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Strength Characteristics of RC Structures Wrapped With FRP –A Review

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Abstract: Strengthening of reinforced concrete structures is given top priority in construction sector across the world. Due to ageing of existing structures and change of expected load patterns, the stability of structure may be reduced. In this case, Fibre Reinforced Polymer (FRP) materials have been recognized as vital constituents to solve stability issues of the modern concrete structures. The FRP material has improved structural performance in terms of stability, stiffness, strength and durability. Fibre-Reinforced Polymers wrapping is one of the widely used technique to restore the strength of a concrete structures.This review paper focuses on various wrapping techniques of fiber-reinforced polymer sheets for external strengthening of reinforced concrete structures such as reinforced circular columns, square beams, columns and column-beam joints. The purpose of this study is to present a constructive critical review of the techniques for FRP retrofit concrete structures.

Keywords: Fiber reinforced polymer (FRP), wrapping techniques, FRP sheets, column, Beam, strength characteristics

INTRODUCTION

Advanced composite materials have found expanded use in aerospace, marine and automobile industries during the past few decades (1960 onwards) due to their good engineering properties such as high specific strength and stiffness, lower density, high fatigue endurance, high damping and low thermal coefficient (in fiber direction), etc. Civil engineers and the construction industry have begun to realize potential of composites as strengthening material for many problems associated with the deterioration of infrastructures. Now a day's many countries, repair and retrofitting of existing structures have become a major part of the construction activity. The rehabilitation of concrete structures is winding up progressively because of the need to maintain and enhance the vast built environment acquired from the twentieth century. Over the most recent two decades, there has been an expanding enthusiasm for utilizing fibre reinforced polymer (FRP) composites to repair and strengthen reinforced concrete (RC) structures. The external bonding of FRP strips or sheets/fabrics are one of the most effective technique. Various aspects of FRPC materials including guidelines for selection of polymer adhesives for concrete have been highlighted by ACI Committee-503(Uomoto et al. 2002).First applications of composites were in the form of rebar's and structural shapes. Later, FRPC laminates were used for strengthening of concrete bridge girders by bonding them to the tension face of girder(Meier 1992).For the increase or to regain the strength of concrete structure now a days FRP of different materials i.e., Carbon Fiber / Aramid or Kevlar Fiber/ Basalt Fiber & Glass Fiber.

1. Repair and rehabilitation of structural elements

The dominant part of restoration works comprises of repair of old deteriorating structures, damage due to seismic activities and other natural hazards. Structural strengthening is also required because of degradation problems which may arise from environmental exposure, inadequate design, poor quality construction and a need to meet current design requirement. Therefore, structural repair and strengthening has received much attention over the past two decades throughout the world. Recent experimental and analytical research have demonstrated that the use of composite materials for retrofitting existing structural components is more cost-effective and requires less effort and time than the traditional means. Historically, composites were first used as flexural strengthening materials for reinforced concrete (RC) bridges, as confining reinforcement for RC columns and unreinforced masonry walls against possible earthquake forces. Apart from strengthening of bridge girders, columns and walls, composites are also used in bridge decks and in cable stayed bridges. Strengthening of beams, columns and beam-column joints are discussed in the sequel.

A. Strengthening of RC beams by using FRP

FRPC plate provided to the portion of elements in tension and placed perpendicular to cracks, tends to increase in strength and stiffness(Norris et al. 1997)(Grace et al. 1999).Nearly 40% strength enhancement is possible for RC beams strengthened with glass fiber reinforced polymer composite (GFRPC) whereas around 200% strength enhancement is achieved with carbon fiber polymer composites (CFRPC) (Heffernan and Erki. 1996). Externally bonded CFRP plates can be efficiently used to strengthen or to repair RC beams. delamination is observed between FRP layers (Buyle-Bodin et al. 2002).Perfect bonding between concrete steel and concrete-FRPC laminate(Thomsen et al. 2004). Considering tension stiffening and force transfer between concrete and FRPC to investigate serviceability criteria(Yang et al. 2003).It was found that repairing the bond damaged zone through concrete confinement leads to substantial regain of flexural stiffness under cyclic loading(Harajli. 2007).Textile reinforced concrete (TRC)TRC performs well compared with CFRP and has qualitatively similar effects on the overall behaviour of the repaired beams(Contamine et al. 2013).Fabric-epoxy continuous U-jackets have reduced the brittleness of the shear failure of beams, tensile strains in stirrups(Nguyen-Minh and Rovňák. 2015)

B. Strengthening of RC columns using FRP

Composite confinement can considerably enhance the structural performance of concrete columns, especially with regard to ductility (Saatcioglu and Grira. 1999).Effects of shape, length, and bond on FRP-confined concrete for square sections less effective in confining concrete than their circular counterparts (Mastrapa et al. 1998). The adhesive bond between concrete and the wrap would not significantly affect the confinement behaviour (Shahawy et al. 2000). Ductility of RC columns can be substantially improved by strengthening using wrapped CFRP sheets(Ye et al. 2003). The influence of the radius of the cross-sectional corners (edges) on the strength of small scale square concrete column specimens confined with FRP composite laminates delivers a uniform confining stress around the circular concrete core, shape changes led to lower ultimate strength(Al-Salloum. 2007).The pretensioning of CFRP creates an initial later stress which delays the start of intense internal cracking of confined concrete (Yazdchi and Salehi. 2008).Carbon FRP jacketing studied when fibers are oriented in the hoop direction increased the stability only for columns with a moderate to low slenderness (l < 40) (Tepers. 2007).The strength and deformation capacity of circular FRP-confined RC columns under eccentric axial loads is substantially improved (Bisby and Ranger. 2010).A significant variation in the behavior of FRP confined concrete comes up when bars are unstable, for a light external strengthening scheme as well as for monotonic or cyclic loading (Rousakis and Karabinis. 2012).The FRP repair of corrosion damaged RC columns not only provides strength and ductility, but also could slow down the rate of the corrosion reaction (Parvin and Brighton. 2014).Several parameters, like CFRP thickness of one , two, three, and four layers, fiber orientations of ±45̊, 0̊, 90̊ and their combination, and eccentricities in the direction of both weak and main axis were studied (Rahai and Akbarpour. 2014).Here researchers are evaluated the performance of natural flax fabric reinforced epoxy polymer (FFRP) composites as external strengthening materials for concrete elements, the increase in peak load and fracture energy by 6-layer FFRP is 374 and 4660 %, respectively and also SEM studies showed the good interfacial bond between FFRP and concrete because of the epoxy adhesive (Yan. 2016).The effects of heating duration, FRP circumferential wraps failed in recovering the original axial stiffness of the columns (Al-Nimry and Ghanem. 2017).To avoid the excessive stress concentration in square-shaped columns, a jacketing technique with rounded column edges needs to be practiced (Soman et al. 2018).

C. Strengthening of RC beam-columns joint by using FRP

It was observed during recent earthquakes that deficient beam-column joints can jeopardise the integrity of entire structures(Said and Nehdi. 2004).FRP joints repair schemes generally enhanced the performance of substandard joints that should achieved the brittle mode of failure to a ductile(Said and Nehdi. 2004).The composite laminate system proved to be effective in upgrading the shear capacity of the non ductile beam-column joint (Ghobarah. 2015). Specimens strengthened using CFRPs show stiffer behaviour than GFRP, Energy dissipation capacity can be increased with the use of small amount of composites (Mukherjee and Joshi. 2005).Seismic performance of the strengthened beam-column joints in terms of their hysteresis response, stiffness, and energy dissipation capacity is evaluated (Li and Chua. 2009).By adding CFRP composites to the non-seismic specimen significantly improved the lateral strength as well ductility (Le-Trung et al. 2010).The effect of ply angle on the improvement of shear capacity and ductility of beam–column connections strengthened with carbon fiber-reinforced polymer (CFRP) wraps under combined axial and cyclic loads (Parvin and Wu. 2008).Fiber anchors can effectively prevent premature delamination of FRP sheets (Li and Kai. 2011). A softened strut-and-tie model (STM) is developed for interior reinforced concrete (RC) beam-column joints provide an alternative modelling method in the seismic assessment and seismic retrofit design of interior RC beam-column joints (Okahashi and Pantelides. 2017).Grooving method (GM), as an alternative to the conventional externally bonded reinforcement (EBR) technique (Mosto and Akhlaghi. 2018). CFRP wrapping at the potential plastic hinge region of columns is a reasonable method for improving the seismic performance and implementing the strong column-weak beam failure mode (Ma et al. 2003).

Table.1. Overview some of existing studies on strengthening and repairing RC structures using FRP wrapping

Researcher	Wrapping material	Shape and Size of specimen	Loading type	Result
(Norris et al.)	CFRP sheets	13 RC beams	monotonic static loading	Obtained different strengths on different orientations
(Salom et al.)	CFRP laminates	Six identical RC spandrel beams, L-shaped cross section	half-cyclic load at predetermined increments	FRP laminates could increase the Torsional capacity of concrete beams by more than 70%.
(Buyle-Bodin et al.)	CFRP-SIKA CarboDur S plates	7 RC beams have a span length of 2800 mm& C/S dimensions of 150×300 mm2	monotonically in four-point bending	Elasto-plastic behaviour is assumed for reinforced concrete
(Yang et al.)	CFRP plates	RC beams-Finite element analysis	monotonic static loading	Concrete cover separation failure mode in FRP strengthened RC beams.
(Contamine et al.)	Textile reinforced concrete (TRC)& CFRP	11 m long RC beams	static and monotonous test	TRC and CFRP qualitatively similar effects on the overall behaviour of the repaired beams.
(Nguyen-Minh and Rovňák)	GFF & CFF	18 Rc beams of 9 GFF & 9CFF	Two concentrated loads	Reduced the brittleness of the shear failure of beams.
(Mastrapa et al.)	E-glass fibers	Twelve 152.5 X 152.5 X 305 mm and thirty 152.5 X 305 mm cylindrical specimens	Uniaxial compression	the confinement effectiveness of the jacket enhance the load-carrying capacity of the column
(Saatcioglu and Grira)	3 layers CFRP	16 round RC columns300mm in dia. and1200 mm high.	compression	Capable of sustaining axial strains in excess of 0.5%.
(Shahawy et al.)	CFRP,AMO CO Thornel carbon yarns	45carbon, wrapped,concrete cylinders with 152.5 mm dia and 305mm height	Monotonically compression	The wrap significantly enhanced the strength and ductility of concrete by curtailing its lateral dilation.
(Ye et al.)	CFRP sheets	Cantilever column fixed to a bottom base beam, b*h-200*200 mm. 20-mm radius	Sustained axial load of 230 kN	Ductility of RC columns improved,strong shear and weak flexure
(Al-Salloum)	FRP composite laminates	16 square concrete columns with 50 mm, 38 mm, 25 mm, and 5 mm corner radii.	axial load	FRP jacket increased both the axial load capacity as well as the ultimate concrete compressive strain.
(Bisby and Ranger)	CFRP,pretensioned epoxy impregnated carbon filament yarns of cylindrical columns		Uniaxial compression	Pressure increases the axial stress at which intense internal cracking of concrete develops.
(Tepers)	CFRP sheets	12 CFRP Confined Cylinders length 600, 1200, 1500, and 2500 mm	Monotonic Uniaxial compression	increased the stability of column @moderate slenderness ratio
(Bisby and Ranger)	CFRP SikaWrap Hex (230C)	circular RC columns with identical height to-diameter ratios (H/D = 4)	Under monotonic, eccentric axial compressive load	strength and deformation capacity under eccentric axial loads is improved
(Rousakis and Karabinis)	CFRP& GFRP sheets	42 prismatic columns of square C/S, with 200 mm side, 30 mm corner radius and 320 mm height	repeated load-unload cycles gradually	Higher improvement of the strain at failure.

(Rahai and Akbarpour)	CFRP sheets with orientation	8 RC columns with rectangular cross-section	under axial load and biaxialbending moment	improvement on the strength and ductility of confined RC columns
(Yan)	Natural flax fabric reinforced epoxy polymer (FFRP) of 12 concrete cylinders with H= 200 mm and dia= 100 mm		Uniaxial compression	Increase in peak load and fracture energy by 6-layer FFRP is 374 and 4660 %, respectively
(Al-Nimry and Ghanem)	CFRP sheets with orientation of 15 RC column specimens by heat damaged		under axial load	Reduced their axial resistance by about 46 and 54%
(Soman et al.)	glass FRP (GFRP)	31 RC columns of size 140 mm × 140 mm × 1200 mm	Concentric Uniaxial compression	Rounding the corners of the rectangular columns enhances the load-carrying capacity
(Mukherjee and Joshi)	GFRP/CFRP sheets& CFRP plate	+ shape Column and beam of 900mm	axial load	Enhancement in its yield load, initial stiffness and energy dissipation capacity.
(Li and Chua)	CFRP strips	Column C/S dimension of 820x280 mm.beam C/S 300x230 mm	axial compression and reversed cyclic load	tremendous increase in strength, stiffness and energy dissipation capacity
(Le-Trung et al.)	Carbon Fiber Reinforced Plastic using T,L&X-shape of CFRP) of T Beam of height 968 mm& L=1142 mm		lateral cyclic loading	seismic performance improved fiber direction inclined at 45^o

II CONCLUSIONS

Application of FRPCs in civil construction both in repair and retrofitting has been reviewed. This study represents the experimental results from concrete structures such as reinforced circular columns, square beams, columns and column-beam joints. External strengthening by composite materials through confinement can upgrade remarkably both strength and strain ductility of such columns subjected to monotonic or cyclic loading. Extent of benefit, however, depends upon many factors such as type, amount, and direction of confining material, size, shape and loading condition of the column. Externally bonded FRPC reinforcement is a viable solution towards enhancing strength, stiffness and energy dissipation characteristics of reinforced concrete beam-column joints.

1] For RC Beams wrapping or retrofitting with CFRP, GFRP sheets and laminates are strengthened the structure by taking different load conditions, when compared to normal RC Beams FRP Beams are tends to brittle failure due to sudden breakup of FRP sheets at ultimate load .

2] For RC beams FRP laminates could increase the Torsional capacity of concrete beams by more than 70%

3] For Columns strength and deformation capacity under eccentric axial loads is improved, but pressure increases the axial stress at which intense internal cracking of concrete develops.

4] FRP jacket increased both the axial load capacity as well as the ultimate concrete compressive strain. Rounding the corners of the rectangular columns enhances the load-carrying capacity.

5] For T-Beams by using Carbon Fiber Reinforced Plastic sheet orientation at an angle of 45° under lateral cyclic loading condition improves the seismic performance.

However, there are some gaps which need to be addressed. For instance, there is a lack of a rationale explanation of the resistance mechanisms involved in the beam-column joints retrofitted with FRP. Experimental and analytical studies are required to understand behaviour of beam-column joints from torsion, ductility. For durability point experimental studies required to analyse the performance of RC structures in different temperature conditions.

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