STRENGTHENING OF REINFORCED CONCRETE BEAMS BY BOLTING OF STEEL AND GFRP PLATES

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INTRODUCTION

Existing concrete beams may need local strengthening to improve its serviceability for many occasions namely due to crack in concrete, corrosion, up-gradation of highways and improving load carrying capacity of the beams. In such cases the external reinforcement of structural member using steel plate may be advantageous over new constructions. The commonly adopted techniques for strengthening and stiffening of RC structure are namely, epoxy bonding of steel plates, epoxy bonding of FRP (Fiber Reinforced Plastic) plates, by providing additional reinforcement, by providing external pre stressing, bolting of steel plates/FRP plates.

In the present study a simple cost-effective method were adopted by bolting steel/FRP plate to the element in the tension zone or shear zone as an additional reinforcement to have maximum effect on ultimate strength, stiffness, deflection and crack control. Basic principle of reinforced concrete design was applied in the design procedure. The method of reinforcement involve the attachments of steel and GFRP plates to Bottom face (tension face) as well as side face of the beam of the existing reinforced concrete members using anchor bolts. The anchor bolts at various spacing along the under side of the member, were the only attachment used in the present retrofit procedures. The construction procedure required little member or plate preparation prior to installation. The anchors used were expansion type. The use of anchors for the entire length of the external reinforcement automatically inhibits tear off behavior near the plate termination prior to design load levels. Precaution was taken to avoid contact with existing flexure reinforcement while drilling.

In the present study existing concrete beams were strengthened and experimental testing was performed. Seven specimens were prepared and tested with attaching external plate to bottom face (tension face) and side face of the beam with wedge type expansion bolts detailed as Reference Beam, Bolted GFRP plate (3 mm thick) to the bottom face of beam, Bolted Steel plate (3 mm thick) to the bottom face of beam , Bolted GFRP plate (6 mm thick) to the bottom face of beam, bolted Steel plate (6 mm thick) to the bottom face of beam, bolted GFRP plate to the side faces (Both side) of the beam, bolted Steel plate to the Side faces (Both side)of the beam. The design/analysis follows the usual procedure of reinforced concrete design according to limit state design theory. It is assumed that the existing member has been design for a ductile failure. Further more it is assumed as the shear capacity of the existing member is sufficient to allow an increase in loading to new level corresponding to flexure failure of the externally reinforced member. Also it was assumed that the anchor provided would be of sufficient strength to allow the external plate to achieve it yield strength.

EXERIMENTAL SET UP

Spacing and edge distance of wedge type expansion bolts

Spacing had been design as per IS 800- 1984 (Cl. 8.10.1(b)(iii) and spacing or pitch between two bolts was 168mm centre to centre distance. The edge distance also calculated as per IS 800- 1984(Cl. 8.10.2(a) The minimum distance from center of any hole to the edge of a plate shall not less than that as given in table 8.2 of IS 800- 1984 i.e. for 12 mm diameter hole the edge distance shall not be less than 19 mm for shear or hand flame cut edge. So provided edge distance was 25mm. Spacing and edge distance are shown in Fig.1 and Fig.2.

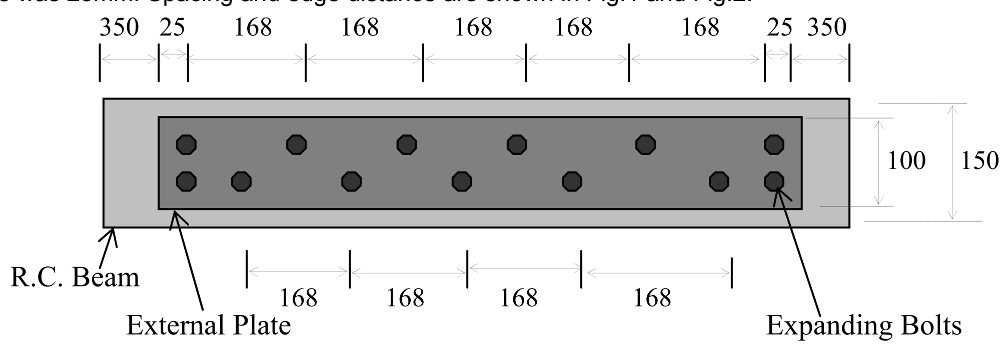

FIG.1. PLAN OF BEAM

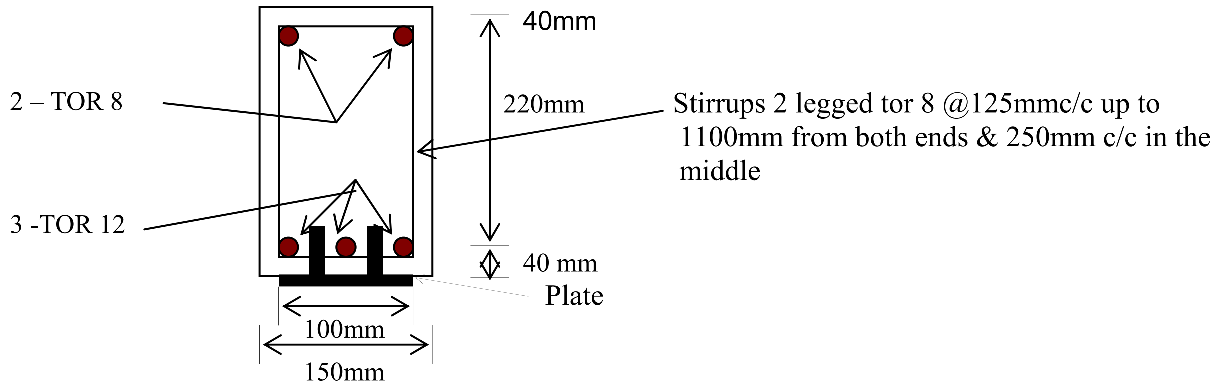

FIG.2. SECTION & REINFORCEMENT

The same procedure for spacing, edge distances and the depth of the hole were being applied to the bolted steel plate of 3mm thick as well as GFRP plate of 6mm thick attached to the bottom face of beam and also external plate (3 mm thickness both Steel and GFRP) bolted to the sides of beam. The diameter of the bolts used was 10 mm and the diameter of the sleeve was 16 mm. Therefore the diameter of the hole was 16 mm and the depth of the hole was 75 mm.
The spacing changed in case of 6 mm steel plate attached to the bottom face of the beam. The same was calculated on the basis of theoretical Ultimate load i.e. No. of bolts = theoretical Ultimate load / Shear capacity of bolt. Therefore, shear capacity of bolt = Maximum permissible stress * c/s area of bolt = $80 * 10^2 * \Pi/4$ = 6.28 KN and No. of bolts = 191.93 / 6.28 =30.56 bolt, say 31 bolts. Therefore, length of plate / No. of bolts the spacing = 2500 /31 = 80.64 mm And as per IS 800-1984 class 8.10.1(b)(iv) When the rivets are staggered at equal interval and the gauge does not exceed 75mm , the distance specified above between the center of rivets may be increased by 50 percent i.e. 80.64 + 80.64 / 2 = 120.96 mm. Therefore, provide the spacing or pitch between two bolts equals to 100mm c/c.

PREPARATION OF SPECIMEN

Since there were three bars of 12mm diameter at bottom face or tension reinforcement and side clear cover to the reinforcement was 35mm. The distance from the side face of beam to the center of hole was 50mm (35mm+12mm+5mm = 52mm).

Before drilling the holes in beam the centre points were first laid-out at the bottom surface of the beam. And after lay-out of the holes the embedded main reinforcement and the stirrups were marked on the surface. If any centre-point of hole coincided with the stirrup or main (longitudinal) reinforcement then its position changed accordingly. At the time of work it was always tried that it would not displaced by 65 mm from its actual centre-position. Care was also being taken that the holes should be at such distance from side of beam so that the bolt should be at the place between the main bars and also it should not be in the cover of concrete. After finalizing the positions holes were drilled of diameter equal to the outer diameter of the sleeve of the expanding bolt. The diameter of the bolt was 6mm, while the outer diameter of the expanding sleeve was 12mm. Therefore drilled holes of 12mm diameter provided with the spacing of 168 mm c/c. These holes were made in two rows. The holes in the second row were staggered to the holes in the first row with the same spacing. The distance from the longitudinal side edge of the beam to the center line of the holes was 52mm and the distance of the center lines of hoes of two rows was 46 mm as shown in Fig.3. The depth of the holes was fixed to 50mm as the length of the bolt was 50mm

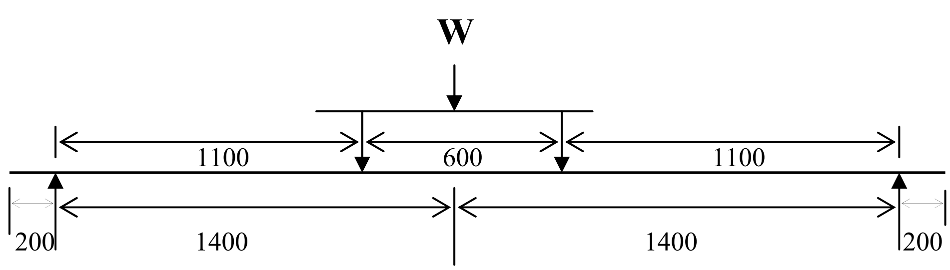

FIG.3. ARRANGEMENT OF LOAD

To secure the steel plate to the tension face of the beam concentric holes were drilled in the steel plate. The diameter of the hole thus drilled should not exceed the diameter of the bolt by 1mm. The expanding sleeve with cone was placed into the concrete hole by hammering slightly. Then the plate was secured against concrete by driving the expanding sleeve. This was done by applying a torque to the bolt and cone at the lower end of the expanding sleeve. The sleeve was pulled into the split anchor shell. Thus the expanded shell was expanded against the wall of the pre-drilled hole and the action provided necessary pre loading friction. As soon as the certain tensile force is exceeded, the cone was further pulled into the shell and the expansion was thus slowly increased up to the maximum probable value and the shell was not displaced when this was done. [1]

The expanding bolts used were the superior shear connector than the ordinary anchor bolts as they provided better grip between concrete and external plate, there by ensuring the composite behavior until the failure. The expanding bolts consisted of a bolt and a nut with expanding sleeve slit anchor shell and a cone. There were two sizes of expanding bolts used one of was 6mm diameter in which the outer diameter of the expanding sleeve was 12mm. These were used in fixing of plates of 3mm thick (GFRP and steel plate), and second was 10mm diameter in which the diameter of the expanding sleeve was 16mm. These were used in fixing of plates of 6mm thick (GFRP and steel plate) to the bottom face of the beam and fixing of plates of 3mm thick (GFRP and steel plate) to the both side faces of the beam. The details of the bolts are shown in figure Fig.4.

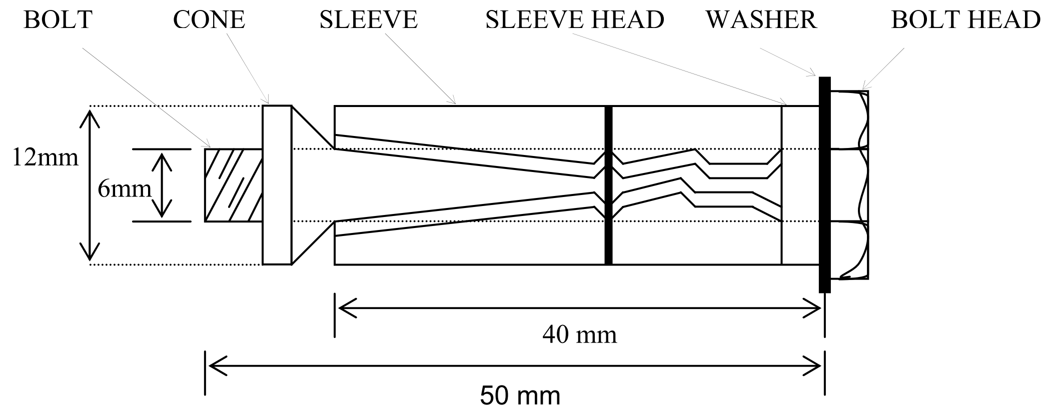

FIG.4. EXPENSION BOLT 6mm DIAMETER

INSTRUMENTATION

Bottom plated beam
Deflection, strain in external plate and horizontal slip in bolt at the ends of the beam were measured experimentally. Three deflection gauges were used for measuring the deflections in the beam. Two gauges were fixed under the load points and one gauge was fixed at the mid-span point of beam. Also two deflection gauges were used for measuring the slip in bolts at the ends of the beam. The arrangements are as shown in the Fig.5. The sensitivity of the dial gauges were of 0.01mm. An electrical resistance strain gauge used for measuring the strain in external plate. The same was bonded to the plate at the center point of the plate. The sensitivity of the strain meter was of micro strain.

PROPERTIES OF MATERIAL

Concrete:
compressive strength (f'_{ck})=47.9 N/mm^2 (predicted by rebound hammer tests) tensile strength of reinforcement bars (HYSD) (f'_S) = 415 N/mm^2
Plates:
Steel plate 3mm thick (f'_{SP}) =307 N/mm^2, Steel plate 6mm thick (f'_{SP}) =327 N/mm^2, GFRP plate 3mm thick (f'_{FP}) =300 N/mm^2, GFRP plate 6mm thick (f'_{FP}) =300 N/mm^2 (Tested on Universal Testing Machine)
Bolts:
1. For 6 mm Diameter Bolt, Shear value = $\Pi d^2/4 * \tau_{vf} = \Pi * 6 * 6 * 80 / 4$ = 2262 N and
2. For 10 mm Diameter Bolt, Shear value = Shear value = $\Pi d^2/4 * \tau_{vf} = \Pi * 10 * 10 * 80 / 4$ = 6283 N (as per IS 800-1984)

REBOUND HAMMER TEST

Rebound hammer tests were performed on all the seven beams. The average rebound number was 44.
From table[4] it was found that cylinder compressive strength = 40.7 N/mm^2 and cube compressive strength = 47.9 N/mm^2.These showed that quality of concrete cast of all the seven beams was of desired strength.

ULTRASONIC PULSE VELOCITY TEST

Quality of concrete of all the seven beams was also checked with the Ultrasonic pulse velocity test. From the test the average pulse velocity was 4.144 km/s which is greater than 3.5 km/s. This showed that the quality of concrete cast of desired strength

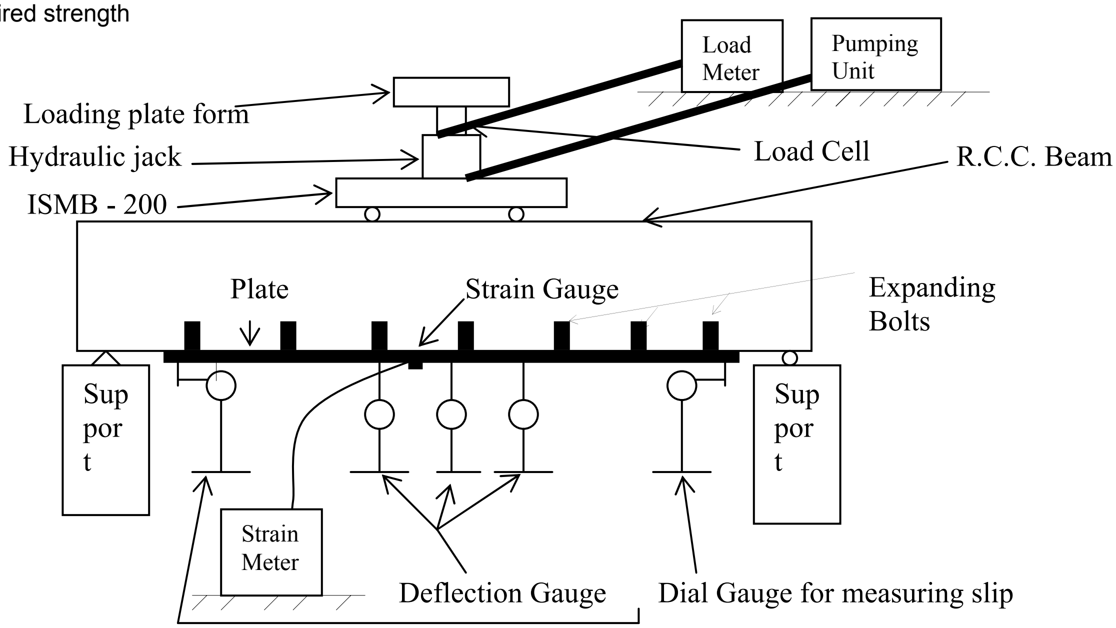

FIG.5. INSTUMENTATION & ARRANGEMENT OF LOADING OF BEAM (BOLTED PLATE TO BOTTOM OF BEAM)

TEST PROCEDURE

Tests were conducted by loading all the seven beams up to the failure to investigate the behavior up to ultimate load. The plates were attached and secure firmly at all bolt positions. In all tests the load was applied in small steps of increments i.e. 0,10,20,30 KN, etc. At each step the measurements for deflection, strain, and slip were carried. During the test procedure a thorough visual examination of beam for signs of new, or progressive cracks were observed. Any new or progressed cracks were also mapped on beam surfaces. The examinations of beams with plate attachment were carried out around the edges on the plate and sides of the beam.

ANALYSIS OF BEAMS

Limit analysis of reference beam was carried out considering rectangular stress diagram of concrete. Resolving forces in horizontal direction i.e. C = T depth of neutral axis was d_{na} =21.35 mm, ultimate moment capacity, M = 34.14 kNm and ultimate load W_u = 65.025 kN. In the same way analysis of bolted GFRP plated beam carried out in which C = T where tensile force considered additionally due to GFRP plate. The depth of neutral axis, d_{na} = 40.74 mm, ultimate moment was increased to M = 59.15 kNm and ultimate load was W_u = 107.55 kN against experimental failure load of 93 kN. The detailed calculation is not shown here for the sake of brevity. The experimental and analytical results are shown in Table 1 for comparison.

RESULTS & DISCUSSIONS

1. For reference beam the failure load was 72 KN, For bolted GFRP plate (3 mm thick) attached to the bottom face of beam, the failure load was 93 KN, i.e. about 129% of the reference beam load and about 86.5% of the predicted load. The predicted load was 107.55 kN, difference in predicted and experimental load was 14.55KN due to the failure of bolts.
2. For bolted steel plate (3 mm thick) attached to the bottom face of beam, the failure load was 95 KN i.e. about 132% of the reference beam load and more than 87% of the predicted load. The predicted load was 108.87KN, difference in predicted and experimental load was 13.87KN due to the failure of bolts also.
3. For bolted GFRP plate (6 mm thick) attached to the bottom face of beam, the failure load was 119 KN, which was about 165% of the reference beam load and about 79% of the predicted load. The predicted load was

151.097KN, difference in predicted and experimental load was 32.097KN due to the slip occurred at the interface of two material i.e. external plate and beam surface.

4. For bolted steel plate (6mm thick) attached to the bottom face of beam, the failure load was 126 KN, which was about 175% of the reference beam load and about 80% of the predicted load. The predicted load was 158.36KN, difference in predicted and experimental load was 32.36KN, possibly due to the slip occurred at the interface of two material i.e. external plate and beam surface.

5. For bolted GFRP plate (3 mm thick) attached to the side faces (both sides) of beam, the failure load was 95 KN, which was about 132% of the reference beam load and about 80% of the predicted load. The predicted load was 119.02KN. The difference in predicted and experimental load was 24.02KN possibly due to the slip occurred at the interface of two material i.e. external plate and beam surface.

6. For bolted steel plate (6mm thick) attached to the bottom face of beam, the failure load was 108 KN, which was about 150% of the reference beam load and about 90% of the predicted load. The predicted load was 120.586KN. The difference in predicted and experimental load was 12.586KN possibly due to the slip occurred at the interface of two material i.e. external plate and beam surface.

7. Details of deflection study for all the seven beams are shown in Table-2.

TABLE 1
EXPERIMENTAL AND ANALYTICAL RESULTS

Beam Type	Posn. Of N.A, d_{na} (mm)	Ult. Moment (kNm)	Analytical Ult. Load (kN)	Exp. Ult. Load (kN)	No. of Bolts required	No. of Bolts provided	Remarks
Reference Beam	21.35	34.14	65.024	72	Nil	Nil	Crushing of concrete at 66kN
GFRP(3mm)	40.74	59.15	107.55	93	20	17	Bolt displaced from position
Bolted Steel plate(3mm)	41.32	59.88	108.87	95	24	17	De-lamination of plate
Bolted Steel plate(6mm)	63.49	87.098 **2**	158.36	126	13	25	Failure gradual
GFRP(6mm)	60.13	83.10	151.097	119	12	17	No de-lamination
GFRP(3mm)	60.13	65.463	119.02	95	10	17	No de-lamination failure in comprn., crushing of concrete
Steel plate(3mm) (on both sides)	61.29	66.32	120.586	108	10	17	No de-lamination failure in comprn., crushing of concrete

CONCLUSION

The following conclusions can be drawn from the present study:

1. External plate (steel and FRP) attached to the bottom face and side faces (both sides) of the beam by bolting produced considerable enhancement of flexural strength to the reference RC beams.
2. External plate attached to the beam also controlled the deflection and cracking of the member.
3. The failure of the externally plated beams was characterized by gradual and ductile behavior.
4. Steel plated beam increased the flexural strength more than the GFRP plated beam by 7% on an average.
5. External plate (steel and GFRP) attached to the bottom face or side faces (both sides) of the beam provided an efficient and effective utilization of materials (i.e concrete and external plate).

REFERENCES

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3. Is 800- 1984 (Code of Practice for General Construction in Steel, pp.96)
Calibration Chart Manual of Testwel Instrument Co.Pp.11-12, Table II [Rebound Hammer]
Concrete Technology By Ghambir, M.L. 7th Reprint 2000, Pp. 258, Table 13.3

TABLE 2

EXPERIMENTAL RESULTS

Table showing the deflection in beam specimens against load

S.NO	LOAD (KN)	DEFLECTION (mm)						
		REFR--ENCE BEAM	GFRP PLATE (BOTTOM FACE)		STEEL PLATE (BOTTOMFACE)		GFRP PLATE (SIDE FACE)	STEEL PLATE (SIDE FACE)
			3mm	6mm	3mm	6mm	3mm (Both Sides)	3mm (Both Sides)
1	0	0	0	0	0	0	0	0
2	10	1.83	1.93	1.51	1.67	2.13	1.11	1.4
3	20	3.03	3.72	2.66	2.21	3.18	3.33	2.76
4	30	4.78	5.44	4.06	4.71	4.52	4.74	4.48
5	40	6.91	7.18	4.61	6.16	5.94	5.33	5.62
6	50	8.38	9.08	7.31	7.65	6.4	8.13	7.06
7	60	11.33	10.46	8.96	8.36	8.98	10.94	8.56
8	70	17.42	16.82	11.55	11.49	10.68	11.88	10.55
9	72	20.22						
10	72	26.22						
11	72	36.12						
12	72	40.02						
13	80		30.28	15.81	13.71	13.95	15.76	13.71
14	90		48.00	22.26	31.4	17.1	33.55	19.11
15	95				36.1	18.99	43.16	22.13
16	100			31.13		21.48		25.31
17	105					25.08		30.31
18	108							40.36
19	110			39.33		27.43		
20	115					28.45		
21	119			48.63				
22	120					30.98		
23	125					35.13		
24	66 (R)	42.32						
25	66 (R)	44.22						
26	79.4 (R)							
27	82 (R)				42.55			
28	82.4 R)				52.6			
29	84.5 (R)							
30	92 (R)		55.28					
31	104(R)			55.43				
32	109 (R)			55.13				