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A Review on the Frp Strengtheing in Different Structural Elements

P. Irin Priscilla[1], Dr. M. Murugan[2]
[1]*Post Graduate Student, Department of Civil Engineering, Government College of Engineering, Tirunelveli, Tamilnadu, India.*
[2]*Assistant Professor, Department of Civil Engineering, Government College of Engineering, Tirunelveli, Tamilnadu, India.*

ABSTRACT:
In the recent years, FRPs are frequently used in the construction industry mainly for retrofitting. FRP can be in repairing damaged structures, strengthening in seismic zones and in extension of the structure. Various researches are made in using FRP as shear, flexure and impact strengthening material in concrete structures. This paper provides the literature review on using FRP composites as strengthening material in concrete structures. This paper takes various factors into considerations such as different wrapping configurations, strengthening techniques, different loading conditions in different structural elements as experimental, analytical and theoretical studies.
KEYWORDS: *FRP strengthening techniques, wrapping configuration, reinforced beams and columns, impact load*

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I. INTRODUCTION

Fibre Reinforced Polymer (FRP) is the composite of fibre and polymer matrix. These FRP have various privileges such as light weight, high strength, durability, ease of handling etc. These advantages lead them to various applications such as automobile industry, construction sector etc. In the construction field, FRP can be used in seismic strengthening and retrofitting. FRP can be used in the form of sheets or mats, strips, laminates, bars in reinforcement or fibres can be mixed with concrete. Various types of FRPs such as Carbon, Glass, Aramid, Basalt can be used. These types have different properties based on the composition and hence can be used depending on the requirements.

II. LITERATURE REVIEW

2.1 FRP STRENGTHENING TECHNIQUES

Islam et al (2005) performed an experimental study on RC deep beams which are strengthened by various FRP external strengthening methods. It was found that CFRP grid placed at normal orientation had the higher load carrying capacity comparatively with other methods of orientation and other methods like CFRP strips and wraps. About 40% increase in strength was recorded while using normally oriented CFRP grids. However, in regular practice it was not found to be effective in deep beams.

Cao et al (2005) studied the debonding behaviour of FRP shear strengthened RC beams. FRP strengthening was made by complete wrapping. Eventually the failure was due to FRP debonding followed by FRP rupture. The strain distribution was noted and results showed that the increase in load applied causes the increase in strain distribution factor. The shear span-to-effective depth ratio was also found to be in relation with strain distribution factor.

Sasmal et al (2011) studied the seismic retrofitting in a non-ductile Beam-Column assembly under cyclic loading. Retrofitting was done using both GFRP wrapping and steel plate jacketing techniques. Results showed that proper retrofitting can redeem the original strength of the existing damaged structure. The suggested method was found to regain the strength of the damaged structure substantially.

Baggio et al (2014) investigated the shear strengthening of shear deficient RC beams by using different types of FRPs and FRP anchors. Results showed that U-wrapped FRP sheets for full depth performed well than partial depth. Due to strengthening the failure mode changed from shear to flexure failure. FRP anchors prevented the brittle failure due to debonding increasing the ductility of the RC beam.

Chen et al (2018) conducted an experimental and analytical study on the effect of FRP confining effect and FRP thickness on the flexural behaviour of FRP - HB bonded strengthened RC beams. It was found that HB strengthening increases both ductility and load carrying capacity in RC beams when the failure mode was fastener detachment and FRP rupture occurring simultaneously. Analytical studies were in correlation with the experimental results.

Chellapandian et al (2019) studied the Hybrid FRP technique for its flexural behaviour in the strengthening of reinforced concrete elements. In this paper, the performance of NSM and EB along with the hybrid combination of both the methods using experimental, analytical and modeling methods. The results showed that using only NSM increased the strength by 85% while EB only increased the ductility. The hybrid method using both NSM and EB increased strength by 160% with significant increase in ductility. The results were found to be similar to that of the results from analytical and modeling methods.

Mhanna et al (2019) experimentally studied the shear strengthening of RC beams using different CFRP configuration wrappings such as U-wrapping and complete wrapping. Comparative study was done between T beams and rectangular beams. Results showed that U-wrapped RC beams failed due to brittle failure caused by FRP wraps debonding while completely wrapped RC beams failed due to FRP rupture increasing the ductility. Hence complete wrapping was preferred than U-wrapping. However, when complete wrapping cannot be done, U-wrapping can be used along with proper anchoring.

Hadhood et al (2019) conducted an experimental and theoretical study on the strengthening on RC beams using short CFRP strips that are externally bonded and fastened by mechanical fasteners. Variations were made by using different spacing-to-fastener diameter ratios. Results showed that reduction of length of the strips up to 44% attain the similar strength as of long externally bonded strips. The spacing-to-fastener diameter ratio of 5.5 was found to perform well comparatively.

Mostofinejad et al (2020) evaluated the effectiveness of warp and woof anchoring method in FRP strengthened RC beams. Results showed that warp and woof technique performed well in comparison with U shaped anchoring. It also increased the load carrying capacity and ductility of the RC beam significantly. Increasing the height of the anchorage did not provide significant changes while increasing the width, increased the strength of the beams.

Nie et al (2020) studied the effect of beam web opening in FRP strengthened RC beams. Results showed that web opening reduced the flexural capacity of the beam while FRP strengthening increased the shear capacity and stiffness. The FRP strengthening increased the ductility of the beam indicating the strong column weak beam hierarchy. This method can be used in existing structures as post cut method was found to be feasible.

Salama et al (2020) investigated the performance of RC beams flexure strengthened externally by side bonded FRP sheets. Results showed that the side bonded beams were less effective than conventional FRP strengthening method. Side bonding reduced the ductility while increasing the strength of the beams. Increase in the width of the side bonding did not affect the increment of strength.

2.2 IMPACT LOADING

Pham and Hong Hao (2016) investigated the behaviour of FRP strengthened RC beams without stirrups under impact loading. Different FRP configurations such as U-wrapping and 45^0 FRP wrapping were compared. It was found that 45^0 wraps performed well compared to U-wrap in displacement and strength. However full wrap is more efficient compared to FRP strips.

Kishi et al (2020) experimentally investigated the effect of low velocity impact load in the FRP flexure strengthened RC beams. Results showed that the failure mode changed from flexure to flexure-shear failure. Maximum deflection reduced due to FRP strengthening against impact loading. Cracks were observed both at the top and bottom of the beam.

Saleh et al (2020) studied the performance of the Glass Fiber Reinforced Polymer (GFRP) bar reinforced concrete beams under low velocity, high intensity impact loads. Results showed that the beams with high shear strength failed by flexure or flexure-shear while low shear strength beams failed in shear under high intensity impact load. Low residual deflections were observed in higher shear capacity beams.

2.3 ANALYTICAL AND THEORETICAL STUDY

Chalioris (2007) proposed an analytical model to predict the torsional behaviour of FRP externally bonded RC beams. An experimental study was conducted to compare both results. Results from analytical and experimental studies were found to be in good correlation. Results showed that continuous FRP sheet wrapping provided higher strength when compared to FRP strips.

Hawileh et al (2019) developed a new finite element model to track the flexural behaviour of RC beams which are strengthened externally by longitudinal side bonded CFRP laminates. Results from the FE model was found to be correlated with the results from experimental and numerical studies. It was found that CFRP side bonded laminates performed well in increasing the load carrying capacity of the RC beams while decreasing the ductility. Meanwhile increase in the reinforcement ratio was found to reduce the load carrying capacity of the RC beams side bonded by CFRP laminates longitudinally.

Kamgar et al (2019) formulated a new method for shear capacity calculation in the FRP strengthened RC beams using MGP method. Experimental results from various papers already published were taken for instances and then verified using the MGP, ANFIS methods along with the formulas from ACI 440.2R, CSA-S806, Fib-TG9.3 and CIDAR. Different types of errors like MAPE, RMSE and R^2 where evaluated. Results showed that errors were reduced in MGP method and the new formulation showed higher precision comparatively.

Shahriari and Naderpour (2020) analysed the reliability of the shear strengthening using FRP sheets of different configurations in shear deficient RC beams. Results showed that the reliability index (β) depends on the shear reinforcement, concrete grade and applied load. It was found that the reliability index decreased with the increase in the applied load. The reliability of the full wrap configuration was found to be the least compared to U-wrap and side bonding configurations.

Kadhim et al (2020) developed a finite element model and conducted an analysis of FRP strengthened RC beams under impact loading condition. It was found that location and velocity of impact load affected the maximum deflection of the RC beam. The model proposed also gave accurate results regarding crack patterns and FRP failure. It was also found that soffit corners that are rounded or arched performed well compared to sharp corners.

Spinella (2019) studied the behaviour of shear deficient RC beams strengthened by FRP using an analytical model. The model proposed took into account, the effect of FRP strain, principal compressive strain along with the effect of the interaction between external and internal reinforcement. Results showed that the effect of the internal and external reinforcements depend on the rigidity of vertical strengthening. The interaction factor showed better accuracy in shear stress.

2.4 CONCRETE FILLED STEEL TUBES

Campione et al (2000) conducted an experimental study on FRC filled steel columns and plain concrete filled columns. Moment-Axial Force diagrams were also made and compared. Results showed that FRC filled steel columns showed high strength and stiffness comparatively. Analytical verification was done using the formulas from American and European codes.

Esfahani and Kianoush (2008) conducted an experimental study on the axial compressive strength of FRP wrapped RC columns of varying cross sections. Results showed that FRP wrapped circular columns performed well comparatively with square columns. However, FRP wrapped RC square columns with rounded corners had higher ductility and strength when compared with FRP wrapped RC square columns with sharp corners.

Smith et al (2010) performed an experimental investigation on the FRP wrap effectiveness in large unreinforced concrete cylinders based on the number of FRP wrap layers and their continuity. Results showed that specimen with more FRP wrap layers with proper overlapping in the discontinuous condition had strength enhancement up to 62%.

Hu et al (2011) studied the behavior of FRP-Confined Circular Concrete-Filled Thin Steel Tubes under Axial Compression. Results showed that a thicker FRP wrap led to a greater enhancement in performance. For the same FRP wrap thickness, the degree of enhancement in the load-carrying capacity is seen to be greater for CFTs with a thinner steel tube.

Zhang et al (2014) studied the behavior of Concrete-Filled FRP Tubes under Cyclic Axial Compression. Results showed that the concrete in CFFTs behave more like the concrete confined by FRP wrap in the cyclic stress-strain aspects. However, the performance of monotonic stress-strain model was found to be better for HSC in CFFTs.

III. CONCLUSION

- Complete wrapping of FRP in RC beams provided higher strength than other wrapping configurations. But in inaccessible places, U-wrap can be used.
- According to reliability factor, complete wrap was considered to be least reliable comparatively with other wrapping configurations.
- Hybrid bonding techniques improved the strength of the structure significantly than conventional strengthening techniques.
- FRP anchors or fasteners prevented the debonding of FRP leading the failure to be FRP rupture rather than FRP debonding.
- Under impact loading, 45^0 FRP wrap performed better than U-wrap configuration in displacement and strength. However full wrap is more efficient compared to FRP strips.
- FRP wrapped circular columns performed well comparatively with square columns. However, FRP wrapped RC square columns with rounded corners had higher ductility and strength when compared with FRP wrapped RC square columns with sharp corners.

- Specimen with more FRP wrap layers with proper overlapping in the discontinuous condition had strength enhancement.

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