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# The use of fiber reinforced polymer for strength and strain enhancements of concrete columns

**Masoud Rasoolian[1*], Omid sarani[2], Reza hasanalipoor shahrabadi[2], Sadeq sarani[2]**

1. Young Researchers and Elite Club, Zahedan Branch, Islamic Azad University, Zahedan, Iran
2. Department of Civil Engineering, Zahedan Branch, Islamic Azad University, Zahedan, Iran

***Corresponding author email:*** Rasoolian.civil@yahoo.com

**ABSTRACT:** When a masonry wall acts as a slab for example due to wind or earthquake loads perpendicular to the plane of the wall, tensile stresses caused by moments and shear stresses occur. The popularity of higher strength concretes in the construction industry has been on a steady incline during the last two decades because of the superior performance and economy offered by high-strength concrete (HSC) over normal-strength concrete (NSC) in a large number of structural engineering applications. An alternative method for strengthening and retrofitting masonry structures is the use of fibre reinforced polymer (FRP) composites, adhered to the surface of the wall to resist lateral loads. The use of FRP composites has emerged as a promising retrofit solution and grown very rapidly in recent years. FRP materials show high strength to weight ratio, resistance to chemical and environmental corrosion, fatigue resistance and formability to complex shapes. They are quick to apply and the cost of these materials has dropped significantly in recent years.
**Key words:** FRP, Shear stresses, URM

## INTRODUCTION

### *Unreinforced masonry*

Unreinforced masonry (URM) walls have a low resistance against lateral loading due to their low flexural capacity and their brittle mode of failure. They are vulnerable to earthquake and wind loading. Therefore effective techniques are needed to strengthen masonry walls and structures against the above actions. Masonry walls are subjected to loads in the plane of the wall and perpendicular to the plane of the wall (Zilch *et al*., 2001). In-plane loads may be vertical load, for example self-weight or imposed loads and horizontal load as seismic or wind loads in the case of shear walls. This kind of loading which is parallel to the plane of the wall is called in-plane loading. The masonry wall may be subjected to loads perpendicular to its plane i.e. wind loads or earthquake loads on external walls. This kind of loading perpendicular to the plane of the wall is called out-of-plane loading.

### *Shear stresses*

When a masonry wall acts as a slab for example due to wind or earthquake loads perpendicular to the plane of the wall, tensile stresses caused by moments and shear stresses occur (Moghadam, 2001). The shear stresses in this case do not cause fracture into the units but rather only a friction failure in the bed joints when the shear capacity of the mortar is exceeded. In this case, shear capacity of the bed joint is reduced to zero (Zilch et al., 2001).

### *Fiber reinforced polymer (FRP)*

An alternative method for strengthening and retrofitting masonry structures is the use of fibre reinforced polymer (FRP) composites, adhered to the surface of the wall to resist lateral loads. The use of FRP composites has emerged as a promising retrofit solution and grown very rapidly in recent years (Ozbakkaloglu et al. 2013).

### *Definition of HSC and NSC*

The popularity of higher strength concretes in the construction industry has been on a steady incline during the last two decades because of the superior performance and economy offered by high-strength concrete (HSC) over normal-strength concrete (NSC) in a large number of structural engineering applications. These beneficial characteristics result in more cost-effective construction of bridges and multistory buildings. However, the use of higher strength concretes in seismically active regions poses difficulties because of the inherently brittle nature of the material. Confining HSC with FRP tubes is an attractive option because of the efficient combination of two high-strength materials to form a high-performance member that benefits from a substantial increase in ductility compared with unconfined HSC members. Research on the compressive behavior of FRP-confined HSC, in general, and on high-strength CFFTs (HSCFFTs), in particular, remain very limited with only a handful of studies reported on FRP-wrapped specimens (Rousakis 2001; Berthet et al. 2005; Mandal et al. 2005; Almusallam 2007; Eid et al. 2009; Wu et al. 2009; Cui and Sheikh 2010; Xiao et al. 2010; Ozbakkaloglu and Akin 2012) and only one on CFFTs (Ozbakkaloglu 2013a).

***The benefits of fiber reinforced polymer***

FRP materials show high strength to weight ratio, resistance to chemical and environmental corrosion, fatigue resistance and formability to complex shapes. They are quick to apply and the cost of these materials has dropped significantly in recent years. The application of FRP materials for strengthening masonry structures is very promising as it preserves the existing walls, requires little surface preparation, light weight materials are used and fast speed of application is achievable. Although the use of FRP composites is a new approach to strengthening, there are limited test data and theoretical models available which could be used as a basis for the design of wall upgrades. According to an experimental study over a full scale 5-storey masonry structure, which was conducted at the University of California, Frieder (2001) explained that the application of advanced composites for strengthening masonry walls have restored more than double the displacement capacity in seismic loads. In this research the loads were applied by actuators, however the detailed behaviour of walls and elements has not been considered. Triantafillou (1998) conducted an experimental study on 12 small scale masonry walls to study the effectiveness of externally bonded FRP laminates for strengthening masonry walls. The results indicated that out-of-plane bending capacity improved significantly. Numerical analysis has been developed and verified via test results. It is now well-understood that the confinement of concrete with fiber-reinforced polymer (FRP) composites can lead to significant improvements in both compressive strength and ductility. A recent comprehensive review study (Ozbakkaloglu et al. 2013) revealed that over 200 experimental studies have been conducted over the last two decades on the compressive behavior of FRP-confined concrete, resulting in the developments of over 80 axial stress-strain models (e.g., De Lorenzis and Tepfers 2003; Lam and Teng 2003; Binici 2005; Bisby et al. 2005; Youssef et al. 2007; Ilki et al. 2008; Wei and Wu 2012; Yazici and Hadi 2012). The majority of these studies focused on FRP-wrapped specimens, and relatively few studies have been reported on the behavior of concretefilled FRP tubes (CFFTs) (Mirmiran et al. 1998; Saafi et al. 1999; Fam and Rizkalla 2001; Hong and Kim 2004; Fam et al. 2005; Ozbakkaloglu and Oehlers 2008a, b; Mohamed and Masmoudi 2010; Park et al. 2011; Ozbakkaloglu 2013a, b, c).

***Small scale specimens***

Small scale specimens have been the focus of existing experimental research on the compressive behavior of FRP-confined concrete, with limited data available on full-scale columns. The aforementioned review study by Ozbakkaloglu et al. (2013) revealed that researchers performed the majority of existing experimental studies on specimens with nominal diameters of 150 mm.

***Rectangular cross-sections***

The implementation of round corners in square or rectangular cross-sections before the application of a continuous FRP layer involves additional costs and often cannot be done (e.g., when a reduced cover is present in a reinforced concrete member). In these cases the use of single strips of FRP locally applied at the sharp corners before the continuous wrapping of the transverse cross-section should be a good alternative technique, able to avoid premature collapse due to local stress peaks in the FRP sheets (Campione et al. 2003).

***Effects of Cross-Section***

Shape of cross-sections of columns can directly affect the confinement effectiveness of externally bonded FRP jackets. According to the previous study enhancement on axial compressive strength and ductility for square or rectangular columns with sharp corners and flat sides is less effective compared to circular ones. This reduction in effectiveness of confinement may be due to the stress concentrations at the corners or inefficient confinement at the flat sides. Therefore, a possible approach to increase the confinementlevel is to modify the cross section of the column to a circular section (Rochette and Labossiere, 2000). Masiaet al. (2004)studied the ductilityand compressive strength of axially loaded square concrete prisms confined with CFRP wrapping. Test results showed that a significant increase in strength and ductility was achieved by CFRP wrapping.They also reported that the strength, strain and effectiveness of the confinement reduced with increase in cross sectional area. Yang et al. (2001) studied the effect of corner radius on the performance of externally bonded FRP reinforcement. It was found that corner radius plays an important role on the performance of the CFRP laminates and as the corner radius decreases, the efficiency of the FRP wrapping also decreases. They also reported that multiple placements of FRP plies slightly improve the efficiency of the laminate except for the square or rectangular section. Kim et al. (2003) conducted compression tests on concrete specimens confined with Carbon Fiber Sheet (CFS) to investigate the effect of various cross-sectional shapes (i.e. square, octagonal and circular) oncompressive strength of concrete members.Theyconcluded that circular section is most effective in load carrying capacity whereas square section is least effective.Test results also showed that octagonal and circular specimens have similar axial strengths for various lamination angles. Rochette and Labossiere (2000) indicated experimentally that FRP confinement for square and rectangular specimens is much less effective in increasing the compressive strength and ductility compared to the circular ones. They also found that an increase in the radius of the column corner increases the axial compressive strength and ductility of the specimens.

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