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General concept for strengthening the reinforced concrete column a wrapping of CF sheet

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Abstract. Fiber reinforced polymer (FRP) composites (the combination of two or more materials). Used more often in the defense and aerospace industries, advanced composites are beginning to play the role of conventional materials (commodities) used for load-bearing structural components for infrastructure applications. These unique materials are now being used worldwide for building new structures as well as for rehabilitating in-service structures.
"FRP" is an acronym for fiber reinforced polymers, which some also call fiber reinforced plastics, so called because of the fiber content in a polyester, vinyl ester, or other matrix. Three are commonly used (among others): composite containing glass fibers are called glass fiber reinforced polymers (GFRP): those containing carbon fibers are called carbon fiber reinforced polymers (CFRP) and those reinforced with aramid fibers are referred to as aramid fiber reinforced polymers (AFRP). This paper presents general concept for strengthening the reinforced concrete column a wrapping of CF sheet.

Keywords: Composite, FRP, CF sheets, wrapping, strengthening.

1. Introduction

The design of concrete member reinforced with fibre reinforced polymer (FRP) has many different design considerations than a steel reinforced concrete member. Confinement of reinforced concrete columns significantly enhances the performance under axial load, bending and shear, because of the increase in concrete compressive strength, the increase in ductility, the increase in shear strength and the higher resistance against buckling of the steel reinforcement in compression. The confinement of columns is achieved by means of internal lateral reinforcement (hoop or closed stirrups) or by external reinforcement (steel or FRP jackets).
A large number of investigations conducted in the laboratory and field applications in buildings and bridges established the viability of composites for improving the performance of axially loaded members.
Rehabilitation and strengthening of structures with inadequate bearing capacity has reached a level of extended design alternatives.

2. General

The repair and strengthening of reinforced concrete (RC) columns through FRP composites includes external FRP wrapping, FRP encasement, and FRP spraying. Confinement is generally applied to members in compression, with the aim of enhancing their load carrying capacity or, in cases of seismic upgrading, to increase their ductility. Numerous experimental studies involving concrete cylinders wrapped with CF sheets have revealed that the tensile strength ascertained in tests on strips of material are not achieved on the member. In Fig. 1.1 it can be seen that at a certain value of the normalized axial concrete strain, the steel reaches yielding and then, from that point on, it exerts a constant lateral (confining) pressure, while FRP exerts a continuously increasing confining action. In principle, the DAfStb guideline together with a corresponding system approval allows the following concrete member strengthening measures to be carried out:

- Flexural strengthening with externally bonded (surface- mounted) CFRP strips, CF sheets and steel plates
- Flexural strengthening with CFRP strips bonded in slots (near-surface -mounted reinforcement)
- Shear strengthening with externally bonded CF sheets and steel plates

Column strengthening with CF sheets as confining reinforcement.

3. Principles and properties of materials relevant to design

The development of the principles for designing confined concrete members is attributed to the French engineer Armand Considére, who in 1902 patented a method for casting concrete elements with a high axial compressive strength. The carbon fibre sheets (CF sheeting) are unidirectionally aligned carbon fibres. The sheeting is characterised by the following properties:

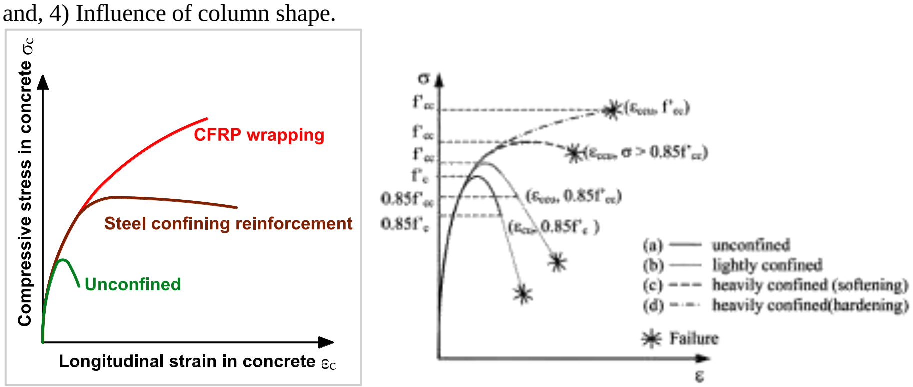
- tensile strength in the direction of fibres;
- modulus of elasticity in the direction of fibres;
- ultimate strain in the direction of fibres;
- geometric dimensions and weight per area
- calculated thickness (equals theoretical thickness)

The selection of materials for different strengthening systems is a critical process. Every system is unique in the sense that the fibres and the binder components are designed to work together. Today there are several types of composite material strengthening systems, which are summarized below:

- Wet lay-up systems
- Systems based on prefabricated elements
- Special systems, e.g. automated wrapping, prestressing, near-surface mounted bars, mechanically attached laminates

4. Effective lateral confining pressureg

Depending on column shape and strengthening lay-out, a non-uniform confining stress distribution is obtained. Next, the following cases are examined: 1) Fully wrapped cylindrical specimens with fibres perpendicular to longitudinal axis, 2) Influence of partial wrapping, 3) Influence of fibre orientation, and, 4) Influence of column shape.



a) b)

Fig. 1.1 a) The effect of confining reinforcement, **b)** Schematic stress-strain behavior of unconfined and confined RC columns (Rocca et al. 2006).

4.1. Fully wrapped cylindrical specimens with fibres

For uniaxially loaded cylindrical concrete specimens, confined with either steel hoop or spiral reinforcement, the effective confining pressure, f_l is calculated as a function of the transverse steel volumetric ratio ρ_{st} and its yield stress f_y, as follows (Fig. 1.2):

$$f_l = \frac{1}{2} k_e \rho_{st} f_y \qquad (1)$$

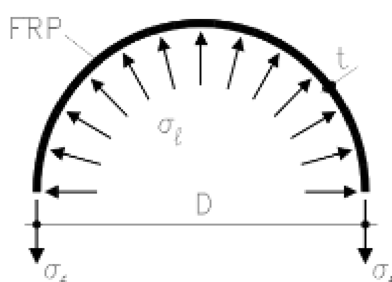


Fig. 1.2 Confining pressure exerted by the FRP.

The lateral confining pressure σ_l can be expressed as a function of the current stress ε_l in the FRP jacket can be rewritten as:

$$\sigma_l = K_{conf}\,\varepsilon_l \tag{2}$$

$$K_{conf} = \frac{1}{2}\rho_j E_j \tag{3}$$

Hence, the lateral confining pressure σ_l exerted by the FRP jacket is calculated based on its current stress $\sigma_j = E_j \varepsilon_j \leq f_j$. The maximum lateral confinement pressure f_l is obtained as:

$$f_l = \frac{1}{2}\rho_j E_j \varepsilon_{ju} \tag{4}$$

4.2. Influence of partial wrapping

If the concrete is partially wrapped, less efficiency is obtained as both confined and unconfined zones exist (Fig. 1.3). In this case, the effective lateral confining pressure is obtained from eq. (5) by introducing a confinement effectiveness coefficient
$k_e \leq 1$. In between two subsequent FRP wraps, the area of effectively confined concrete core A_e is:

$$A_e = \frac{\pi}{4}\left(D - \frac{s'}{2}\right)^2 \tag{5}$$

$$k_e = \frac{\left(1 - \frac{s'}{2D}\right)^2}{1 - \rho_{sg}} \approx \left(1 - \frac{s'}{2D}\right)^2 \tag{6}$$

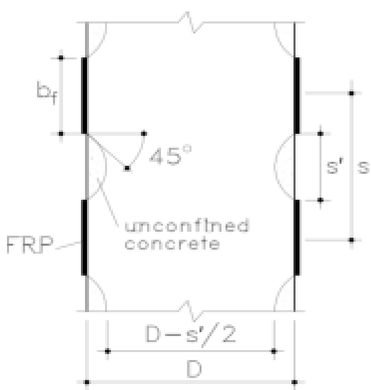


Fig. 1.3) FRP partially wrapped

4.3. Influence of fibre orientation

If the fibres are helically applied, the fibre alignment is less efficient to restrain the lateral expansion of the concrete. Assuming a uniform tension force N_f in the FRP, the confinement pressure exerted by the helical FRP wrapping reinforcement is given by:

$$\sigma_{l,h} = \frac{N_f}{b_f R} \tag{7}$$

In a similar way, the confinement pressure per unit width exerted by circular FRP wrapping reinforcement is obtained as:

$$\sigma_{l,c} = \frac{N_f}{b_f r} \tag{8}$$

the confinement effectiveness coefficient k_e can be defined as:

$$k_e = \frac{\sigma_{l,h}}{\sigma_{l,c}} = \left[1 + \left(\frac{p}{\pi D}\right)^2\right]^{-1} \tag{9}$$

4.4. Influence of column shape

For a square or rectangular section wrapped with FRP (Fig. 1.4) and with corners rounded with a radius r_c, the parabolic arching action is again assumed for the concrete core where the confining pressure is fully developed

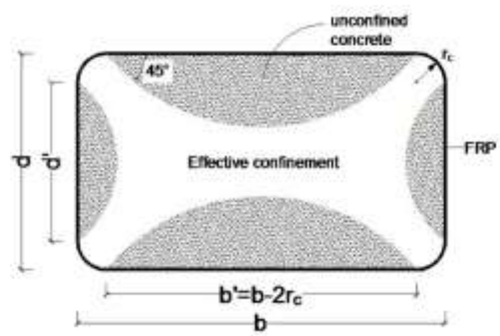


Fig. 1.4 Effectively confined core for non-circular sections.

Taking the sum of the different parabolas, the total plan area of unconfined concrete is obtained as:

$$A_u = \sum_{i=1}^{4} \frac{(w'_i)^2}{6} = \frac{b'^2 + d'^2}{3} \tag{10}$$

the confinement effectiveness coefficient k_e is given by:

$$k_e = 1 - \frac{b'^2 + d'^2}{3A_g(1-\rho_{sg})} \tag{11}$$

the lateral confining pressures induced by the FRP wrapping reinforcement on a square or rectangular cross-section are given as:

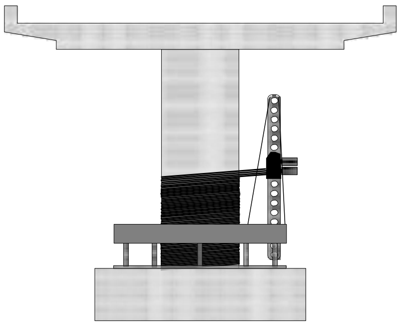
$$\sigma_{lx} = K_{confx}\, \varepsilon_{ju} \tag{12}$$

$$\sigma_{ly} = K_{confy}\, \varepsilon_{ju} \tag{13}$$

4.5. Use of confinement to increase ductility in seismic regions

The ductility factor may be related to the shear capacity V_u of the member after retrofit, and to the moment capacity M_u of the member after retrofit, according to empirical equations of the type:

$$\mu_\Delta = \alpha + \beta(V_u a / M_u) \leq 10 \tag{14}$$



a) **b)**

Fig. 1.5 Automated RC column wrapping. a) Schematic. b) Photograph of robot-wrapper. (fib bulletin 14)

5. Load-carrying capacity of cross-section and member

The strain in the CF sheet is determined from the creep-induced longitudinal deformation ε_{cc} in simplified form for a constant Poisson's ratio. The equation for determining the ultimate strain that may be assumed for a CF sheet is therefore

$$\varepsilon_{ju}=\alpha_r*\alpha_T*\alpha_F*\alpha_E*\alpha_Z*\alpha_{Lu}-\vartheta*\varepsilon_{cc} \tag{15}$$

Various researchers have proposed criteria to guarantee an adequate confining effect

$$\frac{2*t_L*E_L}{D*f_c^2}\geq 0.2 \tag{16}$$

In contrast to unconfined compression members with a doubly symmetric cross- section, the maximum moment capacity is not reached at N_{bal}, but instead at lower axial loads.

$$N_{bal}=0.8*f_{cc}*A \tag{17}$$

The equations for determining the theoretically admissible axial load N_u and the associated moment M_u according to Jiang are as follows:

$$N_u=\theta*\alpha_1*f_{cc}*A_c*\left(1-\frac{\sin(2*\pi*\theta)}{2*\pi*\theta}\right)+(\theta_c-\theta_t)*f_y*A_s \tag{18}$$

$$M_u=N_u*\left(e_1+\left(\frac{l_0}{\pi}\right)^2*\xi_1*\xi_2*\emptyset_{bal}\right)=\frac{2}{3}*\alpha_1*f_{cc}*A_c*\frac{D}{2}\left(\frac{\sin^3(\pi*\theta)}{\pi}\right)+f_y*A_s*\frac{D}{2}\left(\frac{\sin(\pi*\theta_c)+\sin(\pi*\theta_t)}{\pi}\right) \tag{19}$$

Figure 1.6 shows the relationships within the cross-section for a compression member with both types of confining reinforcement.

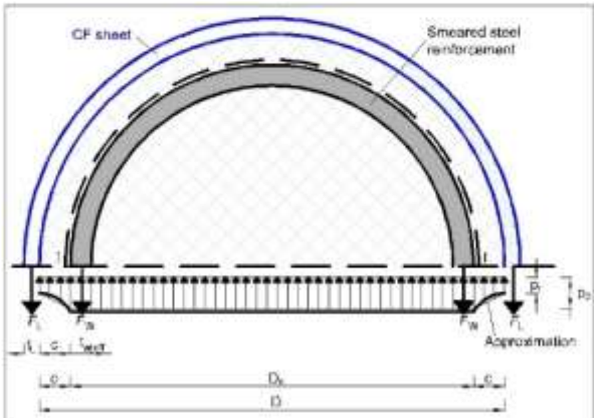


Fig. 1.6. Cross-section of the confined reinforced concrete column (1/2)

6. Distribution of transverse compression

The following factors take into account the non-uniform distribution of the transverse compression over the cross-section owing to the different areas of influence of the confining reinforcement made up of reinforcing steel and CF sheet.
The factors for the non-uniform distribution of the transverse compression according to DAfStb guideline [1] part 1 Eq. (RV 6.90) and (RV 6.91):

$$p_1 = \frac{2*F_L}{D} = \frac{2*t_L*E_L*\varepsilon_{ju}}{D} \tag{20}$$

$$p_2 = \frac{2*(F_L+F_W)-p_1*c}{D_c+C} = \frac{2*(t_L*E_L*\varepsilon_{ju}+t_{W,eff}*f_{wy})-p_1*c}{D_c+C} \tag{21}$$

$$\Delta_p = p_1 - \frac{2*t_L*E_L*\varepsilon_{ju}-(p_1+p_2)*c}{D_c} \tag{22}$$

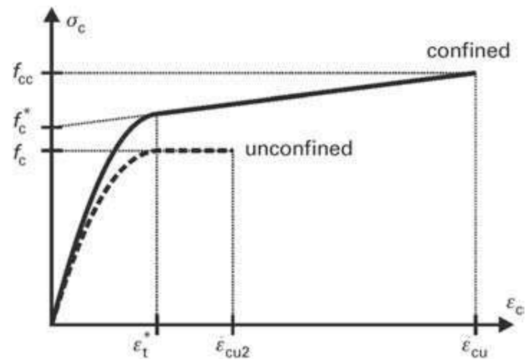


Fig. 1.7 Simplified stress–strain curve for design

At the origin, the slope of the curve is given by the tangent modulus E_c of the unconfined concrete (see Figure 1.7). The design approach is defined by the following equations:

$$\sigma_c=\begin{cases} E_c*\varepsilon_c-\frac{(E_c-E_2)^2}{4*f_c^*}*\varepsilon_c^2 & \text{for } 0\leq\varepsilon_c\leq\varepsilon_t^* \\ f_c^*+E_2*\varepsilon_c & \text{for } \varepsilon_t^*\leq\varepsilon_c\leq\varepsilon_{cu} \end{cases} \tag{23}$$

However, only the effect of the confining CF sheet is used when defining the longitudinal strain ε_{cc} in the confined concrete upon failure of the fibre-reinforced material.

7. Creep of confined concrete

In order to consider the behavior with respect to time, the creep of the confined concrete must be calculated according to DAfStb guideline [1] part 1 Eq. (RV 6.74):

$$\varepsilon_{cc}(\Delta t)=[k_7]*\beta_c(\Delta t)*\beta(f_{cm})*\beta_{0,k}*\frac{\sigma_{cp}}{E_{cm}} \tag{24}$$

8. Analysis at Ultimate Limit State (ULS)

As the acting axial load is less than the axial load resistance of the column, the column load-carrying capacity is satisfactory,

$$N_{Rd}\geq N_{Ed} \tag{25}$$

$$N_{Rd}=\frac{1}{\gamma_{LG}}*\theta*\alpha_1*f_{cck}*A_c*\left(1-\frac{\sin(2\pi\theta)}{2\pi\theta}\right)+\frac{1}{\gamma_s}*(\theta_c-\theta_t)*f_{yk}*A_s \tag{26}$$

The maximum acting moment according to second-order theory taking into account creep deformations is calculated from the first part of Eq. (RV 6.63) according to the DAfStb guideline [1]

$$M_{Rd}=N_{Rd}*\left(e_{tot}+\left(\frac{l_0}{\pi}\right)^2*\xi_1*\xi_2*\emptyset_{bal}*K_{\varphi}\right) \quad (27)$$

9. Analysis serviceability limit state (SLS)

In order to avoid unacceptable damage to the concrete microstructure at the serviceability limit state, DAfStb guideline [1] part 1 section 7.2 (RV 15) specifies that the theoretical thickness of confining reinforcement necessary t_L must comply with the following condition according to DAfStb guideline [1] part 1 Eq. (RV 7.5):

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$$t_L\leq\frac{D}{2*E_L*\varepsilon_{juk}}*\frac{1}{[k_0]}*\left[\gamma_{LG}*\left[\gamma_F*([k_8]-[k_9]*f_{ck})*\left(\alpha_{cc}*f_{ck}+\frac{A_s}{A_c}*|\varepsilon_{c2}|*E_s\right)-\frac{f_{yk}}{\gamma_s}+\frac{A_s}{A_c}\right]-f_{ck}\right] \quad (28)$$

As the thickness of confining reinforcement used is less than the maximum permissible thickness according to DAfStb guideline [1] part 1 Eq. (RV 7.5), the design for serviceability is satisfactory.

$$\Longrightarrow \quad t_L \leq t_{L,max} \quad (29)$$

Conclusions

- Understanding the properties and limits of FRP is very important step in developing the right design solution and utilizing it for the right application in the civil engineering.
- From the review of the literature, it was also concluded there is a need to perform additional research on the FRP retrofit of columns subjected to impact loadings. With further investigations including ways to improve energy absorption capacity and ductility of the structural systems and composite materials, reduction in life cycle costs will outweigh the higher upfront cost of FRP retrofit over conventional retrofit techniques.
- 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.
- The corners of the webs shall be curved at a minimum r ≥ 25 mm. The minimum column diameter complies with, D ≥120 mm
- Intimate contact between FRP system and member is critical

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