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Shear Strength Capacity of Normal and High Strength Concrete Beams Bonded by CFRP Wraps

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Abstract-The usage of fiber reinforced polymer (FRP) is becoming a widely accepted repairing and strengthening aspect in the field of civil engineering in recent years. By the application of polymers of carbon, glass and aramid in the shear zone of the beam, the shear strength can be increased extensively. The present study investigates the enhancement of shear capacity of RC beams using carbon reinforced polymers. Total of 24 beams were casted in the laboratory, out of which, 12 M30 and 12 M70 concrete beam specimens of 150mm width, 200mm depth and 1300mm length. The geometry of all kept constant, but only shear reinforcement was varied. Out of 12 beams of M30, 6 were control beams and 6 were strengthened by using CFRP. Out of 12 beams of M70, 6 were control beams and 6 were strengthened by using CFRP. The strengthened beams showed 34% to 58% increase in shear capacity with respect control beam in normal strength i.e. M30 beams and 28% to 44% in high strength i.e. M70 beams.

Index Term- Fiber reinforced polymer (FRP), carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and aramid fiber reinforced polymer (AFRP), shear capacity.

I. INTRODUCTION

Strengthening and rehabilitation of existing reinforced concrete (RC) structures is becoming an important issue in situations such as demand in the increase of service load levels, repair due to degradation of a member, design/construction defects, and response to requirements of newly developed design guidelines. Older structures designed were found to be structurally unsafe over a period of time. So, the strengthening of structures to increase their service life has become an important aspect in the recent few years. While strengthening the structures cost of materials used for strengthening, good construction practices has to be addressed. Reinforced concrete beams can be deficient in shear capacity due to various factors including improper detailing of the shear reinforcement, poor construction practice, changing the function of the structure accompanied with higher service loads and reduction in, or total loss of the area of the shear reinforcement due to corrosion in a harsh environment.

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An innovative method of beam shear strengthening involves the use of FRP externally bonded to the faces of the member where the shear capacity is deficient. Several schemes are available: FRP plates bonded to the sides, strips of FRP bonded to the sides, or a jacket (wrap) placed along the shear span.

1.1 Fiber Reinforced Polymer (FRP)

Fiber reinforced polymer consist of fibers having high strength to stiffness ratio to produce a composite material in combination of both fibers and matrix to achieve good physical and chemical characteristics at high volume fractions having low ductile stiffness to strength ratio. FRP with polymeric matrix can be considered as a composite. They are widely used in strengthening of civil structural elements. There are many advantages of FRP due to lesser weight, resistance offered towards corrosion and good mechanical properties. The main function of fibers is to maintain stiffness and stability caused by load. The function of the matrix is to keep fibers in position and fix it to the structures. There are mainly three types of fibers dominating the civil engineering industry such as glass, carbon and aramid fibers. FRP sheets that are commercially available vary in thickness from 0.381 to 1.30 mm. One of the main variables which affect the FRP strength is the density of fibers in a sheet. The density varies from 1.8 g/cm^3 for CFRP sheets to 2.5 g/cm^3 for GFRP sheets. FRP sheets that are commercially available vary in thickness from 0.381 to 1.30 mm. One of the main variables which affect the FRP strength is the density of fibers in a sheet. The density varies from 1.8 g/cm^3 for CFRP sheets to 2.5 g/cm^3 for GFRP sheets.

1.2. Methods of Forming FRP Composites

FRP composites are formed by embedding continuous fibers in resin matrix, which holds the fibers together. The common resins are polyester resins, epoxy resins and vinyl ester resins, depending on the fibers used. FRP composites are classified into three types:

- Glass-fiber-reinforced polymer (GFRP) composites
- Carbon-fiber-reinforced polymer (CFRP) composites
- Aramid-fiber-reinforced polymer (AFRP) composites.

II. THEORETICAL STUDIES

Theoretical study was made for 12 normal strength beams i.e. M30 and 12 high strength beams i.e. M70 of same geometry, but varying in shear reinforcement with and without CFRP bonding. Out of 24 beams 12 control beams and 12 beams were wrapped with CFRP. The geometry of all the beams was of length1300 mm and cross section 150 mm X 200 mm. longitudinal section of the beam is as shown in the Fig 2.1.

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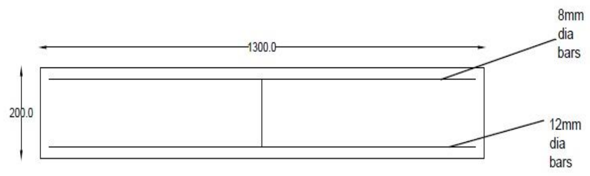

Fig. 2.1 Longitudinal Section of the Beam

Table 2.1 Proposed Beams to be Casted

Grade of concrete	Number of beams	
M30	6	Control beams
M30	6	Bonded with CFRP
M70	6	Control beams
M70	6	Bonded with CFRP

Here for all the cases flexural reinforcement was same but shear reinforcement was different.

2.1 Shear Capacity of Normal Strength (M30) Control Beams

2.1.1 Beam N - CB1 The cross section of the N - CB1 is shown in the fig 2.2. N-CB1 – Normal strength (M30) Control beam of no shear reinforcement

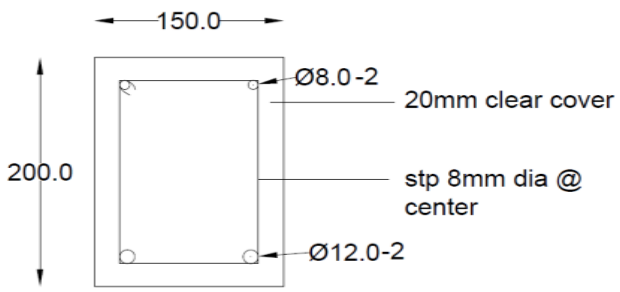

Fig. 2.2 Reinforcement details of Beam N-CB1

Top 8mm 2 No's, Bottom 12mm 2 No's

Clear cover = 20mm

f_{ck} = 30N/mm^2, fy = 500N/mm^2

d = 200 -20 - 12/2 = 174mm.

$V_u = V_{uc} + V_{us}$

$V_{uc} = \tau_{cmax}$ x bd

τ_{cmax} = 3.5N/mm^2 for M30 as per IS: 456-2000

V_{uc} = 3.5 x 150 x 174 = 91.35kN

V_{us} = 0 (No shear reinforcement)

V_u = 91.35kN.

Table 2.2 Ultimate Shear Strengths of M30 Control Beams

Sl. No	Spacing in mm	Beam Designation	V_u, Ultimate shear strength in kN
1	Single	N-CB1	91.35
2	50	N-CB2	243.53
3	100	N-CB3	167.44
4	150	N-CB4	142.07
5	200	N-CB5	129.39
6	250	N-CB6	121.79

2.2 Shear Capacity of High Strength (M70) Control Beams

2.2.1 Beam H–CB1 The cross section of the H–CB1 is shown in the Fig 2.3. H-CB1 – High strength (M70) Control beam of no shear reinforcement

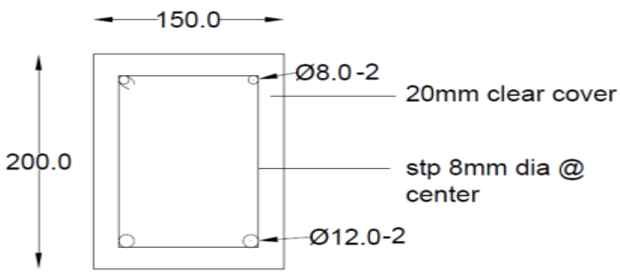

Fig. 2.3 Reinforcement details of Beam H-CB1

Top 8mm 2 No's, Bottom 12mm 2 No's

Clear cover = 20mm

f_{ck} = 70N/mm^2, fy = 500N/mm^2

d = 200 -20 - 12/2 = 174mm.

$V_u = V_{uc} + V_{us}$

$V_{uc} = \tau_{cmax}$ x bd

τ_{cmax} = 4N/mm^2 for M70 as per IS: 456-2000

V_{uc} = 4 x 150 x 174 = 104.4 kN

V_{us} = 0 (No shear reinforcement)

V_u = 104.4 kN.

Table 2.3 Ultimate Shear Strengths of M70 Control Beams

Sl. No	Spacing in mm	Beam designation	V_u, Ultimate shear strength in kN
1	Single	H-CB1	104.40
2	50	H-CB2	256.59
3	100	H-CB3	180.49
4	150	H-CB4	155.13
5	200	H-CB5	142.45
6	250	H-CB6	134.84

2.3 Shear capacity of CFRP strengthened M30 beams

2.3.1 Beam N-SB1 The cross section of the N-SB1 is shown in the fig 2.4. N-SB1 – Normal strength (M30) strengthened beam no shear reinforcement

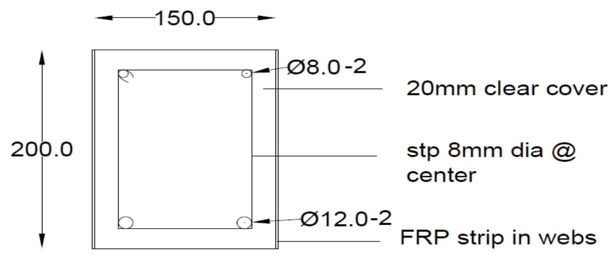

Fig. 2.4 Reinforcement details of Beam N-SB1

Top 8mm 2 No's, Bottom 12mm 2 No's

Clear cover = 20mm

f_{ck} = 30N/mm^2, f_y = 500N/mm^2

d = 200 -20 - 12/2 = 174mm.

$V_n = V_{uc} + V_{us} + V_{frp}$

$V_{uc} = \tau_{cmax}$ x bd

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τ_{cmax} = 3.5N/mm^2 for M30 as per IS: 456-2000
V_{uc} = 3.5 x 150 x 174 = 91.35kN
V_{us} = 0 (No shear reinforcement)
V_{frp} = Φ_{frp} x A_{frp} x f_{frp} x (sinβ + cosβ) x d / S_{frp}
Φ_{frp} = 0.8
A_{frp} = t_{frp} x w_{frp}
t_{frp} = 0.3 mm of Nitowrap carbon fiber from Fosroc limited
w_{frp} = 330 mm
f_{frp} = 563.2 N/mm^2 Nitowrap carbon fiber from Fosroc limited
β = 90^0
w_{frp} = S_{frp} = 330 mm
V_{frp} = 0.8 x 4 x 0.3 x 330 x 563.2 x 174 / 330
V_{frp} = 94.07 kN
V_n = 91.35 + 0 + 94.07
V_n = 185.426 kN.

Table 2.4 Ultimate Shear Strengths of M30 Strengthened Beams

Sl. No	Spacing in mm	Beam Designation	V_u, Ultimate shear strength in kN
1	Single	N-SB1	185.426
2	50	N-SB2	365.25
3	100	N-SB3	276.57
4	150	N-SB4	256.8
5	200	N-SB5	223.35
6	250	N-SB6	210.50

2.4 Shear capacity of CFRP strengthened M70 beams

2.4.1 Beam H-SB1 The cross section of the H-SB1 is shown in the fig 2.5.
H-SB1 – High strength (M70) strengthened beam of no shear reinforcement.

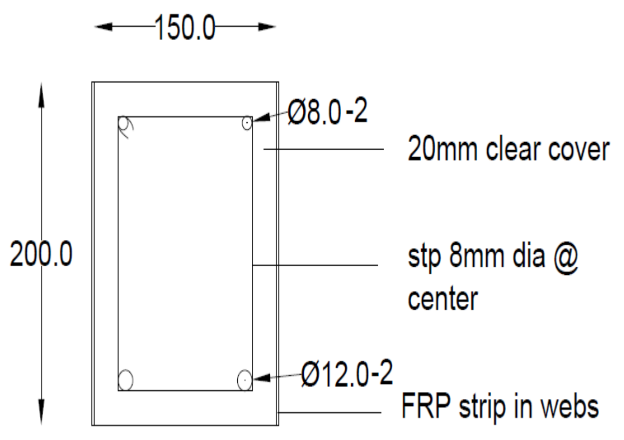

Fig. 2.5 Reinforcement details of Beam H-SB1

Top 8mm 2 No's, Bottom 12mm 2 No's
Clear cover = 20mm
f_{ck} = 70N/mm^2, f_y = 500N/mm^2
d = 200 -20 - 12/2 = 174mm.
V_n = V_{uc} + V_{us} + V_{frp}
V_{uc} = τ_{cmax} x bd
τ_{cmax} = 4N/mm^2 for M70 as per IS: 456-2000
V_{uc} = 4 x 150 x 174 = 104.4 kN
V_{us} = 0 (No shear reinforcement)
V_{frp} = Φ_{frp} x A_{frp} x f_{frp} x (sinβ + cosβ) x d / S_{frp}
Φ_{frp} = 0.8
A_{frp} = t_{frp} x w_{frp}
t_{frp} = 0.3 mm of Nitowrap Carbon fiber from Fosroc limited
w_{frp} = 330 mm
f_{frp} = 563.2 N/mm^2 from Fosroc limited
β = 90^0
w_{frp} = S_{frp} = 330 mm
V_{frp} = 0.8 x 4 x 0.3 x 330 x 563.2 x 174 / 330
V_{frp} = 94.076 kN
V_n = 104.4 + 0 + 94.076
V_n = 198.476 kN.

Table 2.5 Ultimate Shear Strengths of M70 Strengthened Beams

Sl. No	Spacing in mm	Name of the beam	V_n, Ultimate shear strength in kN
1	Single	H-SB1	198.476
2	50	H-SB2	350.659
3	100	H-SB3	274.568
4	150	H-SB4	249.204
5	200	H-SB5	236.522
6	250	H-SB6	228.912

III. EXPERIMENTAL WORK

Experiments were conducted to study the shear capacity of RC rectangular beams with/without FRP using local available materials.

3.1 Materials

3.1.1 Cement

43 grade ordinary Portland cement (OPC) conforming of IS: 8112 was used throughout the experimental work and was tested for physical properties in accordance with B.I.S specification.

3.1.2 Fine Aggregate

Available river sand belonging to zone II of IS: 383-1970 was used throughout the study.

3.1.3 Coarse Aggregate

Quarried and crushed granites stone was used as coarse aggregates. The specific gravity of coarse aggregates of 20mm and downsize was found according to the norms of Indian standards.

3.1.4 Water

Water which is potable and free from all impurities which cause harm for concrete, is used for the generation of concrete. Water is having two important causes in concrete generation, firstly it acts as an lubricant in between cement and fine aggregate and secondly it reacts with a cement to for a paste in turn which become hard as time prolongs.

3.1.5 Metakaolin

It is a mineral admixture obtained due to refining of kaolin clay at high temperature under controlled condition. Usage of mineral admixture in concrete reduces the amount of cement required in the production of high grade concrete and hence reducing heat of hydration.

3.1.6 Reinforcing Steel

All longitudinal reinforcement used was HYSD bars confirming to IS: 1786 - 1979. The stirrups used were 8 mm diameter mild steel bars. Reinforcement details as shown in the fig 3.1.

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Fig. 3.1 Reinforcement details

3.1.7 Carbon Fiber Reinforced Polymer

Nitowrap EP (CF) is a CFRP wrapping system obtained from Fosroc constructive solutions, Bangalore. These wraps are generally used to improve the strength carrying capacity of structural elements and they avoid the deflection in early stages.

Fig. 3.2 Nitowrap CFRP

3.1.8 Superplasticizer

Conplast SP430 (G) is a Super plasticizing slump retaining admixture procured from Fosroc constructive solution. Conplost SP430(G) is used to achieve high degree of workability. Quality of concrete is increased by conplast SP430(G) and hence reducing the water content in production of high grade of concrete.

3.2 Concrete Mix Proportioning

The design of concrete mix is done as per guidelines of IS: 10262 - 2009 with a proportion of 1: 1.63: 2.72 by weight to achieve a grade of M30 concrete. The maximum size of coarse aggregate used was 20 mm. The water cement ratio was fixed as 0.50 and a slump of 25 to 50 mm. Concrete mix design with a proportion of 1: 0.98: 1.22: 2% super plasticizer: 7.5% metakaoline by weight to achieve a grade of M70 concrete. The maximum size of coarse aggregate used is 16 mm. The water cement ratio is fixed at 0.28 and a slump of 75 to 100 mm.

3.3 Form Work

Fresh concrete is to be moulded for required shape and size within the good formwork. So the form work should be rigid and strong to hold the weight of wet concrete without bulging anywhere. The joints at bottom and sides are sealed to avoid leakage of cement slurry. Mobil oil was then applied to the inner faces of form work. The bottom rests over thick polythene sheet laid over rigid as floor. The reinforcement is then placed within the form work carefully with a cover of 20mm on sides and bottom by placing concrete cover blocks.

Fig. 3.3 Form Work

3.4 Mixing of Concrete

The mixing of concrete is done using a standard mechanical mixer complying with IS: 1791 and IS: 12119. First coarse and fine aggregates are fed alternately, followed by cement. Then required quantity of water is slowly added into the mixer to make the concrete workable until a uniform color is obtained. The mixing is done for two minutes after all ingredients are fed inside the mixer as per IS: 456-2000.

3.5 Compaction of Concrete

All the specimens are compacted by using tamping rod of size 600mm length and 16mm diameter. Compaction is done in three layers of 25 strokes in each layer. Finally, the top surface of concrete leveled, finished smooth by using a trowel and wooden float. After six hours, the specimen detail and date of concreting is written on top surface to identify it properly.

3.6 Curing of Concrete

The specimens are taken out of the mould after 24 hours, shifted to concrete floor, covered all round with wet jute bags. Potable water is sprinkled 6 times per day to keep the jute bags wet, to allow concrete for perfect curing. The curing is continued for 28days.

3.7 Strengthening of Beams using GFRP

3.7.1 Surface preparation

Concrete surface is to be treated should be free from all kinds of chemical agents and unevenness or grout holes. The surface before wrapping is to be treated for depressions by nitocote VF epoxy putty.

3.7.2 Mixing

The contents should be thoroughly stirred before mixing to disperse settlement caused due to storage of materials. Mixing of base, hardener and materials is carried out for at least couple of minutes, with the help of mixing paddle.

3.7.3 Primer

Epoxy primer is to be applied on the prepared surface. Application of epoxy is made by brush and allowed to dry for a day before the application of saturant.

3.7.4 Saturant

Nitowrap is to be applied on the primer.

3.7.5 Nitowrap CF

Carbon fiber wrap is to be cut in the required form and to be pasted on the surface by pressing with spatula and rolling by roller to remove the air bubbles for single layer and the same procedure is to be followed for multiple layers for strengthening by fiber wraps.

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3.7.6 Curing

The specimen is to be air dried for at least six or eight hours so that the coating will be free from air bubbles and it is fully cured in 7 to 10 days.

IV. RESULTS AND DISCUSSIONS

Here, an attempt was made to bring out the comparative study between the experimental data and theoretical data regarding, Shear strength and deflection. All the 24 beams are tested one by one in the loading frame. Three dial gauges are fixed below the beam each one at quarter span, mid span and three fourth span. The load is gradually increased up to failure.

4.1 Cracking Pattern and failure modes of M30 Control beams

4.1.1 Beam N-CB1

Fig. 4.1 Loading Arrangement

Fig. 4.2 Failure of Beam N-CB1

The beam was gradually loaded up to failure. The loading arrangement and cracking pattern of the beam is as shown in the fig 4.1 and fig 4.2. Hair cracks were appeared at right span bottom and progressed upwards. It was a pure shear failure. The theoretical ultimate load as per Limit state method 91.35kN and experimental results showed an ultimate load of 126.05kN.

4.2 Cracking Pattern and Failure Modes of M70 Control Beams

4.2.1 Beam H-CB1

Fig. 4.3 Failure of Beam H-CB1

The beam is gradually loaded up to failure. Cracking pattern of the beam is as shown in the fig 4.3. Hair cracks are appeared at left span bottom and progressed upwards. It is a pure shear failure. The theoretical ultimate load as per limit state method 104.40kN and experimental results showed an ultimate load of 135.52kN.

4.3 Cracking Pattern and Failure Modes of CFRP Strengthened M30 Beams

4.3.1 Beam N-SB1

Fig. 4.4 Failure of Beam N-SB1

The beam was gradually loaded up to failure. Cracking pattern of the beam is as shown in the fig 4.4. Hair crack was appeared at mid span bottom and progressed upwards. It is a pure flexure failure. The theoretical ultimate load as per limit state method 185.426kN and experimental results showed an ultimate load of 192.10kN

4.4 Cracking Pattern and Failure Modes of CFRP Strengthened M70 Beams

4.4.1 Beam H-SB1

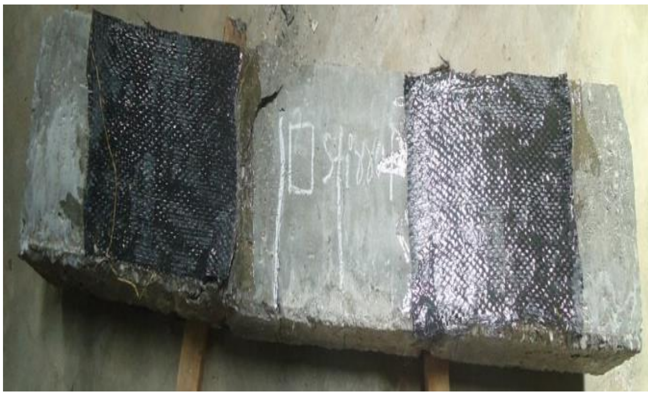

Fig. 4.5 Failure of beam H-SB1

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The beam is gradually loaded up to failure. Cracking pattern of the beam is as shown in the fig 4.5. Hair crack is appeared at mid span bottom and progressed upwards. It is a pure flexure failure. The theoretical ultimate load as per limit state method 135.60 kN and experimental results showed an ultimate load of 212.10 kN.

Table 4.1 Comparison of Theoretical and Experimental Results of Ultimate Loads of Control Beams

Sl. No	Control Beam Designation	Failure Mode	Ultimate Load kN	
			Theoretical	Experimental
1	N-CB1	Shear	91.35	126.05
2	N-CB2	Shear	243.53	270.70
3	N-CB3	Shear	167.44	183.05
4	N-CB4	Shear	142.07	163.75
5	N-CB5	Shear	129.39	159.65
6	N-CB6	Shear	121.78	140.00
7	H-CB1	Shear	104.40	135.52
8	H-CB2	Flexure	256.59	280.92
9	H-CB3	Shear	180.49	202.51
10	H-CB4	Shear	155.13	178.30
11	H-CB5	Shear	142.45	165.42
12	H-CB6	Shear	134.84	158.80

Table 4.2 Comparison of Theoretical and Experimental Results of Ultimate Loads of GFRP Strengthened Beams

Sl. No	Strengthened Beam Designation	Failure Mode	Ultimate Load kN	
			Theoretical	Experimental
1	N-SB1	Flexure	185.426	195.2
2	N-SB2	Flexure	333.573	365.25
3	N-SB3	Flexure and Debonding	261.516	276.57
4	N-SB4	Flexure and Debonding	236.516	256.82
5	N-SB5	Flexure	223.46	223.35
6	N-SB6	Flexure	205.826	210.50
7	H-SB1	Flexure	198.476	212.10
8	H-SB2	Flexure	350.659	380.825
9	H-SB3	Flexure	274.568	390.05
10	H-SB4	Flexure	249.20	261.95
11	H-SB5	Flexure	236.522	246.15
12	H-SB6	Flexure	228.912	238.912

V. CONCLUSIONS

1. The initial cracks in the strengthened beams appears at higher load compared to the control beams.
2. Control beams of both normal and high strength concrete the failure was observed at shear zone. But after strengthening at shear zone for the same variety of beam the initial cracks were developed within the flexural zone and further increase in the load it propagated towards shear zone, but the clear cut observation was made that due to CFRP sheet bonded at shear zone increases the shear capacity of beams.
3. The beams were strengthened by two sides wrapping in the shear zone, the shear capacity increased by 22% to 58% in normal strength i.e. M30 beams and 10% to 19% in high strength beam.
4. CFRP wrapping is more effective to normal strength beams compare to high strength beams.
5. Due to bonding made by CFRP sheet at shear zone makes beam to mail at flexure zone which in turn gives sufficient warning before sudden failure compared to that of shear failure.
6. Restoring or upgrading the shear strength of beams using CFRP sheet can result in increased shear strength with no visible shear cracks. So restoring the shear strength of beams using CFRP can be a highly effective technique.

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