Comparative Study On Effect Of Various FRP Wrappings With Varying Patterns On Load Bearing Capacity Of Confined Concrete Columns

P.Nikhil Kumar\textsuperscript{a}, M. Achyutha Kumar Reddy\textsuperscript{b}

\textsuperscript{a}P.G Student, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India-522502.

\textsuperscript{b}Faculty, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India-522502.

Abstract

Retrofitting of concrete structures has become an alarming need considering the hazards to which they are exposed these days. The age of the structure is directly proportional to the vulnerability towards damage and this calls for immediate care to be taken. Strengthening of key structural members like columns is one of the methods which can affect the overall strength on a large scale. Among the various retrofitting and strengthening methods available, Fiber reinforced polymer (FRP) wrapping is considered to be easily workable and also affects the structural integrity on a very minimal scale. In this experimental study, RCC columns are wrapped using Carbon fiber reinforced polymer (CFRP), Glass fiber reinforced polymer (GFRP) and Polypropylene fiber reinforced polymer (PFRP) with varying configurations of wrapping to check their efficiency in improving the load carrying capacity and deflection under the application of axial load. The fibre fabric employed in this study is bi-directional. It has been concluded that the concrete columns wrapped with CFRP have higher load bearing capacity and better resistance against deflection compared to other columns deployed using the remaining two fibres.

Keywords: Retrofitting, Wrapping, Fiber reinforced polymer, Carbon, Glass, Polypropylene, CFRP, GFRP, PFRP, Deflection

Email: nikhilpulipati2903@gmail.com
1. Introduction

In the few past decades, we have observed diverse damage of structures caused due to earthquakes. The lateral loads induced from these earthquakes mainly affect the structural members like beams and columns. Retrofitting is one of the main approach of which the construction industry is in dire need. Therefore, there’s an alarming need of repair and retrofitting of the members to make them resistant to lateral loads[1]. One of the widely used technique for this is FRP wrapping.

Fibre-reinforced plastic (FRP) (also called fiber-reinforced polymer, or fiber-reinforced plastic) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass (in fibreglass), carbon (in carbon fiber reinforced polymer), aramid, or basalt. Rarely, other fibres such as paper, wood, or asbestos have been used. The polymer is usually an epoxy, vinyl ester, or polyester thermosetting plastic, though phenol formaldehyde resins are still in use. Fibre reinforced polymers (FRP) are composites used in almost every type of advanced engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and civil infrastructure such as bridges and buildings. These composites are lightweight, non-corrosive, exhibit high specific strength and specific stiffness and can be effortlessly tailored to satisfy the performance requirement[2]. These are also chosen because of their high strength-weight ratio, good fatigue performance and also provides resistance against deterioration caused due to the environment[3]. The retrofitting performance of FRP depend on different parameters such as: fiber types, thickness of FRP, being uni- or multi-directional, etc[4].Hence, these are increasingly being considered as an enhancement to and/or substitute for infrastructure components or systems that are constructed of traditional civil engineering materials, like concrete and steel. In FRP wrapped columns, the core of the member in the most affected portion due to lateral forces and the FRP wraps take these lateral forces[5]. Various FRP fabrics are used to strengthen the structural members against lateral loads providing the required longitudinal reinforcement. Some of the main materials employed are glass, carbon, aramid along with some natural fibres like jute, coir and banana fibres. Compared to jacketing by steel or concrete, wrapping is found to be more economical and has higher workability.

Satwik et al.[6] investigated the effect of CFRP wrapping on the compressive strength of preloaded cylindrical concrete specimens and concluded that the specimens
wrapped with a single layer of CFRP has 55% of increase in strength and a 80% increase in axial deformation compared to unwrapped specimens. The CFRP wrapping has been observed to increase the strength of pre damaged specimens in this study. Kinjal V Ranolia et al.[7] carried out experimental and analytical studies on cylindrical concrete specimens wrapped with various configurations and introduction of cracks in E-glass fibres. It was concluded that the specimens were observed to fail in the middle part when they were fully confined and in the top and bottom parts when they were confined partially and it took place at top and bottom portion in case of partially confined specimens. There were also cases where the FRP fabrics couldn’t take the applied axial load on the member because of poor bonding mechanism between the concrete and the polymer fabric[1]. Costas. P. Antonopolos et. al concluded that column-beam retrofitting column-beam joints with FRP enhances the structural strength and also stated that mechanical anchorage also plays an important role in controlling the debonding failure between the FRP material and the concrete members[8].

Though there were previous studies dealing with comparison between CFRP and GFRP and their effect on the compressive strength of concrete, there was study lacking where they were wrapped with varying configuration with also an additional fibre fabric in comparison which is Polypropylene. Hence, this experimental investigation deals with the strength comparison of columns wrapped with CFRP, GFRP and PFRP with three varying mechanisms of wrapping.

2. Material Properties

The concrete employed in this study was of grades M30 with a mix proportion ratio of 1:1.9:3.1. The materials used in the mix are OPC cement of grade 53 and coarse aggregates of both 12mm and 20mm diameters contributing 40% and 60% of the whole quantity respectively and river sand was used as the fine aggregate. The superplasticizer used was Hi-bond. The reinforcement made with Fe415 steel of the columns consisted of 4 bars of 12mm diameter and 6 stirrups of 8mm diameter with a spacing of 100mm c/c. A cover of 40mm was provided on both ends of the columns. Square columns were casted whose dimensions were 150*150*700 mm which were let to cure for 28 days.

The fabrics deployed are made of three different materials namely Glass, Carbon and Polypropylene. The attachment of the fabrics around columns was done using Araldite epoxy
resin and Araldite epoxy hardener. The fabrics are deployed with varying thickness and configurations. Each fibre fabric was wrapped in three varying patterns around the concrete columns specifically fully wrapped with a single layer, fully wrapped with a double layer and partially wrapped. Figures 1 and 2 describe the reinforcement detailing of the column and the types of wrapping patterns respectively.

![Figure 1. Reinforcement Detailing of Column](image1)

![Figure 2. Types of Wrapping patterns](image2)
3. **Experimental Investigation:**

Firstly, the amount of materials required for the selected grade of concrete was calculated by designing the mix proportion. Upon calculation, the amount of materials needed for the 1m$^3$ of concrete were found to be 72.35kg of cement, 31.11kg of water, 225.05kg of coarse aggregate and 137.18kg of fine aggregate. OPC Cement was acquired from a trusted local dealer and is of grade 53. The concrete mix was added with 0.5% of admixture for workability and then the mix was introduced into the miller.

![Miller Mixing](image)

**Figure 3. Miller Mixing**

The mix was worked upon in the miller with introduction of water content in frequent intervals and was let to roll for about 1-2 minutes and ultimately the resultant mix was collected in a vessel. Simultaneously, the columns moulds of required size were cleaned and oil was smeared on the inner surface for easy debonding between the concrete sample and the mould after it gets set. Then, the concrete mix was filled in the moulds carefully to attain a smooth finishing. These concrete filled moulds were placed in a safe place so that they don’t get affected by the climatic or surrounding conditions and were left to set for 2 complete days. After thorough examination of the columns, they were demoulded and were placed in the curing tank one by one.
Figure 4: Casting and Curing of Specimens
Experimental studies have been carried out on 20 concrete column specimens out of which 18 columns were wrapped with any of the three fibres either fully or partially while the remaining 2 columns were tested with control mix. The deflections of the columns when load is applied on them are measured using Linearly Varying Displacement Tool (LVDT) placed at the central point of the specimen. The control mix column which is introduced on the loading frame for carrying out the axial load test can be observed in Figure 3.

Later, the remaining 18 columns were deployed for FRP testing with varying wrapping patterns of CFRP, GFRP, PFRP to be conducted on the loading frame. Before wrapping, the columns were cleaned and smoothened to make them more workable and efficient for resin application. Each of the three types of FRP was wrapped around the columns using epoxy resin and hardener and allowed to set for 2 hours. Each fiber fabric was wrapped in three varying patterns namely single layered fully wrapped, double layered fully wrapped and double layered centre wrapped. The FRP wrapped columns were then installed on the Loading Frame to conduct the compressive strength tests. The nine various wrapping mechanisms on a whole were distributed to the 18 columns finally giving us 2 columns each for every case of wrapping. They were tested and the average of the two recorded load values was considered and presented as the final value. Table 3 discusses the wrapping of each specimen below.
Table 3. Specimen Details

| S.no | Specimen | CFRP | GFRP | PFRP |
|------|----------|------|------|------|
| 1.   | C-A      | -    | -    | -    |
|      | (control)|      |      |      |
| 2.   | C-B      | SLFW | -    | -    |
| 3.   | C-C      | DLFW | -    | -    |
| 4.   | C-D      | DLCW | -    | -    |
| 5.   | C-E      | -    | SLFW | -    |
| 6.   | C-F      | -    | DLFW | -    |
| 7.   | C-G      | -    | DLCW | -    |
| 8.   | C-H      | -    | -    | SLFW |
| 9.   | C-I      | -    | -    | DLFW |
| 10.  | C-J      | -    | -    | DLCW |

SLFW- Single layered fully wrapped.
DLFW- Double layered fully wrapped.
DLCW- Double layered centre wrapped.

Results and Discussions:

When the control mix column C-A has been tested on the loading frame, a load of 342.56KN has been registered with a deflection of 3.62 mm. In this case, the cracks on the column were observed to be present near the top face of the column and seen to pass to the centre portion. As the column exhibited splitting cracks, we can confirm that this column has failed due to compressive failure due to axial load. The columns C-B, C-C and C-D which were wrapped using CFRP with varying patterns of wrapping namely single layered fully wrapped (SLFW), double layered fully wrapped (DLFW) and centre wrapped (CW) have recorded their strengths as 519.64KN, 489.8KN and 465.4KN respectively when subjected to axial load on the loading frame with a maximum deflections of 1.46mm, 1.98mm, 2.92mm.
respectively. The GFRP fabric was deployed around the specimens C-E, C-F, C-G in the same three patterns and gave the strength values of 483.2KN, 459.4KN and 421KN with the deflection readings of 1.56mm, 2.30mm, 3.15mm respectively. The final three columns C-H, C-I, C-J wrapped with PFRP gave the strength values as 428.2KN(DLFW), 401.78(SLFW) and 376.8KN(CW) with the deflections of 2.68mm, 2.96mm, 3.37mm respectively. Table 4 discusses the comparison among the loads and deflections of the specimens.

Table 4. Comparison of load and deflection results

| S.no | Specimen | Ultimate load (KN) | Deflection (mm) |
|------|----------|--------------------|-----------------|
| 1.   | C-B      | 519.64             | 1.46            |
| 2.   | C-C      | 489.8              | 1.98            |
| 3.   | C-D      | 465.4              | 2.92            |
| 4.   | C-E      | 483.2              | 1.56            |
| 5.   | C-F      | 459.4              | 2.30            |
| 6.   | C-G      | 421.0              | 3.15            |
| 7.   | C-H      | 428.2              | 2.68            |
| 8.   | C-I      | 401.78             | 2.96            |
| 9.   | C-J      | 376.8              | 3.37            |
Figure 6. Failure of Specimens
Figure 4 displays the failure of the specimens in which we can perceive the following. Though the GFRP wrapped members displayed rupture of the fabric around them, there were slight/no fibre ruptures observed in the other two cases of PFRP and CFRP. These members were found to attain failure without any deformation in the wrapped FRP fabrics. Hence, a possibility of an occurrence of debonding failure between the FRP fabric and the column surface can be considered which ultimately led the concrete alone to consume the axial load applied on the member without much contribution from the PPFRP and CFRP fabrics installed. Figure 4 and Figure 5 represents that the CFRP wrapped specimens have higher strengths compared to the other specimens and the relation between load and deflection of each specimen respectively.

![Figure 7: Load comparison on specimens](image)

Figure 7. Load comparison on specimens
Figure 8. Load vs Deflection

Conclusions:

This study mainly deals with the experimental investigation conducted to evaluate the behaviour of columns wrapped with CFRP, GFRP and PFRP fabrics with varying schemes of wrapping. Two unwrapped specimens and the remaining 18 FRP wrapped specimens which are tested on the loading frame for axial load provided the following conclusions.

- The columns which were fully wrapped with a single layer of CFRP, GFRP and PFRP showed an increase of 43%, 34% and 17% in the compressive strength respectively.
- Double wrapped specimens displayed an increase of 52%(CFRP), 41.5%(GFRP) and 25.4% (PFRP) in their load bearing capacity.
- The final case of wrapping at centre depicted a rise in strength by 36%, 23% and 10.2% when wrapped with CFRP, GFRP and PFRP fabrics respectively.
- Double layer fully wrapped specimens were observed to depict the highest development in their strength.
- CFRP wrapped columns have shown comparatively less deflection values compared to the other two fibre fabrics deployed ones.
• CFRP fabrics were observed to provide the best confinement among the FRP fabrics deployed and hence the most efficient material to improve the compressive strength of RCC columns.
References:

[1] S. Durgadevi, S. Karthikeyan, N. Lavanya, and C. Kavitha, “Materials Today: Proceedings A review on retrofitting of reinforced concrete elements using FRP,” Mater. Today Proc., no. xxxx, 2020, doi: 10.1016/j.matpr.2020.03.148.

[2] Norsuzila Ya’acob1, Mardina Abdullah1, 2 and Mahamod Ismail1 et al., “We are IntechOpen , the world ’ s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %,” Intech, vol. 32, pp. 137–144, 1989, [Online]. Available: http://www.intechopen.com/books/trends-in-telecommunications-technologies/gps-total-electron-content-tec-prediction-at-ionosphere-layer-over-the-equatorial-region%0AInTec.

[3] Q. Qiu and D. Lau, “A novel approach for near-surface defect detection in FRP-bonded concrete systems using laser reflection and acoustic-laser techniques,” Constr. Build. Mater., vol. 141, pp. 553–564, 2017, doi: 10.1016/j.conbuildmat.2017.03.024.

[4] A. Kheyroddin, H. Arshadi, M. R. Ahadi, G. Taban, and M. Kioumarsi, “Materials Today: Proceedings The impact resistance of Fiber-Reinforced concrete with polypropylene fibers and GFRP wrapping,” Mater. Today Proc., no. xxxx, 2021, doi: 10.1016/j.matpr.2021.02.116.

[5] A. Cascardi, F. Micelli, and M. A. Aiello, “An Artificial Neural Networks model for the prediction of the compressive strength of FRP-confined concrete circular columns,” Eng. Struct., vol. 140, pp. 199–208, 2017, doi: 10.1016/j.engstruct.2017.02.047.

[6] M. C. Sathwik, M. H. Prashanth, S. C. Naik, and A. Satish, “Experimental and numerical studies on compressive behaviour of CFRP wrapped cylindrical concrete specimens subjected to different pre-loading conditions,” Mater. Today Proc., vol. 27, no. xxxx, pp. 327–335, 2020, doi: 10.1016/j.matpr.2019.11.041.

[7] K. V. Ranolia, B. K. Thakkar, and J. D. Rathod, “Effect of different patterns and cracking in FRP wrapping on compressive strength of confined concrete,” Procedia Eng., vol. 51, no. NUiCONE 2012, pp. 169–175, 2013, doi: 10.1016/j.proeng.2013.01.025.
[8] C. P. Antonopoulos, T. C. Triantafillou, and M. Asce, “Experimental Investigation of FRP-Strengthened RC Beam-Column Joints Experimental Investigation of FRP-Strengthened RC Beam-Column Joints,” vol. 0268, no. February, 2018, doi: 10.1061/(ASCE)1090-0268(2003)7.