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Experimental investigation of substandard RC columns confined with SRG jackets under compression

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ABSTRACT

This paper aims to explore the behaviour of substandard reinforced concrete (RC) columns confined with Steel-Reinforced Grout (SRG) jackets under monotonically increasing uniaxial compression. A total of 24 specimens of short RC columns of square cross section were designed to fail due to longitudinal reinforcement buckling. Single-layered SRG jackets were applied to 18 of these specimens, whereas the rest served for control without SRG jackets. Parameters of this investigation were the type and density of the steel fabric as well as the corner radius of the cross section. The employed SRG jacketing managed to increase the strength and strain capacity and postpone the buckling of the longitudinal steel bars to occur at higher compressive strain level. Confinement effectiveness with respect to the lateral confining pressure exerted by the used SRG jacketing is discussed along with the observed mode of failure.

1. Introduction

Old-type reinforced concrete (RC) members are characterized by poor quality of materials and insufficient reinforcement detailing (Fig. 1(a-b)). Transverse reinforcement representative of the construction practice before the 1970's in South Europe comprises smooth bars with their ends simply overlapping at the corner, placed at large distance between them which may increase further in case of stirrups rendered ineffective due to corrosion as shown in Fig. 1(c). Such a sparse arrangement of stirrups results in a large unsupported length of the longitudinal reinforcing bars, rendering them susceptible to buckling failure when subjected to a critical compressive load. The safe performance of the whole building could be jeopardized by localized damage in the plastic hinge regions of the columns, where sideways buckling of compression reinforcement is expected to occur due to lateral shear distortion of the member in that region (Fig. 1(d)).

Previous research has identified the key role of the ratio of stirrup spacing, s, to bar diameter, D_b, in the stability of compression reinforcing bars supported laterally by stirrups [e.g. 1–5]. The values of s/D_b could range between 6 and 8 in case of high to moderate ductility RC members [6]. For slenderness ratios higher than eight ($s/Db > 8$), the compression reinforcing bars could reach buckling stage when their compressive stress reaches yielding point [5]. According to the detailing of the pre-1970's era, s/D_b could receive any value between 10 and 40 [7].

The beneficial effect on the compressive performance of substandard R/C columns, when CFRP jackets are used effectively as external confinement, was observed in the past [8,9]. Moreover, composite systems with inorganic (e.g. FRPs) and organic binders (e.g. TRM) are efficient in preventing premature bar buckling and postponing it to higher ductility strain levels e.g. [7,10,11]. When the longitudinal reinforcement reaches conditions of instability at the critical axial strain, the bar bends laterally to maintain compatibility with the increasing axial strain of the supporting concrete core [3]. Wrapping with the composite fabrics allows the concrete in compression to increase its strain capacity. As long as the strain capacity of the confined concrete is higher than the critical strain at the onset of reinforcement buckling, the member will deform further up to the point where the stress concentrations will limit the effectiveness of the composite jacket as lateral support of the longitudinal reinforcement (Fig. 1(e)) [6]. In a recent study of Bournas and Triantafillou [12] the superior behaviour of TRM jackets compared to FRP jackets has been demonstrated. It has been observed that TRM jackets allow for higher local deformations as they are able to deform outward without early fiber rupture. Thus, during buckling, when longitudinal bars bend outward at the corners of the section, TRM jackets receive the developed stress concentrations without failure.

Steel-Reinforced Grout (SRG) jacketing is a relatively new composite system where high strength steel reinforced fabric is combined with cementitious grout [13]. Earlier studies conducted on SRG confined

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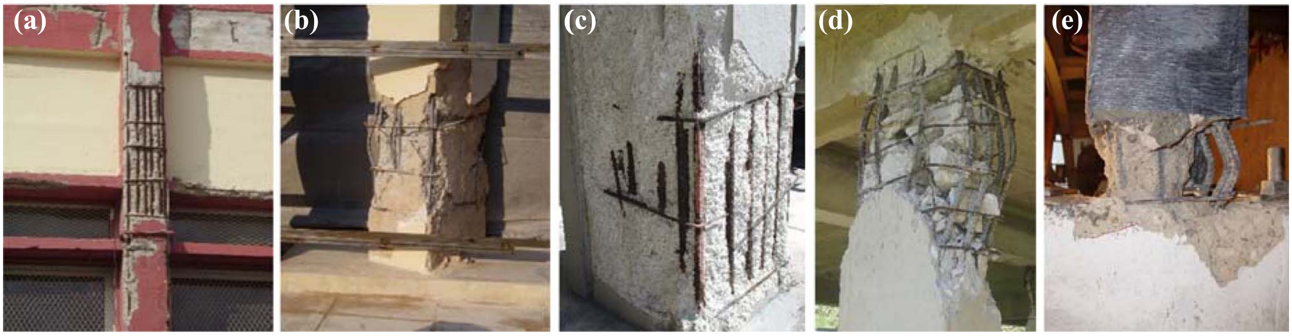

Fig. 1. (a)–(c) Reinforcement detailing of RC columns built before the 1970's in South Europe; (d) Failure due to reinforcement buckling; (e) Buckling of longitudinal reinforcement in FRP-jacketed RC columns (source: personal files).

concrete under uniaxial compression have demonstrated the efficiency of the system in increasing strength and axial strain capacity [14–16]. In the present study, the effectiveness of SRG jacketed lightly reinforced RC columns was experimentally investigated. The specimens were designed as to be susceptible to rebar buckling failure with the compression reinforcing bars losing their stability prior or close to yielding. The ratio of stirrup spacing to longitudinal bar diameter was equal to 20. Alternative single-layered SRG jackets were applied to 18 square cross section columns, whereas 6 more were used as control specimens. Experimental evidence has shown that the single-layered SRG jackets increased strength and deformation capacity. The lateral confining pressure exerted by the jackets was sufficient to increase the compressive strain ductility, thus delaying bar buckling failure to occur at higher compressive strain level.

2. Experimental program

2.1. Test specimens and material properties

The experimental program comprised twenty-four RC column specimens representative of the construction practice before the 1970's in South Europe. These specimens had a 150 mm square cross section representing a 1:2 scaled model of a prototype column with a 300 mm square cross section. The height of the specimens was defined at 600 mm due to restriction imposed by the available loading frame. With the aspect ratio being equal to 4 ($=h/b = 600/150 = 4$, where h is the height of the specimen, b is the width of the cross section) no stability problems were expected to occur [17,18].

The specimens, with a geometry in mm as shown in Fig. 2, featured a low percentage of longitudinal reinforcement and sparse transverse reinforcement, representative of old type detailing. Longitudinal reinforcement comprised four corner 10 mm diameter bars (4∅10, longitudinal reinforcement ratio, $\rho_\ell = 1.4\%$) and 6 mm diameter stirrups with their ends bent at 90^0 spaced at s = 200 mm (∅6/200). The s/D_b ratio was selected to be high ($s/D_b = 20$) complying with old type detailing requirements of that era. As seen in Fig. 2, three additional 8 mm stirrups (tie ends were welded) were placed at the specimen ends near the loading surfaces, to prevent local cracking of concrete due to stress concentrations. The concrete cover was equal to 15 mm.

The twenty-four columns were divided into two groups based on whether the four corners of the square cross section were rounded off or not. Fifteen out of the twenty-four columns had their corners rounded off by a corner radius r = 25 mm. Parameters of investigation were apart from the corner radius, the type (12X, 3X2) and the density of the fabric (1 cord/cm, 2 cords/cm) (Fig. 3). The geometrical and mechanical properties of a single cord 12X and 3X2 as measured in tests conducted are presented in Table 2 [15] and the average stress–strain curves appear in Fig. 4. The density was 1 cord/cm and 2 cords/cm corresponding to an equivalent thickness of 0.062 mm and 0.124 mm, respectively. The axial stiffness of the 1 cord/cm and 2 cords/cm steel fabric utilized herein is equal to about 1/3 and 2/3 of the axial stiffness of a common carbon fabric (≈25,000 N/mm, Table 2).

Six specimens (3 from each group) served as control specimens. The rest of the specimens (18 in total) were strengthened with a single-layered SRG jacket with an overlap length that covered three full sides of the specimen [16].

The 24 columns were cast in one batch and tested in two consecutive days. The average compressive strength at the days of the tests was equal to19.4 MPa. The 10 mm diameter ribbed bars had a yield stress of $f_{sy} = 555$ MPa, ultimate stress $f_{su} = 629$ MPa corresponding to StIIIb used in seismic applications in the 1970s. The 6 mm diameter smooth bar reinforcement used for the stirrups had a yield stress of

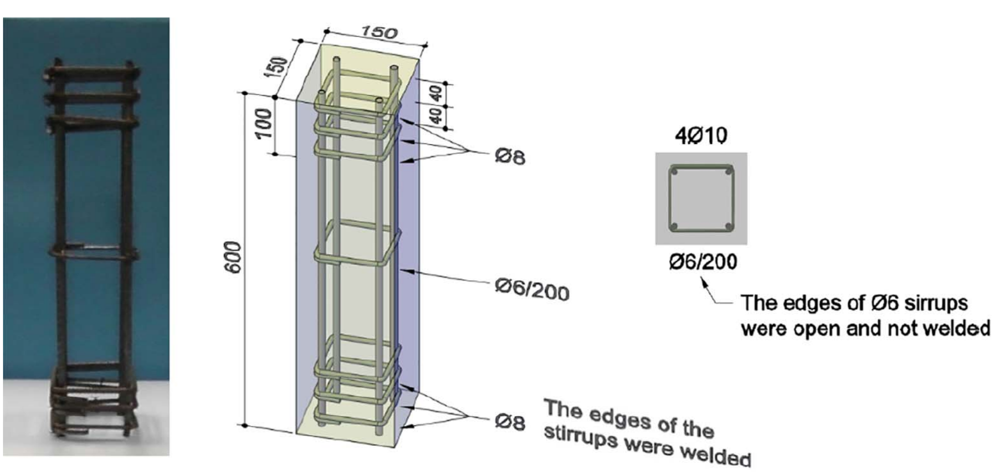

Fig. 2. Geometry and reinforcement detailing of the columns (dimensions in mm).