# Strengthening of Composite Column using Fiber Reinforced Polymer

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**Abstract**:

*Fiber Reinforced Polymer (FRP) systems for strengthening concrete structures are an alternative to traditional strengthening techniques, such as concrete jacketing. In this study a columns of old residential building of G+1 floor was strengthen using FRP system since user wanted to add two more floor on it. Different types of Fiber (Viz. carbon Fiber, Glass Fiber, Aramid Fiber) were considered for it. Design guidelines given by American Concrete Institute 440 is followed for manual calculations to find out number of FRP wraps and for modeling and analysis purpose ANSYS software is being used which encompass finite element method.*

***Index Terms*** *- ANSYS, Composite columns, FEM, Fiber wrapping.*

## I. INTRODUCTION

In today's growing economy, infrastructure development is also raising its pace. Many reinforced concrete and masonry buildings are constructed annually around the globe. With this, there are large numbers of them which deteriorate or become unsafe to use because of changes in use, changes in loading, change in design configuration, inferior building material used or natural calamities, thus leading to repairing and retrofitting of them. Some of widely used repair techniques are concrete Jacketing, Steel Jacketing, Precast Concrete Jacketing and Fibre Reinforced Polymer (FRP) Jacketing. In the past few decades world has seen outstanding advances in the use of composite materials in structural applications.

A composite material is basically a combination of two or more materials, each of which retains its own distinctive properties. The term composite is applied to materials that are created by mechanically bonding two or more different materials together. The resulting material has characteristics that are not characteristic of the components in isolation and composite action is developed when two load carrying structural members are integrally connected and deflect as a single unit. Most commonly, composite materials have a bulk phase, which is continuous, called the matrix; and a dispersed non-continuous, phase called the reinforcement, example: reinforced concrete (steel rebar in concrete). FRP strengthening systems use FRP composite materials as supplemental externally bonded reinforcement. FRP systems offer advantages over traditional strengthening techniques: they are lightweight, relatively easy to install, and are noncorrosive. Due to the characteristics of FRP materials as well as the behaviour of members strengthened with FRP, specific guidance on the use of these systems is needed.

## II. COMPOSITION OF FRP COMPOSITES:

### *A. The elements below given are the essential elements of FRP composites:*

***Resins*** - The primary functions of the resin is to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together, and protect the fibers from mechanical and environmental damage.

***Reinforcements*** - The primary function of fibres or reinforcements is to carry load along the length of the fibre to provide strength and stiffness in one direction.

***Fillers*** - Fillers are used to improve performance and reduce the cost of a composite by lowering compound cost of the significantly more expensive resin and imparting benefits as shrinkage control, surface smoothness.

***Additives*** - Additives and modifier ingredients expand the usefulness of polymers, enhance their process-ability or extend product durability.

In addition to above primer and putty fillers are also used in application of FRP systems.

### *B. Different Types of resins used with composites*

Resins are classified into two major groups: Thermoplastic resins which melt when heated and solidify when cooled. Thermoset resins, however, cannot be melted or reshaped by the application of heat and pressure, and therefore suitable for civil applications. Thermoset resins have four sub-categories as given below and are generally used in FRP systems.

***Polyester resin***- The most commonly used resin in glass reinforced plastic construction is the polyster resin and they have exhibited good performance.

***Epoxy resin***- The extensive use of epoxy resin in industry is due to ease with which they can be processed, excellent mechanical properties in composites, high hot and wet strength properties.

 

***Vinyl ester resin***- Being a combination of the principles of epoxy and polyester resin, they have close resemblance to polyester resins, but have chemistry similar to epoxy resins. It is superior to polyster resins because it offers greater resistance to water.
***Phenolic resin***- The main characteristic of phenolic resin is their excellent fire resistance properties. They have inferior mechanical properties to both polyester resins and epoxies, but have higher maximum operating temperature, much better flame retardant.

Table I: Properties of resins

| [Properties/ Resin Type] | Unsaturated Polyester | Epoxy |
|---|---|---|
| Density (g/cm3) | 1.2–1.3 | 1.2–1.3 |
| Elastic Modulus (GPa) | 2–3 | 2–4 |
| Tensile Strength (MPa) | 20–70 | 60–80 |
| Elongation (%) | 1–5 | 1–8 |
| Glass transition temperature(°C) | 70–120 | 100–270 |

### *C. Types of Fibers/Reinforcement used in FRP*

The most common types of Fibres are Carbon, Glass and Aramid; Carbon fiber reinforced polymer (CFRP), Glass fiber reinforced polymer (GFRP), and Aramid fiber reinforced polymer (AFRP) respectively.

***Carbon fiber material:***

Carbon fibers with three grades: high-strength, high-modulus, and ultra- high modulus are the most frequent fibers for civil engineering applications. These fibers are costlier but have high tensile strength and low Creep Rupture failure. As elasticity modulus of carbon fibers increases, the strain capacity declines, and this makes ultra-high modulus carbon fibers unsuitable for repair and strengthening purposes.

***Glass fiber material:***

Glass fibers are also categorized in three groups: E-glass, S-glass, and C-glass, with the first group being the most common type for civil applications. What makes glass fibers even more favorable is high strength to cost ratio. However, strength and stiffness degradation of glass fibers over time and under environmental effects should be taken into consideration.

***Aramid/Kevlar fiber material:***

Kevelar-29 and Kevelar-49 are the most frequent types of Aramid fibers for civil engineering applications. Aramid, unlike the two aforementioned fiber types, suffers from a low compressive to tensile strength ratio. This makes Aramid fibers almost inefficient when subjected to cyclic loading especially when Aramid reinforced polymers are used as vertical laminates.

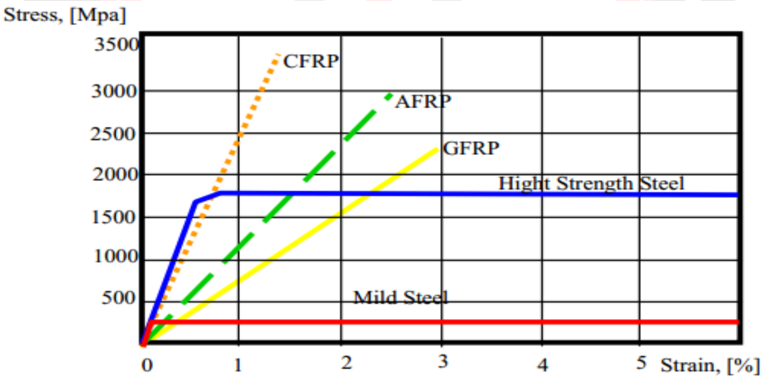


Fig 1.Stress strain behavior of typical fiber.

### *D. Stress Transfer in between FRP and Column*

FRP produces passive confinement in which lateral expansion is limited by confining concrete with FRP sheets; therefore tension axial forces are created in these confining elements. The increase of axial load in the column in this case increases the degree of confinement. The fibers confine the concrete and increase the axial strength by creating a triaxial stress condition. Tri-axial stress refers to a condition where only normal stress act on an element and all shear stresses are zero. An example of a tri-axial stress state is hydrostatic pressure acting on a small element submerged in a liquid.

  

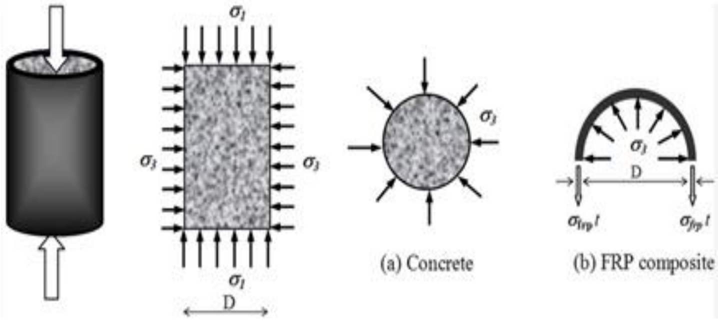


Fig 2. Stress transfer in Composite

## III. METHODOLOGY FOR FRP WRAPPING OF COLUMNS

Following procedure is used to wrapping FRP

***a) Grinding and surface preparation*:** grinding the plane surface followed by removing all the sharp corners.
***b) Primer Coating**:* It also makes the surface very smooth so that the epoxy sticks to the surface nicely
***c) Installation technique:***
***Wet lay-up***: flexible sheet or fabrics of raw or pre-impregnated fiber are saturated with an epoxy adhesives resin and placed on the surface of the concrete. As a result the resin acts both as the adhesive and as the FRP matrix.
***Hand lay up:*** The second technique involves application of epoxy throughout the surface where fiber is to be put followed by the adhesion of pre-cured rigid FRP strips or plates to the surface.
***d) Sand Sprinkling*:** A second coat of epoxy is then applied. After which, sand sprinkling and a minimum layer of 12mm thickness of polymer modified mortar covering is done. This is done to enhance the life of fiber wrap system.

## IV. STRUCTURAL DETAILS

With additional two floor on an old residential G+1 building, the load on the existing structure will increase. Structural details of central columns are given below
Height of column= 3m, Column size=230mm*230mm, longitudinal bars=4-12mm dia, stirrups=8mm dia at 192mm c/c.

***Load on structure***

| *For G+1 Structure:* | *For G+3 Structures:* |
|---|---|
| Load on First floor column: 155 KN | Load on First floor column (P1): 465 KN |
| Load on Ground floor column: 310 KN | Load on Ground floor column (P2): 620 KN |

Load carrying capacity of existing column=390KN

## V. DESIGN PROCEDURE FOR FRP SYSTEM

***Design guidelines:***

For design of strengthening, a composite action is assumed between fiber and existing concrete, with assumptions -

- No slip between FRP and Concrete.
- Shear deformation within adhesive layer is neglected.
- Tensile strength of concrete is neglected.
- FRP jacket has a linear elastic stress-strain relationship up to failure.

Because long-term exposure to various types of environments can reduce the tensile properties and creep-rupture and fatigue endurance of FRP laminates, the material properties used in design equations should be reduced based on the environmental exposure condition.

***Stress-strain behaviour of Concrete***

 

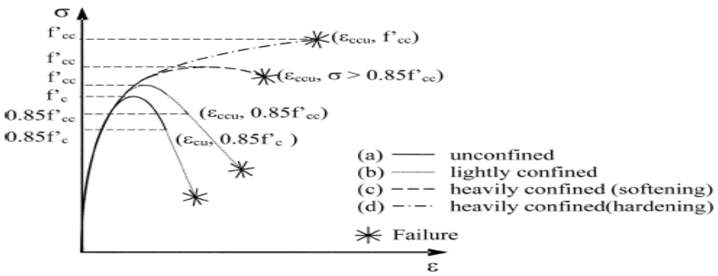


Fig 3. Stress-strain behavior of unconfined and confined RC columns (Rocca et al. 2006)

where, *fc'*-Specified compressive strength of concrete, *f´cc*- Compressive strength of confined concrete, *εcu*- Ultimate axial strain of unconfined concrete corresponding to 0.85*fco'* or maximum usable strain of unconfined concrete, in./in. (mm/mm),which can occur at 0.85*fc*' or 0.003, depending on the obtained stress-strain curve, *εccu*- Ultimate axial compressive strain of confined concrete corresponding to 0.85*f'cc* in a lightly confined member (member confined to restore its concrete design compressive strength), or ultimate axial compressive strain of confined concrete corresponding to failure in a heavily confined member,

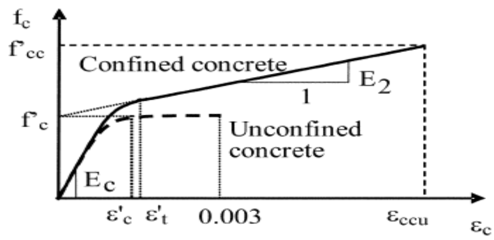


Fig 4.Stress-strain model by Lam and Teng(2003a,b) for FRP-confined concrete

Where, ε'*c*- Maximum strain of unconfined concrete corresponding to *f'c,* ε'*t*- Transition strain in stress-strain curve of FRP confined concrete, Ec- Modulus of elasticity of concrete, *εc*- Strain level in concrete

For non-pre-stressed members with existing steel-tie reinforcement, the axial compression strength is given by

$$f'_{cc} = \frac{1}{0.85(A_g - A_{st})}\left(\frac{\emptyset P_{n\,req}}{0.80\emptyset} - f_y A_{st}\right) \qquad (1)$$

Where**,** *Ag*- Gross area of concrete section, *Ast*- Total area of longitudinal reinforcement, φ- Strength reduction factor, *Pn*- Nominal axial compressive strength of a concrete section, *fy*- Specified yield strength of non prestressed steel reinforcement

***Number of wraps:***

No. of wraps can be calculated by below given formula

$$f_l = \frac{2E_f n t_f \varepsilon_{fe}}{D} \qquad (2)$$

Where, *n*- Number of plies of FRP reinforcement, *tf*- Nominal thickness of one ply of FRP reinforcement, *D*- Diameter of compression member of circular cross section, *εfe*- Effective strain level in FRP reinforcement attained at failure, *Ef*- Tensile modulus of elasticity of FRP, *fl*- Maximum confining pressure due to FRP jacket

TABLE II: Number of calculated wraps using ANSYS

| | First Floor column (P1) | Ground Floor column (P2) |
|---|---|---|
| No of Carbon layers | 1 | 2 |
| No of E glass layers | 2 | 6 |
| No of Kevlar layers | 1 | 3 |

## VI. RESULTS AND ANALYSIS

The ground floor and first floor central columns wrapped with carbon, glass and Kevlar fibers were analyzed using ANSYS and in all 6 cases were considered. Results based on the ANSYS analysis are compared with failure criterions.

 

### *A. Failure criterion:*

***Lateral Strain versus Rupture strain of Fibre:***

Axially loaded FRP wrapped column observed typical failure by rupture of FRP layer. Basis this lateral strain induced due to applied loads are compared with the rupture strain.

Table III: Lateral strain verses rupture strain

| Fiber Type | Lateral strain (P1) | Lateral strain (P2) | Rupture Strain of Fibre |
|---|---|---|---|
| Carbon Wrap | 0.000350 | 0.000453 | 0.0167 |
| Glass Wrap | 0.000371 | 0.000370 | 0.0200 |
| Kevlar Wrap | 0.000375 | 0.000347 | 0.0250 |

***Maximum axial compressive strain:***

The maximum axial compressive strain in the FRP-confined concrete εccu should be limited to 0.01 to prevent excessive cracking and the resulting loss of concrete integrity.

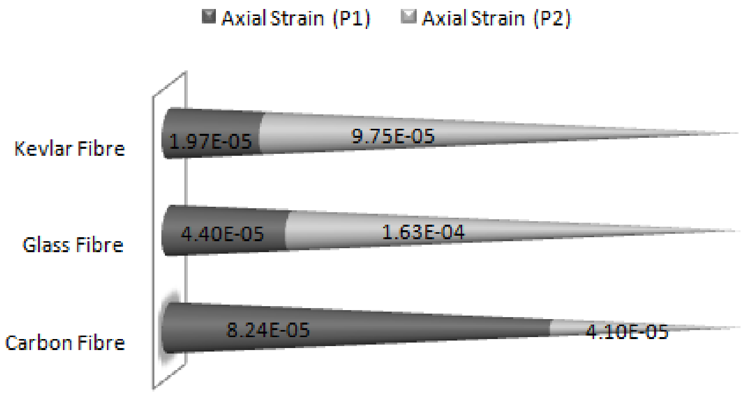


Fig 5.Maximum Axial strain in fibers (Left to right- Axial Strain (P1) and Axial Strain (P2))

***Permissible Stress Vs Equivalent stress:***

Stresses developed due to additional load on the columns are within the permissible stress.

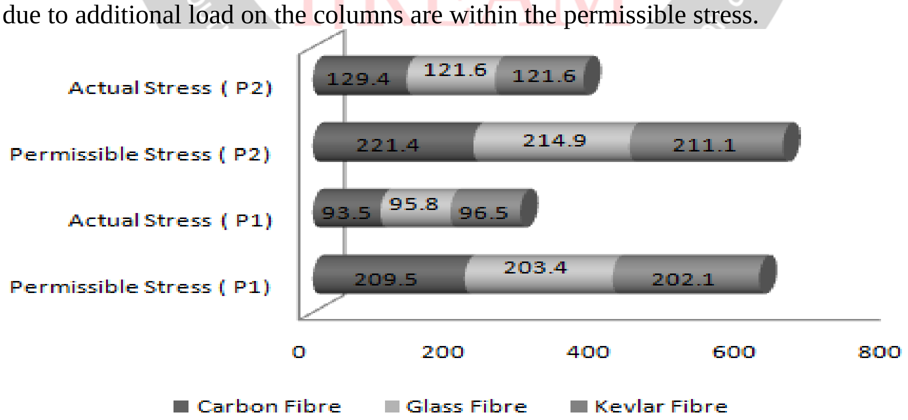


Fig 6. Stress in Fibers (Left to right- Carbon, Glass and Kevlar)

### *B. Cost Comparison:*

Summary of Total cost of different fibre wraps as per different loadings conditions is given below:

Table IV: Cost comparison

| Fiber Type | Avg. rate per layer of fibre | Total cost for P1= 465 KN | Total cost for P2= 620 KN |
|---|---|---|---|
| Carbon Wrap | INR 4104/- | INR 4104/- | INR 8208/- |

 

| | | | |
|---|---|---|---|
| Glass Wrap | INR 1897/- | INR 3794/- | INR 11382/- |
| Kevlar Wrap | INR 2167/- | INR 2167/- | INR 6501/- |

## VII. DISCUSSION

- It was found that Ultimate axial compressive strain in all the fibres is less than 0.01 and hence safe.
- Lateral strains induced in the FRP wraps due to two different loads are within permissible rupture strain of the fibres and hence the structure is safe.
- It was inferred that stress as per ANSYS results are within permissible stress limits and hence structure is safe.

## VIII. CONCLUSION

- Ground floor column was able to take minimum additional loading of 60% and first floor column was able to take minimum additional loading of 19% after FRP wrapping as compared to unwrapped column.
- The software results using Finite Element Analysis showed in general a good agreement with ACI committee's design recommendation.
- The calculated wraps were sufficient to handle the additional loads on the column and were able to satisfy the checks provide by the ACI committee.
- CFRP wrapping is costlier when compared to GFRP and KFRP wrapping for lower loadings however when loading increases KFRP became the least costly and GFRP became costliest amongst the three.
- Fibre reinforced polymer wrapping can be used effectively for strengthening of columns.

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