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Concrete softening effects on the axial capacity of RC jacketed circular columns

Giovanni Minafò *, Maurizio Papia

Università degli Studi di Palermo, Scuola Politecnica, Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali – DICAM, Viale delle Scienze, 90128 Palermo, Italy

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ABSTRACT

Among the different strengthening techniques to repair RC structures, reinforced concrete (RC) jacketing is one of the most commonly adopted, especially for columns. Its wide application is due to its easy application and relatively reduced cost with respect to other methods (e.g. FRP wrapping, Shape Memory Alloy active confinement). The target of RC jacketing is to increase axial, flexural capacity and ductility of weak existing members by means of two main effects: confinement action provided by the jacket and composite action between external jacket and inner concrete.

Different theoretical studies have been carried out to calculate the strength enhancement due to confinement action and most of these are based on the adaptation of classical models for confinement evaluation in RC members. However, experimental investigations on compressive behaviour of RC jacketed sections have shown that the actual axial capacity could be substantially lower than that analytically evaluated with classical confinement models. This fact could be explained by taking into account the presence of tensile stresses developing in the jacket, due to the different dilatation of the inner core and the external jacket. This phenomenon is relevant especially in members where the concrete properties of the jacket are different with respect to those of the core, causing the premature failure of the external layer. This paper presents a simplified approach able to evaluate these effects. In particular RC jacketed circular columns are analysed as case study and the member is studied by considering the different concrete properties of core, jacket and cover. Circumferential and radial stresses are firstly calculated under the assumption of linear elastic behaviour and plane strain state. The model is extended in the non-linear range by adopting a secant constitutive law. Finally, comparisons are made with experimental data available in the literature, showing good agreement and explaining some experimental results.

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1. Introduction

Nowadays, the reinforced concrete (RC) jacketing technique is always more frequently adopted to retrofit existing weak columns, with the goal of increase their strength and ductility. The method consists of casting a RC layer (jacket) around the column, in order to increase the confinement effect on the member and/or enlarge the transverse cross section. The effect provided by the jacket depends on whether or not it could be considered as directly loaded (i.e. when the jacket is continuous and well connected with the slabs) or indirectly loaded (i.e. when a gap exists between the jacket and the slabs). In the first case, composite action between external jacket and inner concrete and confinement could be effective, while if the jacket is indirectly loaded the main effect of the technique is related to the confinement pressure induced from the external layer to the inner column. In both cases it is clear that the amount of transverse and longitudinal steel is crucial for the overall efficacy of the technique, as well as the thickness of the jacket.

A great number of research works were carried out in the past about strengthening techniques for RC members. As an example, a recent literature review on the compressive behaviour of RC columns reinforced with steel angles and strips has been made in [1]. Researchers performed an experimental investigation and validated the main theoretical models available in the literature to predict the experimental results. Similarly, a study has been performed in [2] on the reliability of analytical compressive stress-strain laws for Fiber Reinforced Polymers (FRP) confined concrete in circular columns. The existing models to predict the stress

* Corresponding author.
E-mail address: giovanni.minafo@unipa.it (G. Minafò).

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strain-curve of FRP confined concrete were reviewed and verified over a large test database and the performance of each theoretical stress–strain model was assessed by means of statistical indicators.

Concerning RC jacketing, several studies were addressed to in the past to clarify the key parameters affecting the efficacy of the technique [3–8]. From an experimental point of view, studies were addressed mainly on the behaviour of axially loaded members and columns subjected to axial compression and uniaxial bending. The most relevant experimental data refers to Ersoy et al. [3], Takeuti et al. [4] and Branco et al. [5]. These researches investigated on different aspects such as the effect of preload, the influence of interface treatment on the structural behaviour, and the reinforcement slippage in column-footing models.

From a theoretical point of view and with reference to the compressive behaviour, Campione et al. [6] proposed a theoretical approach to calculate proper constitutive laws for old and new concrete and for steel, by adapting the model proposed in [9] of confined concrete to square jacketed sections. In this way, the analytical provisions [6] of the compressive behaviour of jacketed columns refers only to existing models for RC members, and confinement effects are derived by adapting the expressions of efficiency coefficients and confinement pressure. The reliability of this approach [6] was verified with some experimental results [3,4], and proved to be consistent only in some cases. In fact, it has been shown that in other cases a substantial overestimation of the axial capacity could be achieved. This fact could be explained by taking into account the presence of tensile stresses developing in the jacket, due to the different dilatation of the inner column and the external jacket. The mutual interaction between core and jacket could lead to bending effects, causing a complex stress state in the concrete.

This paper presents a simplified approach able to evaluate softening effects in circular RC jacketed columns. In the first stage of the study, an analytical stress analysis is performed aiming to find hoop and radial stresses in each portion of the column. The column is modelled as six interacting coaxial hollow cylinders and stresses are calculated under the assumption of linear elastic behaviour, isotropic conditions and plane strain state. The model is finally extended in the non-linear range by adopting a secant constitutive law. Hoop and radial stresses are calculated in each concrete layer for a fixed value of axial strain and this stress analysis is performed until reaching a defined biaxial failure surface.

In the second part of the analytical study, the uniaxial stress-strain laws of concrete in compression by Mander et al. [9], Ahmad and Shah [11] and Cusson and Paultre [10], (see Table 1), are adopted for each layer and modified on the basis of the previous stress analysis. In particular, the value of ε_z^* found with the previous calculation is adopted as the axial strain corresponding to peak axial stress. These modified stress-strain laws of concrete in compression are assumed for each concrete layer and adopted to calculate the compressive response of the column.

Table 1
Analytical models for the compressive stress-strain behaviour of concrete adopted in the "existing literature models".

Normal Strength Concrete (NSC)	
Confined Mander et al. [9]	Unconfined Ahmad and Shah [11]
$\sigma_c = f_{cc}\frac{x\cdot r}{r-1+x^r}$ $x = \frac{\varepsilon}{\varepsilon_{cc}}$ $r = \frac{E_{c0}}{E_{c0}-E_{sec}}$ $\varepsilon_{cc} = \varepsilon_{c0}\cdot\left[1+5\left(\frac{f_{cc}}{f_{c0}}-1\right)\right]$	$\sigma_c = f_{cc}\frac{x\cdot\beta}{\beta-1+x^\beta}$ $\beta = 1.4276\cdot\exp\left(0.0247f_{c0}\right)$
High Strength Concrete (HSC)	
Confined Cusson and Paultre [10]	Unconfined Ahmad and Shah [11]
$\sigma_c = f_{cc}\cdot\exp\left[k_1(\varepsilon-\varepsilon_{cc})^{K_2}\right]$ $f_{cc} = f_{c0}\cdot\left[1+2.1\left(\frac{f_{eff}}{f_{co}^s}\right)\right]^{0.7}$ $\varepsilon_{cc} = \varepsilon_{c0}+0.21\left(\frac{f_{eff}}{f_{co}}\right)^{1.7}$	$\sigma_c = f_{cc}\frac{x\cdot\beta}{\beta-1+x^\beta}$ $\beta = 1.4276\cdot\exp\left(0.0247f_{c0}\right)$

2. Theoretical background: application of classic additive approach for the calculation of the compressive response

The case study here examined refers to RC jacketed columns with circular transverse cross section (Fig. 1a). In general, the analytical compressive response of an axially loaded RC member can be obtained by summing the response of each constituent element, e.g. concrete and steel area. As discussed in the introduction section, this kind of approach allows taking into account the effect of confinement and the different concrete properties, if proper constitutive laws are assumed. However, this method could lead to some errors when applied to RC jacketed members, depending on the properties of concrete composing the jacket.

For the sake of clarity, the response of specimens C2N and C3N tested in [4] is shown in Fig. 2a and b and compared to a possible theoretical response, obtained with the classic additive approach. The main the geometrical and mechanical details of specimens here adopted for comparison are summarized in Table 2 in terms of shape of the section, size of the core D, compressive strength of concrete in the core $f_{c,co}$ and in the jacket $f_{c,j}$, amount and yield

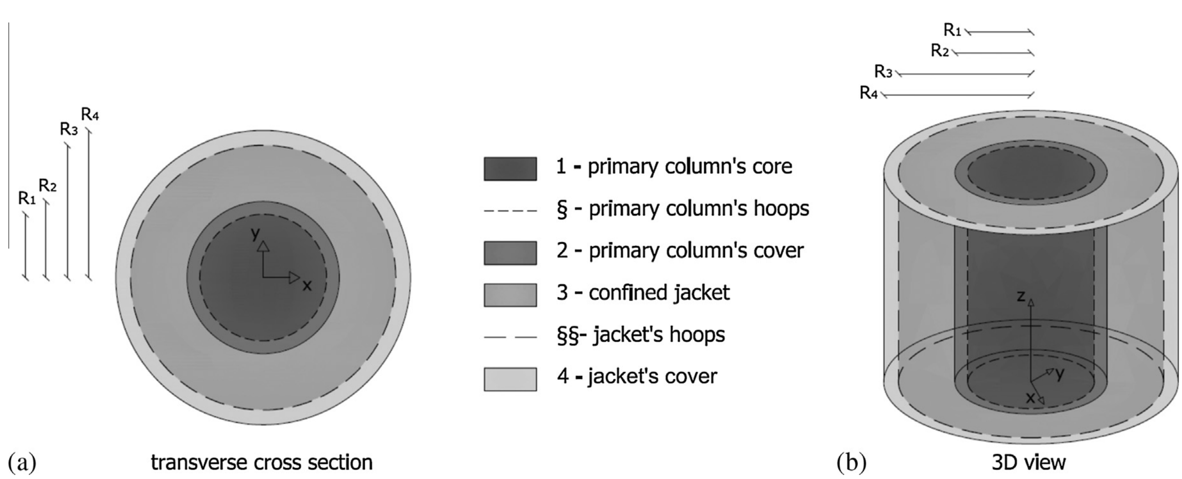

Fig. 1. Case study; (a) Transverse cross section; and (b) circular column.

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