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Grouted sleeve connections used in precast reinforced concrete construction – Experimental investigation of a column-to-column joint

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ABSTRACT

The results of an experimental campaign concerning full-scale tests on precast reinforced concrete column-to-column connections made with grouted sleeve splices are presented. The precast column units had a square cross-section with the side of 500 mm. Eight 20 mm-diameter bars protruding from one unit were grouted into corrugated steel sleeves encased in the other unit. The column-to-column connections were subjected to *three monotonic tests (axial tension and four-point bending with and without axial compression) and to two cyclic tests (four-point bending and shear).*

In the tension test failure took place far from the interface between the precast units and highlighted the effectiveness of the stress transfer along the splice region. In all other tests, damage developed at the interface between the two units. In the bending tests with and without axial compression significant over-strengths with respect to design resistances computed for equally-reinforced monolithic members were attained. Because of the reduced thickness of the interface between the precast units, the rotation that concentrated at the interface led to a moderate reduction of the global bending stiffness. In the shear test the pure shear capacity of the bars crossing the joint was achieved. The cyclic bending test showed a ductile and stable hysteretic behavior of the connection.

1. Introduction

The structural behavior of precast Reinforced Concrete (RC) frames is essentially ruled by the connections between the various monolithic elements. Therefore, an appropriate connection design is a major key to a successful prefabrication. Connection performance is influenced by multiple factors, including building manufacture, erection and maintenance. The great interest for the role of the connections between precast elements is shown by numerous publications available on this topic [1–8].

Precast industrial buildings not based on seismic design criteria may suffer heavy damages even in the presence of moderate earthquakes. Just to keep to a recent example, in the case of the 2012 Emilia earthquakes [9], absence or inadequacy of connecting systems between the precast members determined disastrous losses of support of roof slabs or main girders in a huge number of buildings [10]. For this reason, modern seismic design codes require adequate structural ductility and compliance with capacity design. To this aim, the seismic performance of precast concrete structures was extensively investigated over the last decade within several European research projects [11–13], and design rules for connections in precast structures were published in a specific booklet [14].

In Japan' and New Zealand's extensive experience, several monolithic equivalent, ductile precast RC construction systems incorporating non-prestressed connections were developed for a weak beam-strong column behavior [4,6,15–17].

In the connection system referred to as System 2 in [4,15], suitable for multi-story buildings, the protruding longitudinal bars from the column below cross vertical holes preformed in the precast beam unit and extend above the top surface of the beam itself (see for example Fig. 5–9 in [6] or Fig. 11 in [15]). The columns of the story above, provided with steel sleeves in the bottom part, are positioned above the top surface of the beam units, so as to receive the longitudinal bars of the lower columns. The sleeves in the columns are then grouted to obtain full continuity at the connections.

In the system referred to as System 3 in [4,15], T-shaped precast units are connected with one another using grouted steel sleeves for the column bars and cast-in-place joints at midspan for the beams (see for example Fig. 5–13 in [6] or Fig. 4c in [15]). Therefore, also this system requires the continuity of the column reinforcement through a grouted joint, typically located at the column bottom end.

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Recently, a very ductile connection technology suitable for precast frames to be realized in high-seismicity regions was proposed in [18].

With particular regard to the connections between precast column elements, or between precast columns and their foundations, two main approaches may be used.

The first approach ensures the continuity of the column longitudinal reinforcement making use of proprietary grouted steel sleeves [6,19]. A general detail of the connection system is shown in Fig. 5–33 reported in [6] (see also Fig. 13 in [15]). The use of steel sleeves requires the oversizing of the transverse reinforcement in the proximity of the column end sections, and may determine a greater distance between longitudinal bars and concrete surfaces with respect to the cast-in-place construction.

The second approach consists in using non-contact lap splices of the longitudinal column bars [4,6,15–17,20–26]. A general detail of the connection system is shown in Fig. 5–35 reported in [6]. In particular, the longitudinal bars protruding from one column unit are grouted into corrugated steel ducts encased in the other unit. Adjacent to each duct, two smaller-diameter bars are present, each having at least half of the cross-section area of every grouted bar.

When used for column-to-foundation joints in seismic regions, the previously described connection systems represent a viable alternative to the traditional construction method involving monolithic columns inserted into a precast or cast-in-place pocket foundation.

In spite of its considerable simplicity, the connection system using non-contact lap splices of the column bars still lacks a comprehensive experimental characterization. In [20,21], the results of tests in the presence of bending and axial compression were presented. The grouted sleeve connections showed ultimate capacities comparable to that of monolithic columns and damages restricted to the joint section. The columns presented a square cross-section with the side of 200 mm, where four corrugated steel tubes with the diameter of 50 mm were arranged. Therefore, the dimensions of the test specimens barely were of practical use.

Similar connection systems, but specifically tailored to column-to-foundation joints, were proposed and tested in [23–25] and, recently, in [26].

In [25], the cyclic response of grouted sleeve connections (labeled "GS4") was compared with those of a cast-in-place column-to-foundation connection ("CP") and of a precast column inserted into a pocket foundation ("PF"). All columns had square cross-section with the side of 400 mm. In specimens "GS4", the connection was obtained by means of four 26 mm-diameter projecting bars protruding from the foundation and grouted into the sleeves encased in the column. Adjacent to each sleeve, two 18 mm-diameter longitudinal bars were positioned. Thus, the reinforcement ratio of the joint section was substantially coincident with that of the precast column. Specimens "GS4" showed localization of flexural cracks at the column base. Their moment resistance was almost the same as that of the other specimens. Due to the confinement induced by the steel sleeves on the grout, that prevented buckling of the projecting bars, a higher displacement capacity was obtained in comparison with specimens "CP" and "PF". To obtain a further reduction of the column damage, and then make the post-seismic repair easier, the adoption of an unbonded length of the grouted bars was also proposed in [25,27].

In the column-to-foundation connection system recently described in [28], the bars protruding from the bottom column section are inserted into box-section steel tubes embedded in the footing, and then grouted. The square column cross-section has the side of 400 mm. A 133 mm-diameter steel centring tube is used to facilitate the assembly phase. This tube extends into the column for 380 mm, yielding a contribution to stiffness and strength of the connection, and moving the critical region upwards.

Also in bridge structures the joints between precast concrete components play an important role on the overall seismic performance. Recently, prefabricated bridge elements and systems were reviewed in [29], where grouted duct connections for column-to-footing and column-to-cap beam joints were presented.

In the present paper, a grouted sleeve connection for precast RC columns that makes use of non-contact lap splices of the longitudinal bars is proposed (Fig. 1). A detailed description of the connection system is reported in Section 2. Differently from the experiments available in the literature on similar connections, generally restricted to the case of cyclic bending in the presence of a constant axial compression [20–26], the experimental campaign presented in this and in a subsequent research was aimed at a comprehensive characterization of the connection proposed.

In this paper, four combinations of axial load N and bending moment M were investigated, i.e., (1) axial tension ($N \neq 0$, $M = 0$), (2) monotonic and (3) cyclic bending ($N = 0$, $M \neq 0$), and (4) combined axial compression and bending ($N \neq 0$, $M \neq 0$). In addition, a test with the joint section subjected to a prevailing transverse shear was conducted. Note that the connection is referred to as column-to-column connection, although a compressive axial load was applied to the specimen in only one of the tests. In fact, columns in single-story buildings or peripheral columns in multi-story buildings may be subjected to a very low axial compression.

In a subsequent research, the same connection system will be tested in cyclic bending combined with constant axial compression.

2. Description of the grouted sleeve connection

The connection is obtained by lap-splicing the longitudinal reinforcing bars of two stub columns (Fig. 1a). The column units have square cross-section with the side of 500 mm. Stub column A contains eight corrugated steel sleeves. Just as many projecting bars are encased in stub column B. To realize the connection, stub column A is lowered into the right position, so as to insert the bars protruding from stub column B into the corrugated sleeves. The sleeves are then grouted using high-strength shrinkage-compensated mortar. The interface gap of 10 mm between the column units is sealed at the same time.

The total length of the lap splice is 2 m (Fig. 1b). The regular longitudinal reinforcement of the column units is comprised of 20 mm-diameter deformed bars placed at mid-sides and corners of the cross-section (cross-section D-D in Fig. 1c). The projecting reinforcement is also comprised of 20 mm-diameter deformed bars encased in stub column B (cross-section A-A in Fig. 1c). The corrugated sleeves encased in stub column A (cross-section C-C in Fig. 1c) present outer diameter of 63 mm and thickness of 0.8 mm. The joint section is characterized by the presence of the eight projecting bars only (cross-section B-B in Fig. 1c), resulting in a reinforcement ratio $\rho_l = 0.01$. Along the lap splice, square and diamond-shaped stirrups with the diameter of 8 mm and spacing of 100 mm are provided (Fig. 2). The clear concrete cover is 42 mm. Therefore, the minimum distance of the centroidal axis of regular and projecting bars to the concrete surfaces is 60 and 80 mm, respectively (Fig. 1c). The aforementioned reinforcement details comply with the recommendations reported in Section 8 of [30]. Note that, in analogy with precast structural typologies common in Italy, the column units are provided with a 100 mm-diameter drainpipe in centroidal position.

In Fig. 3 the cross-section located along the splice region of stub column A is compared with the column cross-section of the connection system investigated in [26], similar to that analyzed in [25]. In the present proposal the corrugated sleeves are positioned along the sides of the column cross-section rather than at the