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Experimental and Numerical Study of GFRP Wrapped RC Beams Subjected To Flexure

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Abstract: **-- The rehabilitation of existing Reinforced Concrete (RC) structures becomes necessary due to defects in design/construction, ageing, damage due to earthquake/fire, corrosion of reinforcing steel, demand in the increased service loads and revisions in the design guidelines. Rehabilitation of RC structures can be done in various ways such as repairing, retrofitting & strengthening. Fiber Reinforced Polymers (FRP) has emerged as the promising material for rehabilitation of deficient RC structures and accepted by construction industry due to ease of application. Beams are flexural elements in RC framed structures. From the previous researchers, it is revealed that most of the work is done to study the flexural behavior of RC beam deficient in flexure by applying GFRP laminates for full length on tension face of the beam or U-wrapping. In this way, the GFRP laminates applied on shear zone cannot be efficiently utilized for flexure strengthening. In the present research work, the effect of varying length of GFRP laminate on flexural behavior of deficient RC beams was investigated. The investigation was done on beams with GFRP laminates applied on tension side and subjected to three-point static loading system. Finite Element Analysis (FEA) of the similar specimens were carried out using ANSYS. The results obtained from ANSYS were in good agreement with the experimental investigation. From the test results, it was observed that flexural capacity of RC beams varied with the length of GFRP laminate applied.**

Index Terms **- Reinforced Concrete, Rehabilitation, GFRP, Flexural Strengthening, FEA.**

I. INTRODUCTION

Reinforced concrete (RC) is widely used in the construction of many civil engineering structures such as buildings, bridge decks, girders, offshore structures, parking structures, etc. Deterioration of RC structures occurs mainly due to ageing, poor maintenance, corrosion of reinforcement, exposure to harmful exposure conditions, natural hazards like earthquake, accidents such as collision, fire, explosion, etc. These deteriorated structures cannot take the load for which they are designed. Structures like bridges, flyovers require restoration and repair for increased volume, traffic loads, etc. Many building structures need to upgrade due to additional storey. A large number of structures constructed in the past using older design codes in different parts of the world are structurally unsafe according to the new design codes and hence need upgradation. Design methodologies are also changing with the growing research in various areas of construction engineering. So the existing structures may not qualify to the current requirements. Complete replacement of such structures leads to incur huge amount of money and time. Hence retrofitting is the acceptable way of enhancing load carrying capacity and extending the service life of these structures. Fiber Reinforced Polymer (FRP) has emerged as promising material for retrofitting of structural elements. It is used to enhance strength of new and existing RC elements. Deflection and cracking behavior of RC elements depend on the flexural tensile strength of concrete. Reinforcement increases ductility and large deflections in structural element provide a good warning prior to complete failure of the flexural element. In RC framed structure beam is a flexural element and the collapse of it results in the failure of the structure. Therefore, the flexural capacity plays vital role in the performance of RC beams. Failure of beam in flexure is ductile in nature hence FRP sheets are normally applied on tension face of beam for flexural strengthening. At present different types of FRP materials are available in the market such as Carbon Fiber (CFRP), Glass Fiber (GFRP), Aramid Fiber (AFRP) etc. But from economy and strength point of view GFRP sheets are mostly preferred in the construction industry. Many researchers investigated performance of GFRP wrapped RC beams subjected to flexure. Anumol Raju et.al. (2013) investigated flexural strength of RC beams retrofitted externally using different types of fibers viz. steel fibers, polypropylene fibers, carbon fibers, etc. They concluded that use of GFRP sheets for retrofitting of beams is the most suitable option as it

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 3, Issue 1, January 2018

provides strength as well as economy [1]. Hamid Saadatmanesh et.al. (1991) studied flexural behavior of RC beams by applying GFRP sheets to the tension face and found sufficient increase in flexural strength of beams. They also found that GFRP wrapping delayed formation of cracks in the beam and the crack width was significantly reduced even though it was appeared at higher loads [2]. Sing et.al. (2007) applied GFRP sheets on tension face in one, two and three layers. They found that flexural strength increased with number of layers of GFRP sheets applied. Failure was due to debonding of GFRP sheets and crack was observed to be initiated from interface between the adhesive and the concrete [3]. Kaushal Parikh et.al. (2012) varied arrangement and layers of GFRP sheets. The failure of beams was found to be due to debonding of GFRP and the cracks were shifted from flexure to shear-flexure region [4]. Tarek H. Almusallam et.al. (2005) investigated flexural behavior of RC beams by varying layers and application pattern of GFRP sheets. GFRP laminate was applied on tension face of beam and in the form of U-wrap. They observed that beams strengthened by applying GFRP sheets on tension face failed due to GFRP sheet rupture and crushing of concrete whereas beams strengthened by U-wrap failed due to crushing of concrete [5]. P. Parandaman et.al. (2014) carried out performance evaluation of the beams experimentally and using ANSYS. Different types of FRP sheets were applied on tension face for full length of the beams. It was found that FRP bonding enhances the flexural capacity of beams [6].

From the previous research it is revealed that GFRP laminates is one of the best options for retrofitting of beams as it provides strength and economy. In practice GFRP sheets are normally applied on tension face for full length of the RC beam for flexural strengthening. When the beams subjected to flexure, flexural effect is predominant in the midspan region and reduces towards the support. So GFRP sheets may not be required near the support region. From the previous research it is observed that majority of the researchers have studied flexural capacity of beams by using different types of FRP laminates, orientations, layers, etc. and most of them have applied GFRP laminates on entire tension face. But limited research is available on length optimization of GFRP laminates. The present work aims to study the effect of application of GFRP laminates with varying lengths on the tension face of the RC beam subjected to flexure. Computer simulation is a robust tool for assessing performance of RC structures. Such simulation can be effectively used to find the optimal and cost-effective design solutions. Hence aim of the present study is to conduct analysis of the RC beams retrofitted with GFRP laminates with varying length (as considered in the experimental work) using ANSYS software and compared the results with that of the experimental work.

II. EXPERIMENTAL PROGRAM

A. Materials and Concrete Mix Design

All the test specimens were cast using M20 grade of concrete. Ordinary Portland cement of nominal strength 53 MPa conforming to IS: 12269-1999, river sand conforming to zone-I according to IS:383-1970as fine aggregate and crushed stone as coarse aggregate in two sizes 20mm and 10mm in the proportion of 60% & 40% respectively were used in the preparation of concrete mix. Using w/c ratio 0.50, the concrete mix was design as per IS: 10262-2009 for 100mmslump. The mix proportion obtained was 1:1.82:2.70. According to IS:516-1959, average 28 days cube compressive strength obtained was 29.6 MPa. TMT bars of diameter 10mm and 8mm in the preparation of beam specimens. The ultimate tensile strength and modulus of elasticity of the steel was 704MPa and 200076 MPa respectively. Unidirectional GFRP sheets of nominal thickness 1.0mm and brand Maxtreat Fibernet was used for retrofitting. Maxtreat epoxyresin was used for binding the GFRP sheets on the surface of concrete. Tensile strength and modulus of elasticity of GFRP was 2600 MPa and 73GPa respectively.

B. Preparation of specimen

In the present experimental work, fifteen flexure deficient RC beam specimens were cast. All the specimens have dimension of 150mmx 250mmx 700 mm. Two bars of 10mm diameter on tension face and two bars of 8mm diameter on compression face as anchor bars were used in the beam. 8mm diameter and 100mm c/c spacing stirrups were provided. Details of the beam specimen are as shown in Fig. 1. The specimens were categorized into five cases as per length of GFRP laminate applied. In case I, specimens were considered as control specimens, without GFRP laminate application. Specimens in case II, case III, case IV and case V were strengthened with GFRP laminates with length of 600mm, 400mm, 300mm and 200mm respectively. The specimens were cure for 28 days at room temperature. The GFRP laminate was epoxy bonded in the center to the tension face of the beams. Before applying the sheets onto the beams, the concrete surface was made smooth using sand paper and cleaned with an air blow to remove all dirt and debris. The epoxy resin consists of hardener and saturant, which was mixed in

IFERP
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Vol 3, Issue 1, January 2018

the specific proportion as per guidelines given by manufacturer. The epoxy resin was then applied on the prepared concrete surface. The GFRP sheets were then pressed onto the concrete surface on the top of the epoxy resin coating. The epoxy resin was allowed to harden for 24 hours.

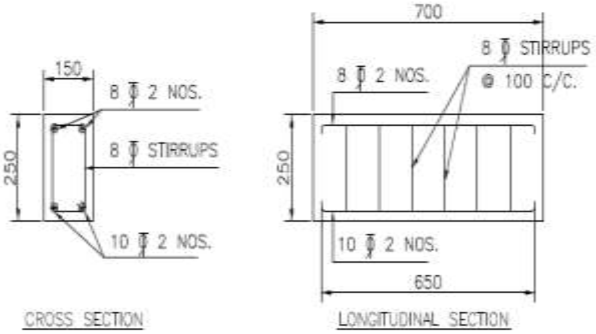


Fig. I: Longitudinal and cross section of beam specimen

C. Test setup

After 24 hours of GFRP laminate application, the beam specimens were tested for flexural strength as per IS: 516-1959 subjected to three-point loading system using UTM of capacity 1000kN.The test setup is shown in Fig.2. The load was applied gradually at a constant rate of 5kN per minute upto failure of beam. For measurements of deflection; dial gauge was attached at mid span of the beam. At the load interval of 5kN deflections were recorded. Development of crack and its propagation on beam surface was carefully observed and recorded throughout the testing duration up to the ultimate failure of beam.

Fig.II: Flexural test setup

III. NUMERICAL PROGRAM

A. Material Properties

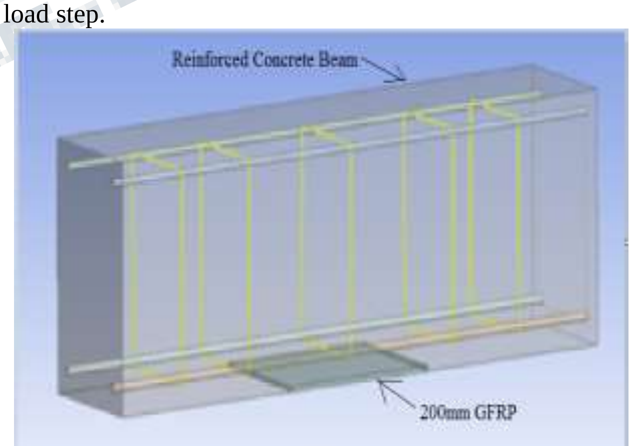
In the research, ANSYS Workbench 16.0 was used as a tool for modeling and numerical analysis of the beam specimens. Mechanical properties of material specimens used in modeling the specimens are given Table 1.

Table I: Material Properties

Materials	Density (kg/m3)	Elastic Modulus (MPa)	Poison's ratio
Reinforced Concrete	2548	27386	0.2
Reinforcing Steel	7850	200076	0.3
GFRP	2570	73000	0.2

B. Modelling

The beam specimens of each case were modeled with the varying length of GFRP sheets and control beam specimen without GFRP sheets. A generalized plot of the beam specimen strengthened with GFRP laminate of length 200mm and 600mm is as shown in Plot 1. Similar to experimental work, loading system was simulated for ANSYS modeling. Fixed support conditions were provided on both the bottom edges in the model. A concentrated load was applied on the models in a load step of 5 kN. The load step helped to determine deflection of beam for each load step.



GFRP laminate of 200mm length

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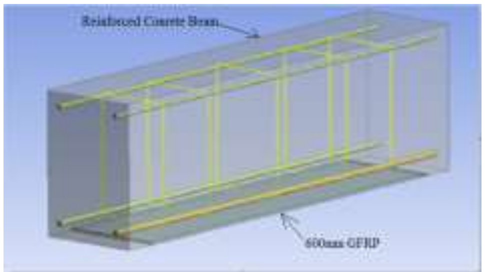
Vol 3, Issue 1, January 2018



(b) GFRP laminate of 600mm length

Plot.I. Plot of the beam specimen strengthened with GFRP laminate

C. Meshing

The beam models were meshed and nodes were generated. Greater the number of nodes and elements, greater is the accuracy achieved in the results. After reaching a certain limit for number of nodes and elements, the accuracy remains constant even with further increase of nodes/elements. Therefore, convergence criteria were used and the meshing was defined accordingly. The number of nodes generated for control beam specimens were less as compared to the GFRP strengthened beams. Total 66605 nodes &12939 elements were generated for control beam specimen meshing. The number of nodes and elements for GFRP strengthened beams specimens were increased due to contact surface generated between GFRP and concrete beam and it varied with the length of GFRP laminate.

IV. RESULTS AND DISCUSSION

From the experimental test results and numerical analysis, the effect of GFRP laminate application and its length on failure mode, cracking behavior, load carrying capacity and load-deflection behavior of beams is presented. Failure Mode From the experimental test it was found that failure mode of control specimens was flexural failure whereas failure mode of strengthened specimens was either GFRP debonding or concrete splitting. The failure initiated due to debonding of GFRP laminates from concrete surface followed by shear failure. The GFRP debonding was observed to be initiated at the edge of the laminate as shown in Fig. 3

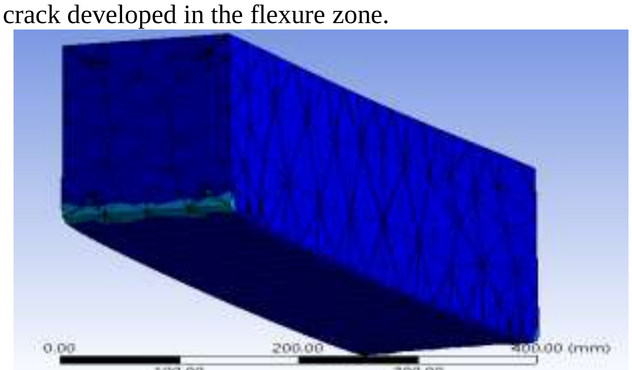
(a) GFRP laminate of 200mm length

(b) GFRP laminate of 600mm length

Fig. III: Failure mode of beams specimens

B. Cracking Behavior

In control beam, the crack was observed to be initiated in the pure bending region at midspan section at bottom of the beam. The crack was found to be propagated vertical and became failure crack. Other cracks found to be observed in the flexure or flexure-shear zone. At failure, width of these cracks was less than that of the first crack. In all GFRP strengthened beams, the first crack was observed to be initiated in the flexure zone. With the increase in loads, the crack propagated in the vertical direction but crack width does not increase even at failure as found in control beams. The failure crack was observed to be initiated at the edge of GFRP laminates, propagated inclined towards the top of the beam. Similar crack behavioral pattern was observed in results obtained from ANSYS as shown in Plot.2 The width of this crack was found to increase with increase in load and at failure was found to be more than that of first crack developed in the flexure zone.



Plot II: Crack behavior pattern for GFRP laminate of 600mm length

B. Load Carrying Capacity

Percentage increase in load carrying capacity of beams specimens corresponding to variation of GFRP laminate length in presented in Graph 1. Table 2 presents average

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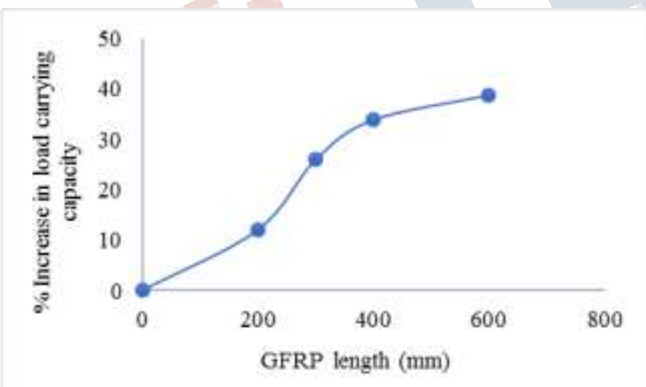
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 3, Issue 1, January 2018

load at first crack and at failure of the beam specimens with variation in GFRP laminate length. From the test results it is observed that load required to develop first crack on the concrete surface is influenced by length of GFRP laminate. Also, failure load increased with the increase in GFRP laminate length. It indicates that ductile behavior of beam enhanced with the application of GFRP laminate and length of GFRP laminate has significance influence on the serviceability and load carrying capacity of the beam. Highest load carrying capacity was found for the beams strengthened with 600mm length GFRP laminate.

Table II: Average load at first crack and at failure

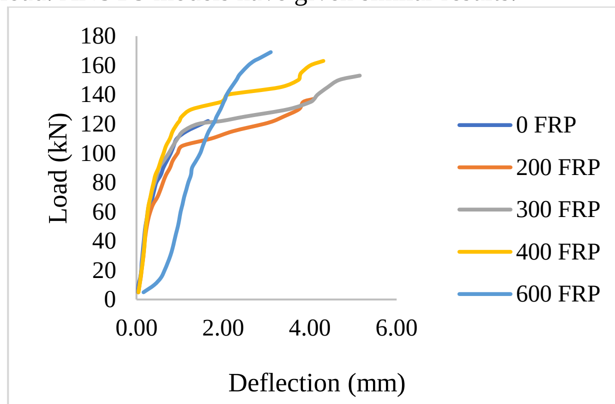
Case No.	Length of GFRP laminate (mm)	Avg. loads at first crack (kN)	Avg. failure load (kN)	% Increase in failure load
1	0	65.33	121.67	-
5	200	67.66	136.67	12.04
4	300	69.67	153.33	26.02
3	400	73.00	163.00	33.97
2	600	77.66	169.00	38.91



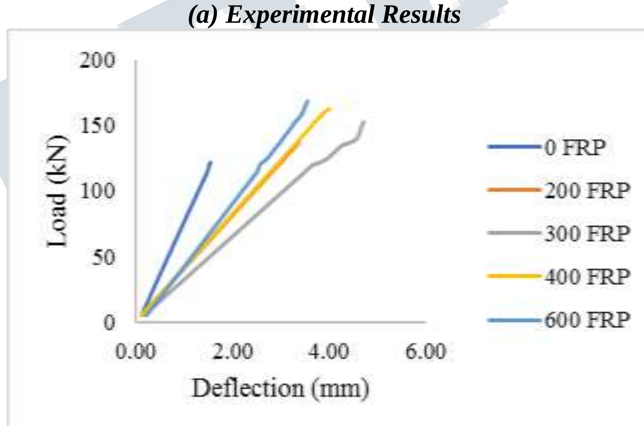
Graph I: Percentage Increase in Strength corresponding to GFRP Length

D. Load Deflection Behavior

Deflection in beam specimens for variation in length of the GFRP laminate for the experimental specimens and ANSYS models is presented in Table 1. Curves were plotted for the failure load and deflection of the various cases for experimental results and values obtained from ANSYS. The curves are as shown in Graph 2. From the graphs, it is observed that GFRP laminate enhances stiffness of the beams. Beams with 600mm length GFRP laminate showed minimum deflection with highest failure load. ANSYS models have given similar results.



(a) Experimental Results



(b) ANSYS Results

Graph II: Load-deflection curves for beams with varying length of GFRP laminate

Table III: Deflection of Various Cases.

Case No.	Length of GFRP laminate (mm)	Experimental Avg. Deflection (mm)	ANSYS Deflection (mm)
1	0	1.54	1.65
5	200	4.08	3.37
4	300	4.77	4.71
3	400	4.31	4.00
2	600	3.10	3.54

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 3, Issue 1, January 2018

V. CONCLUSION

Based on the experimental results and observations, and numerical analysis using ANSYS following results are drawn

1. Experimental results indicate that externally bonded GFRP laminates is an effective method of strengthening reinforced concrete beams.
2. GFRP laminates when applied on tension face of the beams for full length, significantly enhances flexural capacity of the RC beams.
3. Failure of the GFRP strengthened beams was due to debonding between GFRP laminates and concrete surface.
4. In GFRP strengthened beams, the failure crack shifted from flexure zone to shear zone indicating enhancement in the flexural capacity of the beams due to GFRP application.
5. GFRP laminates enhanced ductility of the beams.
6. Experimental and ANSYS values show good agreement with each other since the change in final values are within the permissible limits.

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