Experimental and Analytical Study on Behaviour of RCC Beams Strengthened with GFRP

Sachin M. Kulkarni [1], Dr. Vishwanath K. G.[2]

[1] *Assistant Professor, Jain College of Engineering, Belagavi.*
[2] *Principal and Director, Jain College of Engineering, Belagavi.*

Many of the Reinforced Concrete (RC) structures fail to withstand the designed loads due to the ageing of structures and constant deterioration caused by environmental changes. To increase the life of structure various strengthening techniques are adopted out of which strengthening of structure by glass fiber reinforced polymer (GFRP) is a simple method, when compared to other type of strengthening methods. Currently there is no provision for retrofitting guidelines as per the code of practice in Bureau of Indian Standard (BIS) to recommend the strengthening procedure.

In this paper, a validation of experimental and analytical study is dealt with respect to the behavior of RC beams. The experimental and analytical study of RC beams strengthened with FRP is presented.

For the analytical study, Abaqus® software is used; this software gives the results of above test which is almost similar to experimental study. So, this software may be use to study the behavior of heavily loaded structures.

Keywords — Abaqus®, RCC, FRP, Flexural Strength.

1. INTRODUCTION

The concrete structure has its own importance in recent days. The durability of concrete structure will be more, compared to structures constructed by using other type of materials like steel, wood etc. and also the maintenance is very easy when compared to other type of structures. Currently the “Rehabilitation and Restoration” of concrete structure is playing a major role in civil Engineering field; the major challenging task is to select suitable strengthening method which will improve the strength and serviceability of the structures. The structure can be strengthened for various requirements depending on the situations.[1]

- Improper maintenance.
- Increasing service loads.
- Structural modification works.
- Concrete related problems, and
- Natural disasters like earthquakes, floods, etc.

There are different materials for jacketing which forms a method of retrofitting, such as concrete jacketed with steel element and natural fibers. Each of these methods and materials has its own importance and is opted based on the requirement and case of application. These retrofitting techniques are expensive; require skilled labors and its take more duration for applications. Application of GFRP will be one of the simplest methods for retrofitting the existing structures. GFRP has high strength ratio, high stiffness to weight ratio, flexibility in design, non corrosiveness, high ultimate strength and lower density. Due to lower density, application is easier.

1.1 Introduction about Abaqus

Finite Element models for analysis of beams with surface bonded FRP plates are not rare in the literature; use of commercially available software for analysis and design of conventional civil engineering structures need the facility of incorporating additional layers of different materials integrated to the virgin beam. However, for individual purpose it is desirable that suitable software is made available and designers along with proper guidelines can use them for appropriate modeling and analysis of beams with surface bonded FRP plates. [2]

To fulfill this requirement, a commercially available software ® 6.14-1 is chosen. However, as the first step towards this purpose, it is necessary to assess the suitability of the software for the simpler case i.e. modeling and analysis of the virgin beam without additional layer. **Abaqus®** software gives approximation near to the experimental results in static linear state. [3]

2.0. Methodology for present investigation

For conducting the experimental study, six specimens made of reinforced cement concrete beams were cast. The beam dimension was 700 x 150 x 150 mm, having same reinforcement for all reinforced concrete members. A mix proportion of 1:1.8:3.33 with w/c ratio of 0.5 was used. Mix design was carried out as per IS10262. Trial cubes were cured and tested for 7 and 28 days. All beams specimens were tested for flexural strength to determine deflection and stresses after 28 days of curing. The analysis for this beams are carried out using **Abaqus®** software and results obtained were compared with experimental studies. The following parameters are studied in this paper;

1. Maximum deflection of RCC beams for ultimate load carrying capacity, with and without external strengthening by GFRP wrapping.
2. The flexural behavior of RC beams with and without external strengthening by GFRP wrapping.
3. To validate the experimental results with FEM tool (**Abaqus®**).

3.0 FLOWCHART OF PRESENT STUDY

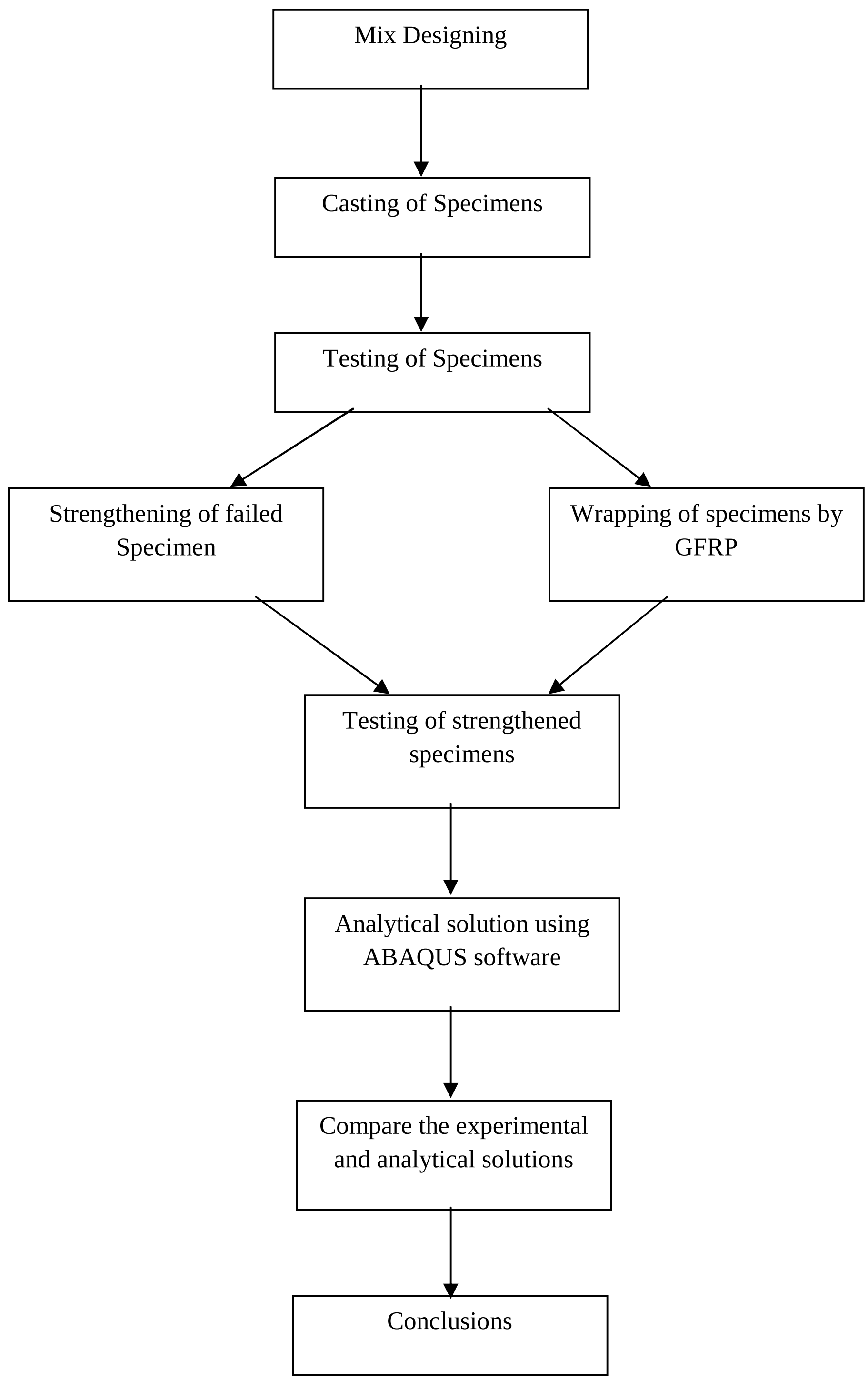

Fig.1 Flowchart

3.1 MATERIAL

Ordinary Portland Cement (OPC) of 43 grades was used; the initial time of setting time is 30 minutes and specific gravity of cement 3.15, standard consistency 33%. Fine aggregate used was clear sand passing through 4.75mm sieve with a specific gravity of 2.6. The grading zone of aggregate was zone III, as per IS. Coarse aggregate used were angular crushed aggregate with specific gravity of 2.8. Concrete mix design of 1:1.8:3.3 is adopted to get design strength of 15 MPa. The water cement ratio of 0.5 is used [5]. HYSD bar of 8 mm for main steel and mild steel bars of 6 mm diameter are used for shear reinforcement. GFRP sheet of modulus of elasticity of 70GPa and thickness taken as 0.6mm was applied with the help of vinyl-ester resin adhesion element is used for strengthening of RC members.

3.2 CASTING OF SPECIMEN

The reinforcement details for the RCC beam are shown in Fig 1.[4]

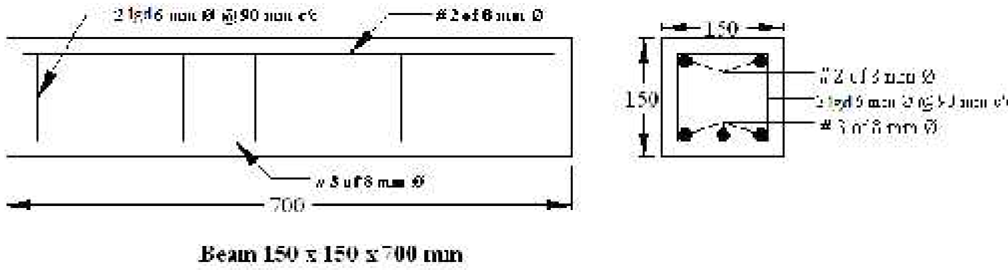

Fig.2

3.3 STRENGTHENING OF SPECIMENS

The surface of RC members to be wrapped is cleaned with water and air to remove the dust and other impurities presence on the surface of the member and for clear visibility of cracks. They are allowed to dry completely. Vinyl-ester resin is applied on the surface of the member with the thin layer as shown in Fig 2. The fiber sheet is placed on the specimen surface by stretching on either side and again resin is applied on the sheet and rolled with steel rod by applying uniform pressure on the sheet so that all air bubble inside get expelled out as shown in Fig 3. Then the specimen is kept it for 24 hours for air drying at room temperature.

Fig. 3

Fig. 4

3.4. TESTING OF SPECIMEN

Flexural strength test with two points loading, on a UTM is conducted after curing for a period of 28 days. The detail loading is as shown in Fig.5. The surface of RC members to be wrapped is cleaned for visibility of cracks. The above procedure is repeated for failed beam after strengthening the member by GFRP Sheet shown in Fig 6 to 8.

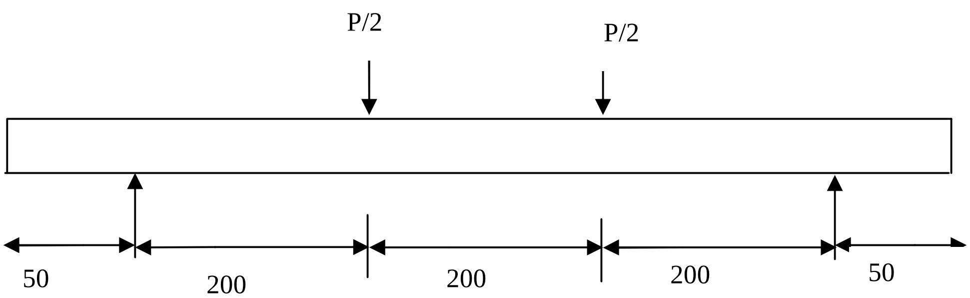

Fig. 5 Loading Diagram

Fig. 6 Experimental Setup

Fig. 7 Failed RCC Beam Specimens

Fig. 8 Failed RC Beam wrapped with GFRP

4.0 MODELLING IN ABAQUS ®

The following elements are used during the modeling for **Abaqus®** solutions.

- For concrete: 8 node linear brick element reduced integration (Designated as C3D8R) is considered.
- For reinforcement: 3 node quadratic 3-D truss element (Designated as T3D3) is considered
- For GFRP: Shell element of S4R family is used.
- The mesh is used essentially in the analysis of model in this software, so the mesh is provided to the surface of RC members before analysis is carried. The beam is simply supported at the both end, gradually applying two vertical point loads on RC beam, Failed RC Beam strengthened by GFRP, and RC beam strengthen by GFRP. The application of load is as shown in Fig. 4.[6]

4.0 Results and Discussion

The analytical results for flexural strength test result are compared with experimental and mathematical solutions. The deflection is validated with all three above mentioned solutions. The validation of results is given in Table 1. The following observations are made after analysis.

1. The analysis is carried out using the following; Gross moment of Inertia (I_g), Effective moment of Inertia (I_{eff}) and Cracked Moment of Inertia (I_r). The condition is $I_r < I_{eff} < I_g$.
2. From Table 1 it is observed that the solution using mathematical and analytical tool is validated considering different values of moment of inertia.
3. a. For RCC beam without FRP, it is observed that gross moment of inertia is taken into account for calculation of tensile stresses and for compressive stresses effective and cracked moment of inertia depending upon the rate of loading as noted in Table 1.
   b. For RCC beam with FRP wrapping the gross moment of inertia is considered for calculation of stresses. This is due to the wrapping of beam with FRP; the beam is confined against deflection and resulting in change in moment of inertia and stresses.
4. After wrapping beam with FRP the neutral axis shift towards the tension face as the FRP element adds additional tensile resisting force.
5. From the Table 1 it is observed that the percentage variation of stress is more for compressive stress.
6. For the applied load till 30kN(elastic range), effective moment of inertia will the resist the bending stress till the crack starts to initiate.
7. Once the crack starts to propogate there will be disintegration of concrete matrix which reduces the resisting moment of inertia from I_{eff} to I_r till the failure.
8. This shift in moment of inertia is initiated from from 30kN load the position where crack get initiated and starts to propogate.
9. The crack is initiated at bottom(tensile) earlier compared to that of the top fibre (comp). This early initiation of crack require more area of resistance due to which the gross moment of inertia is used during crack propogation.
10. Since concrete is strong in compression and compressive stress is at top, the total stress is resisted by effective moment of inertia and cracked moment of inertia in stages.
11. The behaviour at bottom fiber is tensile in nature for which total cross section helps in resisting the tensile nature of bending stress.

12. The observed deflection value in is based on gross moment of inertia will help in resisting the

deflection.

13. The observations in Table 2 indicates, the stress resistance is due to composite action considering the gross moment of inertia. This indicates that there is no loss of moment of inertia during its entire load cycle till the crack is intitated.
14. The deflection observed in table 2 is less than the deflection values observed in table 1. This implies that the confinity offered by the FRP helps in controlling the deflection which is the govering parameter as per limit state of serviciablity.
15. The application of FRP at the bottom fiber has lead to shift in neutral axis thus reducing the moment arm thus reducing the rotation effect created by compressive and tensile force.

Table 1: Results of RCC Beam

Load (kN)	Compressive Stress at top MPa	Theoretical compressive stress(MPa) based on			Tensile Stresses at bottom MPa	Theoretical tensile stress (MPa) based on			Deflection (mm)	Theoretical deflection value (mm)		
		I_g	I_{eff}	I_r		I_g	I_{eff}	I_r		I_g	I_{eff}	I_r
10	**2.19**	1.59	1.69	2.87	1.35	1.488	1.58	2.68	0.05	0.05	0.054	0.09
		Percentage Error				Percentage Error				Percentage Error		
		27.39	22.83	23.69		9.27	14.55	49.63		0	7.4	4.0
20	**4.393**	-3.18	5.14	5.74	2.7	2.97	4.79	5.36	0.10	0.10	0.19	0.18
		Percentage Error				Percentage Error				Percentage Error		
		27.61	14.4	23.3		9.09	43.63	49.63		0	43.68	40.55
30	**6.59**	4.78	8.58	8.611	4.04	4.46	8.02	8.04	0.150	0.151	0.27	0.27
		Percentage Error				Percentage Error				Percentage Error		
		27.46	23.19	23.46		9.42	49.63	49.75		0.66	44.44	45.0
40	**8.79**	6.37	12.03	11.48	5.4	5.95	11.23	10.72	0.200	0.202	0.38	0.36
		Percentage Error				Percentage Error				Percentage Error		
		27.53	26.93	23.43		9.24	51.9	49.63		0.99	47.36	44.9
50	**10.98**	7.97	15.47	14.35	6.747	7.44	14.45	13.4	0.251	0.252	0.49	0.45
		Percentage Error				Percentage Error				Percentage Error		
		27.14	29.02	23.48		9.31	53.3	49.65		0.4	48.78	44.8
60	**13.18**	9.56	18.92	17.22	8.09	8.92	17.67	16.08	0.300	0.303	0.599	0.54
		Percentage Error				Percentage Error				Percentage Error		
		27.46	30.33	23.46		9.3	54.22	49.69		0.99	49.9	45.0

Note: I_g= Gross moment of Inertia
I_{eff}= Effective moment of Inertia
I_r = Cracked Moment of Inertia

Table 2: Results of RCC Beam strengthened with FRP

Load (kN)	Compressive Stress at top MPa	Theoretical compressive stress(MPa) based on			Tensile Stresses at bottom MPa	Theoretical tensile stress (MPa) based on			Deflection (mm)	Theoretical deflection value (mm)		
		I_g	I_{eff}	I_r		I_g	I_{eff}	I_r		I_g	I_{eff}	I_r
10	**3.167**	2.61	2.42	6.76	1.284	0.95	0.88	2.45	0.04	0.043	0.040	0.11
		Percentage Error				Percentage Error				Percentage Error		
		17.58	23.59	53.15		26.01	31.46	47.59		6.9	0	63.6
20	**6.335**	5.21	11.05	13.53	2.567	1.89	4.01	4.92	0.1	0.086	0.18	0.22
		Percentage Error				Percentage Error				Percentage Error		
		17.75	42.67	53.18		26.37	35.98	47.83		14	44.44	54.54
30	**9.5**	7.82	19.02	20.29	3.851	2.84	6.91	7.38	0.15	0.13	0.315	0.33
		Percentage Error				Percentage Error				Percentage Error		
		17.68	50.05	53.18		26.25	44.27	47.81		13.33	52.38	54.55
40	**12.67**	10.43	26.31	27.05	5.135	3.79	9.56	9.83	0.2	0.17	0.44	0.45
		Percentage Error				Percentage Error				Percentage Error		
		17.68	51.84	53.16		26.19	46.29	47.76		15	54.55	55.56
50	**15.84**	13.04	33.34	33.81	6.41	4.74	12.12	12.29	0.25	0.216	0.55	0.56
		Percentage Error				Percentage Error				Percentage Error		
		17.8	52.49	53.15		26.05	47.11	47.84		13.6	54.55	55.36
60	**19.0**	15.64	40.24	40.57	7.702	5.69	14.63	14.76	0.3	0.26	0.667	0.673
		Percentage Error				Percentage Error				Percentage Error		
		17.68	52.78	53.17		26.12	47.35	47.82		13.33	55.02	55.42

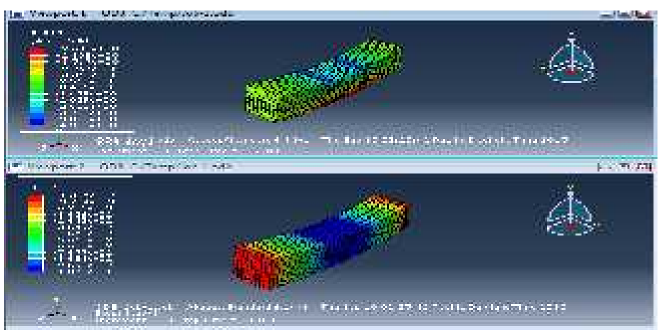

Fig.9 Abaqus® Model and result diagram

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BIOGRAPHIES

Sachin M. Kulkarni is an academician with more than 10years of teaching experience . He is pursuing his Ph.D. in Civil Engineering from Visvesvaraya Technological University, Belgaum. His area of interest is Rehabilitation, Finite Element Analysis, Structural Analysis.
Email id: sachinkulkarni1@gmail.com

Dr. K. G. Vishwanath is Principal and Director of Jain College of Engineering, Belagavi. He has more than 29 years of teaching experience. He published 01 international journal, 02 national journals and presented 01 international conference. His area of interest is Rehabilitation, Concrete technology, Structural Dynamics, Structural Analysis.
Email id: vishwakg@yahoo.co.in