Retrofitting of Reinforced Concrete Beam with Glass Fiber Reinforced Polymer Strips and Sheet

Aleesha Alexander
PG Student
Dept. Of Civil Engineering
Younus College of Engineering and Technology
Kollam, Kerala

Nimesh Mohan M
Assistant Professor
Dept. Of Civil Engineering
Younus college of Engineering and Technology
Kollam, Kerala

I. INTRODUCTION

Today, Glass Fibre Reinforced Polymer (GFRP) materials are being used worldwide for the retrofitting and repair of deficient and old infrastructures such as bridges and buildings. Over the years these structures have suffered severe strength and stiffness due to aggressive environmental conditions such as humidity, saltwater and alkali solutions. Advanced fibrous composite materials such as GFRP can eliminate the problem of corrosion and substantially increase the strength and stiffness of the internally reinforced with GFRP bars. In the case of Reinforced Concrete (RC) beams, externally strengthened with GFRP plates and fabrics and exposed to aggressive environmental conditions, however the bond between the GFRP plate and surface of the RC beam significantly affects the strength of externally reinforced RC beams. Thus it is essential to investigate the overall response of the RC beams externally strengthened with GFRP plates and fabrics and exposed to different environmental conditions.

The technology industries have increased enormously in the last few decades and looks set for significant further expansion. This has been largely because of the high specific stiffness and strength of these materials. However, other properties such as fatigue resistance, property tailoring and manufacturing flexibility are also of significance in certain applications. GFRP structures in aerospace and other structural applications are generally subjected to some form of cycling loading, i.e. fatigue. In the laboratory, fatigue is generally approximated as a sinusoidally varying load or stress, characterised by the load ratio, frequency and maximum force. This type of loading can be termed standard fatigue (SF). However, real-life loading histories often involve vibrating loads that can propagate in structural elements as cyclic impacts. This phenomenon is known as impact fatigue (IF). IF is of major importance to the structural integrity of components and structures due to its detrimental effect on performance, which can occur after a relatively small number of low amplitude cycles. The external bonding of high-strength Fibre

Reinforced Plastics (FRP) to structural concrete members has widely gained popularity in recent years, particularly in rehabilitation works and newly builds structure. Comprehensive experimental investigations conducted in the past have shown that this strengthening method has several advantages over the traditional ones, especially due to its corrosion resistance, high stiffness-to-weight ratio, improved durability and flexibility in its use over steel plates. The use of Fibre Reinforced Polymer (FRP) materials in civil infrastructure for the repair and strengthening of reinforced concrete structures and also for new construction has become common practice. The most efficient technique for improving the flexural strength of deteriorated RC members is to externally bond Fibre-Reinforced Polymer (FRP) plates or sheets. FRP composite materials have experienced a continuous increase of use in structural strengthening and repair applications around the world in the last decade.

GFRP can be produced with higher strength and higher modulus of elasticity than steel, hence improving the flexural, shear strength, and deflection of structural member. Furthermore, the corrosion resistance characteristic gives more advantage on using FRP in reinforced concrete where it can be used for structures exposed to corrosive condition. The usage of FRP as reinforcement is very new and restricted to rehabilitation work on buildings. The main reason is because the lack of experience in handling this material and cost of using it.

Fibre Reinforced Polymer (FRP) composites are widely used for strengthening concrete structures because they have many advantages over conventional strengthening methods. Much research has been carried out over the past decade into the performance of concrete beams strengthened in shear with externally bonded FRP composites. Previous experimental studies have shown FRP composites are effective in increasing the shear capacity of Reinforced Concrete (RC) beams. Despite numerous interesting studies, the shear behaviour of RC beams strengthened with FRP is not well understood. The majority of tests have been carried out on simply supported beams without steel stirrups strengthened with complete side wrap, U-wrap or full wrapping of the section with Glass Fibre Reinforced polymer (GFRP) sheet.

II. MATERIALS

- Cement: Ordinary Portland cement of 53 grade conforming to IS 12269:1987 was used for the study.
- Fine aggregate: M-sand with 4.75 mm maximum size was used as fine aggregate.
- Water: Potable water is generally considered as being acceptable.
- GFRP Sheet: Glass Fibre Reinforced Polymer sheet were used for retrofitting the beam.
- Epoxy Resin: To bind the GFRP sheet with RC beam.

The aim of preliminary investigation studies was to obtain the mix proportion for concrete. Then the properties of constituent materials were determined.

III. MIX DESIGN

Concrete mix of M25 grade was used for all beams and it was designed as per IS 10262:2009 and the mix proportion was obtained as 1(cement):1.946(sand):3.085(gravel) by weight. The water/cement ratio was 0.52.

A. Specimen details

The test program consisted of twenty six R.C.C. beams categorized into thirteen groups. The beam has a cross section of (150 ×100) mm with an overall length of 1200mm.

Fig.1. Cage of Beam

B. Reinforcement details

All beams were reinforced with two numbers of 10 mm diameter steel bars in tension side (bottom) and two numbers of 8 mm diameter steel bars in compression side (top). All beams were provided with 10 numbers of 6 mm diameter steel stirrups. Beams were tested simply supported and were subjected to two point loads symmetrically placed at equal distance from the center line of the beam.

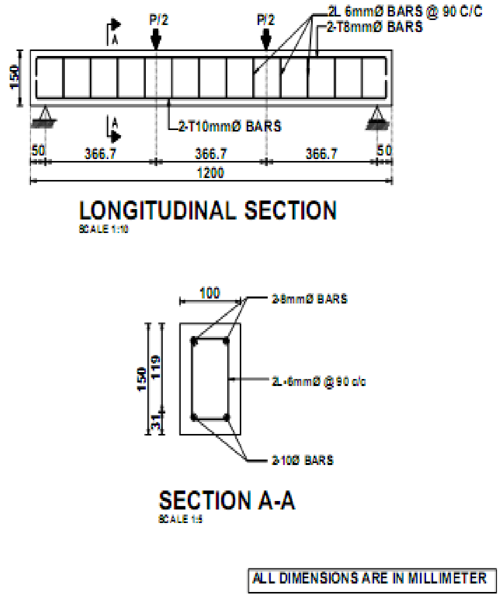

Fig.2. Reinforcement details (flexural)

IV. APPLICATION PROCEDURE OF GFRP WRAPPING

A. Preparation of specimen surface

As per recommendations of retrofitting work to get strengthening of structural elements, Surface preparation is an important task in our experimental work. This task was done with the help of Emery cloth stone for smooth surface and brush for cleaning the dust.

B. Preparation of retrofit test specimens

The CFRP sheets were bonded to the tension face of the specimens after 28 days of casting. Before applying the epoxy, the concrete surface was smoothened and cleaned to insure a good bond between the epoxy glue and the concrete surface. The epoxy was hand-mixed and hand-applied at an approximate thickness of about 1 mm. The bond thickness was not specifically controlled, but the excess epoxy was squeezed out along the edges of the sheet, assuming complete epoxy coverage.

C. Wrapped specimen details

The experimental program consists of strengthening using glass fiber reinforced polymer. The beans of the first group CB were tested with no strengthening or repair considered as control specimens. The beams of the second and third group were strengthened with U shaped GFRP strips of 50mm width spaced at 50mm with single and double layer respectively. Fourth and fifth group of beams were strengthened with 45° angle strips of 50mm width in single and double layer. 60^0 angle strips were used in sixth and seventh group in single and double layer. Side sheet, full sheet and U sheet wrappings single and double layers were correspondingly used in the eighth, ninth, tenth eleventh, twelfth and thirteenth groups.

TABLE 1 SPECIMEN LABELING

Beam Designation	Experimental Variables		
	Wrapping style	No. of Layers of FRP	Angle of FRP Wrapping
CB	Control Beam	-	-
US	U wrapping	Single	-
UD	U wrapping	Double	
45^{O} AS	Angle wrapping	Single	45^{O}
45^{O} AD	Angle wrapping	Double	45^{O}
60^{O} AS	Angle wrapping	Single	60^{O}
60^{O} AD	Angle wrapping	Double	60^{O}
SSS	Side Sheet wrapping	Single	-
SSD	Side Sheet wrapping	Double	-
FSS	Full Sheet wrapping	Single	-
FSD	Full Sheet wrapping	Double	-
USS	U Sheet wrapping	Single	-
USD	U Sheet wrapping	Double	

V. RESULTS AND DISCUSSION

A. *Properties of fresh concrete*

Studies conducted on fresh concrete. Then slump and compacting factor of fresh concrete is given in table 2.

TABLE 2 PROPERTIES OF FRESH CONCRETE

Properties	Value
Slump (mm)	25
Compacting factor	0.8

B. *Properties of hardened concrete*

1) *Cube compressive strength*

From the cube compressive strength study under water curing reveals that the age of curing increases the cube compressive strength. Then the compressive strength of concrete mix were determined at 7 and 28 days of curing is 28.89 N/mm^2 and 33 N/mm^2 respectively.

2) *Splitting tensile strength*

Splitting tensile strength of cylinder is determined at 28 days of curing is 3.04 N/mm^2.

3) *Flexural strength of beams*

Flexural strength was determined at 28 days of curing is 3 N/mm^2.

C. *Behaviour of flexural beams*

All beams were tested under two point loading condition in the loading frame of 200 tonne capacity. Load was applied by oil jack, then these beams were loaded up to the first flexural cracking and it was observed at an average load of 5kN. Only control beams were loaded up to the ultimate load. Twenty four out of twenty six beams wrapped with GFRP strips and sheets for retrofitting and improving the ultimate load when compared with that of control beam. The improvement in ultimate load was more for double layer than that of single layer. The load deflection behaviour of the specimens were studied. The energy absorption capacity which is the area under the load deflection curve and the ductility factor which is the ratio of the deflection at the ultimate load to the deflection at the yield load,were studied. Comparison of results were made between the FRP wrapped strip and sheets specimens and the control beam. The FRP wrapped specimens showed improvement in the properties compared to control beam.

All the beams wrapped with FRP showed improvement in properties when compared to the control beam. There was improvement in the ultimate load of wrapped specimens when compared with that of control beam. The improvement ultimate load was more for double layer than that of single layer. Sixty degree FRP angle strips wrapped beams showed higher improvement in properties when compared to the control beam and the other different types of strip wrapping. Full sheet wrapped beams also shows higher improvement in properties when compared to the control beam and the other different type of sheet and strip wrappings bur it is not economical.

TABLE 3 DETAILS OF BEAM TESTED

Specimen	Ultimate load (kN)	First crack load (kN)	Deflection corresponding to ultimate load
CB	44	12	3.8
US	50	15	4.9
UD	51	17	4.9
45^{O} AS	53	17	4.8
45^{O} AD	54	19	4.7
60^{O} AS	55	20	4.6
60^{O} AD	56	21	4.5
SSS	62	20	5.0
SSD	64	21	5.3
FSS	68	23	4.6
FSD	70	24	4.8
USS	65	22	4.9
USD	67	23	5.2

The results showed that the flexural capacity of the wrapped specimen increases as the area of the wrapping increases. Also, as the number of layers of FRP increased the flexural capacity. The sheet wrapped beams showed better improvement in flexural capacity compared to that of the strip wrapped specimens. Because FRP wrapped area is more in sheet wrapping than that of strip wrapping. The sixty degree angle strip wrapping showed better improvement in flexural capacity compared to other type of strip wrapping. The full sheet wrapping also showed better improvement in flexural capacity compared to other type of sheet wrapping.

TABLE 4 PERCENTAGE INCREASE IN FLEXURAL CAPACITY OF STRIP WRAPPED SPECIMENS COMPARED TO CONTROL BEAM

Beam Designation	No. of layers of FRP	Percentage increase in flexural capacity compared to control beam
CB	-	-
US	Single	13%
UD	Double	16%
45^{O} AS	Single	20%
45^{O} AD	Double	22%
60^{O} AS	Single	25%
60^{O} AD	Double	27%

TABLE 5 PERCENTAGE INCREASE IN FLEXURAL CAPACITY OF SHEET WRAPPED SPECIMENS COMPARED TO CONTROL BEAM

Beam Designation	No. of layers of FRP	Percentage increase in flexural capacity compared to control beam
CB	-	-
SSS	Single	40%
SSD	Double	45%
USS	Single	47%
USD	Double	52%
FSS	Single	54%
FSD	Double	59%

D. Load deflection behaviour of beams

The specimens were tested under monotonically increasing load until failure. As the load increased, beam started to deflect and flexural cracks developed along the span of the beams. Eventually, all beams failed in a typical flexure mode. Fig. 4.6 shows an idealized load-deflection curve at mid-span of beams. The progressive increase of deflection at mid-span is shown as a function of increasing load. The load-deflection curves indicate distinct events that were taking place during the test. These events are identified as first cracking (A), yield of the tensile reinforcement (B), crushing of concrete at the compression face associated with spalling of concrete cover (C), a slight drop in the load following the ultimate load (C'), and disintegration of the compression zone concrete as a consequence of buckling of the longitudinal steel in the compression zone (D). These are typical flexure behaviour of reinforced concrete beams. All beams behaved in a similar manner, although the distinct events shown in Fig. 3 were not clearly identified in all the cases.

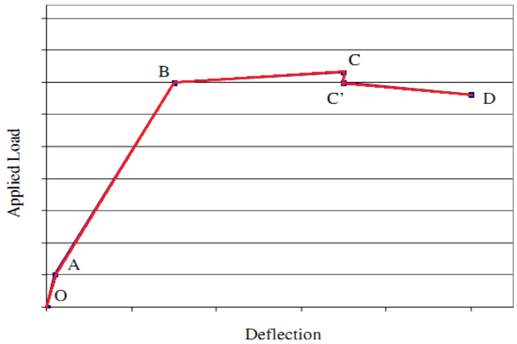

Fig. 3 Idealized load-deflection curve at mid-span

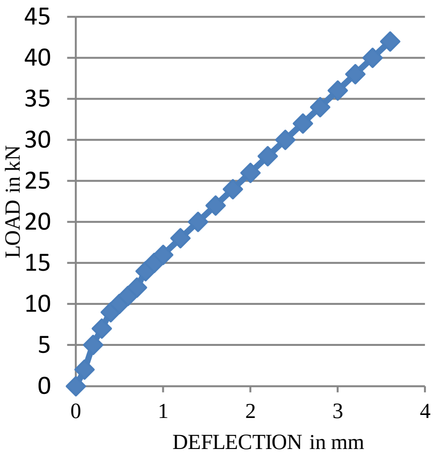

Fig.4. Load-deflection curve for control beam

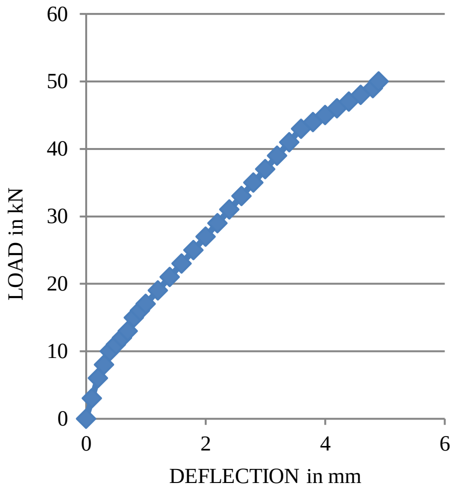

Fig.5. Load deflection curve for u strip wrap specimen - single layer

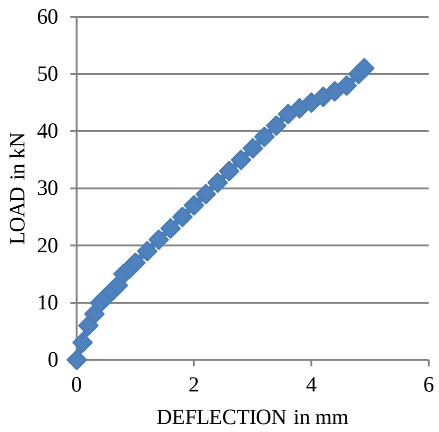

Fig.6. Load deflection curve for u strip wrap specimen - double layer

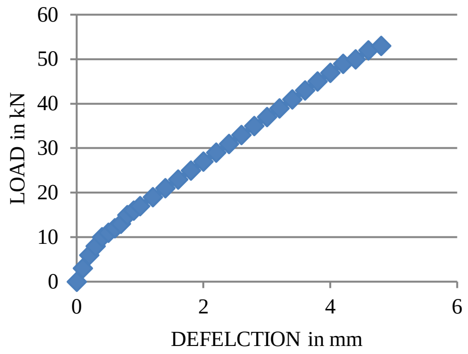

Fig.7. Load deflection curve for 45^0 angle strip wrap specimen - single layer

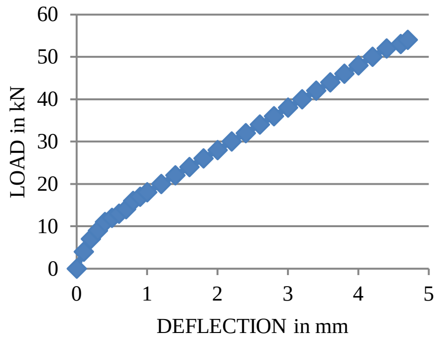

Fig.8. Load deflection curve for 45^0 angle strip wrap specimen - double layer

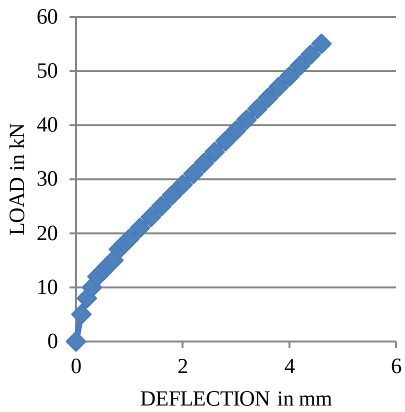

Fig.9. Load deflection curve for 60^0 angle strip wrap specimen - single layer

VI. CONCLUSIONS AND SCOPE OF FURTHER WORK

A. Conclusions

An experimental investigation was carried out to study the effect of glass fiber reinforced polymer strips and sheets to retrofitting the flexural beams. Six different wrapping styles were adopted. In these number of layers of FRP were kept as variables. A total of 26 beams were cast and were tested under monotonic loading. Based on experimental results following conditions are arrived at.

- Flexural load carrying capacity of retrofitted beam increases with FRP wrap than control beams.
- The FRP wrapped specimens showed improvement in the ultimate load. As the number of layers of FRP was increased the ultimate load carried by the specimens also increased. In the case strip wrapped specimens 60 degree angle double wrap is better and also in the case of sheet wrapped specimen full sheet wrapped specimen is better.
- Ultimate and first crack load of 60 degree angle double wrapped specimen is more compared to the other strip wraps and double layer full sheet wrap specimen shows improvement in the first crack and ultimate load compared to other sheet wrap.
- Wrapping of beams with FRP was found to be an effective method for repair and retrofitting of beams.
- Flexural retrofitting also increases the shear strength of concrete.

B. Scope of further work

- Attempts can be made to study the shear behaviour of FRP wrapped beams.
- The work can be extended by using FRP reinforcement bars.
- Attempts can be made to study the FRP wrapped specimen with more number of layers.
- Study can be extended by using aramid

REFERENCES

[1] Ahmed S. Debaiky, Mark F. Green and Brian B. Hope (2007), Modelling of Corroded FRP Wrapped Reinforced Concrete columns in axial compression.

[2] Anders Carolin, Björn Täljsten and Arvid Hejll (2005), Concrete Beams Exposed to Live Load during Carbon Fibre Reinforced Polymer Strengthening.

[3] M. Faizan Tahir (2013), Effect of Carbon Fibre Reinforced Polymer Confinement on the Fire Damaged and Un-heated Reinforced Square Columns.

[4] Fatih Alemdar ,Regan Gangel, Adolfo Matamoros, Ph.D., A.M.ASCE, Caroline Bennett, Ph.D., A.M.ASCE, Ron Barrett-Gonzalez, Ph.D. ,Stan Rolfe, Ph.D., P.E., Hon.M.ASCE and Hao Liu (2014), Use of CFRP Overlay to Repair Fatigue Damage in Steel Plates under Tension Loading.

[5] C.Higgins, G.T.Williams, M.M. Mitchell, M.R. Dawson and D.Howell (2012), Shear Strength of Reinforced Concrete Girders with Carbon Fibre Reinforced Polymer: Experimental Results, ACI Title no.109-S70.

[6] Hiran D. Yapa and Janet M. Lees (2014) Rectangular Reinforced Concrete Beams Strengthened with CFRP Straps.

[7] Ida Bagus Rai Widiarsa and Muhammad N.S. Hadi (2013), Performance of CFRP Wrapped Square Reinforced Concrete Columns Subjected to Eccentric Loading.

[8] Kam Yoke M.Loo,Stephen J.Foster, and Scott T. Smith (2012), Fatigue behaviour of Carbon Fibre Reinforced Polymer Repaired Concrete Beams, ACI Title no.109-S69.

[9] Kumar K. Ghosh and Shamim A. Sheikh (2007), Seismic Upgrade With Carbon Fibre Reinforced Polymer of Columns containing Lap Spliced Reinforcing Bars.

[10] Muhammad N. S. Hadi, M.ASCE and Ida Bagus Rai Widiarsa (2013), Axial and Flexural Performance of Square RC Columns Wrapped with CFRP under Eccentric Loading.