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RESEARCH ARTICLE

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FINITE ELEMENT ANALYSIS OF COMPOSITE BEAMS

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ABSTRACT

Concrete structural components exist in structures in different types. To understand the response of these components during loading is crucial for the development of an overall efficient and safe structure. Different methods have been utilized to study the response of structural components. Finite element analysis is used to analyze the composite reinforced concrete (RC) beams. The beams are reinforced with steel and FRP bars. The RC beams are designed and analyzed for an effective span of 3 m. The beam is subjected to linear action of three different live loads acting as two point loads on RC beam. The three different percentages of reinforcement ratios are taken for steel and fibre reinforced polymer (FRP) bars. Static responses of all the beams are investigated in terms of strength, stresses and compositeness between bars and concrete. The linear and non-linear analysis of steel reinforcement and FRP bars beams are investigated using finite element method (FEM). The linear finite element (FE) results are verified using IS 456-2000 code for steel reinforcement bars and ACI 440-2006 for FRPs bars. The results show that the maximum compressive stress is found maximum in GFRP bars for linear FEM analysis. For non-linear analysis maximum compressive and tensile stresses are developed in AFRP and minimum in GFRP at 12.1 kN load. Although the initial cost of CFRP and GFRP are more than steel, and the use of FRPs is beneficial instead of steel as it is corrosion resistant, weighs 1/4th of steel, and also it reduces the maintenance cost to a greater extent.

Key words: reinforced concrete beams; finite element analysis; stress; reinforcement modeling.

I INTRODUCTION

The traditional reinforcement methods in reinforced concrete (RC) beam have been accepted for several years as a common practice amongst designers and contractors. Fiber reinforced polymer (FRP) is endlessly used for reinforcing new structures, and also for healing of the existing structures. FRP composites, in form of sheets, rods, cables and plates have proven to be a future alternative to steel reinforcements because of their light weight, high specific strength, no corrosiveness, and specific stiffness are easily constructed.FRP reinforcement is accessible in different forms such as bars, grids, prestressing tendons and laminates to serve a wide range of applications. The most frequent types of fiber used in structural applications are glass (GFRP), carbon (CFRP)and aramid (AFRP). The GFRP is the least costly but has lower strength and significantly lower stiffness compared to other alternatives. CFRP is more stiffener, long-lasting, and costlier. AFRP has an improved durability and admirable impact resistance.

Fiberglass is a cheaper compound material made from glass fibers in a polymeric matrix (GFRP). The fibers give the main load carrying capability of the material and the polymer serves to protect the fibers and allow load transfer for them. FRP composite materials have been used as internal and external reinforcement in the field of civil engineering constructions. It has been used as internal reinforcement for beams, slabs and pavements [2, 5] and also as external reinforcement for rehabilitation and strengthening different structures [13]. FRP composites developed primarily for the aerospace engineering and defence industries.The first all-composite bridge superstructure in Miyun, China, in 1982, they have been gradually gaining acceptance from civil engineers as a new construction material. During the last decades, they proved to be useful in a few areas as: in the form of sheets and strips for strengthening existing bridges and to some extent, as reinforcing bars as an alternative to steel reinforcement in RC beams.

The main purpose of the present studyis to used FRPs as a reinforcement in RC beams. The results and observations presented in this paper are usefulfor engineers to predict the compressive and tensile stresses developed in RC beam using FRPs.

II LITERATURE REVIEW

The various research works are carried out on performance of FRP using experimental, analytical and numerical methods. Srinivasan and Sathiya [8] studied the flexural behavior of RC beams using FE analysis. The performed study attempts to compare the results from elastic analysis of a reinforced beam under transverse loading with the theoretical analysis.

Jayajothi et al. [9] carried out the non-linear finite element analysis of RC beams strengthened in flexure and shear by FRP laminates. It was observed that the ultimate load carrying capacity of all the strengthened beams was higher as compared to the control beams.

Patil, et al. [10] studied experimentally and analytically the reinforced concrete deep beamsubjected to two point loading with three different span/depth (*L*/*D*) ratios using non-linear FEM. Acomparison between FEM results and experimental results in terms of strength, flexural strain and deflection of concrete beams was carried out.It was found that smaller the *L*/*D* ratio, the more pronounced was the deviation of strain pattern at mid-section of the beam. As the depth of the beam increases the variation in strength, flexural stress and deflection were found to be more.More and Kulkarni [11] studied flexural behaviour of AFRP strengthened RC beams of M-25 grade of concrete. The experimental program included strengthening and testing of simply supported rectangular cross-section beam strengthened with AFRP sheets.Shinde et. al. [13] studied the flexural behaviour of RCC beam wrapped with GFRP sheet. It was observed that RCC beamswere weak in flexure.

III OBJECTIVES

The main objectives of the present study are:

- To observe the effect of strengthening of simply supported RC beam subjected to two point loads reinforced with steel, CFRP, GFRP, and AFRP.
- To investigate the beam subjected to three different reinforcement ratios and static live loads. The beams are analysed using theoretical and linear and non-linear FEM ANSYS software.
- To study the flexural behavior of reinforced concrete beams reinforced longitudinally as well as transversely with steel and FRP reinforcement subjected to two point loading.

IV FINITE ELEMENT MODELING

The composite RC beams are analysed using FEM ANSYS software. The beam having length (*L*) = 3 m, width (*B*) = 250 mm and depth (*D*)= 300 mm as shown in Figure 1 is considered for the present analysis. The quarter RC beam is modeled, taking *L* =*L*/2, *B* = *B*/2 and *D* = *D* due to symmetryas shown in Figure 1. The modelling of RC concrete beam involves defining element type for materials, real constant, material properties, loading, meshing and boundary conditions.

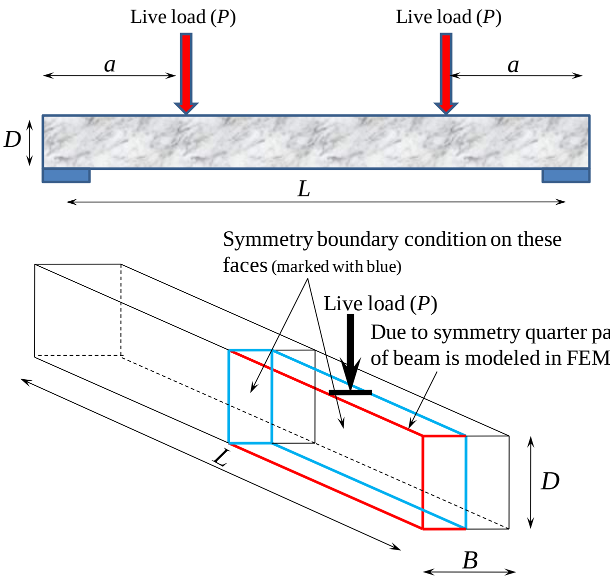

Figure 1: FEM model of RC beam.

Solid65 element is used for modeling concrete and Link8 element is used for modeling steel, CFRP, GFRP and AFRP reinforcement bars as shown in Figure 2. The material properties of concrete and steel are taken as per IS 456-2000 [8] and FRPs are taken from ACI 440-2006 [3]. The material properties are illustrated in Table 1. The M25 grade of concrete is used.

Table 1: Material properties

Parameters	Concrete	Steel	CFRP	GFRP	AFRP
Unit wt. (N/mm^2)	2.5×10^{-5}	7.85×10^{-5}	1.6×10^{-5}	2.1×10^{-5}	1.4×10^{-5}
Ultimate compressive strength (N/mm^2)	25	NA	NA	NA	NA
Tensile strength (N/mm^2)	2.5×10^{-4}	2×10^{-5}	1.52×10^{-5}	4.14×10^{-4}	8.27×10^{-4}
Elastic modulus (N/mm^2)	22	415	2070	552	1172
Poisson's ratio	0.2	0.3	0.2	0.2	0.2

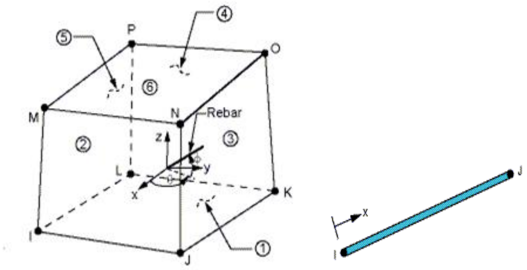

Figure 2: Solid65 and link8 FE elements.

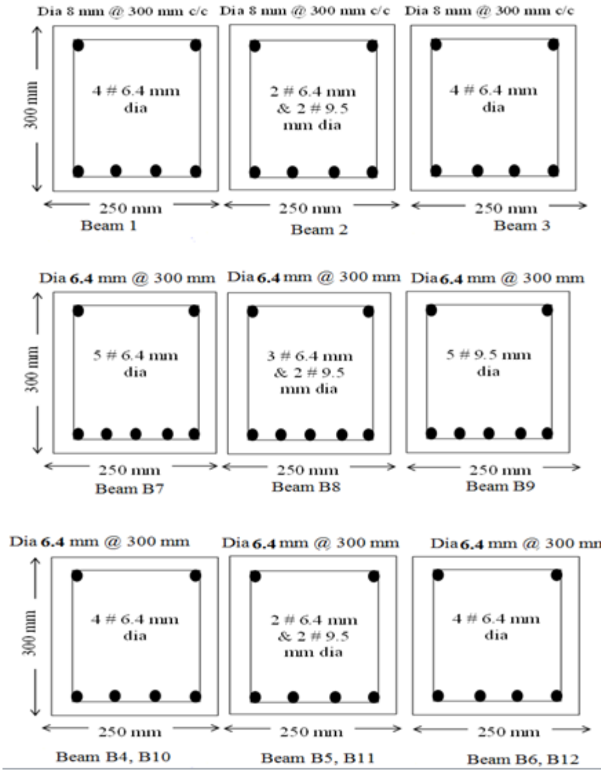

Figure 3: Reinforcement detail of RC beams.

In all nine beams, three each are strengthened with CFRP, GFRP and AFRP bars, respectively. More three beams are used as control specimens are strengthened with steel reinforcement bars designed as under-reinforced RC beam. Table 2 shows the details of applied live loads and Figure 3 shows the reinforcement ratios on the beam. In top and bottom reinforcement for beam B1 to B3 steel is used, beam B4 to B6 CFRP is used, beam B7 to B9 GFRP is used and beam B10 to B12 AFRP is used. The reinforcement ratio for FRP beams is less than steel reinforcement.

Table 2: Details of reinforcement ratio and live load on beam

Beam	Live load (kN)	Reinforcement ratio (%)			
		Steel	CFRP	GFRP	AFRP
B1, B4, B7, B10	7.5	0.27	0.17	0.27	0.17
B2, B5, B8, B11	9.8	0.35	0.27	0.37	0.27
B3, B6, B9, B12	12.1	0.41	0.37	0.47	0.37

For linear & non-linear analysis of RC composite beam, the stress strain curve for concrete, steel and FRP using different codes [1, 4] are shown in Figures 4, 5 and 6.

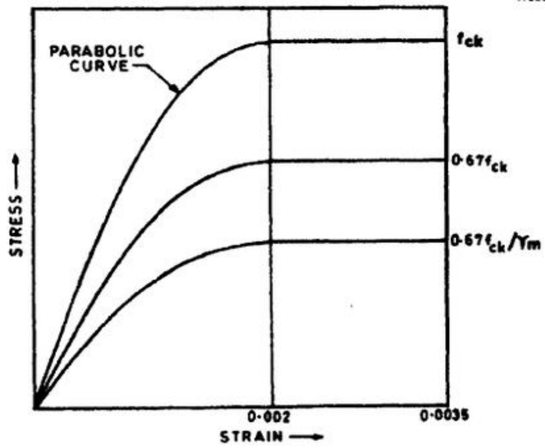

Figure 4: Stress-strain curves for concrete as per IS 456-2000.

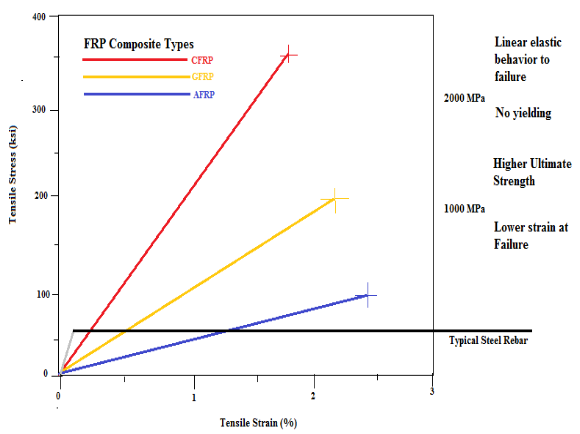

Figure 5: Stress-Strain Curves for FRPs as per ACI 440-2006.

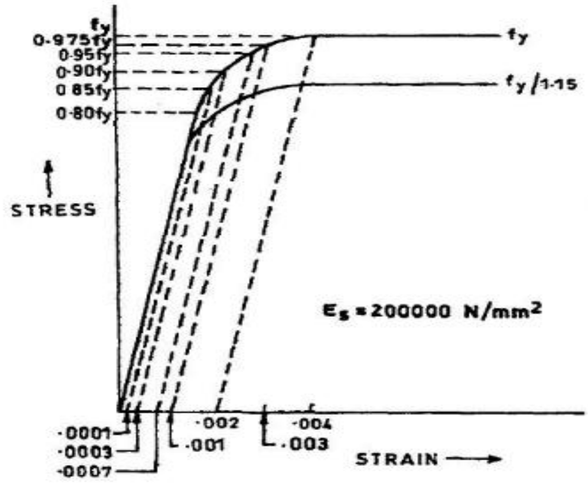

Figure 6: Stress-strain curves for steel as per IS 456-2000.

V RESULTS AND DISCUSSIONS

In order to check the accuracy of the present FE model of the linear RC beam, the FEM results are compared with the theoretical approach. The beam is analysed using theoretical approach based on IS 456-2000 and ACI 440-2006. The maximum compressive and tensile stresses are given by:

Maximum compressive stress, $f_c = M\frac{y_c}{I_{tr}}$ (1)

Maximum tensile stress, $f_t = M\frac{y_t}{I_{tr}}$ (2)

Tables3(a) and 3(b) show the comparison of maximum compressive and tensile stresses in RC beams using steel and FRPs bars based on theoretical and linear FEM. There is a small difference between the two methods.

Figure 7(a) shows the maximum compressive stress in RC beam for steel and FRP bars using linear FEM. The maximum compressive stress increases with increase in load value and it is found maximum in GFRP bars.

Figure 7(b) shows the maximum tensile stress in RC beam for steel and FRP bars using linear FEM. The maximum tensile stress is developed in GFRP bars.

Table 3(a): Compressive stress in RC beams in N/mm²

Beam	Load (kN)	Compressive stress (N/mm²)							
		Steel		CFRP		GFRP		AFRP	
		Ansys	Theoretical	Ansys	Theoretical	Ansys	Theoretical	Ansys	Theoretical
B1, B4, B7, B10	7.5	1.91	2.97	2.19	2.78	2.71	3.01	2.44	3.069
B2, B5. B8, B11	9.8	2.74	3.68	3.28	3.50	3.52	3.77	3.52	3.81
B3, B6. B9. B12	12.1	3.83	4.31	4.11	4.21	5.57	4.52	4.34	4.5428

Table 3(b): Tensile stress in RC beams in N/mm²

Beam	Load (kN)	Tensile stress (N/mm²)							
		Steel		CFRP		GFRP		AFRP	
		Ansys	Theoretical	Ansys	Theoretical	Ansys	Theoretical	Ansys	Theoretical
B1, B4, B7, B10	7.5	1.29	2.92	1.47	2.79	1.71	3.00	1.54	3.07
B2, B5. B8, B11	9.8	1.84	3.59	2.21	3.48	2.23	3.76	2.23	3.79
B3, B6. B9. B12	12.1	2.58	4.21	2.76	4.14	6.49	4.51	2.74	4.516

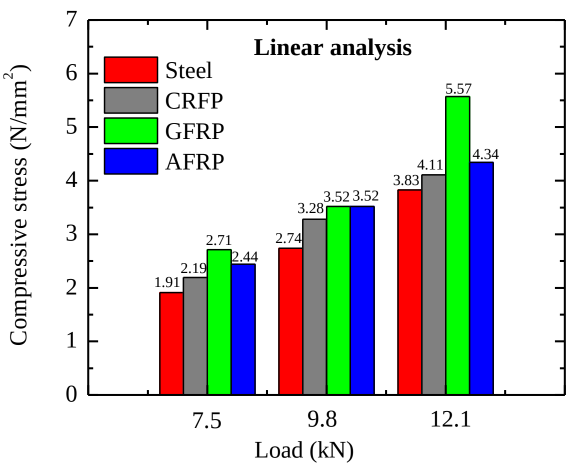

Figure 7(a): Maximum compressive stress in RC beam using linear analysis

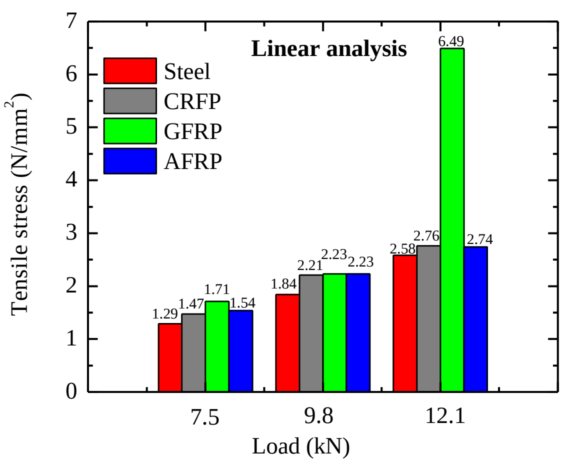

Figure 7(b): Maximum tensile stress in RC beam using linear analysis

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Table 4 shows the maximum compressive and tensile stresses in RC beam using non-linear FEM. Figures 8(a) and 8(b) show the maximum compressive and tensile stresses in RC beam for steel and FRP bars using non-linear FEM, respectively. It observed that both the stresses are maximum in AFRP at 12.1 kN load and minimum in GFRP at 12.1 kN load.

Table 4: Compressive and tensile stresses in N/mm^{2}using non-linear FEM

Beam	Load (kN)	IS 456-2000		ACI 440-2006					
		Steel		CFRP		GFRP		AFRP	
		comp. stre	tens. stre	comp. stre	tens. stre	comp. stre	tens. stre	comp. stre	tens. stre
B1,B4,B7,B10	7.5	1.79	2.16	2.90	3.47	3.61	4.32	3.34	3.88
B2,B5.B8,B11	9.8	3.71	4.36	4.45	5.20	4.87	5.61	4.84	5.63
B3,B6.B9.B12	12.1	5.57	6.49	5.57	6.50	4.85	5.60	5.95	6.94

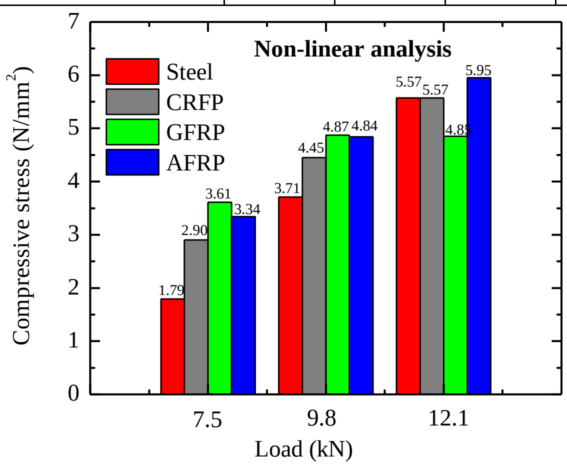

Figure 8(a): Maximum compressive stress in RC beam using non-linear analysis

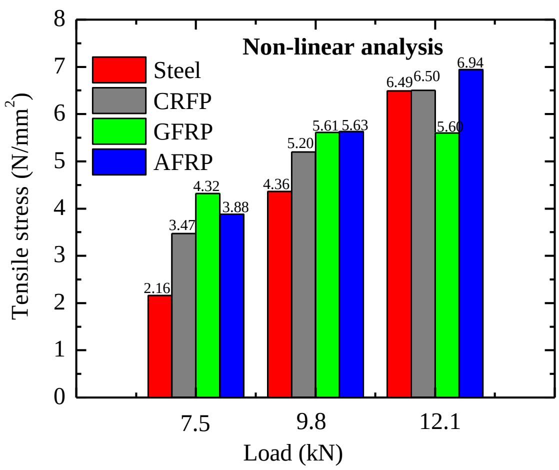

Figure 8(b): Maximum compressive stress in RC beam using non-linear analysis

VICOST COMPARISON

Cost analysis of composite RC beams is carried out using the rates from the current specifications. Table 5 shows the cost comparison between the steel, CFRP, and GFRP bars used for RC beams subjected to three different live loads considered in the present analysis. Figure 9 shows the bar chart of the comparison. It is observed that the initial cost of construction of RC beams using CFRP and GFRP bars as compared to steel reinforcement is more, however in the future; it becomes cost effective in the long run due to following advantages of FRP bars: (i) GFRP is corrosion free, (ii) use of GFRP reduces concrete cover and eliminates corrosion protection measures, and (iii) using GFRP may minimize expensive repair work required in case of steel reinforcement.

Table 5

Comparative cost analysis of composite RC beams

Load (kN)	Cost of Steel (Rs/-)	Cost of CFRP	% Difference	Cost of GFRP	% Difference
7.5	374	960	22	1089	25
9.8	422	1060	20	1395	29
12.1	517	1124	19	3985	41

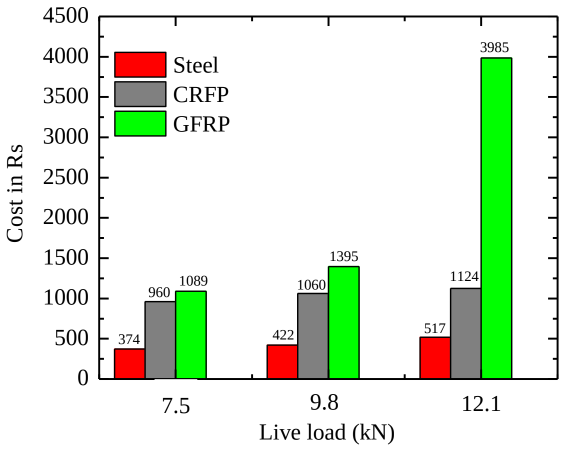

Figure 9: Cost comparison

VII CONCLUSIONS

The conclusions made from the present analysis are as follows:

1. The results from finite element analysis are in good agreement with the theoretical values of compressive and tensile stresses for simply supported beam with two point loading.
2. Increasing applied live load value from 7.5 kN to 12.1 kN has a significant effect on reinforcement ratio.
3. The maximum compressive stress is found maximum in GFRP bars for linear FEM analysis. For non-linear analysis maximum compressive and tensile stresses are developed in AFRP at 12.1 kN load and minimum in GFRP at 12.1 kN load.
4. Although the initial cost of CFRP and GFRP are more than steel, and the use of FRPs is beneficial instead of steel as it is corrosion resistant, weighs 1/4th of steel, and also it reduces the maintenance cost to a greater extent.

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