Confining Concrete Columns with FRP Materials

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Abstract

Fiber Reinforced Polymers (FRP) as a kind of composite materials have became widespread in the strengthening of reinforced concrete structures as an alternative way of traditional strengthening methods. Usage of such polymers as an important application of composites for strengthening has rapidly increased in recent years. Confinement of concrete as a type of inelastic, non-homogenous, non-linear and brittle material has considerable advantages in strengthening with externally bonded by FRP. The lightweight and high strength capacity of FRP sheets and strips which may eliminate the low tension capacity and brittle behavior of concrete sections gain considerable increase in construction industry. In this study codes for strengthening concrete columns investigated to discuss the confinement effect of concrete by FRP material including the mechanical properties.

Keywords: Stress-strain models, reinforced concrete sections, strengthening

Introduction

In the last decade, the use of fibre reinforced polymers (FRP) as reinforcement is rapidly growth in many civil engineering applications such as rehabilitation of RC (Reinforced Concrete) buildings, strengthening of bridge piers, etc. These materials with advantages of high strength capacity, high resistance to corrosion, lightweight and ease of application have been caused rapid increase in construction industry. The purpose of such composite materials is to obtain the new features by creating superior properties of a new material production other than existing components. The superior properties of FRP enhance the strength and ductility capacities to be one of the best options in strengthening as external reinforcement (Erdil, 2013; Anil, 2008; Smoak 1996). In order to investigate the gain in strength and ductility of concrete columns several methods have been researched and proven effective in increasing the axial load capacity of reinforced concrete columns. These methods include concrete, steel, and fiber reinforced polymer (FRP) jackets. Lateral confinement using FRP or spiral reinforcement has been demonstrated to increase compression strength, deformability, and energy absorption capacity of concrete (Ozbakkaloglu and Akın, 2011; Canbay et al., 2006; Campione et al., 2004).

FRP reinforcement behaves linear elastic up to failure and exerts an ever-increasing confining pressure on the concrete core to gain stress and strain capacity in case of loaded axially. The confining mechanism provides a considerable enhancement in the strength and ductility of concrete. There are various studies experimentally investigating the strength and strain capacities by retrofitting existing concrete columns with various strength levels wrapped with several layers of FRP to examine the performance of FRP composites to improve for seismic strengthening in structural engineering (Oncu et al., 2010; Moehle, 2000). The results of such studies obviously indicate that provides significant increase in failure stress and strain of the confined concrete.

Materials and Methods

Strengthening is the process of enhancing capacity of damaged components of structural concrete to its original design capacity, or an improving over the original strength of structural concrete. Confinement of concrete with externally bonded FRP is an important application of FRP composites. Fiber-reinforced polymer strengthening technique is essentially composed of high tensile-strength fibers bonded to the concrete surface using an epoxy resin in a matrix of polymer resin. The epoxy resin process refers to a "matrix" material of reinforced with fibers provides bond strengths exceeding the shear or tensile strength of the concrete. These FRP products are mostly used as external reinforcement in the construction industry in the form of bars, cables, sheet materials and plates. FRP products may succeed in the same or better reinforcement objective of commonly used metallic products such as steel reinforcing bars, prestressing tendons, and bonded plates (Bisby and Williams, 2004). High strength polymer fabrics are used in Strengthening of reinforced concrete beams against bending and shear, slabs against bending, enhancement of the shear capacity, ductility and compressive strength of columns. Use of fibre reinforced polymer materials in concrete strengthening has rapidly increased on site into different shapes as referenced material in many applications by Task Grup 9.3 FRP (2001) as shown in Fig.

1.

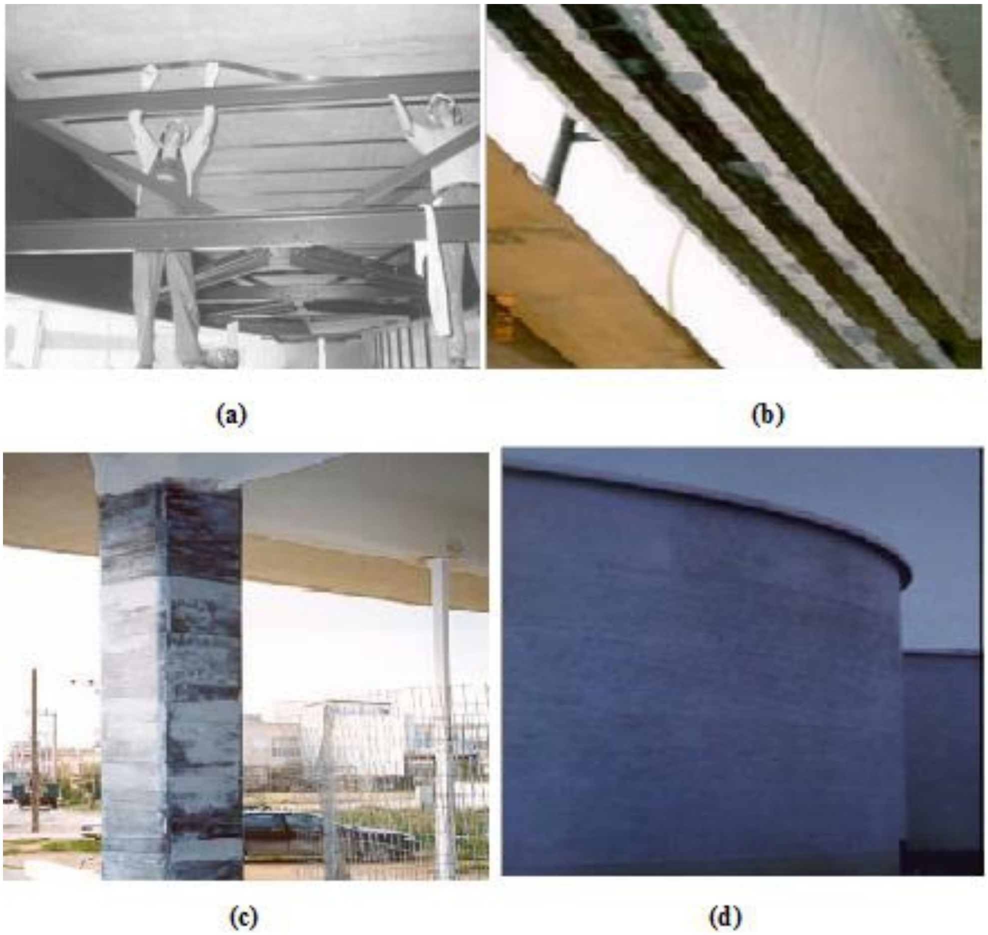

Figure 1. Some typical FRP application examples in strengthening reinforced concrete structures: (a) flexural strengthening of slab; (b) flexural strengthening of beam; (c) strengthening and confinement of a column; (d) wrapping of a concrete tank.

Bonding FRP systems are useful tools to increase the axial compression strength and also increase ductility capacity of a concrete member. In case of earthquake resistance capacity, enhancing the ductility of members subjected to combined axial and bending forces is one of the main objectives of strengthening of concrete sections. The characteristic stress-strain behavior of FRP-confined concrete is related to to determine the confining pressure and the resulting increase in the compressive stress in the concrete. On the other hand for FRP confined concrete to generate force-deformation relationship models proposed by codes ACI440.2R-02, ACI440.2R-08 and Turkish Earthquake Code (TEC2007) are available to determine the effectiveness of polymer amount on specimens. The confinement strength of the concrete model related to the confinement pressure;

$$f'_{cc} = f'_{co} + k_1 f1 \quad (1)$$

where, f_1 is confinement pressure and k_1 is coefficient of effectiveness, f'_{cc} is compressive strength of confined concrete and f'_{co} is unconfined concrete strength. The fundamental properties of FRP materials evaluated to enhance strength and ductility of concrete sections the ACI 440 and TEC2007 code requirements summarized (Erdemli and Karasin, 2014; Erdil et al., 2011).

TEC 2007 Model: This model is defined in section 7E titled as "Effects of FRP Confinements on Strength and Ductility of Reinforced Concrete Columns" in TEC 2007. The code evaluates strength and ductility enhancement using FRP confined concrete columns. For strength enhancement it is stated that in order to increase the axial load capacity of a column using FRP material strength of confined columns given as;

$$f_{cc} = f_{cm} \left(1 + 2.4(f_1 / f_{cm})\right) \geq 1.2 f_{cm} \quad (2)$$

$$f_1 = \frac{1}{2} \kappa_a \rho_f \varepsilon_f E_f \quad (3)$$

where $f_{cc} = f'_{cc}$ is compressive strength of confined concrete, $f_{cm} = f'_{co}$ is unconfined concrete compressive strength, ρ_f is defined as the volumetric ratio of FRP and κ_a is defined as section effectiveness factor for rectangular cross section as;

$$\rho_f = \frac{2\, n\, t_f (b + h)}{bh} \quad (4)$$

$$\kappa_a = 1 - \frac{(b - 2r)^2 + (h - 2r)^2}{3bh} \quad (5)$$

Where n and t_f are number of plies and nominal thickness of one ply of FRP reinforcement respectively, b, h are dimensions of rectangular cross section and r is radius of corners rounded rectangular sections to turn an elliptical section.

$$\varepsilon_f \leq 0.004 \text{ and } \varepsilon_f \leq 0.50\, \varepsilon_{fu} \quad (6)$$

ε_f and ε_{fu} are effective and ultimate strain level of FRP reinforcement, and E_f is a tensile modulus of elasticity of FRP. In order to check enhancement of column ductility ultimate strain capacity indicated as

$$\varepsilon_{cc} = 0.002\ (1+15\ (f_1 / f_{cm})0.75\ ) \quad (7)$$

The model implies at least 20% strength enhancement of the current compressive strength.

ACI440Model: In the part 12 of ACI440.2R-02, it is indicated that wrapping FRP systems completely around certain types of compression members will confine those members, leading to increases in axial compression strengths. Bonding FRP systems to concrete members can also increase the axial tension strength of the member. Confinement is also used to enhance the ductility of members subjected to combined axial and bending forces. In this code equations related to strength and strain are introduced for strengthening of concrete members subjected to axial force. The strength of confined concrete can be computed from Eq. (8) using a confining pressure as result of the maximum effective strains that can be achieved in the FRP jacket given in Eq. (9).

$$f'_{cc} = f'_c \left[2.25 \sqrt{1 + 7.9 \frac{f_1}{f'_c}} - 2 \frac{f_1}{f'_c} - 1.25 \right] \quad (8)$$

$$f_1 = \frac{\kappa_a \, \rho_f \, \varepsilon_{fe} \, E_f}{2} \quad (9)$$

The effective strain in the FRP jacket is limited to Eq. (10) as;

$$\varepsilon_{fe} = 0.004 \leq 0.75\, \varepsilon_{fu} \quad \text{and} \quad \varepsilon_{fu} = C_E\, \varepsilon^{*}_{fu} \quad (10)$$

where C_E is environmental-reduction factor for fiber and resin type of Carbon/epoxy given as 0.95 and ε^{*}_{fu} is ultimate rupture strain of FRP. The ρf and K_a parameters for noncircular sections to obtain confining pressure defined as;

$$\rho_f = \frac{2\, n\, t_f\, (b + h)}{bh} \quad (11)$$

$$Ka = 1 - \frac{(b - 2r)^2 + (h - 2r)^2}{3bh\,(1 - \rho_g)} \quad (12)$$

In equations (11) and (12) ρf is FRP reinforcement ratio, ρ_g is ratio of the longitudinal steel reinforcement area to the cross-sectional area of compression member and r, b, h are the radius of the edges and dimensions of the section. It is noted that for rectangular sections with aspect ratios b/h exceeding 1.5, or one of the face dimensions b or h, exceeding 900 mm it is assumed that confining effect of FRP jackets is negligible, unless testing demonstrates their effectiveness. Than enhancement of column ductility with FRP indicated as;

$$\varepsilon'_{cc} = \frac{1.71(5f'_{cc} - 4f'_c)}{E_c} \quad (13)$$

where E_c is modulus of elasticity of concrete and ε'_{cc} defined as increased ductility of a section results before compressive failure from the ability to develop greater compressive strains in the concrete.

Conclusion

The usage of FRP composites in strengthening applications has many superiorities such as high tensile strength, Modulus of Elasticity, resistance to corrosion, the lightweight, speed and ease of application. It is noted that FRP strengthening are powerful techniques to enhance stres-strain performance of existing reinforced concrete structures which may need strengthening or retrofitted due to incorrect calculations and applications, the low quality of concrete, inadequate lateral reinforcement, change of usage, additional storey, environmental factors, poor workmanship etc.

The models of TEC2007 and ACI 2002 codes with respect to the stress - strain relation of concrete sections confined by fiber composites show some variations as comparing to each other. It is noted that reinforced concrete members wrapped with FRP materials for strengthening improve enhancement of compressive strength and ductility capacity of confined concrete.

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