achieve a 28th day compressive strength of 25MPa, IS 10262:2009 and IS 456:2000 were employed for the mix design. The mix proportion selected is 1:1.690:2.852 with w/c 0.4 and super plasticizer of 0.2% of cement content. To obtain the compressive strength, 418.96 kg/m³ of ordinary Portland cement, 708.39 kg/m³ of fine aggregate and 1194.75 kg/m³ of coarse aggregate were used.

The FRP composite used were fabricated via wet layup process and were made up of woven carbon fibers. Mechanical properties of carbon fiber and epoxy utilized in this study are provided in Table-2 according to the manufacturer's catalog.

Table -2: Material Properties

Item	Thickness (mm)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Density (g/cc)	Elongation
CFRP	0.75	4000	230	1.8	1.7%
Araldite (Epoxy)	—	4800	—	1.17	9%

2.3 Strengthening Procedures

All beams except control beams were strengthened using EBR and GM methods. Carbon Fiber Reinforced Polymer (CFRP) sheets were used to strengthen the RC beam specimens. The basic procedures carried out in strengthening the RC beam specimens are described below.

• EBR Method

Externally Bonded Reinforcement (EBR) technique is the most common method to strengthen reinforced concrete structures. In this method, after surface preparation, CFRP sheets were adhesively bonded to the tension face of the concrete member using Araldite (Epoxy). The purpose of surface preparation is to remove contamination and polish the concrete surface to promote its adherence capacity. RC beams strengthened by EBR method is considered as the strengthened control beams. Parameters like number of layers and bond length of CFRP sheet were varied.

• GM Method

In order to strengthen the specimens using grooving method, grooves were first cut into the tension side of RC beams and the CFRP woven fabrics were bonded therein with appropriate groove filler. A special concrete saw was used to cut the grooves at the bottom surface of the beam. Groove

depth for all beams were kept constant as 10 mm. Volume of grooves in each beam is also kept as constant as 210000mm², but with varying pattern such as; single longitudinal groove, double longitudinal groove, longitudinal end groove and transverse grooves. Dimensions of grooves are shown in the Fig- 3. Different stages of strengthening of RC beams by GM method is shown in Fig -4.

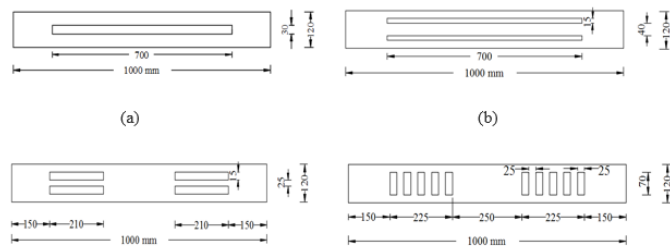


Fig -3: Groove Patterns

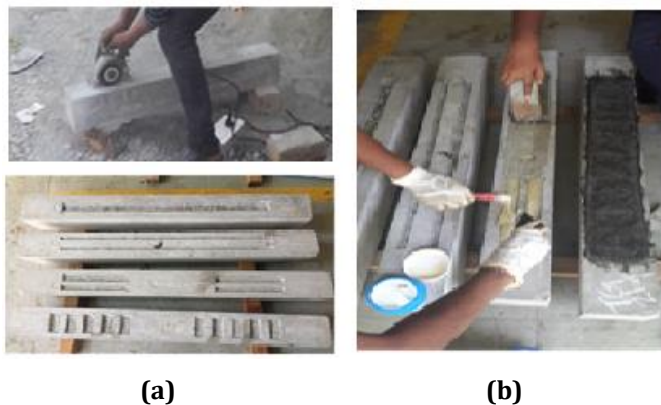


Fig -4: (a) Groove Cutting (b) Filling Grooves with Epoxy and Fixing CFRP Sheets

3. RESULTS AND DISCUSSIONS

3.1 Load Carrying Capacity

Table-3 provides the results obtained from the experimental tests carried out on control beam and beams strengthened by both EBR and Grooving Method. The strengthening methods to the RC beams with CFRP sheet caused superior load-carrying capacity and reduced ultimate deflection.

Both EBR and Grooving Method increases the performance of RC beam specimens in terms of load carrying capacity. However, RC beams strengthened by Grooving Method achieved much higher load resistance compared to EBR specimens. Test results shows that grooving method increases the load carrying capacity up to 79% more than the ordinary beam, whereas EBR method increases load capacity up to 28%. Compared to the grooving patterns, beam with longitudinal end groove shows the maximum load carrying capacity.

Table-3: Summary of Test Results

Sl. No	Beam ID	P _u (kN)	Δ _u (mm)	% increase in ultimate load w.r.t CB
1	CB	36	19	—
2	UCB1L700BL	42	14	16.67
3	UCB2L700BL	45.6	12.5	26.67
4	UCB3L700BL	46	10	27.78
5	UCB2L650BL	44	13	22.22
6	UCB2L600BL	42.8	13.8	18.89
7	IGIL700BL	46.4	10.5	28.89
8	1G2L700BL	51.8	9.5	43.89
9	1G3L700BL	56	11	55.56
10	1G2L650BL	48	9	33.33
11	1G2L600BL	46.6	8.5	29.44
12	2G2L700BL	57	12	58.33
13	LEG2L700BL	64.4	9	78.89
14	TEG2L700BL	60.4	9	67.78

P_u- Ultimate load, Δ_u- Midspan deflection corresponding to failure load

3.2 Failure Modes

The failure modes of all beams are shown in Fig -5 to 18. The control beam was failed due to concrete crushing after steel yield mechanism. All beams strengthened by EBR method were found to be failed by debonding of CFRP sheet from concrete substrate before utilizing its maximum capacity. All beams strengthened by Grooving Method (except 1G3L700BL) were found to be failed by FRP rupture. Debonding of CFRP sheet in 1G3L700BL is due its excess thickness; hence it is experimentally proved that two layers of CFRP sheet improved the performance of RC beam without debonding.



Fig -5: CB

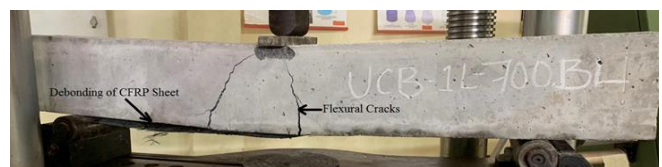


Fig -6: UCB1L700BL

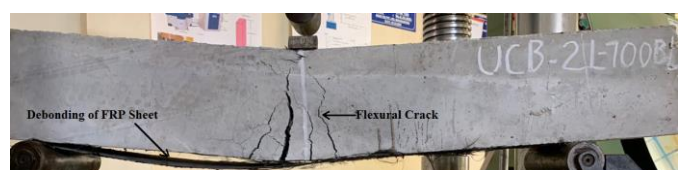


Fig -7: UCB2L700BL



Fig -8: UCB3L700BL



Fig -9: UCB2L650BL



Fig -10: UCB2L600BL



Fig -11: 1G1L700BL



Fig -12: 1G2L700BL



Fig -13: 1G3L700BL



Fig -14: 1G2L650BL



Fig -15: 1G2L600BL



Fig -16: 2G2L700BL

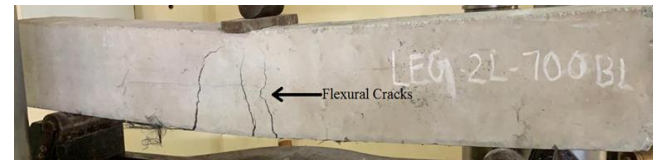


Fig -17: LEG2L700BL

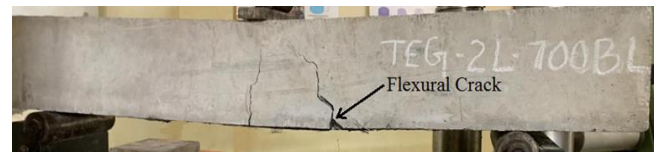


Fig -18: TEG2L700BL

3.3 Parametric Study

• Effect of Strengthening Method

In table- 3, the ultimate loads of the strengthened beams have been compared with the control beam specimen. It can be observed that maximum load carrying capacity of UCB1L700BL has increased 16.67% compared to CB. This increase is 28.89% for 1G1L700BL specimen. That means 10.48% increment has been occurred for 1G1L700BL compared to UCB1L700BL specimen. When two layers of FRP is used, 13.6% increment in ultimate load has been occurred for the beam strengthened with Grooving Method compared (1G2L700BL) to the EBR strengthened (UCB2L700BL) specimen; whereas 19.15% increment has been occurred when three layers of FRP is used. In chart-1, a comparison has been made for ultimate loads of specimens, showing the significant influence of strengthening techniques on the ultimate load carrying capacity of the beams. From the figure it is clear that three layers of CFRP sheets for GM method gives maximum strength. But due to the debonding problem with three layers of CFRP sheet, two layers are considered as effective.

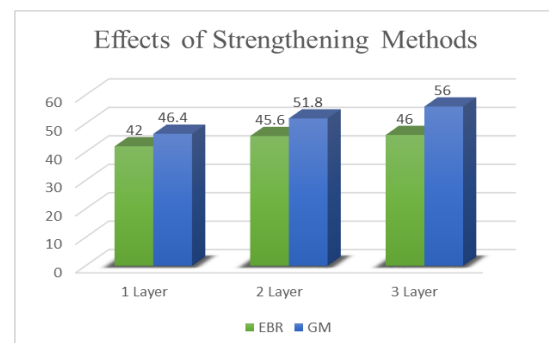
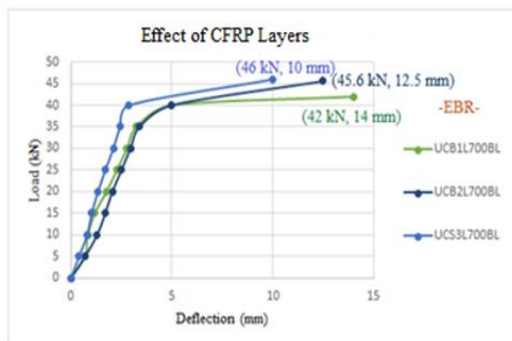


Chart -1: Comparison between the ultimate loads of specimens with different strengthening methods.

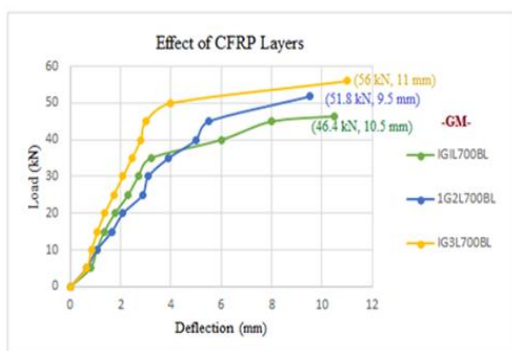
In fact, due to the better performance of Grooving Method in transferring the stresses between CFRP materials and concrete substrate, beams strengthened with GM method could experience much higher loads than the beams strengthened with EBR method.

• **Effect of Number of CFRP Layers**

Number of CFRP layers has an important role in the strengthening of RC beams. Debonding phenomena is directly depends upon the number of FRP layers used. Chart-2 shows the effect of number of CFRP layers on the load carrying capacity of RC beams strengthened by both EBR method and Grooving Method. The data collected from beams UCB1L700BL, UCB2L700BL, UCB3L700BL, 1G1L700BL, 1G2L700BL and 1G3L700BL were used to analyse this influence.



(a)



(b)

Chart-2: Effect of Number of CFRP Layers strengthened by (a) EBR Method (b) Grooving Method

Load carrying capacity of specimens strengthened by Grooving Method is increased by 28.89%, 43.89% and 55.56% for 1G1L700BL, 1G2L700BL and 1G3L700BL respectively when compared to the control beam; whereas this increment for UCB1L700BL, UCB2L700BL and UCB3L700BL is 16.67%, 26.67% and 30.56% respectively. Maximum load carrying capacity was achieved when three layers of FRP sheets were used. But the specimen 1G3L700BL was failed by the debonding of CFRP sheet from the concrete surface. In EBR method of strengthening, all beams were found to be failed by debonding of CFRP sheet from concrete substrate before utilizing its maximum capacity. But the

failure method in Grooving Method is much more improved because of more contact between the CFRP and concrete surface.

• **Effect of Bond Length**

For all strengthening methods, bond length has a great influence on the flexural performance. As the bond length increases the load carrying capacity increases. The specimens UCB2L700BL, UCB2L650BL, UCB2L600BL, 1G2L700BL, 1G2L650BL and 1G2L600BL were used to analyse the effect of bond length on the load carrying capacity of strengthened RC beam specimens. From Chart-3 it is clear that as the bond length increases, load carrying capacity of the strengthened beams increases considerably; 700 mm bond length gives the maximum result. In EBR method, load carrying capacity increases as 18.89%, 22.22% and 26.67%, for 600 mm, 650 mm and 700 mm bond lengths respectively, when compared to the control beam. In GM method this increment is 29.44%, 33.33% and 43.89%.

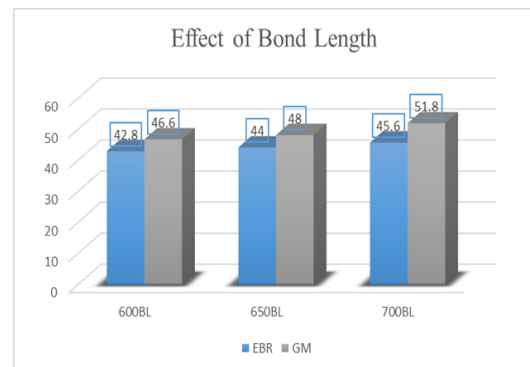


Chart-3: Effect of Bond Length

• **Effect of Groove Patterns**

Four different groove patterns were considered for this study, such as; beams with single longitudinal groove, double longitudinal groove, longitudinal end grooves and transverse end grooves. Chart-4 shows the effects of groove patterns. Load carrying capacity varies with varying groove patterns. Specimen with longitudinal end grooves has the maximum load carrying capacity of 64.4 kN; which is 78.89% higher than the load carrying capacity of control specimen. Specimen with single longitudinal groove pattern has an increment of 43.89% in ultimate load with respect to the control beam specimen. This increment is 55.56% and 67.78% for 2G2L700BL and TEG2L700BL respectively. From the result it is proved that the longitudinal end groove pattern is the best choice to improve the load carrying capacity of RC beam specimens.

Load carrying capacity of beam with single longitudinal groove has the least value. It can be seen that as the number of grooves increases, load carrying capacity increases considerably.

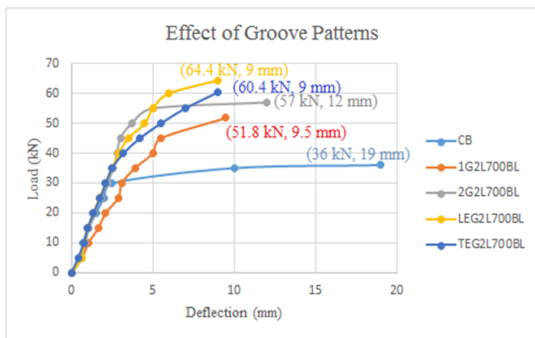


Chart -4: Effects of Groove Patterns

4. CONCLUSIONS

In present study, efficiency of grooving method was investigated through experimental studies. Three point bending tests were conducted on RC beam specimens strengthened via EBR and Grooving methods. Based on the results, the following conclusions can be drawn:

- CFRP fabric properly bonded to the tension face of RC beams can enhance the flexural strength substantially. The EBR specimens exhibit an increase in flexural strength of 16.67% for single layer 26.67% for two layers and 27.78% for three layers of CFRP sheet. But premature debonding was the main problem observed for all specimens strengthened by EBR method.
- GM specimens with single longitudinal groove pattern can exhibit an increase in flexural strength of 28.89% for single layer 43.89% for two layer and 55.56% for three layers when compared to the specimen without any surface preparations. Grooving method performs much more effective when two layers of CFRP sheets were used, which can completely eliminate premature debonding. GM method can utilize higher tensile strength of CFRP sheets and tends to achieve FRP rupture before debonding.
- Load carrying capacity is also affected by the bond length of CFRP sheet. Bond length of CFRP was varied as 700 mm, 650 mm and 600. It was observed that decrease in bond length decreases the load carrying capacity of specimens strengthened by both EBR and GM method. Bond length of 700 mm gives the better result among all strengthened beams.
- Grooving method is a very efficient technique for beams strengthened with multilayers of CFRP sheets and as it was shown, beams strengthened with this method increased ultimate failure load by 28 to 79% as compared to specimen without surface preparations.
- Using GM in different patterns increased the ultimate load carrying capacity compared to the specimens

strengthened by EBR method. Maximum enhancement greatly occurred in longitudinal end grooving.

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