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Structural properties of NSC and HSC beams bonded by GFRP wraps

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Abstract: The use of fiber reinforced polymer (FRP) is becoming a widely accepted solution for repairing and strengthening in the field of civil engineering around the world. The shear strength of a reinforced concrete beam can be extensively increased by application of carbon (CFRP), glass (GFRP) and aramid (AFRP) FRP sheets adhesively bonded to the shear zone of the beam. This paper deals with Theoretical and experimental investigation for enhancing the shear capacity of RC beams using Glass fiber reinforced polymers (GFRP) polymers

Keywords: Fiber reinforced polymer (FRP), carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and aramid fiber reinforced polymer (AFRP).

1. 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. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes.
Since replacement of such deficient elements of structures incurs a huge amount of public money and time. Strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. Infrastructure decay caused by premature deterioration of buildings and structures has lead to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget.
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. 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 composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone. Fibers are the principal load carrying members, while the matrix keeps them in the desired location, orientation and protect them from environmental damages. The fiber imparts the strength, while matrix keeps the fiber in place, transfer stresses between the fibers, provides a barrier against an adverse environment such as chemicals and moisture, protects from abrasion. FRP is an acronym for Fiber Reinforced Polymer and identifies a class of composite materials consisting of brittle, high strength and stiffness fibers embedded at high volume fractions in ductile low stiffness and strength polymeric resins called matrix.

FRP with polymeric matrix can be considered as a composite. They are widely used in strengthening of civil structures such as beams, girders, slab, columns and frames. There are many advantages of FRP due to light weight, corrosion-resistant, good mechanical properties.

The main function of fibers is to carry load, provide strength, stiffness and stability. 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. Each has its own advantages and disadvantages.

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 binds the fibers together. The common resins are epoxy resins, polyester resins and vinylester 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.

2. THEORETICAL STUDIES

Theoretical study is made for 12 normal strength beams i.e. M_{30} and 12 high strength beams i.e. M_{70} of same geometry, but varying shear reinforcement in each beam with and without GFRP bonding. Out of 24 beams 12 control beams and 12 beams are wrapped with GFRP.

The geometry of all the beams is of length1300 mm and cross section 150 mm X 200 mm. longitudinal section of the beam is as shown in the fig 2.1.

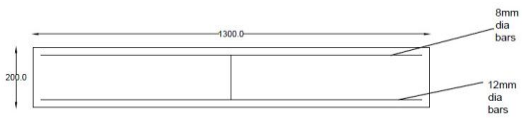

Fig 2.1 longitudinal section of the beam

Table 2.1 Proposed beams to be casted

Grade of concrete	Number of beams	
M_{30}	6	Control beams
M_{30}	6	Bonded with GFRP
M_{70}	6	Control beams
M_{70}	6	Bonded with GFRP

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

2.1 Shear capacity of normal strength (M_{30}) 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 (M_{30}) Control beam of no shear reinforcement

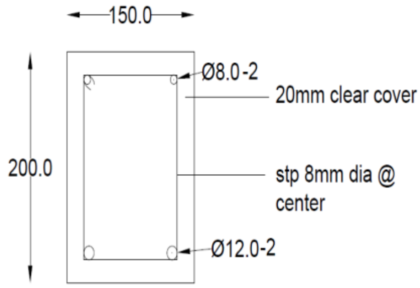

Fig 2.2 Reinforcement details of beam N-CB1

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

Clear cover = 20mm

fck = 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 M_{30} 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 M_{30} 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 (M_{70}) 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 (M_{70}) Control beam of no shear reinforcement

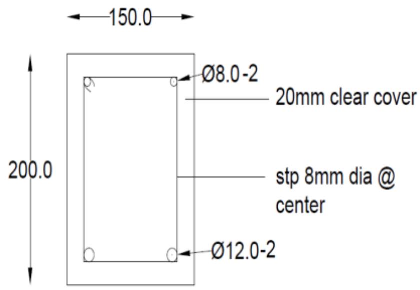

Fig 2.3 Reinforcement details of beam H-CB1

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

Clear cover = 20mm

fck = 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 M_{70} 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.

Table2.3 Ultimate shear strengths of M_{70} 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 GFRP strengthened M_{30} 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 (M_{30}) strengthened beam no shear reinforcement

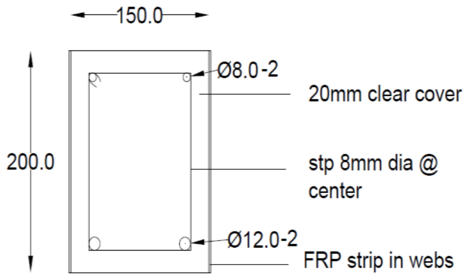

Fig 2.4 Reinforcement details of beam N-SB1

Top 8mm 2 No's, Bottom 12mm 2 No's
Clear cover = 20mm
fck = 30N/mm^2, fy = 500N/mm^2
d = 200 -20 - 12/2 = 174mm.
$V_n = V_{uc} + V_{us} + V_{frp}$
$V_{uc} = \tau_{cmax}$ x bd
τ_{cmax} = 3.5N/mm^2 for M_{30} as per IS: 456-2000
V_{uc} = 3.5 x 150 x 174 = 91.35KN
V_{us} = 0 (No shear reinforcement)
$V_{frp} = \Phi_{frp}$ 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} = 0.36 mm of Nitowrap Glass fiber from Fosroc limited
w_{frp} = 330 mm
f_{frp} = 241 N/mm^2 from Fosroc limited
β = 90^0 (Oriented 90^0 to the horizontal)
$w_{frp} = S_{frp}$ = 330 mm
V_{frp} = 0.8 x 4 x 0.36 x 330 x 241 x 174 / 330
V_{frp} = 48.308 KN
V_n = 91.35 + 0 + 48.308
V_n = 139.65 KN.

Table 2.4 Ultimate shear strengths of M_{30} strengthened beams

Sl no	Spacing in mm	Beam designation	V_n, Ultimate shear strength in KN
1	single	N-SB1	139.65
2	50	N-SB2	291.83
3	100	N-SB3	215.74
4	150	N-SB4	190.37
5	200	N-SB5	177.69
6	250	N-SB6	170.08

2.4 Shear capacity of GFRP strengthened M_{70} beams

3.4.1 Beam H-SB1 The cross section of the H-SB1 is shown in the fig 2.5.

H-SB1 – High strength (M_{70}) strengthened beam of no shear reinforcement.

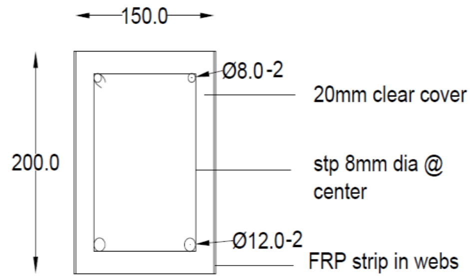

Fig 2.5 Reinforcement details of beam H-SB1

Top 8mm 2 No's, Bottom 12mm 2 No's
Clear cover = 20mm
fck = 70N/mm^2, fy = 500N/mm^2
d = 200 -20 - 12/2 = 174mm.
$V_n = V_{uc} + V_{us} + V_{frp}$
$V_{uc} = \tau_{cmax}$ x bd
τ_{cmax} = 4N/mm^2 for M_{70} as per IS: 456-2000
V_{uc} = 4 x 150 x 174 = 104.4 KN
V_{us} = 0 (No shear reinforcement)
$V_{frp} = \Phi_{frp}$ 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} = 0.36 mm of Nitowrap Glass fiber from Fosroc limited
w_{frp} = 330 mm
f_{frp} = 241 N/mm^2 from Fosroc limited
β = 90^0 (Oriented 90^0 to the horizontal)
$w_{frp} = S_{frp}$ = 330 mm
V_{frp} = 0.8 x 4 x 0.36 x 330 x 241 x 174 / 330
V_{frp} = 48.308 KN
V_n = 104.4 + 0 + 48.308
V_n = 152.71 KN.

Table 2.5 Ultimate shear strengths of M_{70} strengthened beams

Sl no	Spacing in mm	Name of the beam	V_n, Ultimate shear strength in KN
1	single	H-SB1	152.71
2	50	H-SB2	304.89
3	100	H-SB3	228.80
4	150	H-SB4	203.44
5	200	H-SB5	190.77
6	250	H-SB6	183.15

3. EXPERIMENTAL WORKS

Experiments are 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 is used throughout the experimental work. It is tested for its physical properties in accordance with B.I.S specification.

3.1.2 Fine Aggregate

Locally available river sand belonging to zone II of IS: 383-1970 was used for the project work

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 fit for drinking is generally considered fit for making concrete. Water should be free from acids, oils, alkalies, vegetables or other organic Impurities. Soft waters also produce weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement.

3.1.5 Metakaolin

Metakaolin is refined kaolin clay that is fired (calcined) under carefully controlled conditions to create an amorphous aluminosilicate that is reactive in concrete. Like other pozzolans, metakaolin reacts with the calcium hydroxide (lime) byproducts produced during cement hydration.

3.1.6 Reinforcing steel

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

Fig 3.1 Reinforcement details

3.1.7 Glass fiber reinforced polymer

Nitowrap GFRP is a glass fiber composite system from Fosroc constructive solutions. This composite system is used for strengthening columns, beams and slabs of load bearing structures particularly where improvement to shear strength and deformation characteristics is required.

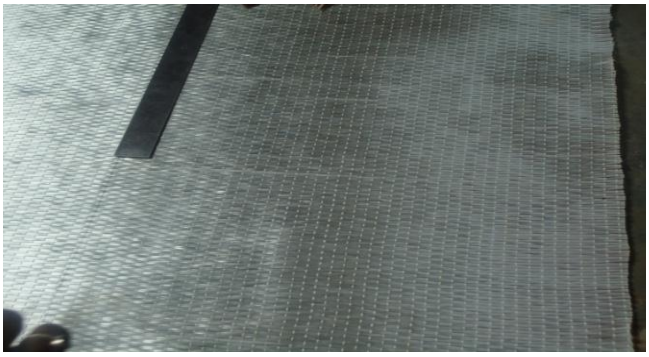

Fig 3.2 Nitowrap GFRP

4.1.8 Superplasticizer

Conplast SP430 (G) is a Superplasticising slump retaining admixture procured from Fosroc constructive solution. Conplast SP430(G) is used where a high degree of workability and its retention are required, where delays in transportation or placing are likely or when high ambient temperatures cause rapid slump loss. It facilitate production of high quality 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 M_{30} concrete. The maximum size of coarse aggregate used is 20 mm. The water cement ratio is fixed at 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 M_{70} 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 being plastic requires good form work to mould it to the required shape and size. 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 cage is then lowered, placed in position inside 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 colour 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 surfaces to be treated shall be free from oil residues, demoulding agents, curing compounds, grout holes and protrusions. The concrete surface to be wrapped shall be structurally repaired prior to treatment, for corrosion induced damage/ structural damage, by epoxy grouting and epoxy/ polymer modified Renderoc repair mortar systems. Any depressions in the concrete substrate shall be repaired with Nitocote VF/Nitomortar FC epoxy putty to even out undulations.

3.7.2 Mixing

Before mixing, the contents of each can should be thoroughly stirred to disperse any settlement, which may have taken place during storage. The base and hardener are emptied into a suitable container and the material is thoroughly mixed for at least 3 minutes. Mechanical mixing using a heavy-duty slow speed (300 - 500 rpm), flameproof drill, fitted with a mixing paddle is recommended.

3.7.3 Primer

The mixed material of Nitowrap 30 epoxy primer is applied over the prepared and cleaned surface. The application shall be carried out using a brush and allowed to dry for about 24 hours before application of saturant.

3.7.4 Saturant

The mixed material of Nitowrap 410 saturant is applied over the tack free primer. The wet film thickness shall be maintained @ 250 microns.

3.7.5 Nitowrap GF

The Nitowrap GF shall be cut to required size and then pressed first by gloved hand on to the saturant applied area and then with a stiff spatula or a surface roller to remove air bubbles.

One more coat of Nitowrap 410 saturant is applied over the glass fabric, Nitowrap GF at 250 microns WFT after a minimum time lapse of 30 minutes. The same procedure shall be followed for multiple layer fibre strengthening.

3.7.6 Curing

The coatings will become tack free in approximately 4 - 6 hours and be fully cured in 7 days.

4. RESULTS AND DISCUSSIONS

The experimental studies on all beams were conducted. Here, an attempt has been 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 M_{30} Control beams

4.1.1 Beam N-CB1

Fig 4.1 Loading arrangement

Fig 4.2 Failure of beam N-CB1

The beam is 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 are appeared at right span bottom and progressed upwards. It is 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 M_{70} 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 GFRP strengthened M_{30} beams

4.3.1 Beam N-SB1

Fig 4.4 Failure of beam N-SB1

The beam is gradually loaded up to failure. Cracking pattern of the beam is as shown in the fig 4.4. 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 139.65KN and experimental results showed an ultimate load of 161.7KN

4.4 Cracking Pattern and failure modes of GFRP strengthened M_{70} beams

4.4.1 Beam H-SB1

Fig 4.5 Failure of beam H-SB1

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 152.71KN and experimental results showed an ultimate load of 158.81KN.

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	Flexural	139.65	161.70
2	N-SB2	Flexural	291.83	323.30
3	N-SB3	Flexural and debonding	215.74	250.74
4	N-SB4	Flexural and debonding	190.37	230.37
5	N-SB5	Flexural	177.69	1213.30
6	N-SB6	Flexural	170.08	202.48
7	H-SB1	Flexural	152.71	158.81
8	H-SB2	Flexural	304.89	310.82
9	H-SB3	Flexural	228.80	233.50
10	H-SB4	Flexural	203.44	207.28
11	H-SB5	Flexural	190.77	193.58
12	H-SB6	Flexural	183.15	184.87

5. CONCLUSIONS

1.The initial cracks in the strengthen beams appears at higher load compared to the control beams.

2.All the control beams are failed at shear zone. After strengthening the shear zone of the beam the initial cracks appears at the flexural zone of the beam and the crack widens and propagates towards the neutral axis with increase of the load. The final failure is flexural failure which indicates that the GFRP sheets increase the shear strength of the beam.

3.The beams were strengthened by two sides wrapping in the shear zone, the shear capacity increased by 19% to 44% in normal strength i.e. M_{30} beams and 10% to 19% in high strength beam.

4.GFRP wrapping is more effective to normal strength beams compare to high strength beams.

5.When the beam is strengthen in shear, only flexural failure takes place which gives sufficient warning compared to the brittle shear failure which is catastrophic failure of beams.

6.The bonding between GFRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to GFRP sheet.

7.Restoring or upgrading the shear strength of beams using GFRP sheet can result in increased shear strength with no visible shear cracks. Restoring the shear strength of beams using GFRP is a highly effective technique.

8.High strength beam undergone a lesser deflection compared to normal strengthened beams.

9.M_{70} GFRP strengthened beams gives lesser deflection and lesser ultimate load carrying capacity compared to M_{30} GFRP strengthened beams.

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