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Strengthening of RC Beams by Wrapping FRP on Steel Bars

Manju R.
M .Tech student
Dept. of Civil Engineering, IIET
Kerala – 686 691, India

Shanavas S.
Associate Professor
Dept. of Mechanical Engineering,
YCE, Kerala – 691 538, India.

Abhilasha P S.
Associate Professor
Dept. of Civil Engineering, VAST
Kerala – 680 501, India.

***Abstract* - This study deals with the experimental and numerical study on RC beams which is strengthened by wrapping FRP on steel rods. The objective of the study was to investigate the improvements in the structural behaviour of RC beams, while steel bars are wrapped with FRP. The fibre used for the study was E-Glass fibre. Flexural test was conducted on RC beams and RC beams in which the steel bars are wrapped with FRP. In Numerical study, ANSYS software was used to build a 3D model of the beams and to analyse the beam structure. Finally the results obtained from the Experimental test and FEM analysis were compared. The result shows that the load carrying capacity of the RC beams can be increased by wrapping FRP on Steel rod.**

Index Terms – FRP, Composite bars, ANSYS, RC beam

I. INTRODUCTION

The use of Fibre Reinforced Polymer (FRP) as reinforcing bars is becoming popular worldwide due to its properties like corrosion resistance and high tensile strength. Other advantages include high strength and stiffness to weight ratios, resistance to chemical attack, controllable thermal expansion and damping characteristics, and electromagnetic neutrality. Many research works has been conducted to analyse the suitability of FRP as reinforced bars. The FRP is made of continuous fibre filaments embedded in resin matrix to form various types of shapes such as bars, structural sections, plates, and fabric.

In conventional reinforced concrete steel bars is being used as reinforcement. Since the steel bars are vulnerable to corrosion in adverse conditions like in marine environment, researches have been conducted to find out a suitable material which can either be used as a replacement for steel bars or can be used to provide a protective layer around the steel bars. One such material is fibre reinforced polymer. The corrosion resistant properties of FRP have been proved in many research works. In this paper a comparison of load carrying capacity of the conventional RC beams and RC beams with steel rods by wrapped with FRP are done. For this purpose, FRP sheets of E-Glass fibre are being used.

II. MATERIALS AND PREPARATION

Portland Pozzolana cement was used for the concrete mix. The initial setting time of the cement was 55 minutes with a specific gravity of 2.91. The M-Sand passing through 4.75 mm sieve was used as fine aggregate. The maximum size of aggregate was 20mm. Potable water free from suspended particle and chemical substances was used for mixing and curing of concrete. Design concrete mix of 1:2.062:2.732 by weight is used. Superplasticizer (RHEOBUILD 1125) was used to increase the workability if necessary. The water cement ratio of 0.45 is used. 3 cubic specimens were cast and tested to determine compressive strength. Mild steel bars of 8mm, 10mm and 12mm diameter was used, $0/90^0$ PW Style Glass fibre fabric and epoxy resin were used for wrapping the steel rebars for casting specimen beams.

A. Preparation of composite bars

The main aim of this Study was to find out the ultimate strength and load carrying capacity of the conventional RC beams and RC beams with steel rods wrapped with FRP.
The procedure of wrapping steel bars with FRP is as shown in figures 1 & 2.

Fig. 1 Wrapping steel bar with epoxy coated glass fibre fabric

Fig. 2 Steel bars wrapped with FRP

B. Casting of beams

Reinforced beams of dimension 500mm x 100mm x 100mm were cast with two bars placed at the bottom of beam with a clear cover of 20mm. 3 specimen beams each were cast reinforcing with 8mm dia bars and also with 8mm dia bars wrapped with FRP. Similar casting was done for 10mm and 12mm dia bars.

III. EXPERIMENTAL STUDY ON BEAMS

The entire specimens were tested in flexural testing machine. Four point loading arrangement was used to test the beam. The loading arrangement was as in figure 3, where, P is the applied load and L is the distance between the supports. The distance between the support points was 400mm and the breadth was 100mm. The overall length of the beam was 500mm.

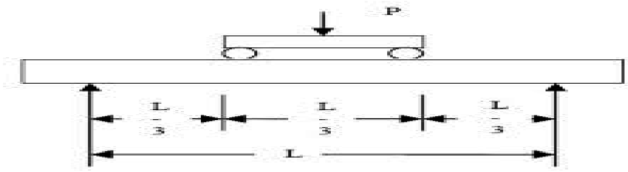

Fig. 3 Loading arrangement in flexural testing machine

The flexural test was conducted to find out the ultimate load which can be applied on the beam as in fig. 4. This ultimate load can be directly read from the dial on the machine. From this value of load obtained from the machine the stress induced on the beam can be calculated using the equation,

$$\sigma = \frac{3P(L-L_i)}{2bd^2} \quad (1)$$

where, σ : stress induced on the beam due to the load P
L : distance between the supports
L_i : distance between the load points
b : breadth of the beam
d : depth of the beam

Fig. 4 Reinforced beam placed for flexural testing

Fig. 5 Crack pattern of reinforced beam

IV. MODELLING AND STRESS ANALYSIS OF SPECIMEN & FULL SCALE BEAMS USING ANSYS

A. Material Model

The assumptions made for the modelling were:

- Material was assumed to be linearly elastic.
- Heat generation and thermal stresses were ignored.
- Material was assumed to be isotropic and homogeneous in nature.

TABLE. 1. PROPERTIES OF E-GLASS FIBRE AND EPOXY

Sl.No	Properties	E-glass Fibre	Epoxy
1	Density, ρ (kg/m^3)	2540	1360
2	Young's modulus, E (GPa)	72.50	3.79
3	Poisson's ratio, γ	0.21	0.40
4	Ultimate tensile strength, σ_u (MPa)	2450	82.75

The young's modulus (E) and poisson's ratio (γ) of the E-glass fibre composite, as in table.2, was found out by laminar theory which can be expressed mathematically as:

$$E = E_f V_f + E_m(1 - V_f)$$
$$\gamma = \gamma_f V_f + \gamma_m(1 - V_f)$$

where,
E_f : young's modulus of the fiber
E_m : young's modulus of epoxy mixture
γ_f : poisson's ratio of the fiber
γ_m : poisson's ratio of epoxy mixture
V_f : composition of the composite, fiber by volume, is 0.60.

TABLE. 2. PROPERTIES OF MATERIALS USED FOR FINITE ELEMENT ANALYSIS

Sl.No	Properties	Steel	Concrete	GFRP
1	Density, ρ (kg/m^3)	7850	2400	2111
2	Young's modulus, E (GPa)	200	30	45
3	Poisson's ratio, γ	0.3	0.18	0.28
4	Ultimate tensile strength, σ_u (MPa)	460	5	1080

In the software ANSYS 13, the analysis of the specimen beams with 8mm dia bars as in experimental study was done. After validating the experimental and software results, the analysis was extended to a full scale beam of dimension 3000mm x 300mm x 300mm with four numbers of 16mm dia bars.

B. Three dimensional modelling

In order to analyse the beams ANSYS 13 was used.

Three dimensional models of the beams were first generated in the ANSYS 13. The dimensions of the specimen beam as in experimental study given were 500mm x 100mm x 100mm. The diameter of the steel bars used is 8mm (2 nos) and is placed at the bottom beam with a clear cover of 20mm. The dimensions of the full scale beam given were 3000mm x 300mm x 300mm. The diameter of the steel bars used is 16mm (4 nos), two of which is placed at the bottom of the beam an two at the top of the beam with a clear cover of 25mm. For generating models of beams reinforced with steel bars wrapped with FRP, wrapping of 2.5mm thick was provided.

C. Mesh generation

After generating the 3-D model of the beam in ANSYS 13 an eight-node solid element, solid 65, was used to mesh the concrete. A Link 180 element was used to mesh the steel reinforcement. A layered solid element, Shell 8 node 281, was used to mesh the FRP composites.

a. Meshing of specimen beams

For specimen with reinforcement of steel bars without FRP wrapping the total number of elements were 15431 with 33612 nodes. For specimen with reinforcement of steel bars with FRP wrapping the total number of elements were 21400 with 45710 nodes.

b. Meshing of full scale beams

For full scale beam with reinforcement of steel bars without FRP wrapping the total number of elements were 27051 with 140958 nodes. For full scale beam with reinforcement of steel bars with FRP wrapping the total number of elements were 82181 elements with 516664 nodes.

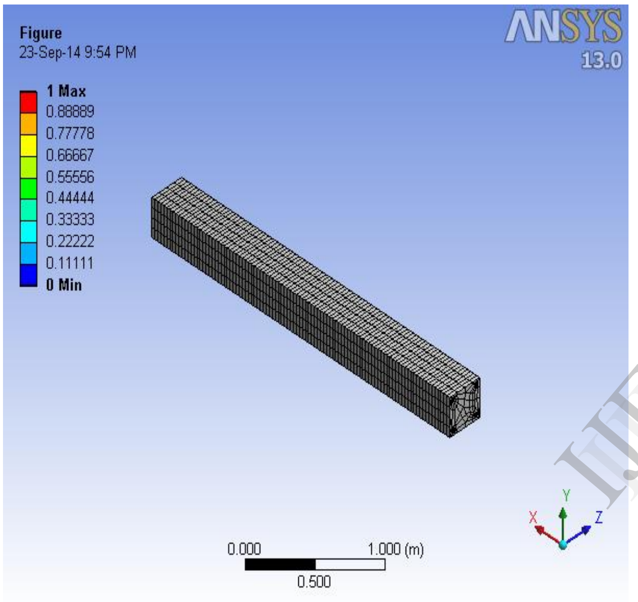

Fig. 6 Meshing of beam with steel bars with FRP wrapping

D. Boundary conditions

Providing boundary conditions to the model means to define the supports and loading conditions.

a. Boundary condition for the specimen beam

The minimum of the ultimate load among the beams with and without FRP wrapping on rebars as obtained in the experimental study of RC beams were applied in ANSYS 13 with a factor of safety of 2.

The ultimate load obtained in case of RC Beam with 8mm steel bar was 33.17 kN and the ultimate load obtained in case of RC Beam with 8mm steel bar wrapped by FRP was 35.83 kN. The minimum of these two cases is 33.17 kN. This minimum value was applied on the specimen with a factor of safety of 2 for the analysis made in ANSYS 13.

Fixed support conditions were provided similar to the support conditions provided in the experimental study.

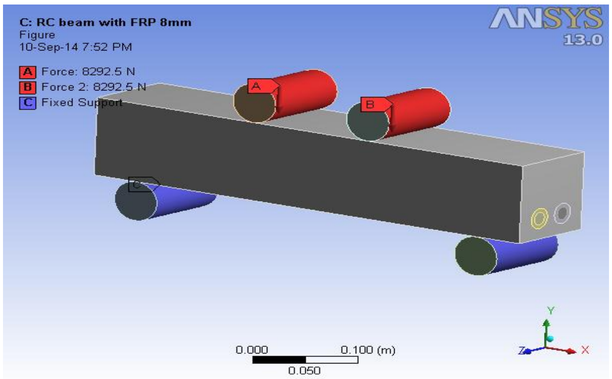

Fig. 7 Boundary conditions of beam with steel bars with FRP wrapping

b. Boundary condition for the Full scale beam

After obtaining the results in ANSYS 13, for the specimen beams, the analysis of the full scale beam was done in the software.

A uniformly distributed load of 5kN was applied on the beam and both ends were made fixed.

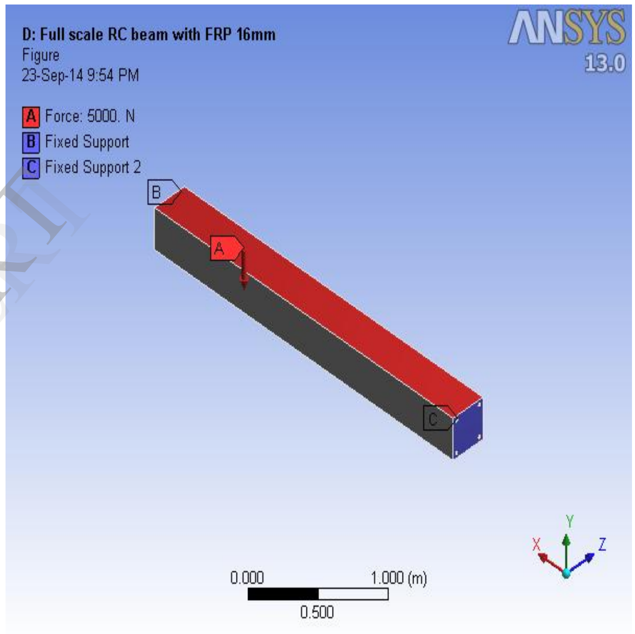

Fig. 8 Boundary conditions of beam with steel bars with FRP wrapping

V. RESULTS AND DISCUSSIONS

A. Results of the experimental study

The entire beams cast were tested for flexural strength and the results obtained were tabulated as shown in Table 3.

TABLE 3. EXPERIMENTAL RESULTS

Sl. No	Type of Beam	Maximum Load (kN)	Ultimate Stress (N/mm^2)
1	RC Beam with 8mm steel bar	33.17	13.268
2	RC Beam with 8mm steel bar wrapped by FRP	35.83	14.332
3	RC Beam with 10mm steel bar	37.67	15.067
4	RC Beam with 10mm steel bar wrapped by FRP	39.83	15.932
5	RC Beam with 12mm steel bar	40.33	16.132
6	RC Beam with 12mm steel bar wrapped by FRP	42.17	16.868

As per the results obtained from the experimental study on the specimen beams cast, the ultimate load carrying capacity of the conventional RC beams with steel bars is less than the RC beams with steel rods wrapped with FRP.

B. Results of the analyses of the specimen beams made in ANSYS 13

The analyses of the specimen beam were also done in ANSYS 13. The result obtained from the software is as shown in figures 9, 10, 11 & 12.

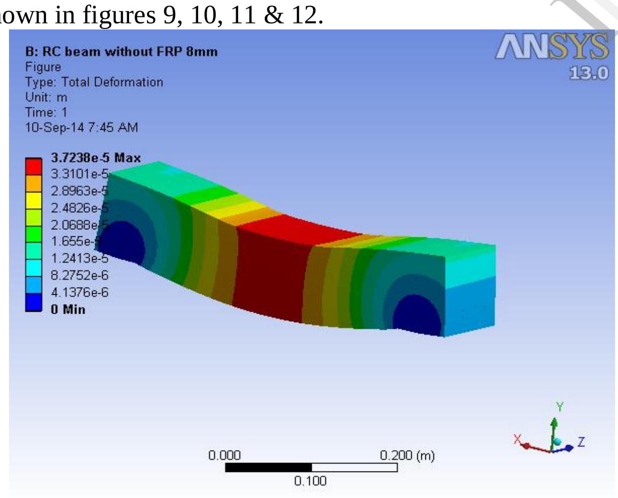

Fig. 9 Deformation of beam with steel bars without FRP wrapping

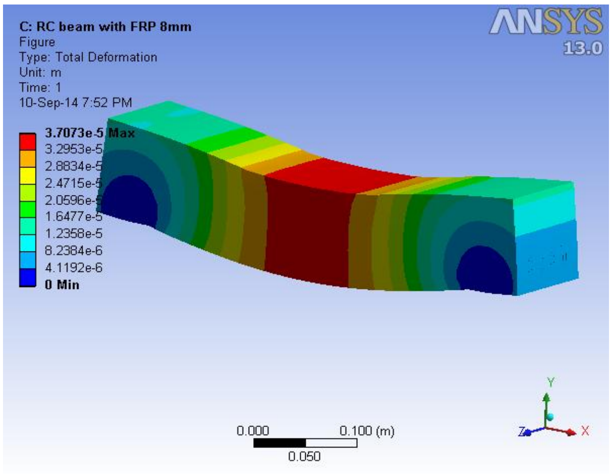

Fig. 10 Deformation of beam with steel bars with FRP wrapping

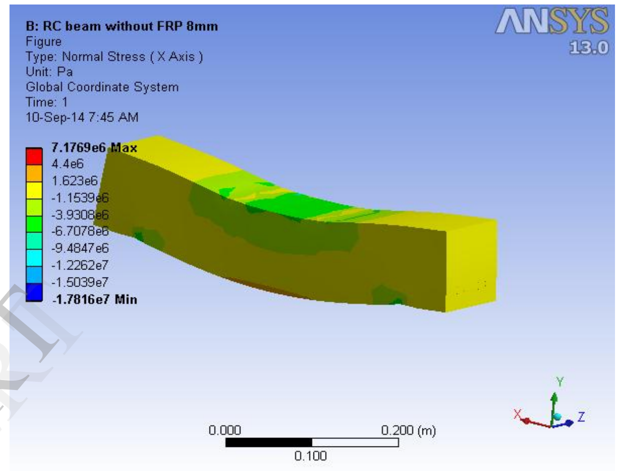

Fig. 11 Normal stress on beam with steel bars without FRP wrapping

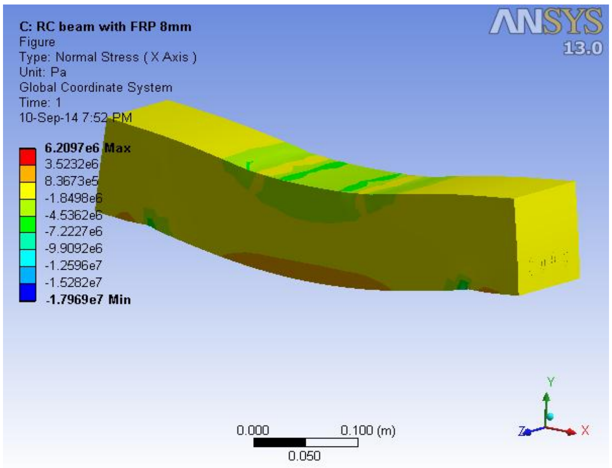

Fig. 12 Normal stress on beam with steel bars with FRP wrapping

The results obtained from the experimental study and from the analyses made in the ANSYS 13 software was compared and tabulated as in table 4.

TABLE 4. COMPARISON OF ANALYTICAL AND ANSYS RESULTS

Sl. No	**Type of Beam**	**Maximum Load (kN)**	**Safe Load (kN)**	**Induced Stress (N/mm^2)**	
				Analytical Result	***Fem Result (Ansys)***
1	RC Beam with 8mm steel bar	33.17	16.585	6.635	7.1769
2	RC Beam with 8mm steel bar wrapped by FRP	35.83	16.585	6.635	6.2097

In the experimental study done on the specimen beams the stress obtained for RC Beam with 8mm steel bar and for RC Beam with 8mm steel bar wrapped by FRP are same.

While in case of results obtained from the software ANSYS 13, the stress obtained for RC Beam with 8mm steel bar is greater that the stress obtained for RC Beam with 8mm steel bar wrapped by FRP are same.

This variation in the result is due to the fact that while analyzing a specimen using ANSYS 13, the software takes into account the structural properties of every material being used in that particular specimen. But in case of finding out the stresses analytically no considerations regarding the fact of specimen having different materials is given.

C. Results of the analyses of the full scale beams made in ANSYS 13

After analyzing the specimen beams analytically and by means of the software ANSYS 13 both the results were compared. Since the results obtained from the experimental study was validated satisfactorily with the ANSYS results, the analysis was then made on a full scale beam of dimension 3000mm x 300mm x 300mm with four numbers of 16mm dia bars in the ANSYS 13. The results obtained from this analysis are as shown in figures 13, 14, 15 & 16.

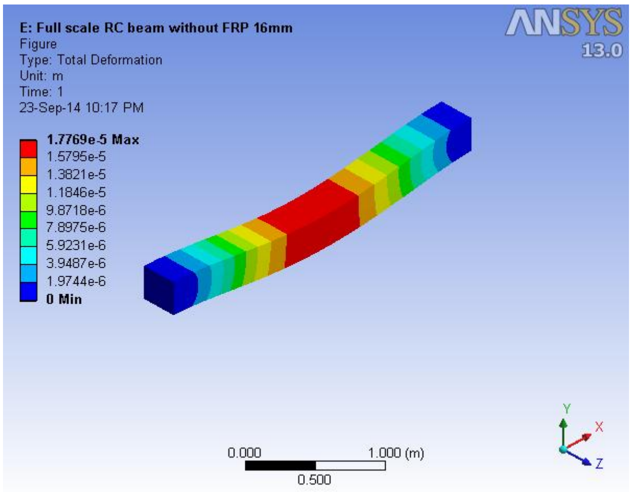

Fig. 13 Deformation of full scale beam with steel bars without FRP wrapping

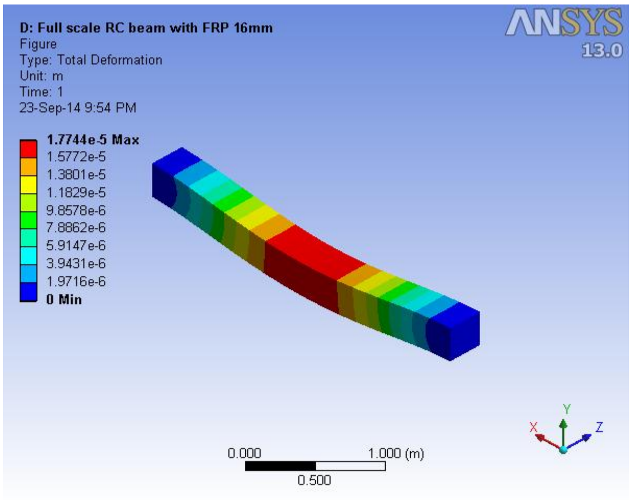

Fig. 14 Deformation of beam with steel bars with FRP wrapping

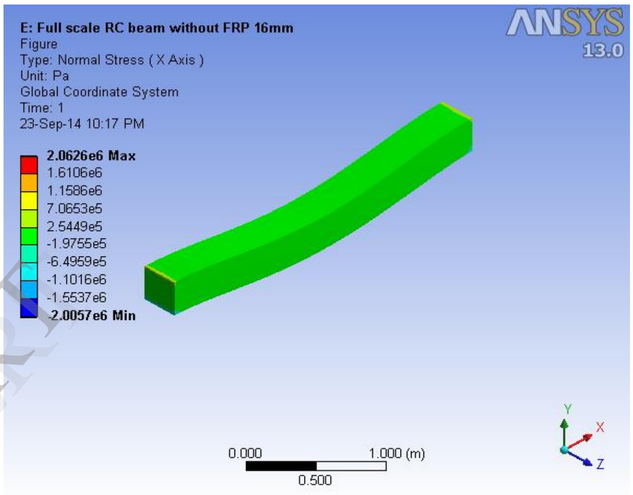

Fig. 15 Normal stress on full scale beam with steel bars without FRP wrapping

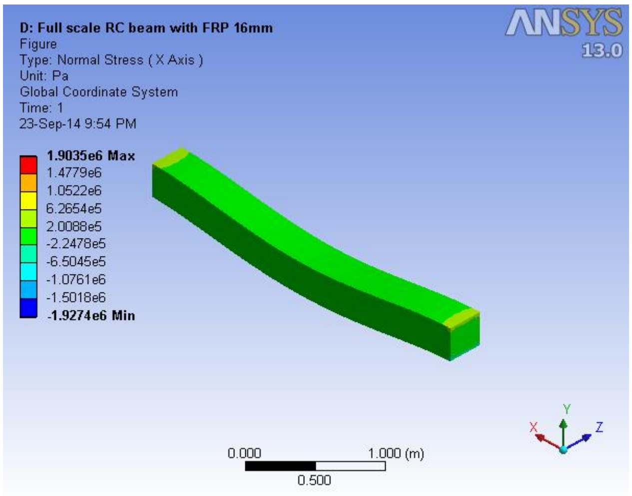

Fig. 16 Normal stress on beam with steel bars with FRP wrapping

VI. CONCLUSIONS

The ultimate load carrying capacities of the concrete beams reinforced with steel bars wrapped using FRP were found out and this test results were compared with the control beams reinforced with steel bars. The analyses were also done using the software ANSYS 13. The following observations were made from the results obtained.

A. Experimental study

- The ultimate load carrying capacity of the beam reinforced with steel bars wrapped using FRP was found to be more than the beam reinforced with steel bars without FRP wrapping.

B. Analyses in ANSYS 13

- The ultimate load carrying capacity of the specimen beam reinforced with steel bars wrapped using FRP was found to be more than the beam reinforced with steel bars without FRP wrapping which satisfies the result obtained from the experimental study. So the analysis of a full scale beam was also done in the ANSYS 13 and the results were obtained satisfactorily.
- The deformation of the beam reinforced with steel bars wrapped using FRP was found to be slightly lesser than the beam reinforced with steel bars without FRP wrapping as per the analysis made in ANSYS 13.
- The stresses induced in the beam reinforced with steel bars wrapped using FRP was found to be lesser than the beam reinforced with steel bars without FRP wrapping. But in the case of analytical results made the stresses induced remains the same in both cases.

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