Engineering Structures 85 (2015) 162–169

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

A practical approach for the strength evaluation of RC columns reinforced with RC jackets

Giovanni Minafò *

Università degli Studi di Enna "Kore", Facoltà di Ingegneria e Architettura, Cittadella Universitaria, 94100 Enna, Italy

A R T I C L E I N F O

Article history:
Received 12 July 2014
Revised 11 December 2014
Accepted 12 December 2014
Available online 29 December 2014

Keywords:
RC columns
RC jacketing
Retrofit
Confinement

A B S T R A C T

Reinforced concrete (RC) jacketing is nowadays one of the most common techniques adopted for seismic retrofitting of existing RC columns. It is used to increase load-carrying capacity and ductility of weak existing members by means of a simple and cheap method. The structural efficiency is related to two main effects: – the enlargement of the transverse cross section; – the confinement action provided by the external jacket to the inner core. Several theoretical and experimental studies were addressed in the past to investigate on how it is possible to calculate the strength enhancement due to these effects and to highlight the main key parameters influencing the structural behavior of jacketed columns. Most of theoretical studies analyzed members subjected to axial compression while the case of axial force and bending moment was adapted only with complex formulations based on numerical approaches, which require the use of a suitable algorithm (e.g. non-linear finite element analyses, sectional fiber models). This paper presents a simplified approach, able to calculate the strength domains for jacketed columns subjected to axial force and uniaxial bending moment. The model takes into account the effects of confinement with proper stress-block parameters, the latter adapted for confined concrete, and of the composite action of jacket and core; buckling of longitudinal bars is considered and discussed with an appropriate stress–strain law for steel in compression. Results are compared with numerical analyses carried-out with the fiber model approach implemented in a commercial software (SAP2000), showing the accuracy of proposed method. Comparisons are also made with experimental results available in the literature in order to validate the model. Finally parametric considerations are made on the basis of adopted model, useful for design/verification purposes.

1. Introduction

Reinforced concrete (RC) jacketing is always more frequently adopted to retrofit existing RC columns with poor structural features. This method consists in casting a concrete layer around the existing member, and reinforcing the jacket with a properly designed amount of longitudinal and transverse reinforcement (Fig. 1). The efficacy of the technique on the structural behavior is related to the enlargement of the transverse cross section, which increases the load-carrying capacity and to the confinement pressure induced by the jacket in the inner column. This confining action allows to increase strength and ductility of the original concrete, and to restrain buckling of longitudinal bars, especially when stirrups in the column are largely spaced.

The efficiency of the RC jacketing is affected from different factors, which has to be taken into account when designing the strengthening technique. Particular attention has to be paid to old-new concrete interface, which could reduce the flexural capacity as observed in [1,2]. If concrete surface of the old member is not roughened, the reduction in the effectiveness of composite column, in terms of flexural capacity, is almost 10%, while if interfaces are well roughened these effects are negligible [3,4]. Furthermore, the long term effects, including shrinkage, have to be carefully taken into account, as stressed in [5].

From practical point of view some studies have proposed design rules for concrete jacketing techniques [6]; specifically, these can be summarized as follow: – the strength of the new materials utilized for the jacket must be greater than that of the column; – the thickness of the jacket should be at least 4 cm for shotcrete application and 10 cm for cast-in-situ concrete; – the reinforcement should be not less than four bars for four-side jacketing and minimum bar diameter 14 mm; – the ties should be minimum 8 mm and at least 1/3 of the vertical bar diameter; – the vertical spacing is at most 200 mm and close to the joint must not exceed 100 mm. In addition, the spacing of the ties should not exceed the

* Tel.: +39 0935 536442; fax: +39 0935 536623.
E-mail address: giovanni.minafo@unikore.it

http://dx.doi.org/10.1016/j.engstruct.2014.12.025
0141-0296/

thickness of the jackets. Furthermore, the surface should be moistened before placing shotcrete and the existing concrete must be heavily sandblasted and cleaned of all loose materials, dust and grease obtaining in this way a well-roughened surface.

Different researches were carried out in the last twenty years to evaluate experimentally the efficacy of the technique on the structural behavior of RC columns. Ersoy et al. [7] tested two series of jacketed columns under uniaxial compression or combined axial load and bending moment. They studied the effectiveness of repair and strengthening jackets and the differences between jackets made under load and after unloading.

Julio et al. [2] carried out an experimental study to analyze the influence of the interface treatment on the structural behavior of columns strengthened by RC jacketing. After testing seven full-scale models of column-footing, they concluded that for undamaged columns a monolithic behavior of the composite element can be achieved even without increasing their surface roughness, using bonding agents, or applying steel connectors before strengthening it by RC jacketing.

Takeuti et al. [8] tested twelve RC-jacketed columns under uniaxial compression with and without preloading. The authors found that the entire core contributes to the axial capacity of the jacketed column, as long as adequate confinement is provided. Also, preloading does not adversely affect the capacity of the jacketed column, while it may increase its deformability.

From a theoretical point of view several research works were addressed to this field. Among these Lampropoulos and Dritsos [5] analyzed the case of jacketed columns subjected to axial load and bending moment by means of non-linear finite element analyses. The authors studied the suitability of a proper formulation to model the old-new concrete interface by comparing numerical results with experimental data. More recently Campione et al. [9] proposed a theoretical model to calculate proper constitutive laws for old and new concrete and for steel, and validated their model with experimental data available in the literature. The case of eccentrically loaded columns was studied by considering a numerical approach based on the discretization of the section by means of the classic fiber model.

Concerning practical methods, different studies [10] focused on the use of "monolithicity coefficient factors", which are used for the design of the strengthened elements. The application of these factors is a 'design approach', proposed not only for the strength evaluation but also for stiffness, and deflection/rotation angle.

It is clear that a combination of a simple calculation method with the use of "monolithicity coefficients" could be a useful tool

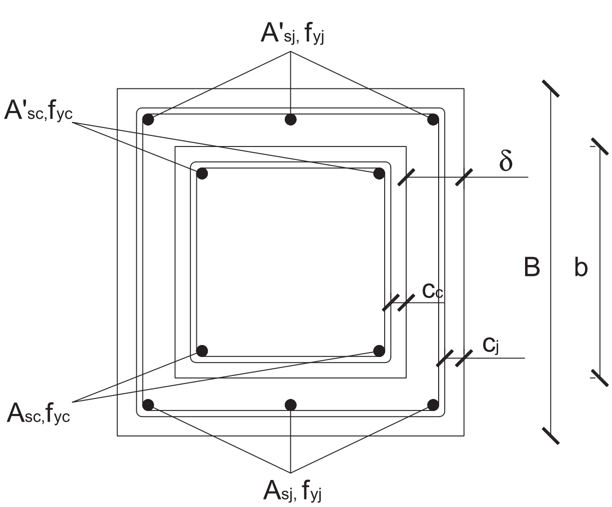

Fig. 1. Case study: square RC section reinforced with a RC jacket.

for practical engineering applications, which allows taking into account the effect of confinement and effective interaction between core and jacket.

The current paper aims to provide a simplified formulation for the calculation of strength domains of square columns reinforced with RC jackets. The proposed approach is based on the determination of some characteristic points defining the interaction domain. The corresponding values of axial force and bending moment are calculated by idealizing the constitutive laws of concrete in compression with stress-blocks, the latter to be calibrated on the basis of the confinement pressure.

It has to be noted that in the proposed model, perfect bond between the old and the new concrete is assumed and the effect of jacket's concrete shrinkage is neglected. It has been proved that both parameters affect the response of the jacketed columns, so they should be carefully addressed when adopting the proposed moment design chart.

In particular, considering the effective connection between old and new concrete, it is well-known that the response of the composite member is complex, thus a practical design procedure should take advantage of a monolithic approach, making use of properly defined "monolithicity factors" [10]. However, if the interface is well-roughened, bond between old and new concrete can be ensured, as experimentally demonstrated in [2].

Additionally, shrinkage effects play an important role on the strength of jacketed columns. In RC jacketed columns concrete shrinkage is restrained by the presence of the initial column [5], so tensile stresses could develop, inducing a biaxial state of stress in the jacket. The flexural capacity reductions due to these effects could be in the range between 23% and 46%, as discussed in [5].

The proposed approach discussed in the following should be adopted in addiction with "monolithicity factors", and with a reduction coefficient for taking into account shrinkage effects.

2. Constitutive laws of constituent materials

As discussed above, the adopted constitutive law has to take into account the effect of confinement. Campione et al. [9] have shown as the well-known model of Mander et al. [11] is suitable to model the compressive behavior of concrete of both jacket and core. Therefore the following relationship is adopted:

$$\sigma_c = \frac{\frac{\varepsilon}{\varepsilon_{cc}} \cdot f_{cc} \cdot r}{r - 1 + \left(\frac{\varepsilon}{\varepsilon_{cc}}\right)^r} \tag{1}$$

with

$$r = \frac{E_c}{E_c - E_{sec}} \tag{2}$$

where $E_c = 5000 \cdot \sqrt{f_c}$ in MPa and $E_{sec} = \frac{f_{cc}}{\varepsilon_{cc}}$.

As well-known, the peak stress f_{cc} and the peak strain ε_{cc} of confined concrete have to be calculated on the basis of the effective confinement pressure f_l by means of the following relations [11]:

$$f_{cc} = f_c \left[2.254\sqrt{1 + \frac{7.94 \cdot f_l}{f_c}} - 2 \cdot \frac{f_l}{f_c} - 1.254\right] \tag{3}$$

$$\varepsilon_{cc} = \varepsilon_{co} \cdot \left[1 + 5 \cdot \left(\frac{f_{cc}}{f_c} - 1\right)\right] \tag{4}$$

with f_c and ε_{co} the peak stress and strain of unconfined concrete.

The confining pressure is simply determinable from rigid body equilibrium of the section in the plane of the stirrup, the latter considered to be yielded. The expressions of confinement pressure induced from external and internal stirrups in the core assume the following form: