MODELLING OF FRP&STEEL-CONFINED CIRCULAR RC SECTIONS

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1 INTRODUCTION

Confining wraps or jackets to rehabilitate and strengthen existing concrete columns has proven to be an efficient technique for seismic retrofit of structures. The behavior of fiber reinforced polymer (FRP)–confined concrete under axial loads has been extensively studied. However, most of the compressive strength models of the confined concrete only consider the increased strength and ductility provided by FRP, neglecting the contribution of the existing steel reinforcement inside the column's section. Even if the existing steel stirrups in a reinforced concrete column are not sufficient to confine the concrete core, they must also contribute along with the FRP jacket in confining the section. Thus, the interaction of steel ties and FRP in evaluating the confining effect should be accounted for.

2 MODELING OF CONCRETE CONFINED WITH STEEL&FRP

The behaviour of confined circular sections under axial load (fig.1) is characterized by the radial lateral dilation, which causes radial confining forces or else hydrostatic confining pressure. Considering this scheme for the case of confinement by means of FRP jacketing, in order to define the confining pressure acting on the section, it is necessary to define the jacket strain, or circumferential strain, parallel to the fibres orientation. Relating the circumferential strain to the strain in the radial direction, the following simple relationship is obtained (ε_r = radial strain, ε_c = circumferential strain, R = radius of the section):

$$\varepsilon_c = \frac{\Delta C}{C} = \frac{2\pi R(1+\varepsilon_r - 1)}{2\pi R} = \varepsilon_r \tag{1}$$

Expectedly, the outcome is that the circumferential strain and the strain in the radial direction are equal. This property has been extensively used to calculate directly the radial confining forces based on experimental data by strain gages attached parallel to the fibres orientation in order to obtain the circumferential strains. Along this line, it seems useful to try and extend the simple calculation above to the case where both steel stirrups and external FRP jacketing are both present (fig 1). Based on figure 1, the steel ties divide the section into two parts: the first is the concrete core and the second is the concrete cover (R_s = Radius of the concrete core, c = concrete cover, ε_r = radial strain).

$$\varepsilon_c = \frac{\Delta C}{C} = \frac{2\pi\left\{\left[R_s\left(1+\varepsilon_{r.core}\right)+c\left(1+\varepsilon_{r.\mathrm{cov}er}\right)\right]-\left(R_s+c\right)\right\}}{2\pi\left(R_s+c\right)} \tag{2}$$

$$\varepsilon_c = \frac{\Delta C}{C} = \frac{R_s\left(1+\varepsilon_{r.core}\right)+c\left(1+\varepsilon_{r.\mathrm{cov}er}\right)}{\left(R_s+c\right)} - 1 \tag{3}$$

However, for the concrete core the following assumption still holds:

$$\varepsilon_{c.core} = \varepsilon_{r.core} \tag{4}$$

As explicitly stated above, the equation of radial strains and jacket strains for the case of both FRP and steel confined concrete in circular sections is not valid anymore. The circumferential strain of the external jacket is based on the radial strains of both concrete cover and concrete core, where in the latter the presence of the steel ties plays an important role.

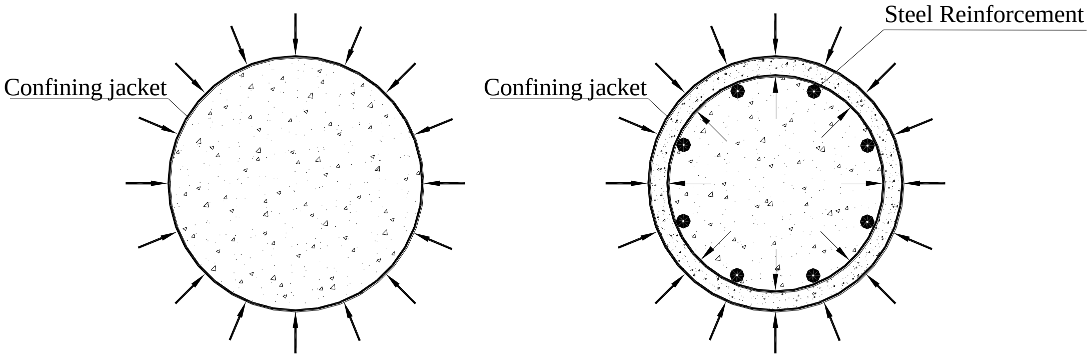

Fig. 1 Circular Concrete Section confined by steel stirrups and/or FRP Jackets.

3 NUMERICAL MODEL

The mechanical properties of concrete (strength, ductility, energy dissipation) are substantially enhanced under a triaxial stress state. In practice, in order to develop a similar stress state, closed stirrups or spiral reinforcement are used, so that, together with the longitudinal reinforcement, the lateral expansion of concrete is limited. This kind of (passive) confinement positively affects the behaviour of the material after the appearance of the internal cracking, which gives rise to the initiation of expansion.

For low strain values, the stress state in the transverse steel reinforcement is very small and the concrete is basically unconfined. In this range, steel and FRP jacketing behave similarly. That is, the inward pressure as a reaction to the expansion of concrete increases continuously. Therefore, speaking in terms of variable confining pressures related to the axial strain level and triaxial models defining stress-strain curves for concrete subject to constant lateral pressure, it can be stated that the stress-strain curve describing the stress state of the section has to cross all active confinement curves up to the curve with lateral pressure equal to the one applied by the stirrups at yielding. After this point, the lateral pressure is still increasing only due to the FRP jacketing, while the steel lateral pressure remains constant. The corresponding stress-strain curve of the section throughout this procedure is stabilizing at the curve with lateral pressure equal to the tensile strength of the FRP jacket plus the yielding strength of steel (excluding the strain hardening behaviour of steel, since ultimate strains of steel are usually much higher that those of FRP jackets).

Based on these considerations, an existing FRP-confined concrete model [3] has been enhanced to include the steel ties contribution and thus model in a more accurate way circular columns with transverse reinforcement and retrofitted with FRP Jacketing. The above model was based on an iteration procedure that needed to be modified as figure 2 shows.

In the procedure below, after imposing an axial strain on the section, a pressure coming from the FRP jacket is assumed. Then, the Poisson's coefficient until steel yield strength and the pressure coming from the steel ties is calculated based on the BGL model [1]. Here, also the longitudinal bars' contribution and the arching action between two adjacent stirrups along the column are taken into account according to that model. The confining pressure in the concrete core is simply the summation of the lateral pressures coming from the two different materials (FRP and steel). The Spoelstra-Monti model [3] after this point is basically used to define the rest of the parameters declared above, applying that model for the two different regions already mentioned. The focal point of the procedure is in the last step where the confining pressure of the jacket is defined based on the circumferential strain of equation (3). At this point, the 14^{th} fib bulletin's [4] factor taking into account partial wrapping can be used too. Finally, due to several influencing factors, among which are the local stress concentrations near failure, an ultimate tensile coupon FRP strain reduced by a k factor (ranging in literature between 50-80%) is used for ending the iteration procedure when FRP jacket arrive at its rupture strain (on passing, it has been observed that k should be even more conservative).

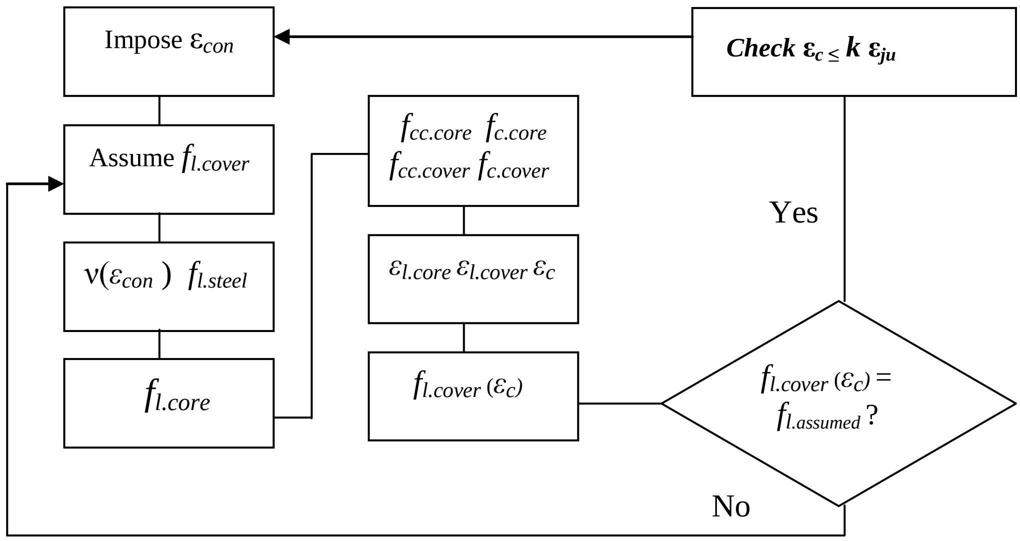

Fig. 2 Iterative Procedure.

4 CORRELATION WITH EXPERIMENTAL RESULTS

Some preliminary comparisons have been carried out by the authors for the validation of the proposed procedure. One of the few extensive experimental studies on large scale FRP wrapped circular columns has been used for that purpose (Matthys et.al. [2]). It includes 8 large-scale columns subjected to axial loading. The columns had a total length of 2 m, a longitudinal reinforcement ratio of 0.9% and 8 mm diameter stirrups spaced at 140 mm. All columns had circular cross section with 400 mm diameter. Different types of FRP reinforcement (CFRP, GFRP & HFRP) have been used to confine the columns. The comparison seems to be satisfactory (fig. 3), however, other correlation studies with more experimental data are currently under way to validate the proposed approach.

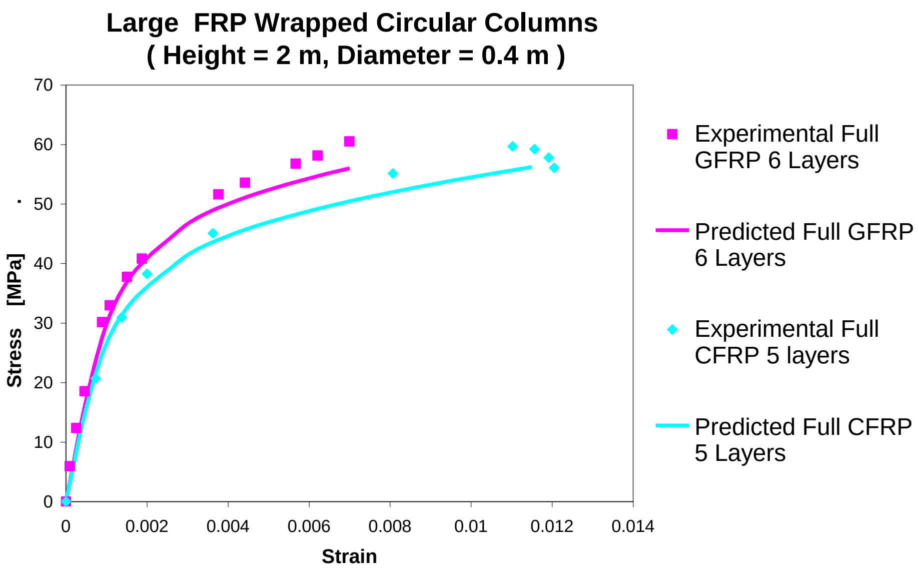

Fig. 3 Correlation with the experimental study by Matthys et.al [2]

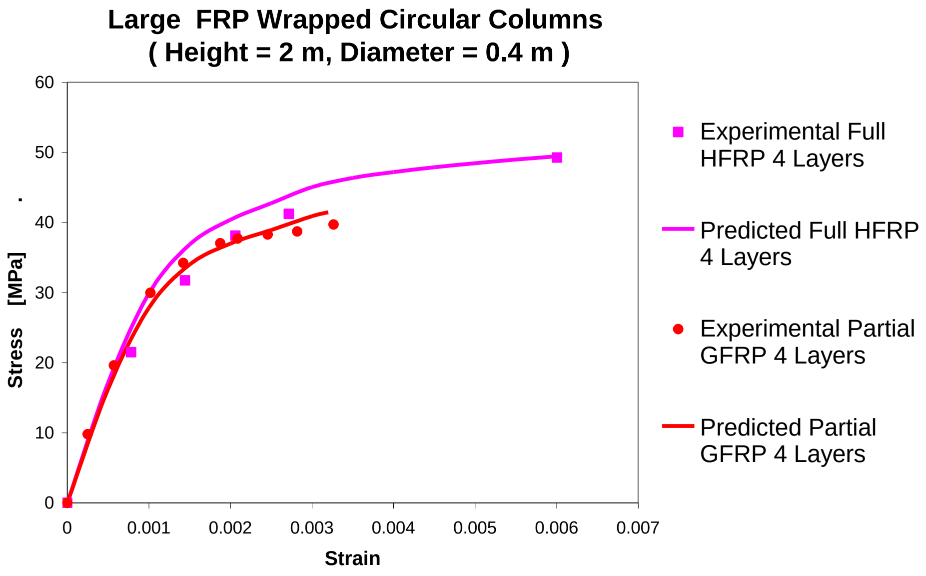

Fig. 4 Correlation with the experimental study by Matthys et.al [2]

5 CONCLUSIONS

Spoelstra and Monti [3] FRP-confined concrete model has been enhanced to take into account the confining effect of the already existing steel reinforcement when retrofitting a reinforced concrete column with FRP jacketing. To this end, the transverse steel reinforcement has been considered not as imposing a constant value of confining pressure, rather, following the steel stress-strain law at each deformation step by using the Braga, Gigliotti and Laterza [1] model, taking into account also the confining effect of longitudinal reinforcement. Finally, compatibility in the lateral direction, inwards for confining pressures and outwards for lateral strains, between the two confining materials (FRP & Steel) has been established. A preliminary correlation with experimental results seems to give promising results.

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