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MODELS FOR CONFINED CONCRETE COLUMNS WITH FIBER COMPOSITES

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ABSTRACT

Many studies have been done to find a convenient representation of physical behavior Fiber Reinforced Polymers for strengthening or retrofitted techniques which can enhance stress-strain performance of existing reinforced concrete structures. FRP composites are used for strengthening applications mainly due to the lightweight, high compressive strength, resistance to corrosion, speed and ease of application and formed on site. Conceptually, the stress strain relation of concrete as a nonhomogenous and nonlinear composite material is not unique that depends on the many variables. In this study some common mathematical models for concrete in the stress-strain relation have been discussed to clarify mechanical behavior of concrete up to ultimate strain. However models of concrete confined by fiber composites corresponding to Stress -Strain relations of TDY2007 and ACI 2002 codes were compared for strengthening concrete sections. Furthermore it is noted that using FRP material increases both strength and ductility of compressive sections.

Keywords: Mathematical Models for Concrete, FRP, Winkler Foundation, Plates, Bending, Finite Grid Solution, Shape Functions.

1. INTRODUCTION

Researches in the area of strengthening concrete elements have received a considerable attention due to their wide applicability in many engineering disciplines. However in recent years many researchers in civil engineering area have been deal with the stress-strain models for Fiber Reinforced Polymers (FRP) confined concrete columns with rectangular and circular sections [1-5] due to high efficiency of improvement for both compression and energy consumption capacity. In the development of such models, a number of important issues including the actual hoop strains in FRP jackets at rupture, the sufficiency of FRP confinement for a significant strength enhancement, and the effect of jacket stiffness on the ultimate axial strain, were all carefully examined and appropriately resolved.

Campione et. al. (2004), investigated the compressive behavior up to failure of short concrete members reinforced with fiber reinforced plastic (FRP). Rectangular cross-sections are analysed by means of a simplified elastic model. The effect of local reinforcements constitute by single strips applied at corners before the continuous wrapping and the effect of round corners are considered. Analytical results are compared to experimental values available in the literature presents a theoretical model for prediction the maximum strength and strain capacities of short compressed column externally wrapped with FRP sheets. Members with rectangular cross sections and sharp or round corners were analyzed.

Shehata et al. [6] investigated the gain in strength and ductility of concrete columns externally confined by CFRP wrapping that included tests on 54 short column specimens. The column cross section shape (circular, square and rectangular) and the amount of confinement expressed in the number of CFRP sheet layers applied to the models (one or two layers) were variables in the study. On the basis of the obtained results, equations were proposed to calculate the confined concrete strength and the ultimate confined concrete strain as a function of the confining lateral stress for each of the cross section geometry used, circular, square and rectangular. Mirmiran et al. [7], studied effect of shape, length and interface bond on FRP-confined concrete. Over 100 specimens subjected to uniaxial compression. Square sections are less effective in confining concrete than circular sections and effectiveness is measured by a modified confinement ratio that is function of the corner radius and the jacket's hoop strength. Length effect in short columns of up to 5:1 and %10 eccentricity and %20strength reduction in pure compression. But adhesive bond doesn't change load –carrying capacity of FRP-confined concrete, mechanical bond considerably enhance the load carrying capacity of the column by providing an effective load distribution mechanism.

Saadatmanesh et al. [8], presented a new technique for seismic strengthening of concrete columns. The technique requires wrapping thin, flexible high-strength fiber composite straps around the column to improve the confinement and, so, its ductility and strength. Analytical models are presented that concrete columns strengthened with composite straps can be used to increase effectively the strength and ductility of seismically deficient concrete columns. The result of the study: failure strain of the concrete increased, in comparison to the unconfined concrete. If the volumes of straps are equal, increase of ultimate axial load and ductility for strengthening with carbon fiber is larger than strengthening with E-glass. The technique they used increased the axial carrying capacity of the column and the ductility factor increases linearly with increase in strap thickness. Saadatmanesh et al. [9], investigated the flexural behavior of earthquake-damaged reinforced concrete columns repaired with prefabricated fiber reinforced plastic (FRP) wraps. Four column specimens were tested to failure under reversed inelastic cyclic loading to a level that can be considered higher than would occur in a severe earthquake. The columns were repaired with prefabricated FRP wraps and retested under simulated earthquake loading. FRP composite wraps were used to repair damaged concrete columns in the critically stressed areas near the column footing joint. The results indicate that the proposed repair technique is highly effective. Both flexural strength and displacement ductility of repaired columns were higher than those of the original columns. The analytical study by Erdemli and Karaşin [10] shows that, reinforced concrete members jacketed with FRP material for strengthening cause enhancement of compressive strength of confined concrete. Also experimental results of confined concrete were compared with Models of Concrete Corresponding to Stress -Strain Confined by Fiber Composites codes TDY2007 and ACI 2002 [11-12]. Furthermore it was concluded that using FRP material increase both strength and ductility of compressive sections. On the other hand the investigation of Oncu et al [13] for determining the behaviour of strengthened RC sections by wrapping with CFRP subjected to cyclic loading shown positive performance.

2. MODELS OF CONCRETE ELEMENTS

Concrete as well-known composite material has been composed of cement paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine (sand) and coarse aggregates (gravel) as typically shown in Fig. 1. Due to chemical reaction called hydration, the cement paste hardens and gains strength to form the rock-like mass known as concrete with component percentages given in Fig. 2.

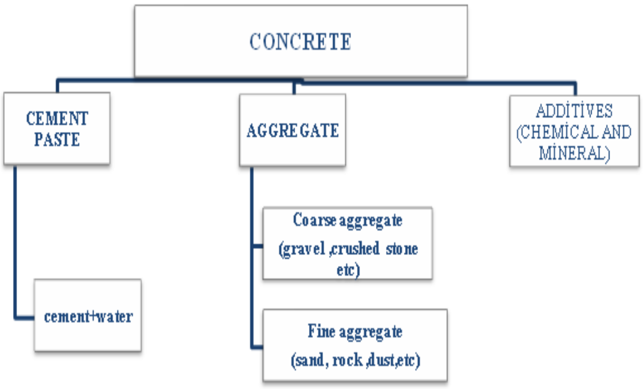

Figure 1. Typical Concrete Components

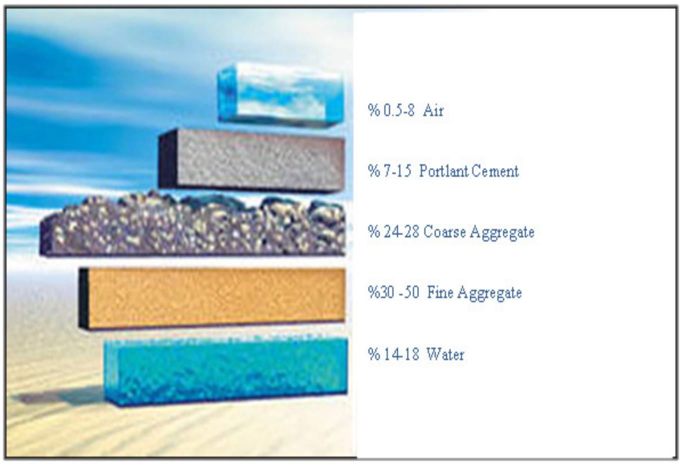

Figure 2. Percentage of Concrete Components

Concrete with the superior sides as high strength under compression with respect to its main component as sown in Fig 3, easy to be given shape, high durability, good fire resistance, high water resistance, low maintenance, and long service life has been used for a long time in the construction of buildings and bridges. Whereas the weak sides of concrete can be noted as poor tensile strength, brittleness, volume instability and formwork requirements. On the other hand it is noted that the first usage of reinforced concrete (which eliminate most of the weakness of concrete by reinforcements) in building construction was reported in the mid of 19. century [14].

Stress strain relation of concrete as a non-uniform composite material is not unique it depends on the many variables or changeable with variables. Many models for the stress-strain relation of concrete have been proposed up to the present. Some common mathematical models for concrete such as Hognestad (1951), Kent and Park (1971), Sheikh and Üzümeri (1982) Models presented as follow.

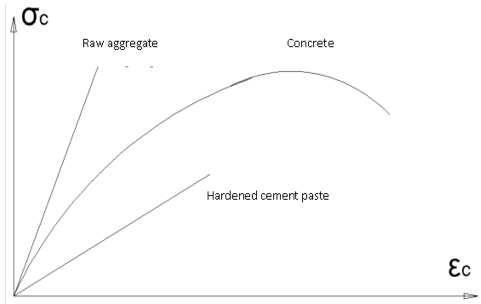

Figure 3. Stress-Strain Diagram of Concrete and Components

Concrete Model Proposed by Hognestad (1951)

The model are widely being used for stress-strain curve to represent behaviour of normal strength and provided to be a satisfactory model for unconfined concrete as shown in Fig.2.4. In the model, σ - ε curve up to the peak portion assumed a second-order parabola and part of the decline is assumed to be a linear. The maximum stress, usually taken as 85% cylindrical strength of concrete ($f_c = 0.85\ f_{ck}$) and the maximum compressive stress corresponding to strain (ε_{c0}) is taken to be 0.002 [14].

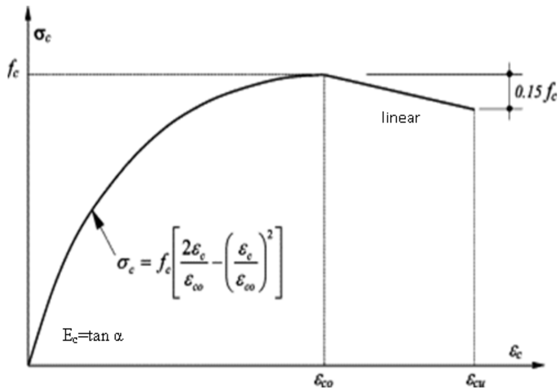

Figure 4. Hognestad Model (1951)

The model for E_c, modulus of elasticity, is proposed to be as in the following equation;

E_c = tan α = 126800 + 460 fc (kgf/cm2)

The part up to the peak of the curve (second degree parabola) can be represented as;

$$\sigma_c = f_c\left[\frac{2\varepsilon_c}{\varepsilon co} - \left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^2\right]$$

It is noted that the ultimate compressive strain, εcu can be taken as 0.0038 with 0.85 fc.

Concrete Model Proposed by Kent and Park Model (1971)

Kent and Park (1971) proposed a stress-strain equation for both unconfined and confined concrete as shown in Fig. 2.5. In their model they generalized Hognestad's (1951) equation to more completely describe the post-peak stress-strain behavior.

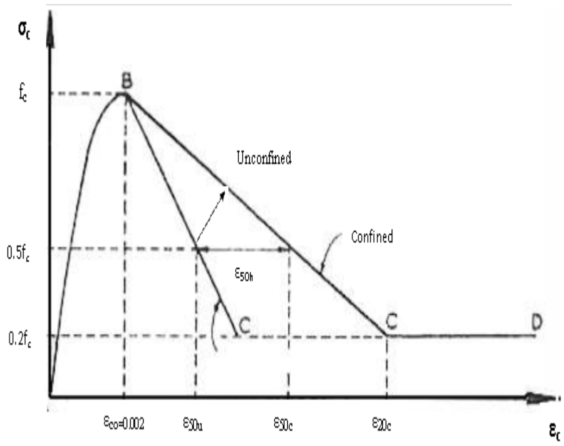

Figure 5. Stress-Strain model for confined and unconfined concrete – Kent and Park (1971) model

In this model the ascending branch is represented by modifying the Hognestad second degree parabola by replacing f_c=f_{ck} and the part up to the peak of the curve (second degree parabola);

$$\sigma_c = f_c\left[\frac{2\varepsilon_c}{0.002} - \left(\frac{\varepsilon_c}{0.002}\right)^2\right]$$

The post-peak branch was assumed to be a straight line whose slope was defined primarily as a function of concrete strength;

$$\sigma_c = f_c\{\,1 - Z(\varepsilon_c - 0.002)\}$$

$$\varepsilon_{50u} = \frac{3+0.0285fc}{14.2fc-1000}$$

$$\varepsilon_{50h} = \frac{3}{4}\,\rho_s\,\sqrt{\frac{b''}{s}}$$

$$Z = \frac{0.5}{\varepsilon_{50u}+\,\varepsilon_{50h}\,-0.002}$$

where; σ_c =Concrete stress; b'' = big size of the core concrete (area inside the stirrup), s = stirrup spacing, ρ_s = stirrup percent density,

$$\rho_s = \frac{A_{so}(a'' + b'')^2}{s(a'')(b'')}$$ where a" = small size of the core concrete.

Concrete Model Proposed by Sheikh and Uzumeri (1982)

Sheikh and Uzumeri proposed a stress-strain equation for confined concrete in tied columns. An analytical model (Sheikh and Uzumeri 1982), which considers distribution of the longitudinal reinforcement and the configuration of the rectangular column ties on the effectiveness of the confinement. The proposed confinement efficiency of confined concrete can be described by Equations and model shown in Fig 2.6.

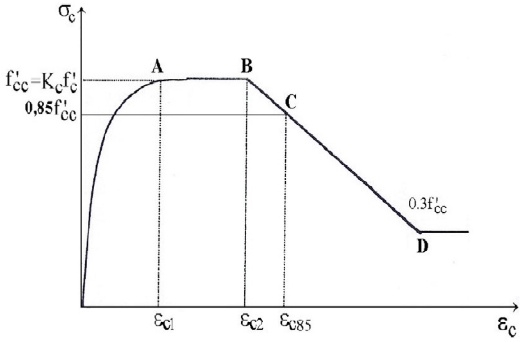

Figure 6. Sheikh and Uzumeri Stress-Strain Model for Confined Concrete (1982)

f'_{cc} = compressive strength of confined concrete; f_c' = cylinder strength of unconfined concrete; K_c = confinement coefficient ,

$$f'_{cc} = Kc.f'_c \tag{1}$$

$$K_c = 1 + \frac{b_c^{\,2}}{140P_{occ}}\left[\left(1-\frac{nC^2}{5.5b_c^{\,2}}\right)\left(1-\frac{s}{2b_c}\right)^2\right]\sqrt{\rho_{sh}\, f_{sh}} \tag{2}$$

$$P_{occ} = 0.85\, f_c{}'\left(b_c{}^2 - A_s\right) \tag{3}$$

where A_s: Cross sectional area of longitudinal reinforcement, C= distance between laterally supported longitudinal bars, s = tie spacing, ρ_{sh} = ratio of the volume of tie steel to the volume of core, b_c =dimension of concrete core, f_{sh} =stres in the lateral steel

$$\varepsilon_{c1} = 80\,.K_{c.}\, f_c'.10^{-6} \tag{4}$$

$$\varepsilon_{c2} = \varepsilon_{c0}\left[1 + \frac{248}{C}\left(1 - 5\left(\frac{s}{b_c}\right)^2\right)\frac{\rho_{sh}\, f_{sh}}{\sqrt{fc'}}\right] \tag{5}$$

$$\varepsilon_{c85} = 0.225\,\rho_{sh}\sqrt{\frac{b_c}{s}} + \varepsilon_{c2} \tag{6}$$

In equation 1 and 2 dimensions should be taken in mm, MPa and kN for the displacements, the stresses and forces respectively.

3. MODELS OF CONCRETE CONFINED BY FIBER COMPOSITES

Model proposed by TDY2007: The confinement strength of the concrete model form generally shown in equation which is related to the confinement pressure;

$$f'_{cc} = f'_{co} + k_1\, f1$$

where, f_1 = confinement pressure, k_1 =coefficient of effectiveness,

This model mentioned information attachment 7.E in TDY2007; 'Effects of FRP Confinements on Strength and Ductility of RC Columns' axial compression strength of confined columns can be received as;

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

where f_{cc} =f'_{cc}= compressive strength of confined concrete, fcm = f'co= unconfined concrete strength. As shown in model, strengthening limited where the compressive strength of confined concrete is not exceed 20% of the current strength, it should not be applied.

$f_1 = \frac{1}{2}\,\kappa_a\,\rho_f\,\varepsilon_f\,E_f$ κ_a defined as a shape factor

$$\kappa_a = \begin{cases} 1 & \text{circular cross} - \text{section} \\ \left(\frac{b}{h}\right) & \text{ellipse cross} - \text{section} \\ 1 - \frac{(b-2r)^2 + (h-2r)^2}{3bh} & \text{rectangular cross} - \text{section} \end{cases}$$

ρ_f is defined as a FRP reinforcement ratio,

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

n = number of plies of FRP reinforcement, t_f =nominal thickness of one ply of the FRP reinforcement, b and h are width of rectangular cross section, and overall thickness of a member $\varepsilon_f \leq 0.004$ and $\varepsilon_f \leq 0.50\,\varepsilon_{fu}$ ε_f and ε_{fu} are a strain level in the FRP reinforcement and design rupture strain of FRP reinforcement and also E_f is a tensile modulus of elasticity of FRP. Enhancement of column ductility with FRP;

To increase the ductility of confining columns with FRP, ratio of the long dimension of column cross-section to short dimension of column-cross-section should not exceed 2.

$(b / h \leq 2)$ and $\varepsilon_{cc} = 0.002\ (1+15\ (f_1 / f_{cm})^{0.75})$

where ε_{cc} is concrete strain corresponding to confined concrete compressive strength.

Model proposed by ACI 440: Bonding FRP systems can be used to increase the axial compression strength and also increase the axial tension strength of a concrete member. Confinement is also used to enhance the ductility of members subjected to combined axial and bending forces. To determine the full stress-strain behavior of FRP-confined concrete, the compressive strain in the concrete (longitudinal strain) must be related to the strain developed in the FRP jacket (transverse strain). The strain in the FRP jacket may then be used to determine the confining pressure and the resulting increase in the compressive stress in the concrete. The confined concrete strength can be computed by using a confining pressure given in following equations that is the result of the maximum effective strain that can be achieved in the FRP jacket.

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

$$f_1 = \frac{\kappa_a\,\rho_f\,\varepsilon_{fe}\,E_f}{2}$$

and the effective strain in the FRP jacket should be limited to;

$\varepsilon_{fe} = 0.004 \leq 0.75\,\varepsilon_{fu}$ and $\varepsilon_{fu} = C_E\,\dddot{\varepsilon}_{fu}$

Table 1. Environmental-reduction factor for various FRP systems and exposure

Exposure conditions	Fiber and resin type	Environmental reduction factor *CE*
Interior exposure	Carbon/epoxy	0.95
	Glass/epoxy	0.75
	Aramid/epoxy	0.85
Exterior exposure (bridges, piers, and unenclosed parking garages)	Carbon/epoxy	0.85
	Glass/epoxy	0.65
	Aramid/epoxy	0.75
Aggressive environment (chemical plants and waste water treatment plants)	Carbon/epoxy	0.85
	Glass/epoxy	0.50
	Aramid/epoxy	0.70

For conditions (ACI2002) shown in Table 2, r represents the radius of the edges of the section and ρ_g is the ratio of the area of longitudinal steel reinforcement to the cross-sectional area of a compression member.

Table 2. Equations f ρg and Ka for circular and noncircular Sections

Circular sections	Noncircular sections
$\rho_f = \frac{4n\, t_f}{h}$	$\rho_f = \frac{2\, n\, t_f\, (b+h)}{bh}$
$Ka = 1.0$	$Ka = 1 - \frac{(b-2r)^2 + (h-2r)^2}{3bh\,(1-\rho_g)}$

The confining effect of FRP jackets should be assumed to be negligible for rectangular sections with aspect ratios *b/h* exceeding 1.5, or face dimensions, *b* or *h*, exceeding 900 mm, unless testing demonstrates their effectiveness. For enhancement of column ductility with FRP for compressive strain is

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

The equation implies that ductility of a section results from the ability to develop higher compressive strains in the concrete before compressive failure.

Experimental result of confined concrete by fiber composites compared with TDY2007 and ACI 2002 models corresponding to stress - strain relation shown that according to analytical study results obtained by ACI 2002 model is close to the experimental results [10, 13]. On the other hand it is noted that TDY2007 experimental results of confined strength is safer than that of ACI 2002. Since both model indicates that using FRP material increase both strength and ductility of compressive concrete sections.

4. CONCLUSION

Many studies have been done to find a convenient representation of physical behavior FRP strengthening or retrofitted techniques which can enhance stress-strain performance of existing reinforced concrete structures. FRP composites are used for strengthening applications mainly due to the lightweight, high strength, resistance to corrosion, speed and ease of application and formed on site. It is noted that reinforced concrete members jacketed with FRP material for strengthening can cause enhancement of compressive strength and ultimate strain of confined concrete. Therefore it can be concluded that for uniaxial compression case such materials improves both strength and ductility of concrete sections

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