Parametric Analysis of Fiber Reinforced Polymer (FRP) Composites for Retrofitting of Structures

Shiva P.B[1] Chetan Gowda R.K[2] Abhishek Pulgur[3] Divakar L[4]
[1]M.Tech Student [2,3,4]Faculty
[1,2,3,4]Ramaiah University of Applied Sciences Bangalore-560054, India

Abstract— Fiber Reinforced Polymer composites have emerged as an alternative to traditional methods for retrofitting of structures as it increases their axial strength, shear strength and seismic resistance. They are popular because of their high strength/stiffness to weight ratio, corrosion resistance, and ease of installation. The common link among all FRP materials are the use of continuous fibers (carbon, glass, aramid etc.) embedded in a resin matrix, the glue that allows the fibers to work together as a single element (ACI 440.2R-02 2002). This paper focusses on the the efficiency of different fiber reinforced polymers for jacketing such as Carbon Fibre Reinforced Polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP) and Aramid Fibre Reinforced Polymer (AFRP) with respect to orientation of fibres and number of layers through parametric study.

Key words: Fiber Reinforced Polymer (FRP), Carbon, Glass, Aramid and Finite Element Analysis (FEA)

I. INTRODUCTION

In recent years, popularity of using FRP composites as external wrapping for the strengthening and repair of concrete structures have been widely increased due to the superior properties of polymer composite materials like high corrosion resistance, high strength, high stiffness, excellent fatigue performance, good resistance to chemical attack and ease of installation etc.,

The common types of FRP materials used are Carbon FRP (CFRP), Glass FRP (GFRP), and Aramid FRP (AFRP). Usually FRP strengthening is done by wrapping around circumferential (hoop) direction of reinforced column to increase its axial strength, shear strength, and seismic resistance. The fibers confine the concrete and increase the axial strength by creating a tri-axial stress condition.

When an earthquake occurs reinforced concrete columns are considered the most sensitive or vulnerable part of a structure as they are major load carrying element of the building. Usually when a structure is designed for minimum cross section size lack of steel reinforcement in under designed columns leads to a weak column—strong beam construction which is leads to disaster when earthquake occurs as the under designed column leads to weak column—strong beam construction.

Many experimental and FEA analysis are carried out on columns which are subjected to uniaxial compressive load only but in reality most of all columns are subjected to eccentric axial load which can be resolved into a uniaxial compressive load and a bending moment due to this columns should be treated as beam-columns (A.R. Rahai et al. 2008). Hence fiber orientation plays an important role in structural design of FRP-wrapped concrete columns also number of layers and the material of the fibres used.

II. MODELLING AND ANALYSIS

A. Introduction to ANSYS

ANSYS is a finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. The ANSYS finite element software (ANSYS 2015), operating on a MS Windows system, was used in this study to simulate the behaviour of unconfined strength of concrete and confined strength of concrete. In general, the conclusions and techniques would be very similar using different nonlinear FEA programs. Each application, but, has its own nomenclature and specialised elements and analysis procedure that want to be used properly. The designer/analyst have to be thoroughly familiar with the finite element tools being used, and have to progress from less difficult to extra complicated problems to gain confidence inside the use of new techniques.

B. Description of the Model

For the parametric analysis based upon materials, orientation and layers of fibres a circular plane concrete model of standard dimensions 150 x 300 mm as shown in the figure 1. The thickness of single layer of FRP wound around the column is of thickness 0.25mm and the layers are varied from one to four. The orientation of fibres taken are 0°, 45° and 90°.

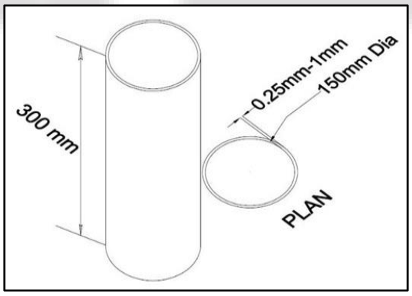

Fig. 1: Model Geometry for Parametric Study

C. Material Property

Concrete: The Young's modulus of elasticity of concrete, Ec is calculated using the equation

$E_c = 5000 \sqrt{f_{ck}}$ N/mm2

$E_c = 22360.6$ N/mm2

Where fck characteristic strength of concrete = 20N/mm2

Poisson's ratio, $\mu = 0.2$

Ultimate uniaxial tensile strength, fcr = 2.8 N/mm2 (IS 456-2000)

The open shear transfer co-efficient value of 0.3 and closed shear transfer co-efficient value of 0.9 was adopted in this project (Damien Kachlakev, 2001; Harish R, 2015; S.S. Mahini, 2007).

To determine the stress-strain relationship of M20 grade concrete, the equations used by Damien Kachlakev is adopted in this project and the values are shown in Table 1.

Sl. No.	Stress (N/mm2)	Strain
1	6	0.00026832
2	13	0.0006485
3	17	0.0010286
4	19	0.0014087
5	20	0.00179

Table 1: Uniaxial Compressive Stress-Strain Curve for Concrete

FRP Composites: Material of the fibres = CFRP, GFRP and AFRP

Number of layers = 1 to 4

Thickness of each layer = 0.25mm

Orientation of the fiber direction for each layer = 0°, 45° and 90°

Elastic modulus, Poisson's ratio and shear modulus of FRP composites are shown in Table 2.

Material	Elastic modulus (MPa)	Poisson's ratio	Shear modulus (MPa)
CFRP (Xiao and Wu)	E_x = 105000 E_y = 5784.2 E_z = 5784.2	μ_{xy} = 0.29 μ_{yz} = 0.40 μ_{xz} = 0.40	G_{xy} = 2144 G_{yz} = 2057 G_{xz} = 2144
GFRP (Feng et al.)	E_x = 65000 E_y = 4000 E_z = 5784.2	μ_{xy} = 0.31 μ_{yz} = 0.39 μ_{xz} = 0.02	G_{xy} = 1761 G_{yz} = 1660 G_{xz} = 1761
AFRP (Rochette and Labossiere)	E_x = 105000 E_y = 5784.2 E_z = 5784.2	μ_{xy} = 0.32 μ_{yz} = 0.35 μ_{xz} = 0.035	G_{xy} = 549 G_{yz} = 547 G_{xz} = 549

Table 2: FRP Composite Properties for Parametric Study

D. *Modelling and Meshing*

Confinement modelling is done by volume modelling of cylinder using hollow cylinder option. A hollow cylinder was generated with the given thickness, diameter and height dimensions. A solid cylinder was also generated with the considered specifications. In this model, the hollow cylinder resembles the FRP composite and the solid cylinder represents the concrete as shown in the figure 2. The hollow cylinder was meshed with SHELL181 for parametric study and the solid cylinder was meshed using SOLID65 shown in figure 3. The coordinate axes of all the elements of hollow cylinder are oriented to the cylindrical coordinate system. Meanwhile for parametric study number of layers and orientation of fibres can be provided to SHELL181 material using Shell Lay-up option as shown in the figure 4.

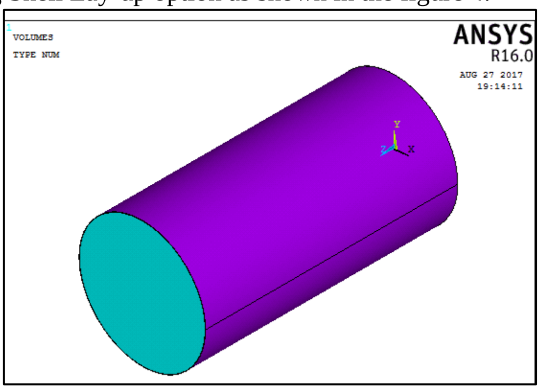

Fig. 2 FEM of FRP Confined Concrete

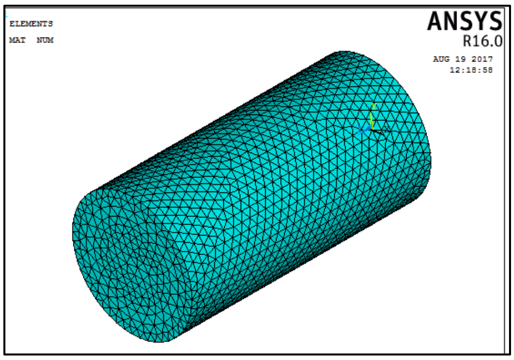

Fig. 3: Tetrahedron Meshing

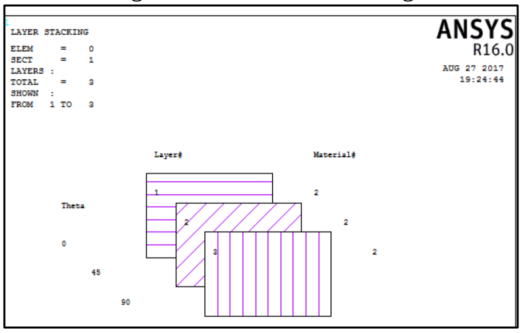

Fig.4 Layers and Orientation of FRP

E. *Boundary Conditions and Loading*

The boundary conditions are: 1) one end of the surface was fixed i.e. all the six degrees of freedom on that surface were constrained. 2) An axial compressive pressure load was applied on the other surface. This type of loading condition and boundary constraints are similar to cylinders under uniaxial compression test.

F. *Simulation*

A nonlinear structural analysis was performed, to include the nonlinear material behavior of concrete and FRP. ANSYS employs the "Newton-Raphson" approach to solve nonlinear problems.

G. *Solution*

When a FRP wrapped concrete column is subjected to a compressive load, concrete will be the initial load bearing member of the structure. The compressive load causes micro-cracks in the concrete. The concrete crushes when its ultimate compressive strength is reached. ANSYS can show the cracking and crushing of the concrete for an applied load. The FRP starts confining the concrete column, when the concrete reaches its ultimate compressive strength. Thus the FRP and the concrete core will carry the load collaboratively. The failure in the structure occurs when the FRP fails. Von-Mises stress failure theory used to predict yielding in material.

III. RESULTS AND DISCUSSIONS

A. *Effect of Orientation of Fibres*

Figure 5, figure 6 and figure 7 suggests that there is a gradual or linear decrease in confinement pressure capacity when the orientation of fibres placed from transverse or direction towards longitudinal direction by an amount of 17%, 12% and 20% for CFRP, GFRP and AFRP respectively. Confinement effectiveness (f_{cc}/f_c) is the ratio of confined strength of concrete to the unconfined strength of concrete.

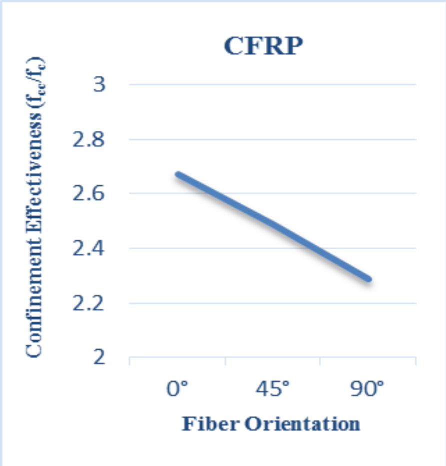

Fig. 5: Orientation of CFRP

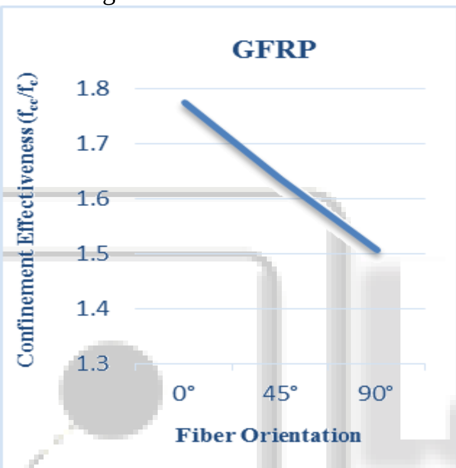

Fig. 6 Orientation of GFRP

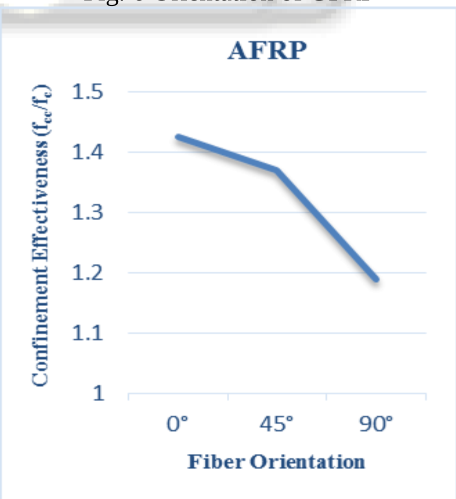

Fig. 7 Orientation of AFRP

B. Effect of Layers of Fibres

Number of layers or thickness of the fibres plays an important role in confinement effectiveness or capacity that can be seen in the figure 8, figure 9 and figure 10 for CFRP, GFRP and AFRP respectively. For a particular orientation that is along hoop direction the variation of stress from single layer to four layers are 13%, 8% and 6%. Hence there is an increase in the strength or compressive capacity of the cylinder with the increase in the layers of the FRP used.

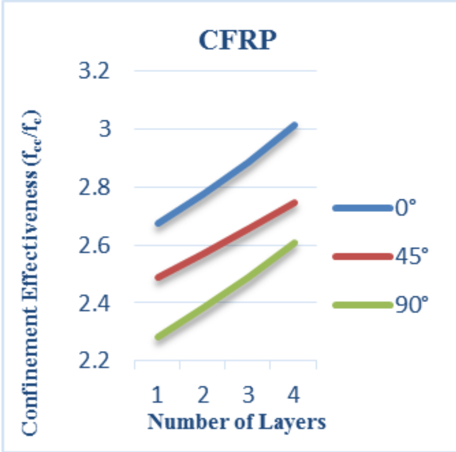

Fig. 8: Layers of CFRP

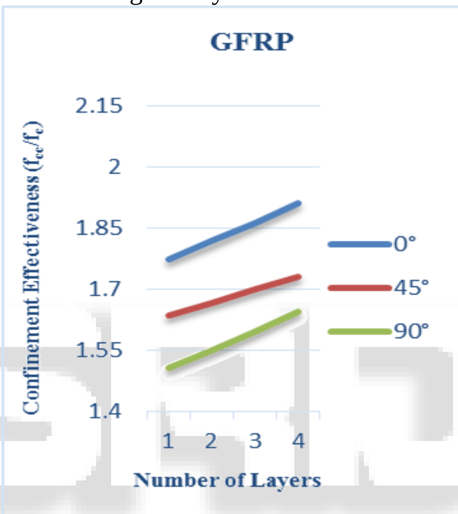

Fig. 9 Layers of GFRP

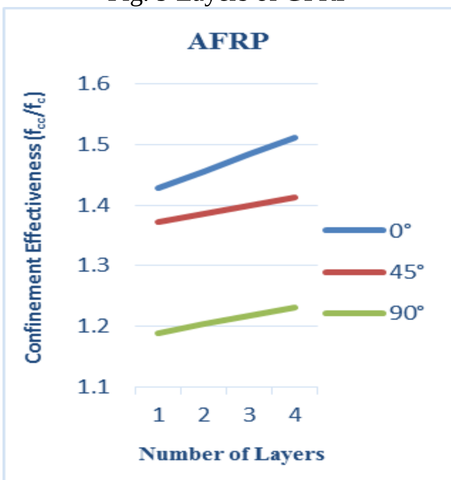

Fig. 10 Layers of AFRP

C. Effect of Material of Fibres

Material of the fibres such as carbon, glass and aramid have a significant role in the strengthening capacity towards the cylinder that can be noticed in the figure 11, figure 12 and figure 13. In the Figure 5.7 it can been noticed that carbon fibre wrapped cylinder yields 50% and 87% more for single layer of glass and aramid respectively for 0° Fiber Orientation.

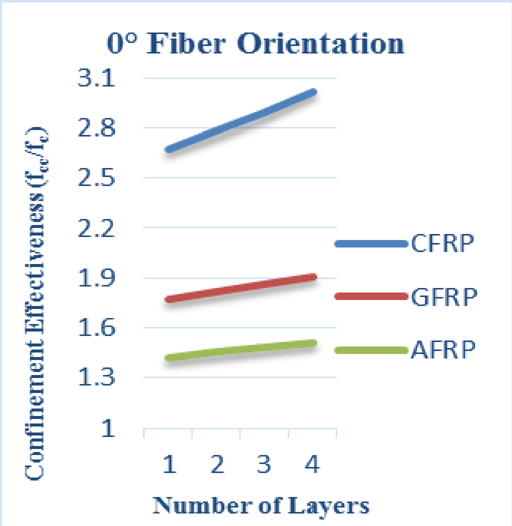

Fig. 11 0°Fiber Orientation

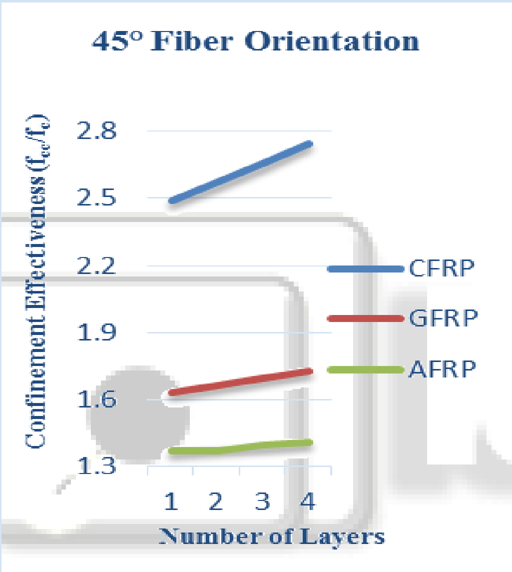

Fig. 12 45°Fiber Orientation

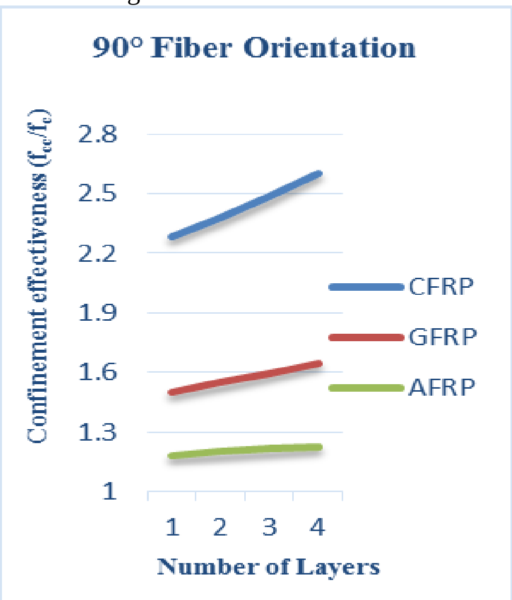

Fig. 13 90° Fiber Orientation

IV. CONCLUSIONS

It has been found that strengthening of a column having FRP laminate subjected to uni-axial compression works best for fiber orientation at hoop direction. The decrease in the confinement capacity of the FRP fibres is mainly because of the reason that fibres have good tensile property than compared to compressive. Hence when the compressive load is applied on the concrete cylinder there is hoop stress developed across it for which the fibres which are oriented perpendicular to the load carries more stress as maximum effectiveness of fibres are expected in tension.

FRP wall thickness has a considerable effect on strength, ductility and failure mode of wrapped concrete cylinders. But the capacity increase is very negligible when compared to the overall economy and the reason for very slight increase is because when the first hoop layer reach the ultimate strength and breaks apart, their forces are transferred to successive layers as it cannot resist the magnified forces, so the other layers are broken suddenly

From the results it has found that CFRP wrapped cylinders outperform GFRP and AFRP wrapped cylinders because of its high tensile strength, modulus of elasticity and other properties.

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