SEISMIC BEHAVIOUR OF PRECAST COLUMN-TO-FOUNDATION GROUTED SLEEVE CONNECTIONS

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Abstract

The results of a set of experimental tests concerning the cyclic behaviour of prefabricated column-to-foundation connections is presented. The tests allow to compare the response of cast-in-place connections against pocket foundation and grouted sleeve solutions. The results demonstrate that grouted sleeves ensure a ductility similar to the one of cast in situ column-foundation connections and of pocket foundations, although a slightly smaller dissipation capacity is observed. It is found that in grouted sleeves connections the damage is localized at the column base, in the thin grout layer existing between the prefabricated column and the foundation. As a result, very little damage may be observed in the column, allowing an easier post-seismic column repair.

Introduction

Warehouses and commercial malls in Italy are generally built using precast reinforced concrete elements. The typical structural layout consists of cantilever columns, connected by simply supported precast and prestressed beams, supporting prestressed concrete roof elements. The foundations are usually made of isolated precast cup-footings, in which the columns are inserted and grouted in-situ. Such a structural layout is extremely cost effective, and sensibly reduces the construction time. However, its effectiveness is seriously hampered when it is intended for construction in seismic areas, particularly if Capacity Design (CD) based codes are adopted in the design process.

According to the European Code (EC8, 2003) or to the new Italian Code (OPCM 3274, 2003), the described layout is defined as an “inverted pendulum” system, which has the characteristic of being statically determinate, with potential plastic hinge regions located only at the base of the columns.

The design of the column footing is carried out by: i) assuming that a plastic hinge might develop at the column base section for the design earthquake event; ii) preventing the formation of any inelastic mechanism in the footing. The latter goal is reached by designing the foundation to resist to the design axial force and to the maximum possible resisting bending moment of the column base section, computed by considering an appropriate overstrength factor.

Adopting a CD approach, the foundation base becomes easily very large, also for medium-sized columns. This issue might be hardly relevant for cast in-situ structures, but could seriously limit the cost effectiveness of pre-cast concrete structures such as those previously described. In fact, due to the dimensions of the foundations, the footings have to be cast-in-situ, making the use of isolated cup-foundations less attractive.

Hence, mat foundations become often more convenient than isolated footings. In this case, the column-to-foundation connection is usually done: i) by using steel base plates; ii) by adopting column pockets, grouted in-situ; iii) by means of grouted sleeves.

Both from the point of view of prefabrication and of seismic response, steel base plates appear to be the least attractive of the three connection types, as they require small tolerances for the on-site placing, and adequate ductility might not be easily ensured in the column base section.

M. Pandey et al. (eds), Advances in Engineering Structures, Mechanics & Construction, 121–128.

Pocket foundations are the most used, at least in Italy, as they ensure ease of placement, and adequate ductility of the column base section after grouting. As a matter of fact, the behaviour of the connection is very much similar to that of cast-in-situ structures. On the other hand, either a thick mat foundation or a collar are required to accommodate the column, with consequent increase of costs related to the construction of the pocket.

Grouted sleeves appear to be the cheapest, hence most convenient, type of connection. However, the seismic response of such column-to-foundation connections is not well documented. In fact, while a large amount of experimental tests have been carried out on columns subjected to cyclic loading (e.g. CEB, 1996), no experimental results concerning the cyclic response of grouted sleeve column-to-foundation connections are available in the literature, at least to the Author's knowledge.

In order to investigate the cyclic behaviour of grouted sleeve connections and to compare the behaviour of such connections with cast-in-situ and grouted pocket column-to-foundation connections, an experimental campaign was set-up at the University of Brescia. The response of five columns (section 400x400mm, height 3200mm), subjected to a cyclic top horizontal displacement history, was investigated, considering different connection details. A constant axial force equal to 600kN was applied to all columns.

Experimental Tests

The experimental tests concerned five specimens with different column-to-foundation connections and approximately the same maximum bending moment capacity. All the specimen tested had a 400x400mm column cross section and a clear height from the foundation to the top equal to 3200mm. The geometry of the tested specimens and the mechanical characteristics of concrete and reinforcing steel are shown in Fig. 1.

Specimens CS and PF are representative of a typical cast-in-situ column-to-foundation connection and grouted pocket foundation, respectively. Specimens GS4 and GS4B are both characterized by having four grouted sleeves. The difference between the two specimens consist in the anchorage length of the ϕ26 bars in the foundation: the former has straight anchored bars, whereas the latter has 90° hooks at the bar ends. Specimen GS8 has 8 grouted sleeves with ϕ22 bars.

The experimental setup adopted is shown in Fig. 2. For all the tests, the axial force, equal to 600kN, was first applied by means of two hydraulic jacks. A cyclic horizontal displacement was then applied at the top of the column by means of a 1000 kN electromechanical screw jack having a 500 mm maximum stroke.

The applied displacement history is shown in Fig. 3. It is observed that the maximum imposed displacement is equal to 200 mm, corresponding to a 6.0% drift, much larger than the maximum drift commonly accepted for prefabricated columns under a design seismic event, equal to 2.5%.

Experimental Results

The experimental load-displacement curves for the tested specimens and the pictures of the critical section at 1% and 2.5% drift, corresponding, respectively, to the drift under the 50% in 50yr and 10% in 50yr probability earthquakes, are illustrated in Fig. 4. Based on the results, the following observations may be made:

- all the columns had almost the same maximum force capacity, equal to 75kN, as expected;
- the cast in situ column (CS) collapsed during the second cycle at 5% drift (160mm), due to the tensile failure of one of the reinforcing bars. At the time of collapse, the residual column strength was 30% smaller than the maximum column strength. Considerable pinching appears in the cycles after the cycles at 2.5%. Up to the cycles at 2.5% drift, representative of the maximum drift under the design earthquake, the column behaviour was stable, and little damage could be observed in the column, as demonstrated by the pictures at 1% and 2.5% drift;

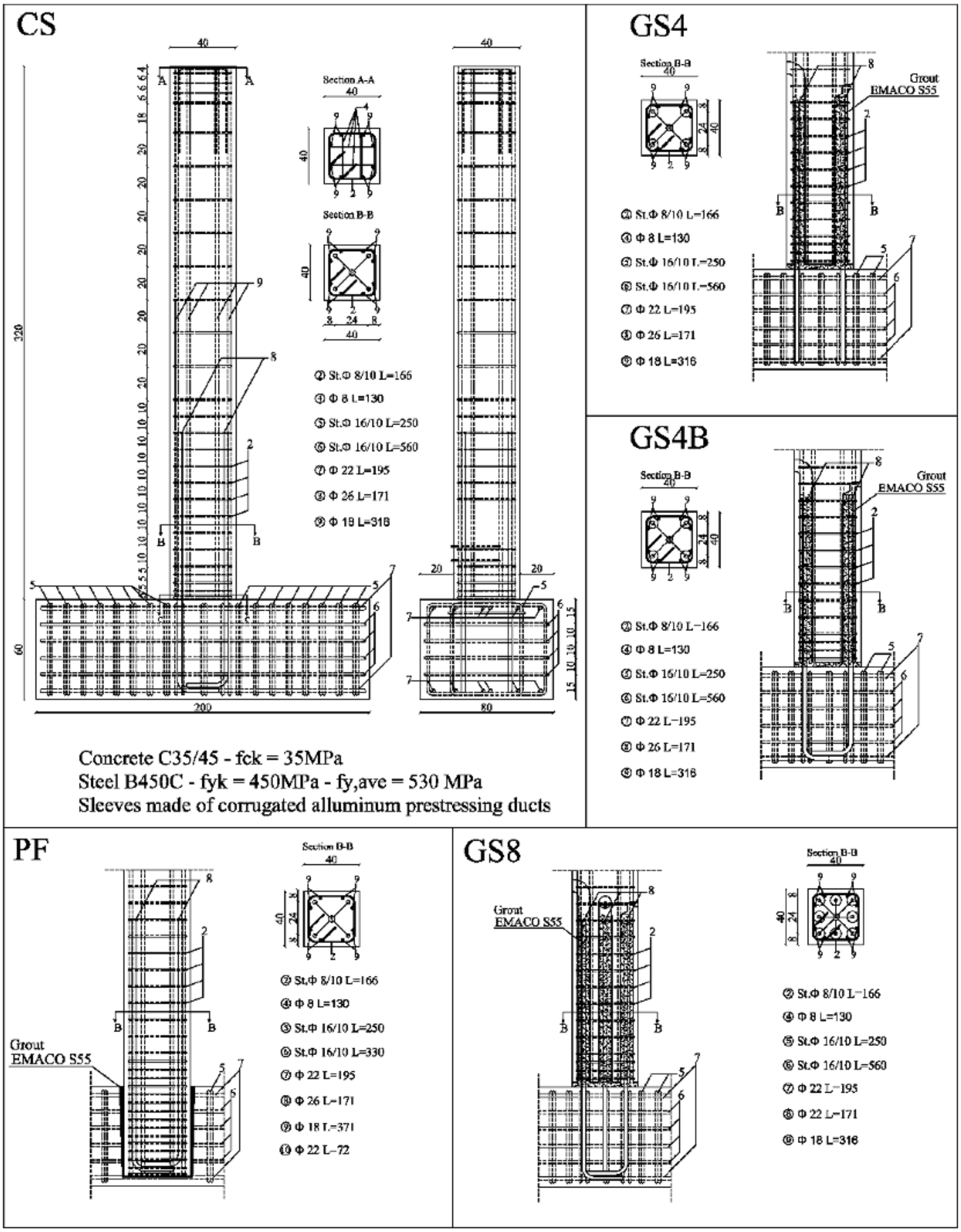

Fig. 1 – Tested specimens (Dimensions expressed in cm): (a) CS, cast in situ column; (b) GS4, column with four grouted sleeves; (c) GS4B, column with four grouted sleeves and 90° hooks in the anchored bars; (d) PF, pocket foundation; (e) GS8, column with eight grouted sleeves.

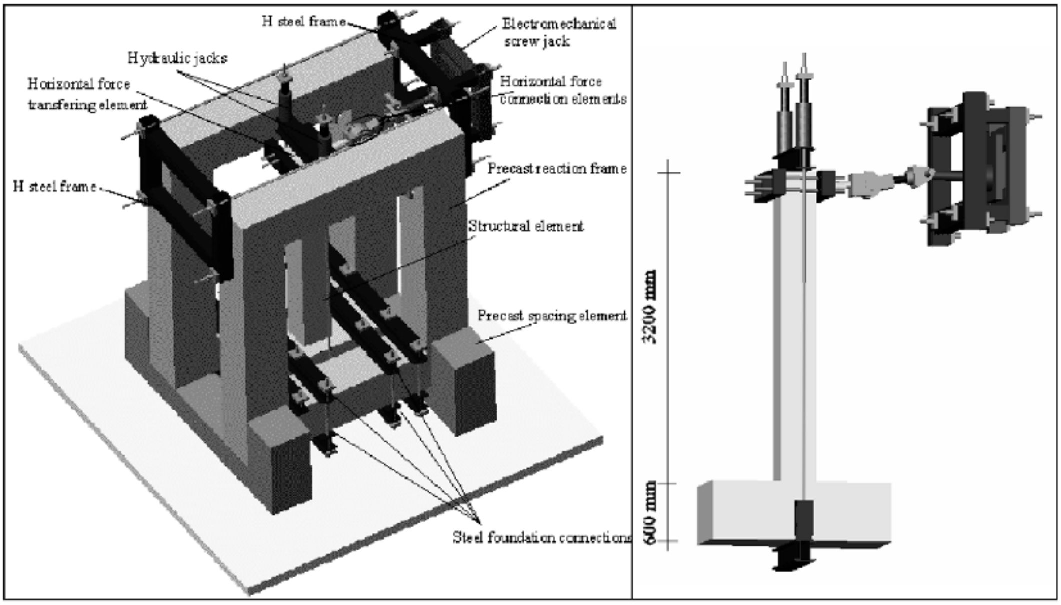

Fig. 2 – Experimental setup: (a) reaction frame; (b) loading system.

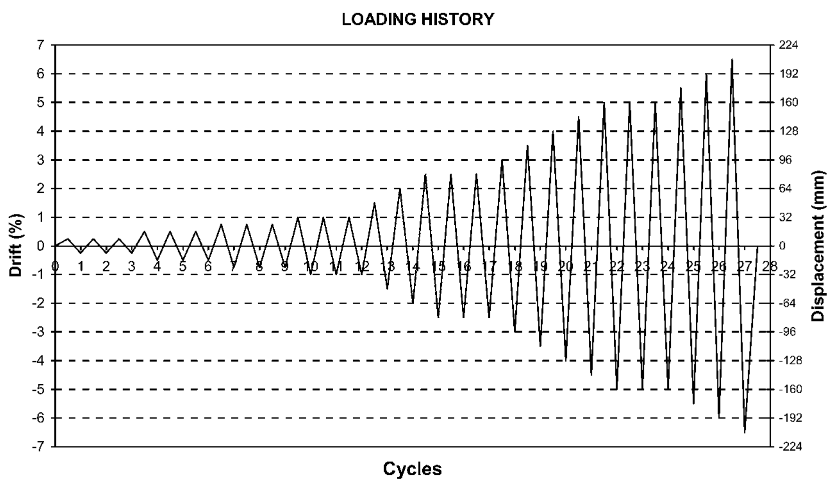

Fig. 3 – Loading history.

- the grouted pocket foundation (PF) solution showed the smallest strength degradation during the cycles. The column strength at the 5% drift cycles is equal to 82% the maximum column strength. Collapse was reached during the first cycle at 5.5% (168mm), due to buckling of the longitudinal bars. Specimen PF showed the most stable behaviour up to collapse among all of the specimen tested;
- all of the grouted sleeves (GS) column-to-foundation connections showed a considerable strength degradation during the cycles. In all cases, the strength of the column at the 5% drift cycle was approximately equal to 2/3 the maximum strength. The maximum strength at the 2.5% drift was approximately equal to 90% the maximum strength. The observed strength degradation is due to the progressive damage of the 20 mm grout layer existing between the precast column base and the foundation. This grout layer eventually crushed and was expelled

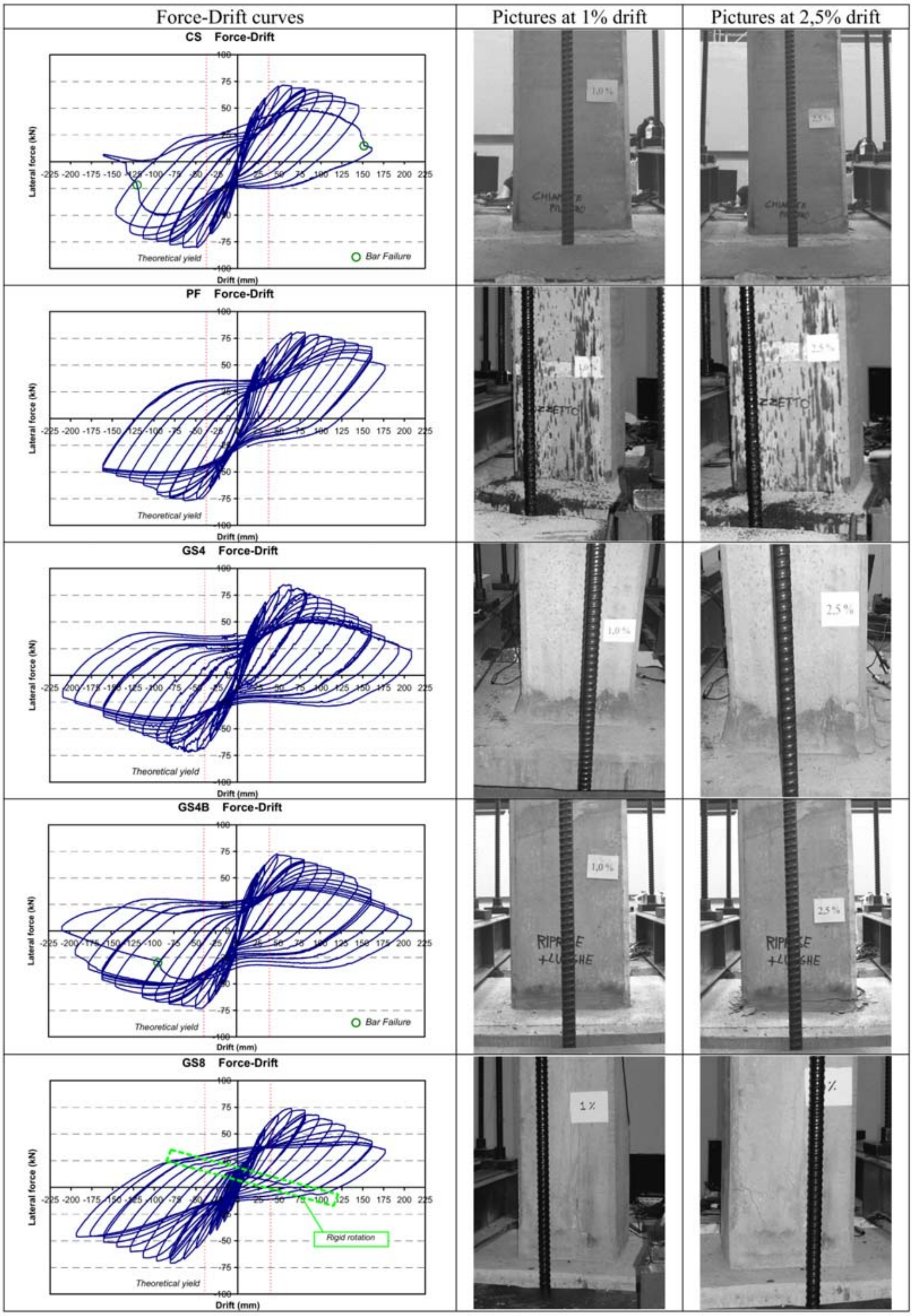

Fig. 4 – Experimental results.

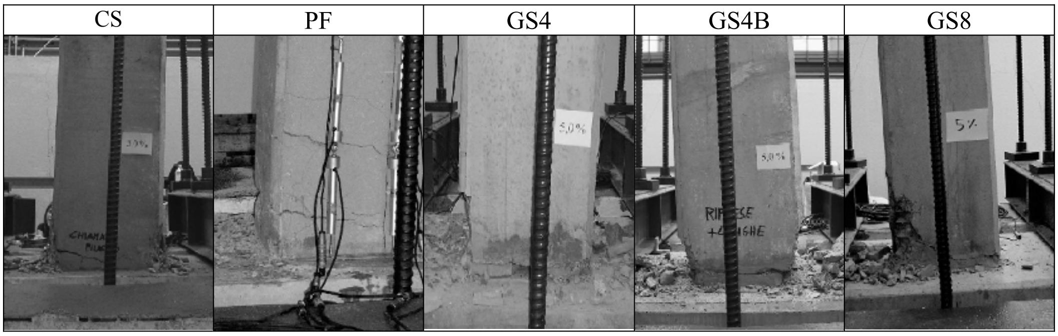

Fig. 5 – Pictures at 5% drift.

from the base, leaving the role to resist compressive forces due to cyclic bending to the grout confined by the aluminium sleeves and to the vertical rebars only;

- A slightly more pronounced pinching is observed in the cycles of the GS specimens. This is due to the aforementioned progressive damage of the base grout layer, leading to a larger strain localization at the column base;
- for all of the GS specimens, the test could be carried out up to the 6.5% drift cycle. The failure of one rebar during the cycle at 6.5% drift was observed only in specimen GS4B. The higher displacement capacity of grouted sleeves compared to cast-in-situ and pocket foundation specimens is due to the heavy confinement induced by the aluminium sleeves on the grout;
- it is observed that, due to an imperfect clamping of specimen GS8 to the reaction frame, a rigid rotation occurred after each loading reversal during the test of this specimen. The observed rigid rotation did not, however, affect the overall response of specimen GS8.

Fig. 5 shows the damage at the base column section corresponding to the 5% drift cycle (maximum displacement equal to 160mm). The following observations may be made;

- specimen CS shows a large localized crack at the base, some minor cracks along the column, and some spalling. The high strain localization observed in this specimen justifies the premature bar failure observed;
- specimen PF is affected by several large cracks spreading along a length approximately equal to the column base dimension. This behaviour is typical of reinforced concrete columns;
- all of the grouted sleeve connections show concrete spalling at the corners, next to the aluminium sleeves, and a considerable crushing of the grout layer at the column base. On the other end, grouted sleeve specimens showed no other noticeable sign of damage;
- although the strain localization at the base of GS specimens should in principle lead to an anticipated collapse of the columns, the existence of heavily confined grout columns within the sleeves effectively prevented an early failure of the connections. Furthermore, the sleeve, and the confined grout within, prevented buckling of the vertical rebars, anchored in the foundation;
- the observed damage patterns allow to conclude that, being the damage limited to the grout layer existing at the base, the remaining part of the column being mostly undamaged, grouted sleeve connections are more easily repairable after a seismic event.

Finally, Fig. 6 illustrates the comparison of the energy dissipated during each cycle by all of the specimens tested.

It is observed that no significant differences exist between specimens CS, PF, GS4, and GS4B up to a 2% drift (64mm). Starting from the 2.5% cycles, specimen PF shows a larger energy dissipation, due to a smaller strength degradation and to a smaller strain localization next to the column base section (Figs. 4 and 5). Negligible differences exist between the remaining specimens up to the collapse of specimen CS, occurring during the first cycle at 5% drift.

Specimen GS8 systematically showed a considerably smaller energy dissipation than the remaining specimens. This is due to the top drift resulting from the sum of two terms, the first related

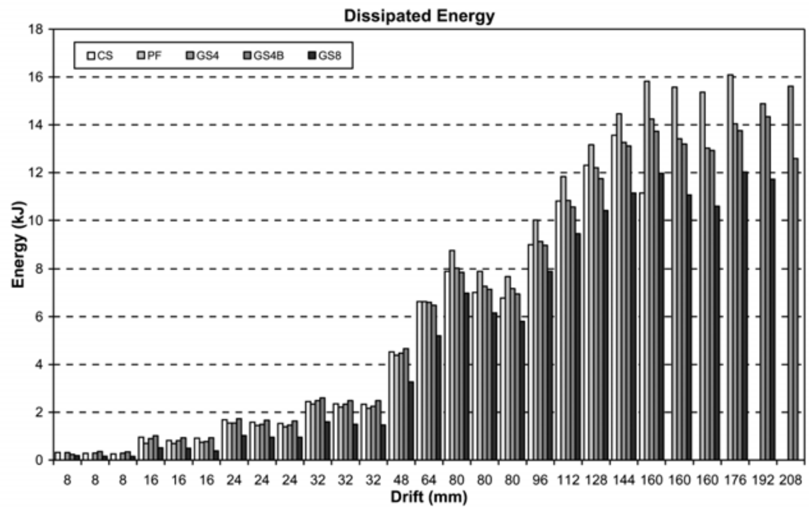

Fig. 6 – Dissipated energy.

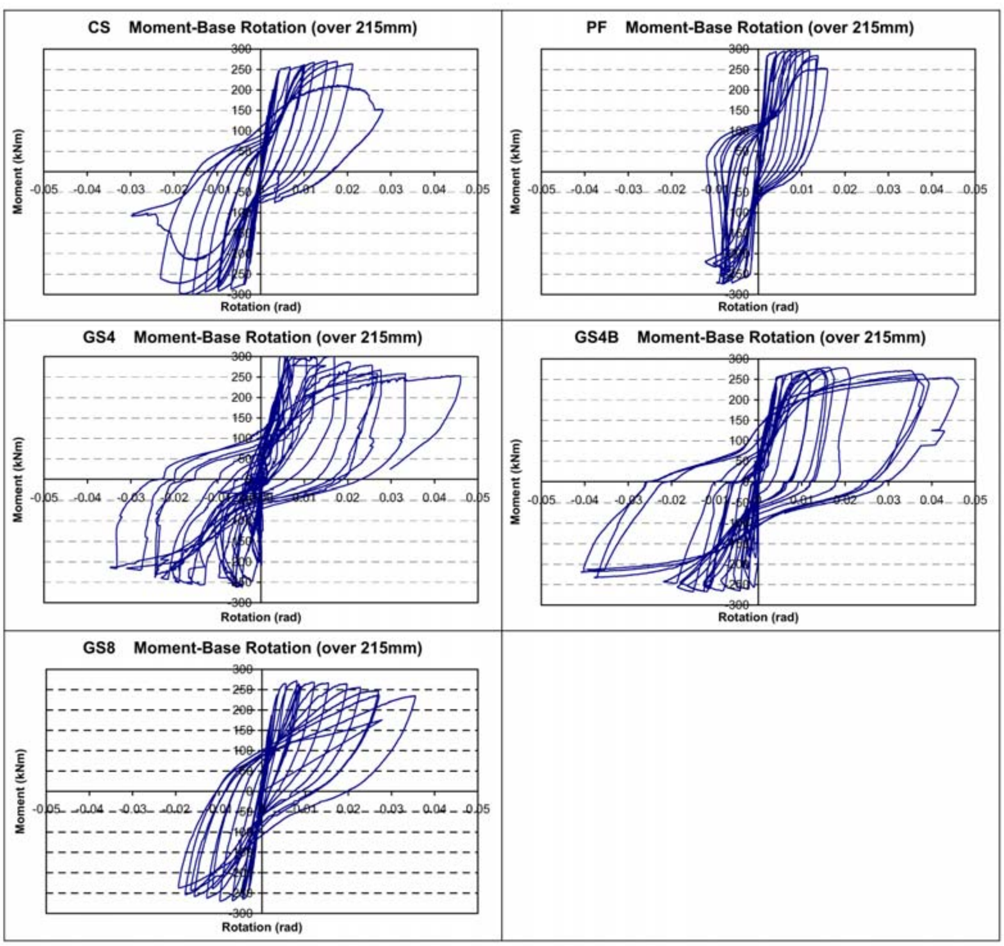

Fig. 7 – Moment-base rotation diagrams (rotation taken over 215mm gauge length).

to the column deformation, and the second due to the aforementioned rigid rotation at the base, the latter implying no energy dissipation.

Fig. 7 shows the moment-rotation diagrams at the column base sections, where the rotation is measured over a 215mm gauge length. The results presented allow the following observations:

- the base rotation is consistently much higher for the grouted sleeve specimens than for the cast-in-situ and pocket foundation specimens. This effect once more demonstrates that a much larger strain localization occurs in the former than in the latter;
- the maximum rotation in the GS specimens is only 20% smaller then the value it would exhibit considering a rigid rotation of the column around its base. This result demonstrates that the behaviour of the column outside the base section is mostly linear elastic, and that very little cracking and damage occurs outside the base section;
- deformations in the CS specimen show a greater localization in the base section with respect to those in the PF specimen. This effect lead to the early rebar failure observed.

Conclusions

The experimental results presented allow to conclude that grouted sleeves ensure a ductility similar to the one of cast in situ column-foundation connections and of pocket foundations, although a slightly smaller dissipation capacity is observed.

The high ductility of the grouted sleeve solutions is related to the high confining effect of the corrugated aluminium sleeves on the grout columns contained within. Furthermore, the presence of a highly confined grout prevents longitudinal reinforcing buckling.

It was shown that, in grouted sleeves connections, the damage is localized at the column base, in the 20 mm grout layer existing between the prefabricated column and the foundation. As a result, very little damage may be observed in the column outside of the base section.

The damage of the base grout layer results in a higher strength degradation for the grouted sleeve connections with respect to more traditional cast-in-situ and pocket foundations solutions.

Due to the damage localization observed, and to the consequent small damage existing along the column, an easier post-seismic column repair has to be expected for the grouted sleeve column-foundation connections, with respect to cast-in-situ or pocket foundation solutions.

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