Enhancement of flexural strength on reinforced concrete beams strengthened with GFRP under cyclic loading.

Sandeep G.Sawant[1], Dr. H.S.Jadhav[2],

[1] Ph. D. Scholar, Shivaji University, Kolhapur, Maharashtra, India.
sgsawant6917@gmail.com

[2]Professor, Rajarambapu Institute of Technology,
Rajaramnagar, Islampur, Maharashtra, India.
hanmant.jadhav@ritindia.edu

***Abstract*: *This paper presents experimental research on reinforced concrete beams with flexural strengthening by Glass fiber reinforced polymer (GFRP) under cyclic loading. A total of 54 beams were cast and externally bonded with different configurations and three beams were cast without Strengthening (control beam). Each beam was tested under reversed cyclic loading under a two-point loading system. The loads are applied as positive and negative loads. The test specimens were evaluated in terms of load-displacement and cracking patterns. The experimental results show that strengthened RC beam load carrying capacity is observed to be in the range of 0 % to 25% for forwarding loading (Positive load) and 23.33 % to 66.66% for reverse loading (Negative load). Deflection is increased in the range 5.34% to 98.96% for forward loading (Positive load) and 0 % to 123.56% for reverse loading (Negative load) as compared to the control beam.*

***Keywords*:** Cyclic loading, Flexural Strength, GFRP, forward and reverse loading

(Article history: Received: 30th April 2022 and accepted 24th July 2022)

1. Introduction

Recently strengthening of RC structures using GFRP has become accepted. The current amount of work is related to fiber- reinforced polymers (FRP) composites as a repair material for the strengthening of structures[1]. A new technique has appeared recently which uses fiber reinforced polymer (FRP) stripes to strengthened the beams which have some favorable characteristics such as being easy to install, immunity to corrosion, and high strength. Fiber materials are used to strengthen a variety of reinforced concrete elements to enhance the flexural, shear, and axial load carrying capacity of elements [2-5]. The use of external FRP reinforcement may be classified as flexural strengthening, improving the ductility of compression members, and shear strengthening. It is well known that reinforced concrete beams strengthened with externally bonded fiber-reinforced polymer (FRP) to the tension face can exhibit ultimate flexural strength greater than their original flexural strength[6-11].Reverse cyclic loading is one of the most challenging cases of forwarding loading and reversed loading [12-18].For the past studies conducted it has been shown that externally bonded glass fiber reinforced polymers (GFRP) can be used to increase the Flexural Strength, shear strength of RC beams.

This paper study effect of different GFRP stripes configuration (width, length, and layers) on RC beam under cyclic loading

2. Experimental investigation

The experimental program consists of testing the 54 GFRP strengthened and three without strengthened RC beams (Control beam) under flexural cyclic loading. Test beams were designed as under-reinforced sections and strong in shear, so they failed in flexure. To develop the flexural strength, beams were mainly strengthened at the bottom face by using GFRP strips. The beams were cast with the same percentage of internal tensile steel reinforcement and applied with different GFRP configurations (length, width, and the number of layers).

2.1 Details of beam specimen

The experimental work consists of the casting of RC beams having grade M30, cross-sectional dimensions of 100mm x 200mm and 1800mm Length and provided 2-10mm Ø bottom reinforcement and 2-8mm Ø top with 6mm Ø vertical stirrups @ 130mm c/c. as shown in fig.1.

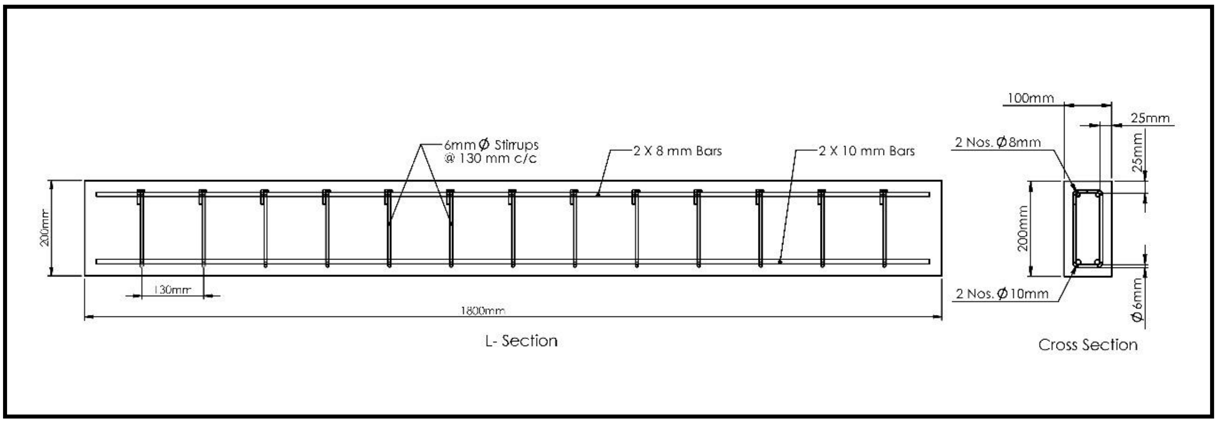


Fig. 1. Beam specimen geometry and reinforcement details

2.2 Casting and curing of beam

The experimental work consists of testing 57 simply supported beams. The mould is arranged precisely and placed over a smooth surface. The sides of the mould exposed to concrete were oiled well to avoid the sidewalls of the mould from absorbing water from concrete and to make easy removal of the specimen. The reinforcement cages were located in the moulds and the cover between the cage and form provided was 25mm. A concrete mix designed for M30 (1:2.15:2.65) and water-cement ratio is 0.45.After remoulding they are cured in pure potable water for 28 days.

2.3 Materials used in the Strengthening of beam

900GSM GFRP strip:

The unidirectional glass fabric is used in the fiber wrap system. The glass material is orientated in the 0º direction with additional white glass cross fibers at 90º. The dry fiber has a tensile strength of 3700 N/mm^2 and E-modulus of 80000 N/mm^2 the elongation at rupture is 4.8 %. Dry fibre thickness is 0.65mm. The use of the resin depends on the roughness of the substrate.

Resin material**:** Primer and resin were useful to the top and bottom areas on the concrete surface where GFRP material was to be placed. The ratio of creation of the primer is base: hardener (1:0.5) and the ratio of creation of the epoxy base: hardener (1:0.35).

2.4 Types of 900GSM GFRP configuration for strengthening

Strengthening of RC beams was used different types of 900GSM GFRP formation like by

(1600mm,1000mm, and 600mm) by width (100mm and 50mm) and by varying numbers of layers (Single, Double, and Three layers). Total 6 types of GFRP stripes were used 1600X100mm, 1000X100mm, 600X100mm, and 1600X50mm, 1000X50mm, 600X50mm with single, double, three layers each for top and bottom surface.

2.5. Specimens preparation for strengthening

The beam surface must be clean and free of entire redundant particles. A grinder was used to remove the face layer which may contain dust from the placement process, and then the beams were blown with compressed air to remove any excess particles. First, apply the primer on the surface after application of primer allows the material to cure for at least 24 hrs or overnight. After that first coat of resin apply on the surface of the beam then GFRP strips were placed in the required area and the final coat of resin is applied on fiber. The layers were pressed using a rubber roller to ensure the equal spreading of epoxy resin under the GFRP strips, also to ensure complete adherence to the concrete surface.

2.6. Test setup and loading pattern

Tests were performed keeping beams in cyclic loading equipment. Cyclic loading is the function of incremental push and pull load. The analysis is also known as push-pull analysis. Each beam was tested under reversed cyclic loading tested under a two-point loading system. The loads are applied as positive and negative loads. The hand-operated screw jack (10T) and LVDT were used for loading and deflection measurement purposes. S type load cell (5T) was placed between jack and beam. LVDT with a least count of 0.001 mm was used for measuring deflection. 5 cycles were imposed. The load cycle consisted of 10KN, 20KN, 30KN, 40KN, and 50KN for both positive and negative loads. The test setup is shown in fig. 2.

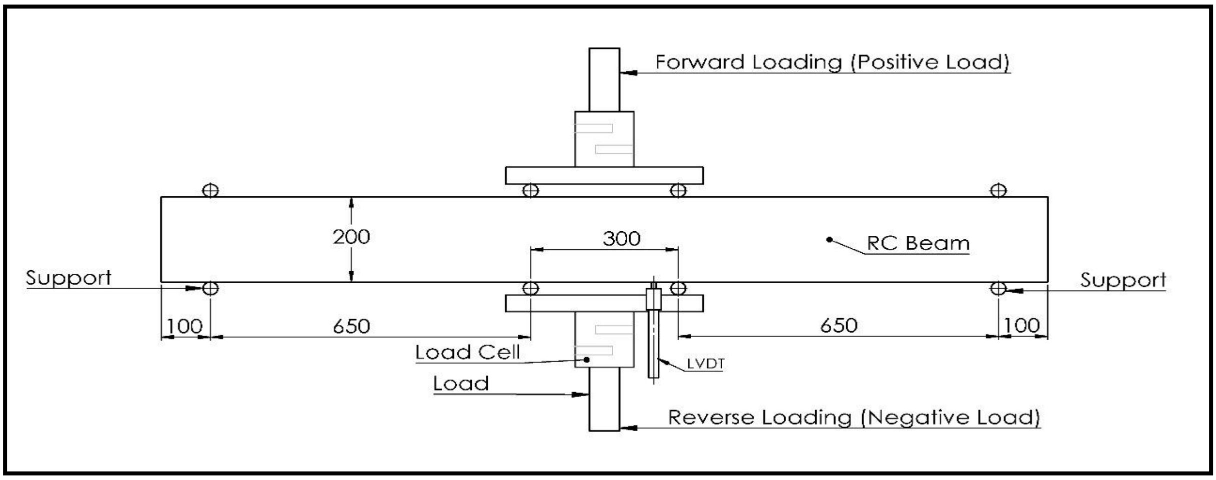


Fig.2 Test Set Up Forward loading (Positive load) and Reverse Loading (Negative load)

3. Discussion of results

3.1 Mode of failure.

The beams were tested under flexural cyclic loading. During the forward loading, cracks have been developed at the bottom of the specimen as the loading was progressed the width of the crack has been widened. And the reverse of the loaded specimen has to be in the reverse positions, cracks have been formed at the top and the cracks already formed in the tension face have to be closed. This opening and closing of the cracks have been established till the final failure of the specimen takes place. The complete cracks pattern of the beams are shown in fig.3

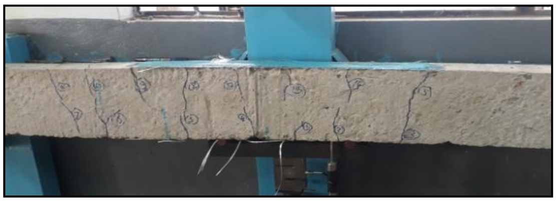



Fig.3 Cracks Pattern of the Beam

3.2 Comparison with experimental data

Comparison between Control beam & Strengthened RC Beams concerning Load and deflection by different length, width, and layers. Maximum load-carrying capacity and maximum deflection under flexural cyclic loading for forward loading (Positive load) and reverse loading (Negative load) as shown in table no.1 and table no. 2 respectively.

Table 1. Load versus deflection for Control beam & Strengthened RC Beams under forward cyclic loading (Positive load)

Sr. no	GFRP STRIPS (900GSM)	Control beam		Single-layer		Double layer		Three-layer	
	(In mm)	Max. Load. (kN)	Max. Deflection. (mm)	Max. Load. (kN)	Max. Deflection. (mm)	Max. Load. (kN)	Max. Deflection. (mm)	Max. Load. (kN)	Max. Deflection. (mm)
B	Control beam 1800X100	40	5.80	-	-	-	-	-	-
B1	1600X100	-	-	50	9.00	50	6.68	50	7.09
B2	1000X100	-	-	50	8.87	50	7.94	50	8.03
B3	600X100	-	-	40	6.11	40	6.27	50	8.75
B4	1600X50	-	-	50	7.09	50	9.21	50	9.47
B5	1000X50	-	-	50	11.16	50	11.54	50	10.19
B6	600X50	-	-	40	6.25	40	6.41	50	8.75

For forward cyclic loading (Positive load) beam specimen B1 load increase by 25 % with a single layer, double layer, and three layers. The maximum deflection of 55.19%, 15.17%, and 22.24% concerning single layer, double layer, and three layers as compared to control beam. For beam specimens B2 load increase by 25 % with a single layer, double layer, and three layers. The maximum deflection of 52.93%, 36.89%, and 38.44% concerning single layer, double layer, and three layers as compared to control beam. For beam specimens, the B3 load was the same for single layer and double layer, increase by 25% in three layers. The maximum deflection of 5.34%, 8.10%, and 50.86 % concerning single layer, double layer, and three layers as compared to control beam. For beam specimens, the B4 load increase by 25 % with a single layer, double layer, and three layers. The maximum deflection of 22.24%, 58.79%, and 63.27 % concerning single layer, double layer, and three layers as compared to control beam. For beam specimens B5 load increase by 25 % with a single layer, double layer, and three layers. The maximum deflection of 92.41%, 98.96%, and 73.68% concerning single layer, double layer, and three layers as compared to control beam. For beam specimens B6 load was the same for single layer and double layer, increase by 25% in three layers. The maximum deflection of 7.75%, 10.51%, and

50.86% concerning single layer, double layer, and three layers as compared to control beam.

Table 2. Load versus deflection for Control beam & Strengthened RC Beams under reverse cyclic loading (Negative load)

Beam ID	GFRP STRIPS 900 GSM	Control beam		Single-layer		Double layer		Three-layer	
	(In mm)	Max. Load. (kN)	Max. Deflection. (mm)	Max. Load. (kN)	Max. Deflection. (mm)	Max. Load. (kN)	Max. Deflection. (mm)	Max. Load. (kN)	Max. Deflection. (mm)
B	Control beam 1800X100	30	5.94	-	-	-	-	-	-
B1	1600X100	-	-	50	5.94	50	6.83	50	8.02
B2	1000X100	-	-	50	7.45	37	5.68	50	4.77
B3	600X100	-	-	37	6.26	40	7.74	30	2.45
B4	1600X50	-	-	50	5.94	46	4.91	50	10.61
B5	1000X50	-	-	50	13.28	42	11.61	40	5.57
B6	600X50	-	-	40	7.30	40	7.53	35	2.40

For reverse cyclic loading (Negative load) beam specimens B1 load increase by 66.66% with a single layer, double layer, and three layers. The maximum deflection of 0%, 14.98%, and 35.01 % concerning single layer, double layer, and three layers as compared to control beam. For beam specimens B2 load increase by 66.66 % with a single layer, three-layer, and load increase by 23.33% with double layers. The maximum deflection increase by 25.42% for the single layer, and decrease by 4.3%, and 19.69% concerning double layer, three layers as compared to the control beam. For beam specimens, B3 load increase by 23.33%, 33.33% for single layer, double layer, and same three layers. The maximum deflection increase by 5.28%,3.30% concerning single layer, double layer, and decrease by 58.75% for three layers as compared to control beam. For beam specimens B4 load increase by 66.66 % with a single layer, three layers, and load increase by 53.33% with double layers. The maximum deflection of 0%, 78.45% concerning single layer, three layers, and decrease 17.34% for double layers as compared to control beam. For beam specimens B5 load increase by 66.66%, 40%,33.33% with a single layer, double layer, and three layers. The maximum deflection increase by 123.56%, 95.45% concerning single layer, double layer, and decrease by 6.22% for three layers as compared to control beam. For beam specimens, B6 load increase by 33.33% with a single layer, double layer, and 16.66% for three layers. The maximum deflection increase by 22.89%, 26.76% concerning single layer, double layer, and decrease by 60% for three layers as compared to control beam.

3.3 Hysteretic curves

From table 1 and 2 hysteretic curves were a plot for control beam and strengthened RC beam as shown in fig.4 and 5

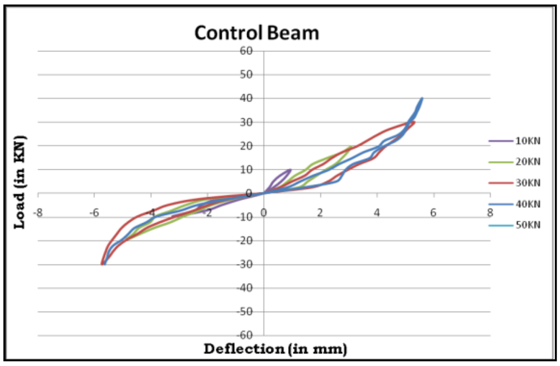
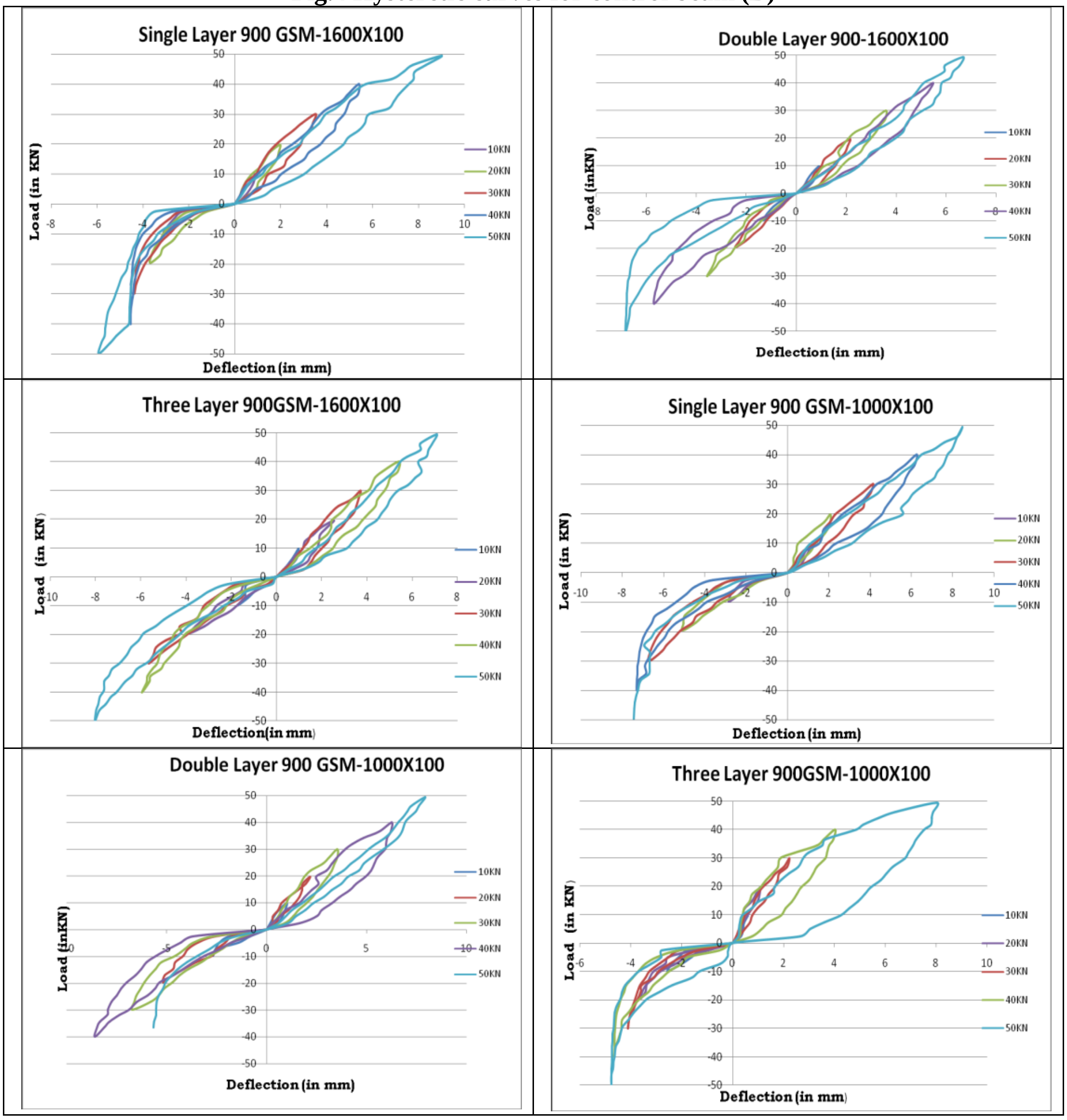
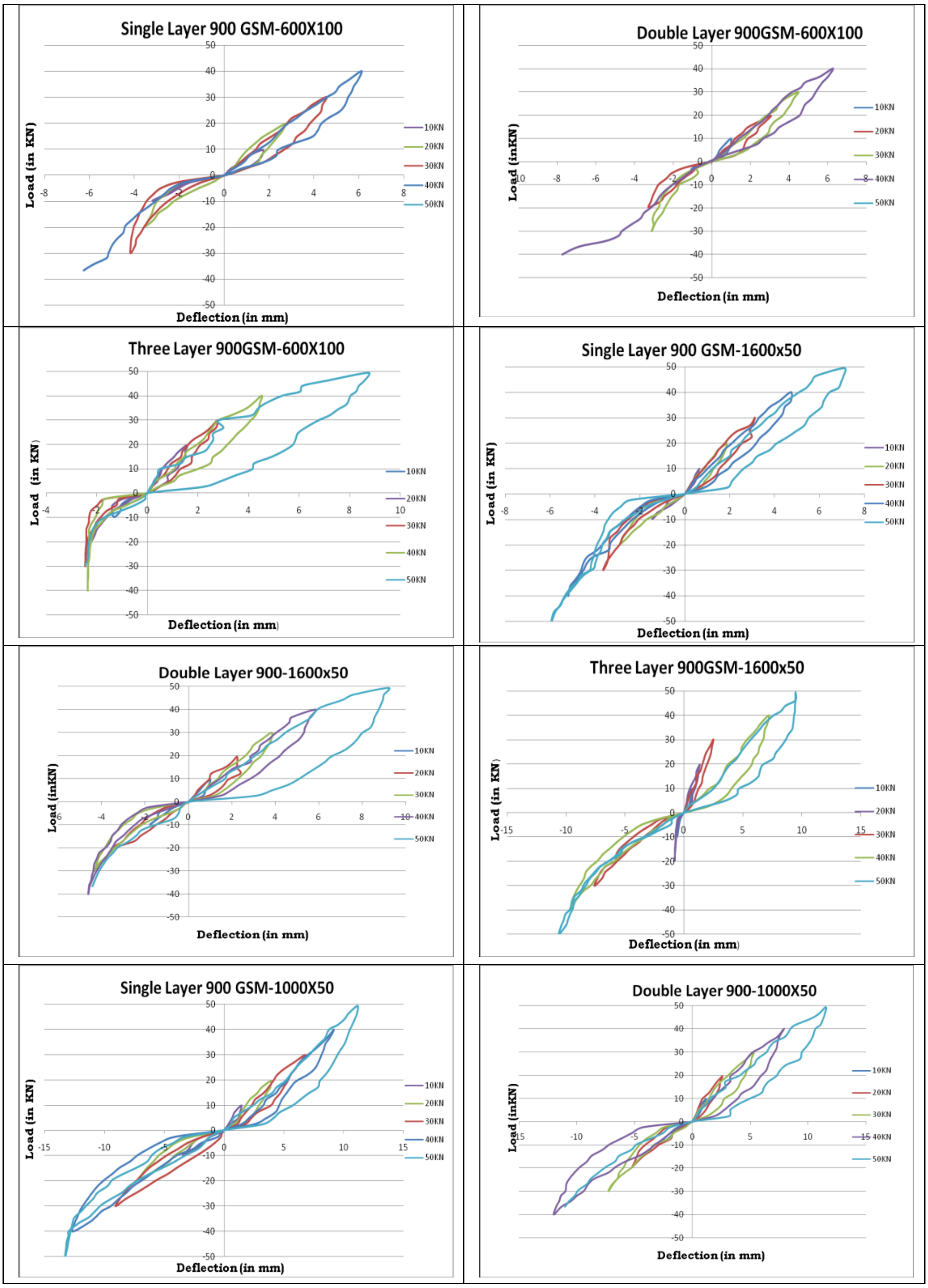


Fig.4 Hysteretic curves for control beam (B)




Single Layer 900 GSM-600X100
Load (in KN)
Deflection (in mm)
10KN
20KN
30KN
40KN
50KN
Double Layer 900GSM-600X100
Load (inKN)
Deflection (in mm)
Three Layer 900GSM-600X100
Load (in KN)
Deflection (in mm)
Single Layer 900 GSM-1600x50
Load (in KN)
Deflection (in mm)
Double Layer 900-1600x50
Load (inKN)
Deflection (in mm)
Three Layer 900GSM-1600x50
Load (in KN)
Deflection (in mm)
Single Layer 900 GSM-1000X50
Load (in KN)
Deflection (in mm)
Double Layer 900-1000X50
Load (inKN)
Deflection (in mm)

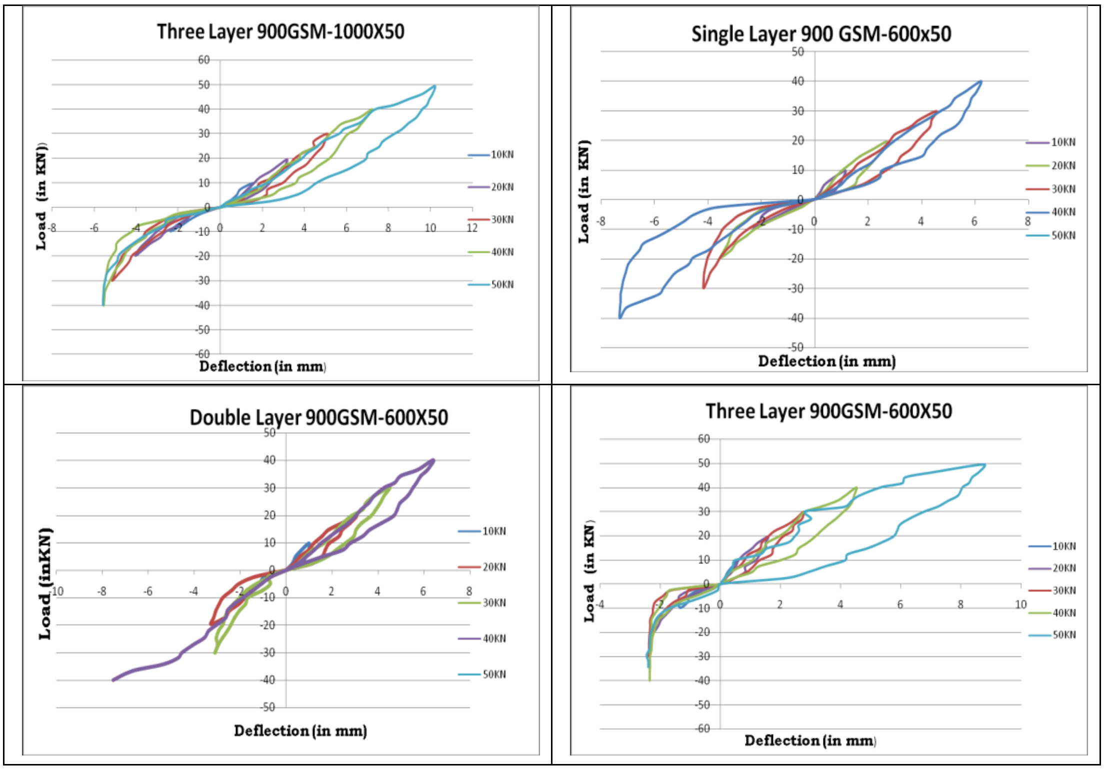


Fig.5 Hysteresis curves of specimens for strengthened RC beam(B1, B2, B3, B4, B5, B6)

Fig.4 and 5 express the hysteresis loops of each specimen obtained in the tests. It can be seen that the control specimens exhibited reduced hysteretic response, which was considered by narrow hysteresis loops and rapid degradation of load-carrying capacity. While the strengthened RC beam displayed more established hysteretic behavior, which was considered by more numbers of hysteretic loops, larger area of hysteretic loops, and slower degradation of load-carrying capacity

4. Conclusions

1.On varying length, width, and the number of layers of 900GSM GFRP strip from 50mm to 100mm and lengths 1600mm,1000mm, and 600mm increase in load-carrying capacity is observed to be in the range of 0% to 25% for forwarding loading (Positive load) and 16.66 % to 66.66% for reverse loading(Negative load).

2. On application of single layer, double layer, and three-layer of 900GSM GFRP strips the deflection is increased in the range of 5.34% to 98.96% for forwarding loading (Positive load). The deflection is increased in the range of 5.28 % to 123.56% and decreased in the range of 0% to 60% for reverse loading (Negative load).

3. Effect of cyclic loading on beams opening and closing of the cracks has been recognized till the failure for single, double, and three layers bonded 900GSM GFRP strips.

4. A flexible epoxy system will certify that the connection line in a single layer, double layers, and three layers 900GSM GFRP strengthened beams do not split before failure and contribute fully to the structural resistance of the strengthened beams with GFRP.

REFERENCES

1 .Pankaj Agarwal, Ankit Gupta, and Rachanna G. Angadi. “Effect of FRP Wrapping on Axial Behavior of Concrete and Cyclic Behavior of

External RC Beam Column Joints" KSCE Journal of Civil Engineering (2014) 18(2):566-573

2. N. Attari , S. Amziane , M. Chemrouk ."Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheets". Construction and Building Materials. Elsevier, September 2012.

3. Jiangfeng Dong , Qingyuan Wang , Zhongwei Guan. "Structural behaviour of RC beams with external flexural and flexural–shear strengthening by FRP sheets." Composites: Part B Elsevier, February 2012.

4. Sing-Ping Chiew, M.ASCE, Qin Sun and Yi Yu, "Flexural Strength of RC Beams with GFRP Laminates" Journal of Composites for Construction, Vol. 11, No. 5,October 1, 2007. ©ASCE, ISSN 1090-0268/2007/5-497–506.

5.N. Aravind, Amiya K. Samanta, Flexural Strengthening of Reinforced Concrete(RC) Beams Retrofitted with Corrugated Glass Fiber Reinforced Polymer (GFRP) Laminates, Curved, and Layer. Struct. 2015; 2:244–253

6. R. Balamuralikrishnan, flexural and cyclic behaviour of RC beams retrofitted with carbon fiber reinforced polymer (CFRP) fabrics, Asian journal of civil engineering (bhrc) vol. 16, no. 1 (2015) pages 67-79.

7. Hassan Falah Hassan, Mu'taz Kadhim Medhlom, Abdullah Sinan Ahmed, Mohammed Husein Al-Dahlak, Flexural performance of concrete beams reinforced by gfrp bars and strengthened by cfrp sheets, Case Studies in Construction Materials 13 (2020) e00417,Elsevier.

8. Harith ALI, Jules ASSIH, Ales LI, Flexural capacity of continuous reinforced concrete beams strengthened or repaired by CFRP/GFRP sheets, International Journal of Adhesion and Adhesives, 2020, Elsevier.

9. Gia Toai Truong, Hye-Hak Lee, Kyoung-Kyu Choi, Flexural behavior of RC beams strengthened with NSM GFRP strips after exposed to high temperatures. Engineering Structures 173 (2018) 203–215, Elsevier.

10. R. Capozucca, E. Magagnini, RC beam models damaged and strengthened with GFRP strips under bending loading and free vibration, Composite Structures 253 (2020) 112730, Elsevier.

11. T.Sankaramoorthy, R.Karthikeyan, G.M.Pradeep, D.Athikesavan, R.Girimurumgan, Improved performance of confinement of RC beam with glass fiber reinforced polymer laminates, Materials today proceeding, 2021, Elsevier.

12. Liu Jin, Wenxuan Yu, Xiao Su, Shuai Zhang, Xiuli Du, Junyan Han, Dong Li, Effect of cross-section size on the flexural failure behavior of RC cantilever beams under low cyclic and monotonic lateral loadings.Engineering Structures 156 (2018) 567–586, Elsevier.

13. Mohammed El-Gendy, Ehab El-Salakawy,Effect of flexural reinforcement type and ratio on the punching behavior of RC slab-column edge connections subjected to reversed-cyclic lateral loads, Engineering Structures 200 (2019) 109703, Elsevier.

14. G. Sakar, R.A. Hawileh, M.Z. Naser , J.A. Abdalla, M. Tanarslan, Nonlinear behavior of shear deficient RC beams strengthened with near mounted glass fiber reinforcement under cyclic loading, Materials and Design 61 (2014) 16–25,Elsevier.

15. Isamu Yoshitakea, Hiroaki Hasegawa, Kodai Shimose,Monotonic and cyclic loading tests of reinforced concrete beam strengthened with bond-improved carbon fiber reinforced polymer (CFRP) rods of ultra-high modulus, Engineering Structures 206 (2020) 110175, Elsevier.

16. Mohammad Razavi, Davood Mostofinejad, Mohammadreza Eftekhar, Behavior of RC columns and those strengthened with FRP composite under an innovative reversing cyclic eccentric axial loading, Engineering Structures 241 (2021) 112438, Elsevier.
17. Saleh Am in , S. K. Elwan , S. Elzeiny , M. Hamad, A. Deifalla, Numerical modeling the effect of an opening on the behavior of exterior beam - column connections under cyclic loading Journal of Building Engineering 40 (2021) 102742, Elsevier.
18. T. Tafsirojjaman, Sabrina Fawzia, David P Thambiratnam,Nicholas Wirth.Performance of FRP strengthened full-scale simply-supported circular hollow steel members under monotonic and large-displacement cyclic loading, Engineering Structures 242 (2021) 112522, Elsevier

Sandeep G.Sawant
Ph. D. Scholar, Shivaji University, Kolhapur, Maharashtra, India.

AUTHOR PROFILE

Dr. H.S.Jadhav
Professor, Rajarambapu Institute of Technology, Rajaramnagar, Islampur, Maharashtra, India.
.