

XX ANIDIS Conference

# Assessment of post-installed bars in full-scale beam-column joints using different adhesives

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## Abstract

Beam-column joints represent critical components in reinforced concrete structures. In recent years, the use of post-installed reinforcing bars has become increasingly widespread for such connections, both in the retrofit of existing structures and in new constructions. Several commercial adhesives exhibit bond strengths significantly higher than typical cast-in reinforcing bars capacities, potentially allowing for a reduction in the required anchorage lengths. This study presents experimental results from full-scale tests on two beam-column joints employing post-installed bars, comparing the performance of two adhesives with different mechanical properties. The results are also compared against current design formulations to evaluate their adequacy in predicting the behavior of such connections.

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Peer-review under responsibility of XX ANIDIS Conference organizers

*Keywords:* Post-Installed Rebars; Beam-column joint; adhesive; concrete cone; pull-out; splitting.

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## 1. Introduction

Post-installed rebar (PIR) systems represent a well-established technique for anchoring reinforcement bars into pre-drilled holes in hardened concrete through the use of injected adhesives. Over the past three decades, extensive research and field application have led to the widespread adoption of this technology, particularly for the connection of reinforced concrete (RC) members in structural retrofitting and strengthening interventions. In recent years, PIR

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have been also applied in new construction, offering advantages such as the avoidance of protruding bars from formworks – thereby facilitating construction sequencing – and providing solutions to common site-related issues such as omitted reinforcement, misaligned overlaps, and safety problems.

Typical applications of PIR systems include connections between RC beams or slabs and vertical elements such as columns or walls, as well as between vertical elements and foundations or slabs. A fundamental distinction between cast-in-place (CI) and PIR lies in the bar geometry: CI rebars generally include bends or hooks (e.g., standard 90° bends) to enhance anchorage performance, whereas PIR must rely solely on straight embedment. Consequently, the anchorage capacity of PIR systems is governed primarily by the bond developed between the rebar, the adhesive mortar, and the surrounding concrete, as well as by the geometrical configuration of the connection. This reliance on bond behavior introduces several design challenges, particularly in scenarios involving limited embedment length or reduced concrete cover. Under such constraints, brittle failure modes such as concrete cone breakout or splitting failure may govern the response. These conditions are particularly important in beam-column joints, which are the main focus of this study, as well as in column-foundation joints where the column is positioned near an edge.

Although both joint types are susceptible to anchorage-related failures, their mechanical behavior differs due to the nature of the boundary conditions. In column-foundation joints, axial compressive loads typically enhance the anchorage performance by increasing confinement. In contrast, beam-column joints are characterized by complex stress states, including high shear forces within the joint core. These forces must be adequately resisted to ensure structural integrity, motivating a considerable body of research focused on their behavior, even in systems with conventional bent CI rebars. Numerous studies have proposed analytical and numerical models aimed at accurately capturing the response of such joints under various loading conditions (Bonacci et al., 1993; Pauletta et al. 2021).

For PIR systems, additional constraints arise from practical considerations related to drilling operations, minimum cover requirements, and available anchorage lengths. These limitations can significantly influence the feasibility and performance of PIR connections, prompting several experimental and numerical investigations aimed at assessing their structural reliability and safety margins (Genesio 2012, Mahadik et al. 2020; Mahrenholz 2020; Cattaneo et al. 2023).

Recent advances in the standardization of PI systems have provided a more robust framework for their design and evaluation. The European Assessment Document (EAD) 332402, published by the European Organisation for Technical Assessment (EOTA), establishes performance criteria and test methodologies for bond characterization of PI rebar systems. Furthermore, Technical Report (TR) 069 offers a comprehensive design approach for rebar end anchorage zones, accounting for relevant failure mechanisms – including concrete cone breakout, pull-out, and splitting failure – based on provisions of EN 1992-4 and system-specific parameters.

The present study aims to investigate the structural response of post-installed beam-column joints, with particular emphasis on the role of adhesive material. Two different injection mortars are compared in terms of their influence on the global mechanical behavior of the connection. The outcomes of this study contribute to a more detailed understanding of bond-dependent joint performance and provide insights for the development of design recommendations tailored to PIR systems in critical RC joints.

## 2. Experimental research

### 2.1. Materials and test specimens

The experimental campaign considered two beam-column joints (BCJ). The specimens were cast in two phases and the beams were connected to the columns by means of post-installed reinforcing bars (PIR). The columns had a dimension of 35 cm × 35 cm and a length of 3.2 m, while the beam size was 30 cm × 65 cm with a length of 2.05 m (Fig. 1). The two specimens differed by the bonding agent used for the post-installation of the longitudinal reinforcement of the beam in the column, called in the following adhesive A and B. Adhesive A was characterized by a characteristic bond resistance in uncracked concrete  $\tau_{k,ucr} = 11.0$  MPa, and in cracked concrete  $\tau_{k,cr} = 6.0$  MPa, while adhesive B was characterized by  $\tau_{k,ucr} = 12.0$  MPa,  $\tau_{k,cr} = 7.0$  MPa. The concrete class was C20/25. PIR were installed according to Manufacturer's Printed Installation Instructions (MPII) with the installation tools provided by the manufacturer (Fig. 2). The test specimens were designed to achieve bond failure of the PIR and compare in this

way the performance of different bonding agents. To this end they were detailed with dense stirrups in the joint panel to avoid a brittle joint failure before and large rebar diameter beyond the limits of EN 1998-1, Section 5.6.2.2 to avoid steel yielding. All PIR had a diameter of 24 mm (average yielding stress 538.8 MPa) and an embedment depth of 300 mm.

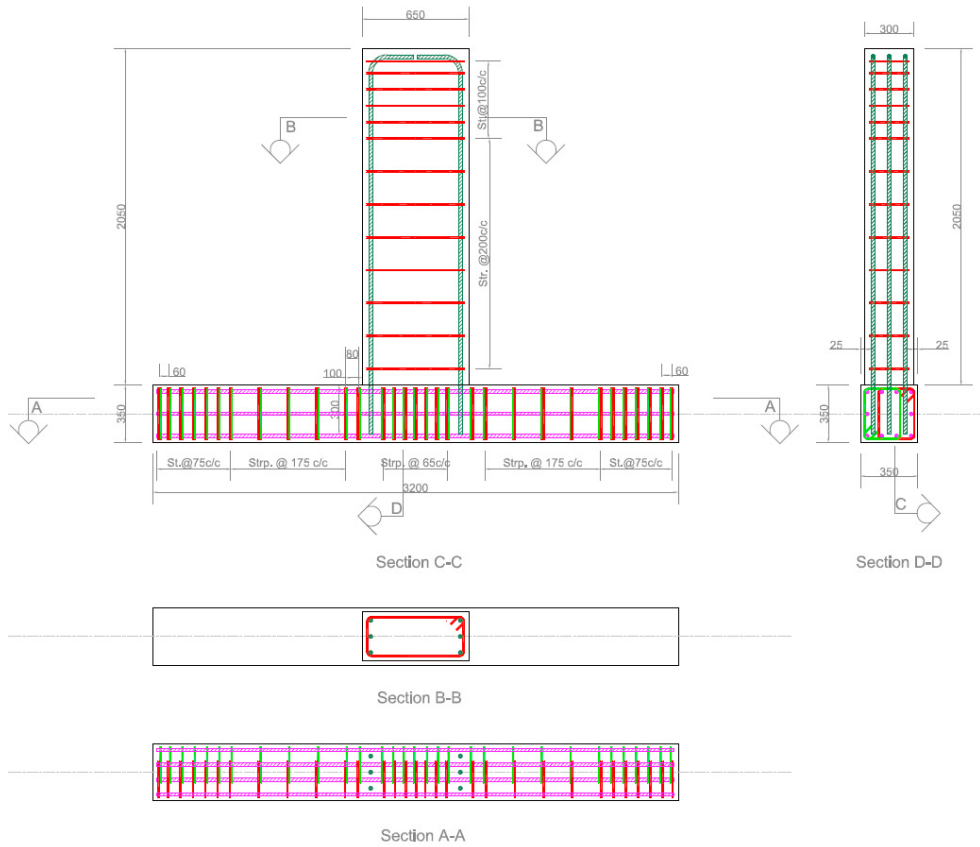


Fig. 1. Beam-column joint specimen.

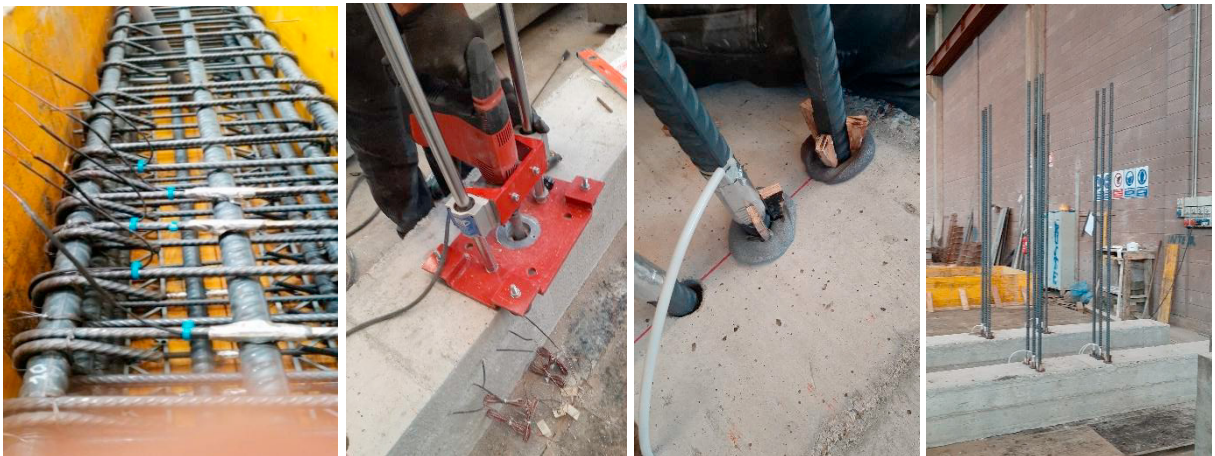


Fig. 2. Specimen preparation.

2.2. Test set-up and test protocol

The tests were performed with a testing frame equipped with a hydraulic jack with load capability of 300 kN. The load was applied to the column through a steel collar (Fig. 3) directly connected to a dowel shaft and to the jack at a level of 1.7 m (axis of the jack - base of the beam).

The specimens were simply supported on steel supports (distance of 3 m). The specimen was restrained by a system made of two steel beams connected to the strong floor by means of four threaded rods. Two additional supports were placed between the steel beams and the RC column to allow the rotation of the beam without sliding. The vertical rods were prestressed in order to have an overall axial load of about 65 kN.

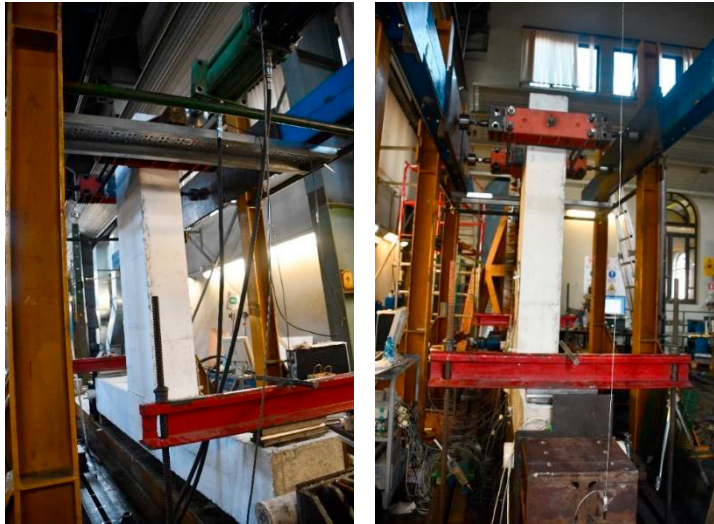


Fig. 3. Test configuration.

2.3. Test monitoring

The PIR and some stirrups were monitored with strain gauges. Each test was monitored with 10 strain gauges (4 on the post-installed rebars and 6 on the column stirrups; Fig. 4) and 14 Linear Variable Differential Transformer (LVDT), but these results are not presented due to the limited length of the paper. All data were acquired with MGCplus and Spider8 HBM data acquisition system. The strain gauges on the beam post-installed rebars were identified by a number (S1-S4) as well the strain gauges on the column stirrups (S5-S10).

The loading protocol consisted of three reversed cycles at different drift levels (5,7,10,15,20,30,40, and 60 mm).

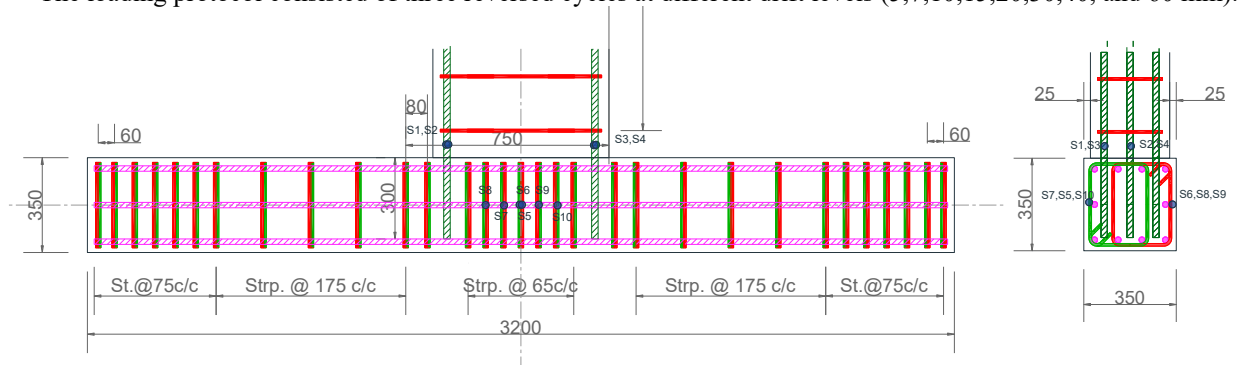


Fig. 4. Strain gauges position.

### 3. Experimental results

#### 3.1. Specimen BCJ-A

The specimen BCJ-A had six post-installed rebars installed with adhesive A.

The concrete compressive strength at the time of the test was 27.6 MPa in the column and 27.5 MPa in the beam. The maximum loads were -210.7 kN (upwards) and +224.5 kN (downwards) both associated to the first cycle at a drift level of 40 mm.

The damage developed progressively during cycles, with the first diagonal crack in the joint at a drift level of 10 mm (in both directions).

The test was stopped at a drift level of 60 mm due to the significant strength degradation in positive direction. An evident detachment between the column and the beam was observed together with a wide damage on the column, both on the top surface (beside the beam) and on the lateral surfaces (Fig. 5).

By removing the loose material on the top surface of the column, three small cones (height of about 50 mm with a diameter of 80 mm) were observed around the post-installed rebar. This suggests a combined cone-pull-out failure of the post-installed rebar. Figure 6 shows the load-drift graph.

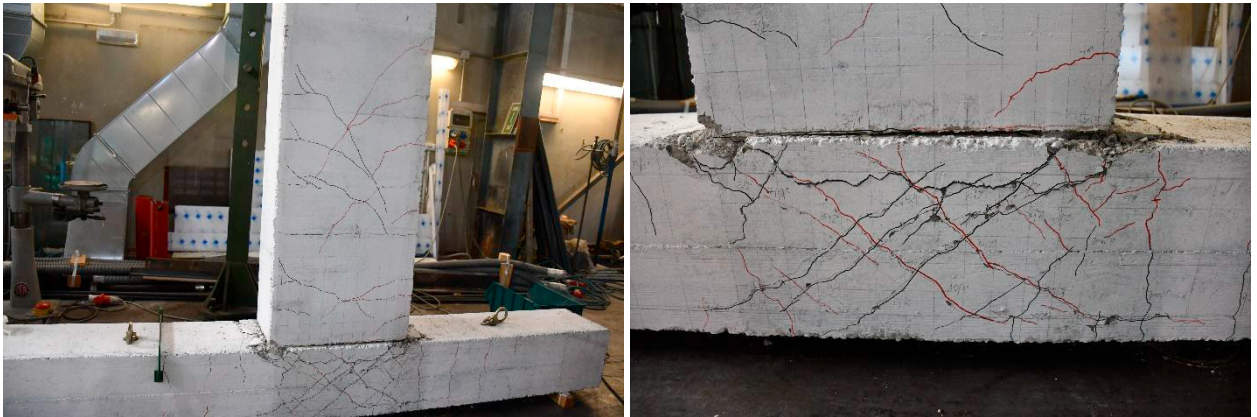


Fig. 5. Specimen BCJ-A after failure.

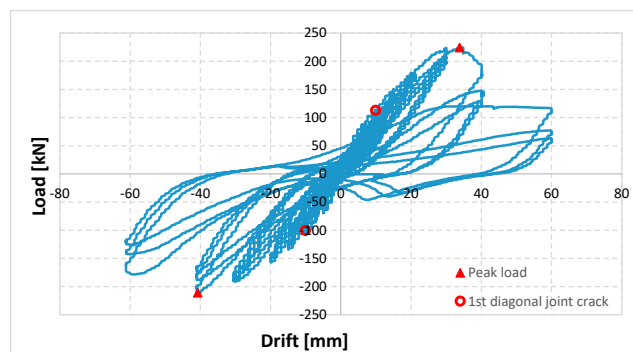


Fig. 6. Load – drift.

The strain gauges placed on the longitudinal bars of the beam recorded significant values (above  $1000 \mu\epsilon$ ) since the beginning of the test (Fig. 7), while strain gauges on the stirrups showed significant measurements starting from a drift of 10 mm (second cycle) (Fig. 8). At the same drift level, diagonal cracks developed in the joint core.

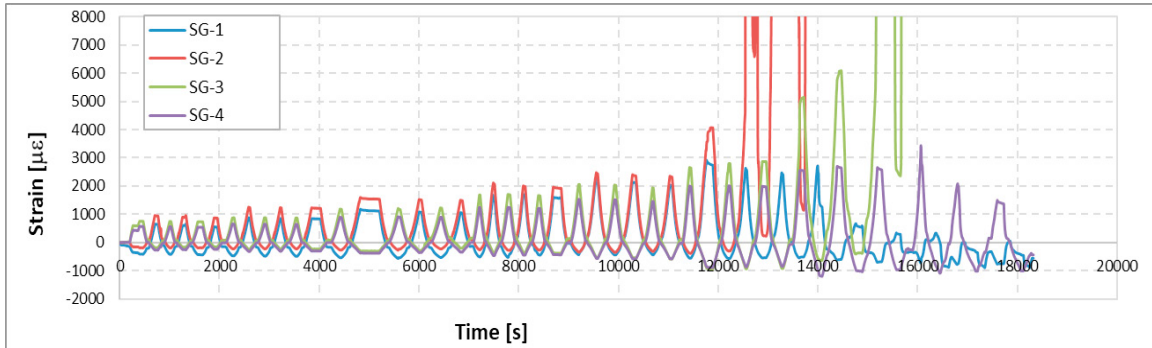


Fig. 7. Strain gauges measurement on the beam rebars.

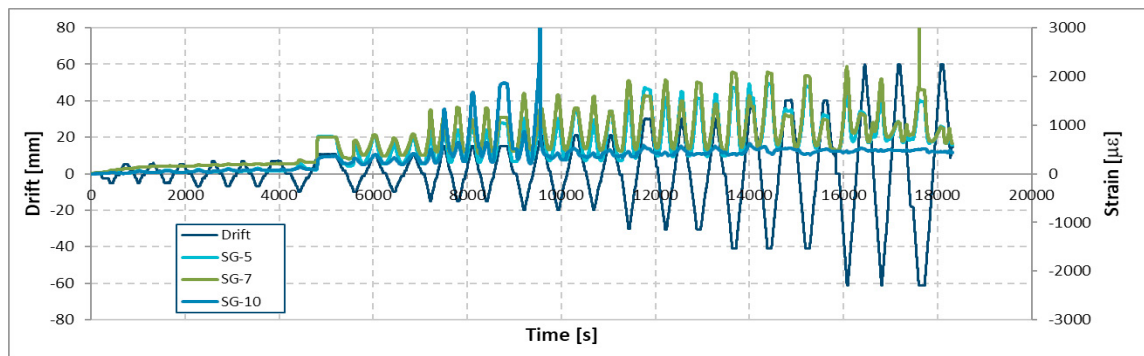


Fig. 8. Strain gauges measurement on the column stirrups and corresponding drift.

### 3.2. Specimen BCJ-B

The specimen BCJ-B had six post-installed rebars installed with adhesive B.

The concrete compressive strength at the time of the test was 26.75 MPa in the column and 26.61 MPa in the beam. The maximum loads were -189.2 kN (upwards) associated to the first cycle at a drift level of 30 mm and +192.2 kN (downwards) associated to the first cycle at a drift level of 40 mm.

A first hairline splitting crack along the post-installed rebar appeared at the first cycle and at the second cycle at 5 mm in negative and positive loading directions, respectively.

The first diagonal crack in the shear panel was observed at a drift of 10 mm (third and second cycle in positive and negative loading directions, respectively).

In positive loading direction at a drift level of 60 mm, the maximum load in the first cycle was reached at a drift value of 39.1 mm. Afterwards, a significant strength degradation was observed. An evident detachment between the column and the beam was observed as well as a wide damage on the column, both on the top surface (beside the beam) and on the lateral surfaces.

In negative loading direction at a drift of 24.5 mm there was a sudden drop of the load due to a sudden crack opening at the interface between the beam and the column, together with a displacement of a lateral restraint. By removing the loose material on the top surface of the column, a clear pull-out failure (mortar-concrete) of the post-installed rebar was observed for a length of about 50 mm. Figure 10 shows the load-drift graph.

The strain gauges placed on the longitudinal bars of the beam had significant values since the beginning of the test, while strain gauges on the stirrups had significant measurement starting from a drift of 10 mm (second cycle) with a similar behavior as in the other specimen. At the same drift level, diagonal cracks developed in the joint core.



Fig. 9. Specimen BCJB after failure.

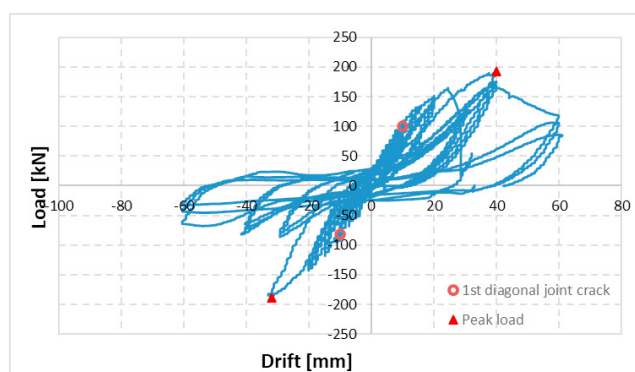


Fig. 10. Load - drift

#### 4. Discussion

The specimens BCJ-B and BCJ-A showed an overall similar behavior and failure mechanism although specimen BCJ-A reached higher peak loads (BCJ-B reached a value of about 85% and 90% of negative and positive peak load of BCJ-A, Fig. 11) and a better behavior at higher drift levels (Fig. 12).

Figure 12 shows the peak load reached at each drift level in the three cycles. By increasing the drift level, the gap between the two specimens increases, with a better behavior of specimen BCJ-A. By considering the degradation at different drift levels (ratio between the peak load at the  $i$ -th cycle over the peak load of the first cycle) it can be noted that the specimen BCJ-A has a lower degradation except for the drift of 40 mm, but in that case the specimen BCJ-B showed a very low peak load already at the first cycle.

The failure pattern of the two specimens were similar, although by removing the damaged concrete at the end of the test the specimen BCJ-B showed a pull-out failure between mortar and concrete, while specimen BCJ-A showed a small cone around the rebars (height of about 50 mm, top diameter of about 80 mm).

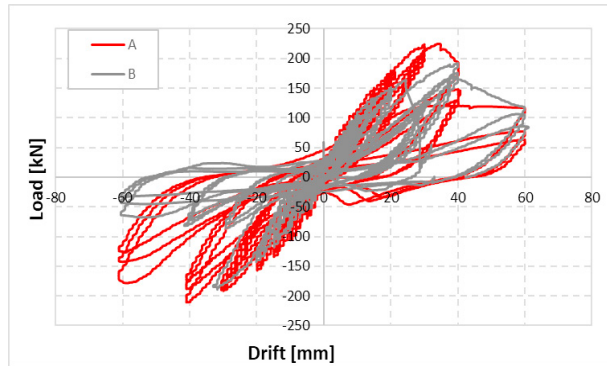


Fig. 11. Load-drift curves: A vs B.

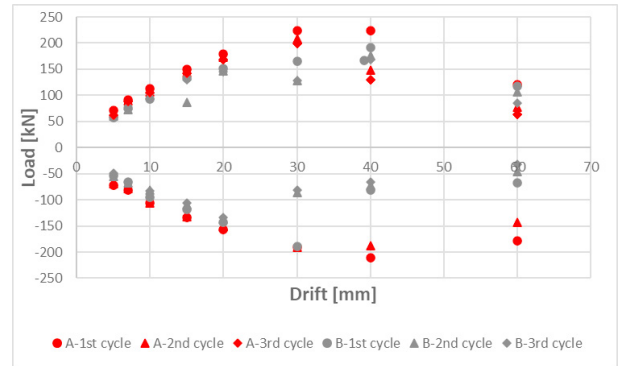


Fig. 12. Peak load at different drift levels: A vs B.

Designing the connection in accordance with TR069 leads to the identification of concrete cone breakout – defined in EN 1992-4 – as the governing failure mechanism, associated with a load producing a bending moment of approximately 25 kNm. It is clear that such a failure mode was not observed during experimental testing and, moreover, appears to be overly conservative. While the presence of transverse reinforcement within the connection undoubtedly enhanced its load-carrying capacity, the design approach prescribed by EN 1992-4 seems excessively restrictive, as it does not take into account, for instance, the beneficial influence of factor  $\psi_{M,N}$  accounting for the effect of compression stresses resulting from the moment resisting actions on the concrete cone capacity.

## 5. Conclusions

The objective of this paper was to discuss the influence of the type of adhesive on the behavior of beam-column joints subjected to cyclic loads. For the examined connection, both adhesives led to yielding of the longitudinal reinforcement, with load levels well beyond those predicted by current design methods. These methods proved to be highly conservative, suggesting that some of the design parameters may require revision, particularly in light of an expanded experimental database. Although both adhesives demonstrated high and comparable load-bearing capacities, the response under cyclic loading with imposed displacements was found to be influenced by the specific adhesive used.

## References

- Bonacci, J., Pantazoupoulou, S., 1993. Parametric investigation of joint mechanics. *Structural Journal* 90(1), 61–71.
- Cattaneo, S., Mahadik, V., Genesio, G., Hofmann, J., 2023. Influence of edge proximity on concrete breakout failure in post-installed RC columns foundation joints. *Materials and Structures* 56, 119.
- EAD-332402, 2019. Post-Installed reinforcing bar (Rebar) connections with improved bond-splitting behaviour under static loading. European Organization for Technical Assessment (EOTA), European Assessment Document EAD 332402-00-0601.
- EN 1992-4, 2018. Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete. British Standard Institution.
- EN 1998-1, 2013. Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings. British Standard Institution.
- Genesio, G., 2012. Seismic assessment of RC exterior beam-column joints retrofitted with haunches using post-installed anchors. PhD Thesis, Institut für Werkstoffe im Bauwesen, Universität Stuttgart.
- Mahadik, V., Sharma, A., Hofmann, J., 2020. Re-evaluation of existing tests on RC connections using post-installed reinforcing bars. *Engineering Structures* 209, 109970.
- Mahrenholtz, C., Eligehausen, R., Reinhardt, H. W., 2020. Qualification and Design of Cast-in-Place and Post-Installed Reinforcing Bar Anchorage. *ACI Structural Journal* 117(2).
- Pauletta, M., Di Marco, C., Frappa, G., Miani, M., Campione, G., Russo, G., 2021. Seismic behavior of exterior RC beam-column joints without code-specified ties in the joint core. *Engineering Structures* 228, 111542.
- TR-069, 2019. Design method for anchorage of post-installed reinforcing bars (rebars) with improved bond-splitting behavior as compared to EN 1992-1-1. European Organization for Technical Assessment (EOTA).