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Reinforcement of Reinforced Concrete Beams using CFRP and GFRP

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ABSTRACT

Concrete, steel and masonry materials are the common materials used for housing, office buildings, bridges, power plant structures and these structures are being deteriorated with age. The deterioration of the structures is due to the design deficiency, materials deficiency, poor workmanship and extreme loads. Most of the investigation reports on strengthening of damaged RC structures are based on patch repairing and using FRP sheets for flexural, shear and compressive strengthening of members. This research work is mainly focused on retrofitting of RC beams using GFRP and CFRP sheets. In this study the flexural behaviour of M 20, 40and M60grade RC beams retrofitted with single, double and triple layers of GFRP sheets is done and all the beams are analysed using ANSYS modelling and compare with the experimental results. From the presence study, it is derived that strengthening of RC beams with GFRP and CFRP sheets can enhance the load carrying capacity of beams and at the same time deflections up to yield stage of loading is increased and further the deflections are reduced up to ultimate stage of loading. The RC beams strengthened with GFRP and CFRP sheets show a marked reduction in crack width at all stages of loading and substantial delay in the formation of first crack.

KEYWORDS: *Concrete, steel, masonry materials, buildings, bridges, RC structures, FRP sheets, GFRP and CFRP, ANSYS modelling*

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1. INTRODUCTION

Fibre reinforced polymers are continuous or non-continuous strong fibres surrounded by a matrix material. The matrix serves to distribute the fibers and transmit the load to the fibres. The bonding between the fibres and the matrix is created during the manufacturing phase and becomes a composite material in the final stages of fabrication when the matrix is hardened. The characteristics of composite materials depend on proportions of reinforcements and matrix, the form of reinforcement, and the fabrication processes. These are a combination of fibre reinforcement and a resin matrix. The resin system holds fibers together and transfers the loads through the fibres to the rest of the structure. In addition to binding the composite structure together, it protects from impact, abrasion, corrosion, other environmental factors and rough handling. The most common resins of the thermoset family are Polyester (orthophthalic and isophthalic), vinyl ester, epoxy, and phenolic. (Daniel, Isaac,2006)

Generally Reinforced Concrete (RC) structures can suffer varying degrees of damage due to several reasons including material deterioration, construction technique adopted, poor workmanship, overloading, aggressive environments, fatigue and corrosion of steel reinforcement embedded in concrete.

Epoxy resins are a broadly used in FRP materials. Epoxy resin systems are extremely high three dimensional crosslink density which results to the best mechanical performance characteristics of all the resins. It can resist high amount of strength and hardness, very good resistance to heat and electricity. The disadvantages of this epoxy is higher cost and processing difficulty. Epoxy systems are effectively used in various applications such as aerospace, defence, marine, sports equipment, adhesives, sealants, coatings, architectural, flooring and many other areas. (Åström,2018)

Most of the investigation reports on strengthening of damaged RC structures are based on patch repairing and using FRP sheets for flexural, shear and compressive strengthening of members. This research work is mainly focused on retrofitting of RC beams using GFRP and CFRP sheets. Most of the experimental studies are carried out in foreign countries and this retrofitting work is carried out with locally available GFRP and CFRP sheets. This study is helpful to understand the retrofitting of RC beams strengthened with GFRP and CFRP sheets according to the Indian environment. It also deals with FEM modelling of beams using ANSYS software to predict load carrying capacity and deflection of control and retrofitted beams. (Åström,2018)

2. LITERATURE REVIEW

Sharba, Amjad Ali K el al. (2021) reviewed several features of Reinforced concrete (RC) beams strengthened with FRP. Also this paper aims to impart a comprehensive insight on adhesive curing, surface arrangement, and failure modes of RC beams modified with FRP. This effect of FRP for enhancing the techniques of rehabilitation is a three-fold task, to strengthen and retrofit of concrete structures, to extend the fatigue life of the structural element, and eliminates the crack growth rate.

Askar el al. (2022) gave a summary of the literature on the flexural and shear behavior of RC beams reinforced with FRP materials under various schemes. The efficiency of various types of FRP materials and processes has also been considered. Moreover, it illustrates a cost comparison of different strengthening schemes and the limitations of FRP strengthening.

Abbasi el al. (2022) Compared experimental investigations, the finite element (FE) technique provides an accurate, cost-effective, and less time-consuming tool, enabling practicing engineers to perform efficient, accurate nonlinear and dynamic analysis as well as parametric studies on RC beams strengthened with EB-FRP. Since 1996, many numerical studies have been carried out on the response of RC beams strengthened using FRP.

Panahi el al. (2021) numerically investigated the flexural strengthening efficiency of reinforced concrete beams with combined externally bonded FRP sheets and near-surface mounted FRP rods.

Rabia el al. (2021) presented a theoretical study taking into account the effect of air bubbles in concrete (as a material manufacturing defect) on interfacial stresses, in reinforced concrete beams, strengthening with an externally bonded FRP composite plate.

Sheth and Gajjar et al (2010) conducted the study of strengthening using FRP in RC beams to increase the strength in flexure. The cross section of the beam was 230 x 450 mm and length of 5 m.

El-Ghandour (2011) investigated beams strengthened for flexure and shear by CFRP sheets. He used different shear and flexure sheet ratios and tested in three point bending. Longitudinal CFRP sheets were used for flexure and U type wraps used for shear. The size of beam was 120 mm x 300 mm x 2000 mm.

Jung Deng et al (2011) conducted test on CFRP strengthened beam and found improvement in strength and stiffness of beam. An analytical solution developed for composite beams using FEM modelling on CFRP strengthened beams. Both analytical and the finite element models (ANSYS, 2003) were used to validate the experimental work carried out by Tavakkolizadeh and Saadatmanesh (2003).

Yasmeen Taleb Obaidat et al (2011) conducted a study on CFRP strengthened RC beams for flexure and shear. They have tested twelve RC beams in four point loading. The mechanical properties of concrete, steel and CFRP laminates were found out. The stiffness of RC beams strengthened by CFRP laminates got increased when compared to control beam.

3. MATERIAL PROPERTIES

Ordinary Portland cement of 53 grades conforming to IS: 12269 - 1987, Ground Granulated Blast furnace Slag (GGBS) conforming to IS: 12089 - 1987, fine aggregates of locally available river sand passing through 3.75 mm sieve and retained on 600 microns conforming of zone II of IS: 383 - 1970, coarse aggregate of crushed granite type passing through 20 mm sieve and retaining on 10 mm sieve conforming of IS: 383 - 1970 with portable water were used as the ingredients in concrete. Specific gravity and sieve analysis tests were conducted on cement, GGBS, fine and coarse aggregate and the results are given in Table 1.

Table 1 Properties of Aggregate, Cement and GGBS

Sl. No.	Properties of Aggregate and Cement	Values
1	Specific gravity of cement	3.14
2	Specific gravity of GGBS	2.83
3	Specific gravity of fine aggregate	2.60
4	Fineness modulus of fine aggregate	2.18
5	Specific gravity of coarse aggregate	2.74
6	Fineness modulus of coarse aggregate	6.66

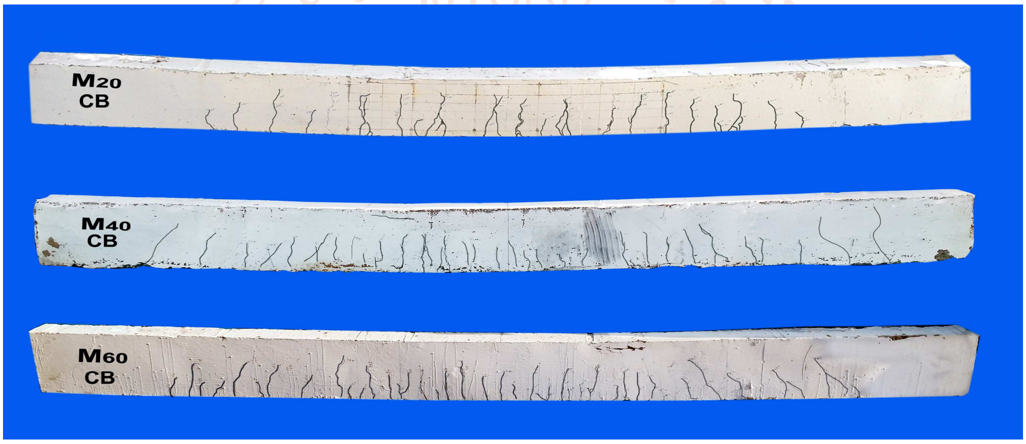
The glass fibre reinforced polymer sheet of 1.5 mm thick was used for retrofitting of RC beams. The fibre orientation is unidirectional direction. The Carbon Fibre Reinforced Polymer sheet is available in 1.5 mm thickness. The fibre is oriented in unidirectional direction.

4. EXPERIMENTAL PROGRAMME

Initially, the properties of concrete was obtained by casting and testing of concrete specimens of cubes (150 mm x 150 mm x 150 mm to determine the compressive strength, tensile strength and flexural strength respectively. The specimens were cast using various grades of concrete such as, M 40, . Ordinary Portland cement, natural river sand and the coarse aggregate crushed on maximum size of 12.5 mm were used and three numbers of specimens were cast and tested to take the average value at different curing period. The specimens were allowed for curing of different periods of 7, 14 and 28 days.

Flexural Behaviour of Control Beams

The static behaviour of beams includes studying the structural behaviour aspects such as deflection, crack propagation and ultimate load carrying capacity of the beam under monotonic conditions. Hence the beams were tested monotonically with simply supported boundary conditions. The crack pattern of beams is shown in Figure1



Control Beam (M 20, M 40, and M 60) Grade

Figure 1 Crack Patterns of Control Beams of Varying Grades

These beams were loaded up to failure and deflections are measured for a load increment of 2.5 kN and these load deflection values were used as base values for other beams.

5. ANALYTICAL INVESTIGATIONS AND RESULT

The concrete material propertiesfor all the grades of concrete used in the beams are shown in Table 2

Table 2 Concrete Material Properties

Grade of Concrete		Compressive Strength (N/mm^2)	Young Modulus (E) (N/mm^2)	Poisson's Ratio (μ)
M 20	RCC	28.40	2.51 x 10^4	0.186
M 40	RCC	50.44	3.52 x 10^4	0.171
M 60	RCC	73.56	4.32 x 10^4	0.160

5.1. MESHING

In Finite Element Analysis meshing requires for a model to analyse (Bathe, 1996). The reinforcement model is meshed using line elements so that the nodes of the lineelements come exactly over the node of the solid elements which are later merged sothat both rebar elements and the concrete elements share the same node (William,1975).

For beam generation total mesh model defined 3225 nodes and 2783 elements are required. The meshing concrete is shown in Figure 2 and meshing reinforcement isshown in Figure 3

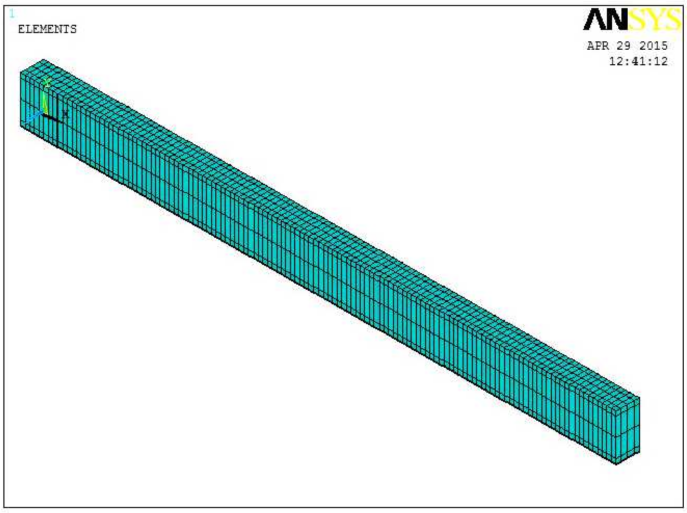


Figure 2 Meshing of Concrete

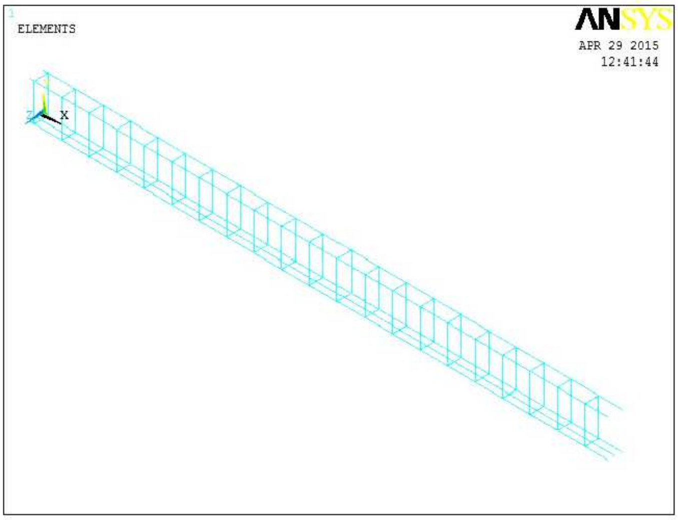


Figure 3 Meshing of Reinforcement

5.2. LOADING AND BOUNDARY CONDITIONS

The entire beam is used for the model. All beams are 125 mm wide, 250 mm deep and 3200 mm long simply supported at both ends. Figure 4 shows the two-point loading system of beam with meshing.

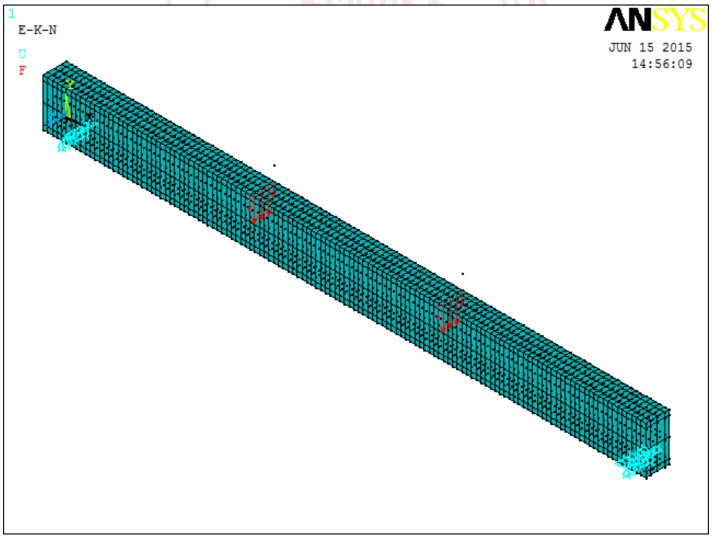


Figure 4 Loading and Boundary Conditions

Table 3 Summary of Test Results

Beam Designation	Ultimate Load (kN)		Max. Deflection (mm)	
	Experimental	ANSYS	Experimental	ANSYS
M 20 CB	37.50	34.00	73.00	70.297
M 20 RB1	57.50	56.00	58.00	56.289
M 20 RB2	74.00	72.30	53.00	51.230
M 20 RB3	80.00	74.00	47.00	44.919
M 40 CB	104.00	103.50	61.50	56.835
M 40 RB1	118.50	112.00	44.50	44.659
M 40 RB2	123.00	120.00	43.50	41.846
M 40 RB3	136.50	126.00	41.00	40.273
M 60 CB	129.50	126.20	52.50	49.000
M 60 RB1	144.00	144.00	49.00	46.785
M 60 RB2	166.50	159.00	44.50	43.000
M 60 RB3	174.00	172.00	43.50	42.578

The Figures below show the comparison of load deflection curve from the finite element analysis and the experimental results for double layer CFRP retrofitted beam. The Figures 5 to 13 show the comparison of load deflection curve from the finite element analysis and the experimental results for triple layer CFRP retrofitted beams.

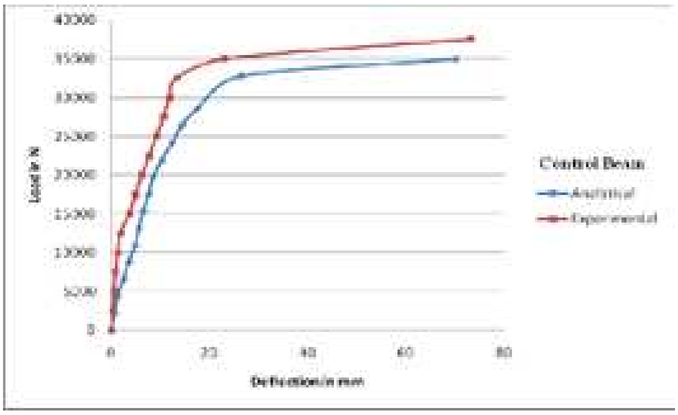


Fig 5 Experimental and Analytical Load Deflection Curves for Control Beam (M 20 Grade).

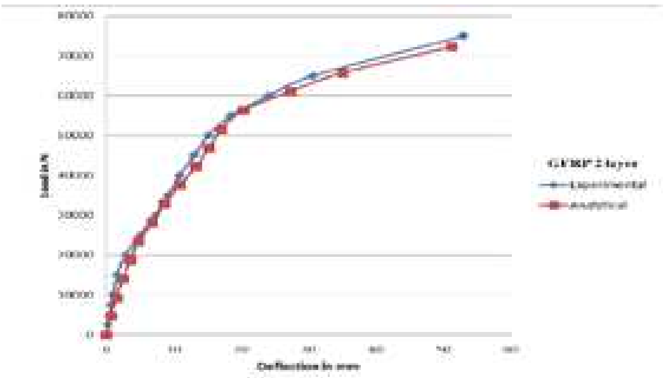


Fig 6 Experimental and Analytical Load Deflection Curves for Single LayerGFRP Sheet Retrofitted Beam (M 20 Grade)

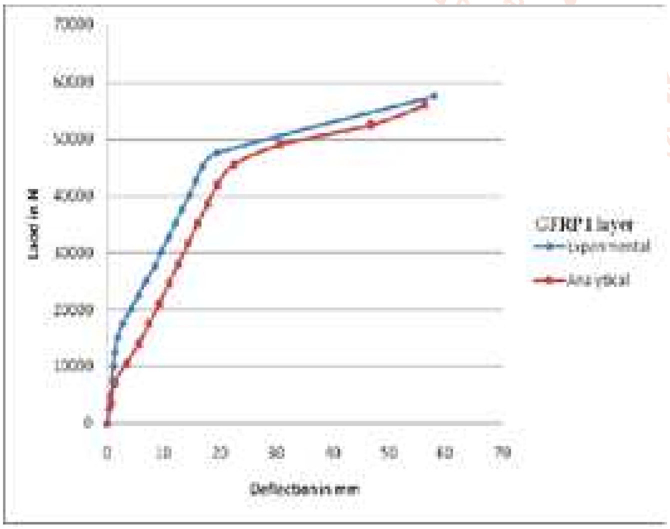


Fig 7 Experimental and Analytical Load Deflection Curves for Double Layer GFRP Sheet Retrofitted Beam (M 20 Grade)

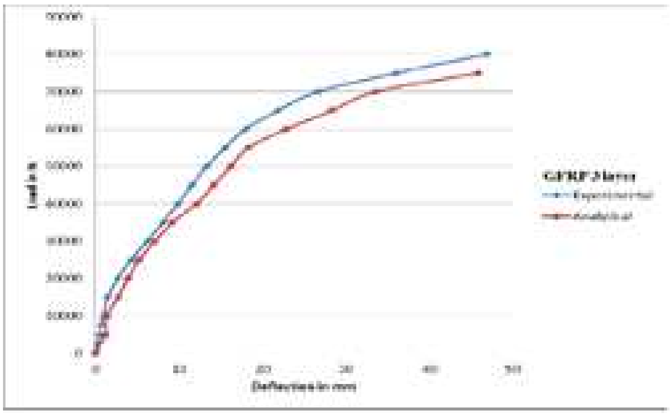


Fig 8 Experimental and Analytical Load Deflection Curves for Triple LayerGFRP Sheet Retrofitted Beam (M 20 Grade)

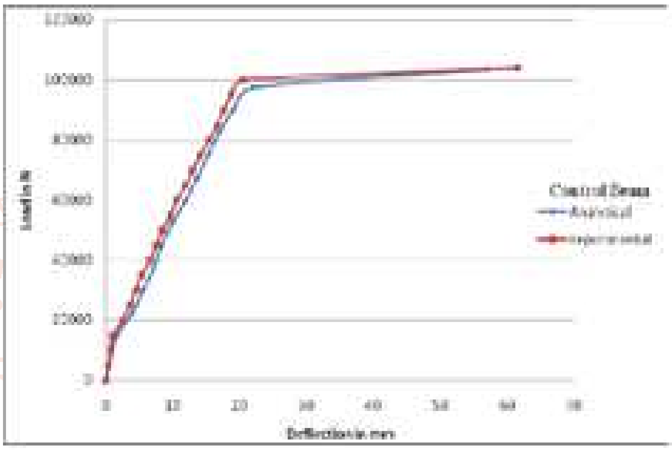


Fig 9 Experimental and Analytical Load Deflection Curves forControl Beam (M 40 Grade)

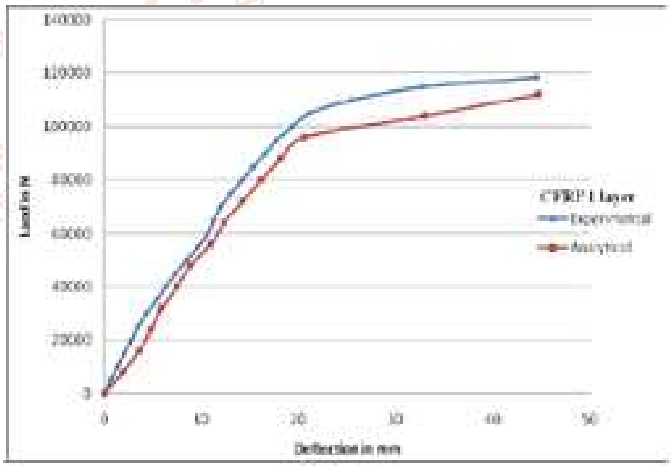


Fig 10 Experimental and Analytical Load Deflection Curves forSingle Layer CFRP Sheet Retrofitted Beam (M 40 Grade)

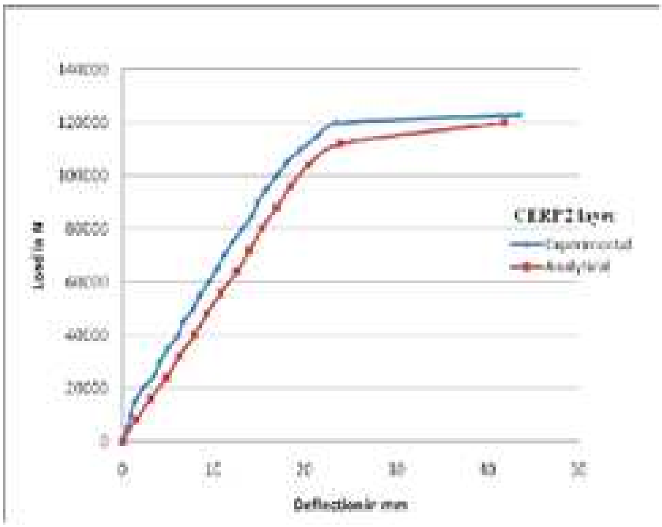


Fig 11 Experimental and Analytical Load Deflection Curves for Double Layer CFRP Sheet Retrofitted Beam (M 40 Grade)

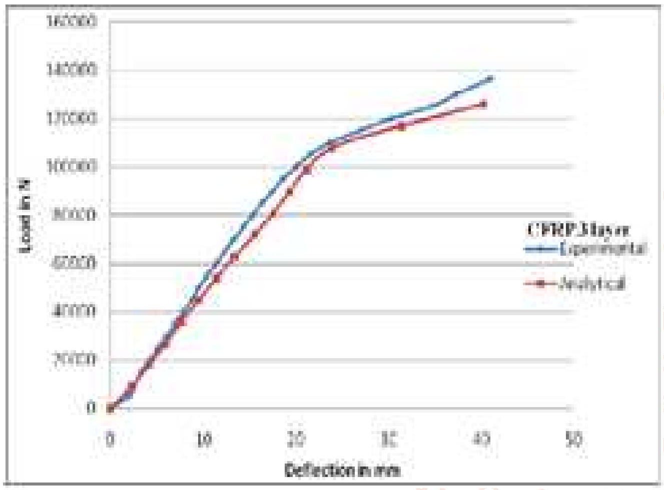
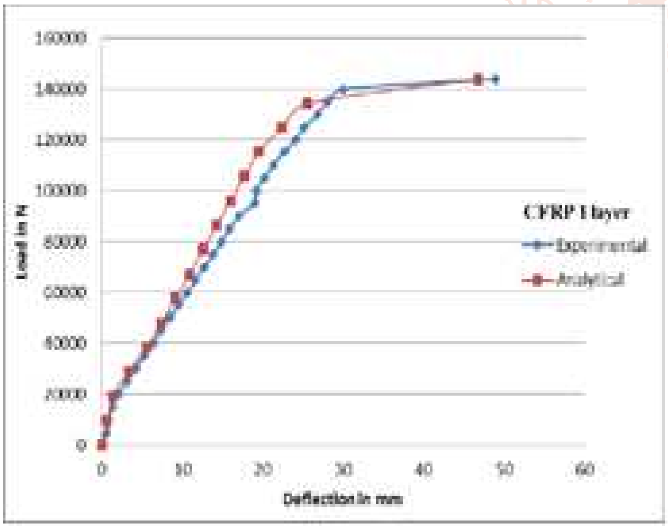


Fig 12 Experimental and Analytical Load Deflection Curves for Triple LayerCFRP Sheet Retrofitted Beam (M 40 Grade)



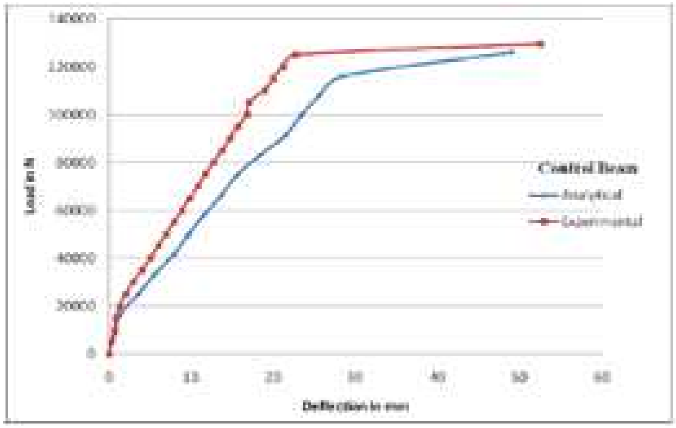


Fig 13 Experimental and Analytical Load Deflection Curves forControl Beam (M 60 Grade)

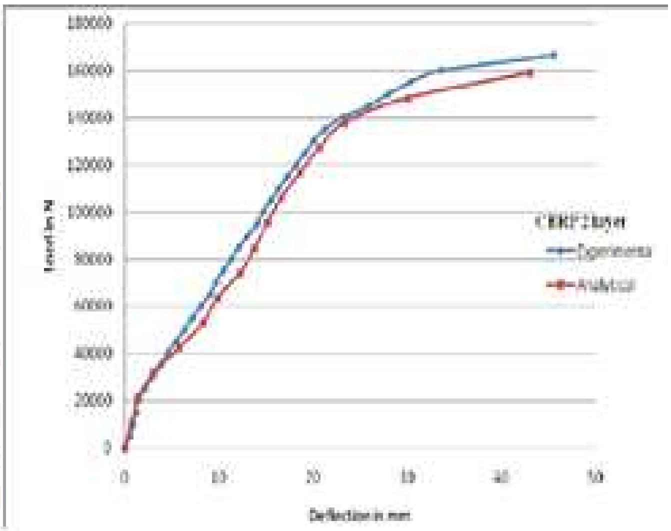


Fig 15 Experimental and Analytical Load Deflection Curves for Double LayerCFRP Sheet Retrofitted Beam (M 60 Grade)

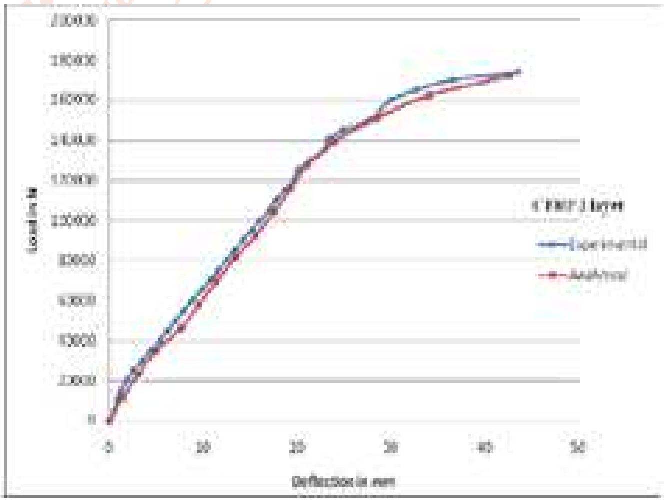


Fig 16 Experimental and Analytical Load Deflection Curves for Triple Layer CFRP Sheet Retrofitted Beam (M 60 Grade)

5.3. Load Deflection Curves

The detailed calculations leading to the evaluation of theoretical load-deflection values ofcontrol beams of different grades of concrete at various stages are shown in Appendix C.The deflections at various load levels of various grades of concrete (M 20 to M 60) beamsare given in Tables 4 to Table 8. The multilinear load deflection curve is obtained for all the grades of concrete beams and compared with the experimental curves. The comparison of theoretical and experimental load deflection curves for various grades of RCC and laminated beams are shown in Figures 17 to 19. Theoretical curve matches with experimental one.

Table 4 Theoretical Load Deflection Values for M 20 Beams

Sl. No.	Description	Load(kN)	Deflection(mm)
1.	Just before 1st crack	10.18	1.04
2.	Position at which start of non-linearity stage	24.80	11.73
3.	Position at which yielding starts	31.00	22.89
4.	Point at which ultimate	32.80	61.29

Table 5 Theoretical Load Deflection Values for M 40 Beams

Sl. No.	Description	Load(kN)	Deflection(mm)
1.	Just before 1st crack	12.64	1.16
2.	Position at which start of non-linearity stage	60.16	10.23
3.	Position at which yielding starts	74.00	13.00
4.	Point at which ultimate	91.40	58.70

Table 6 Theoretical Load Deflection Values for M 60 Beams

Sl. No.	Description	Load(kN)	Deflection(mm)
1.	Just before 1st crack	14.62	1.00
2.	Position at which start of non-linearity stage	79.50	12.80
3.	Position at which yielding starts	108.50	23.93
4.	Point at which ultimate	120.00	50.00

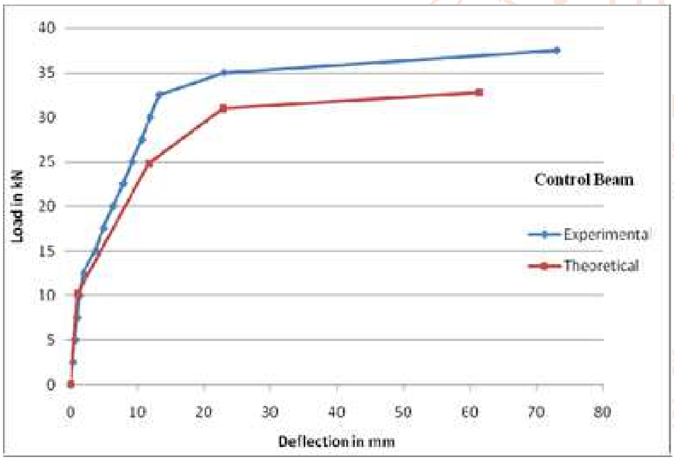


Figure 17 Experimental and Theoretical Load Deflection Curve of ControlBeam (M 20 Grade)

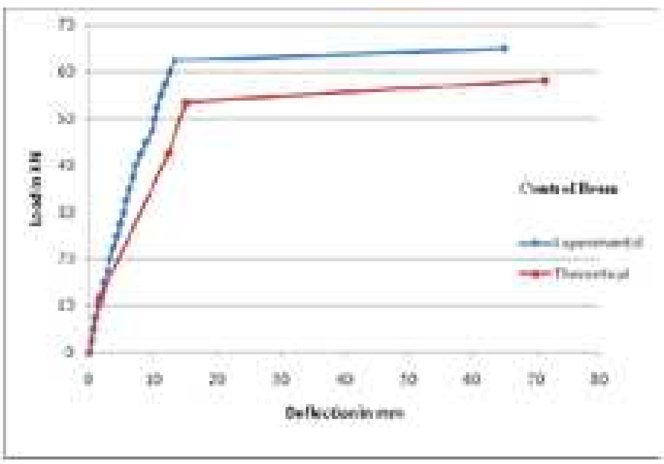


Figure 18 Experimental and Theoretical Load Deflection Curve of ControlBeam (M 40 Grade)

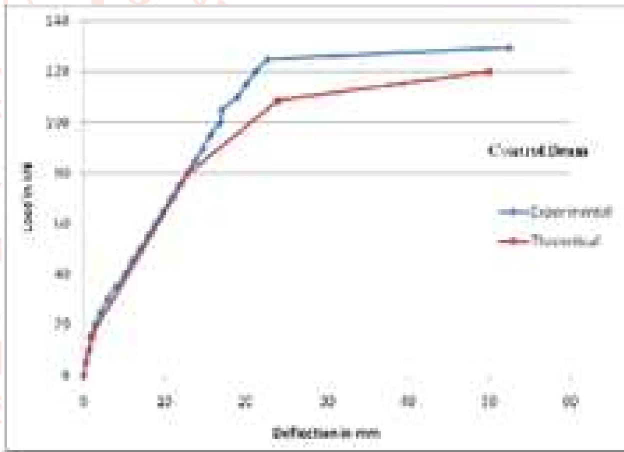


Figure 19 Experimental and Theoretical Load Deflection Curve of ControlBeam (M 60 Grade)

The comparison of experimental and theoretical analysis by section analysis for control beams shown that both are in good agreement with each other.

6. CONCLUSION

From the presence study, it is derived that strengthening of RC beams with GFRP and CFRP sheets can enhance the load carrying capacity of beams and at the same time deflections upto yield stage of loading is increased and further the deflections are reduced upto ultimate stage of loading. The RC beams strengthened with GFRP and CFRP sheets show a marked reduction in crack width at all stages of loading and substantial delay in the formation of first crack.

The cracks distribution indicates that the size and density of crack are lower in the GFRP and CFRP strengthened beams than in the control beams.

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