SEISMIC PERFORMANCE OF OLD RC INTERIOR WIDE BEAM-COLUMN CONNECTIONS UNDER SEISMIC LOADING

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ABSTRACT :

The reinforced concrete moment-resisting frame with wide beam-column connections and one-way joist slabs has been a common structural system within countries within the moderate-seismicity Mediterranean area, such as Spain or Italy. It is still extensively used despite the fact that research has unveiled that this type of system is particularly vulnerable to earthquakes due to its large lateral flexibility, low energy dissipation capacity and the deficient transmission of bending moments from beams to columns. However, many buildings were constructed before these drawbacks became evident, and their safety in the event of a severe earthquake is a matter of great concern.
This paper presents the preliminary results of an experimental investigations aimed at clarifying the seismic behavior, displacement ductility and ultimate energy dissipation capacity of interior wide-beam column connections built in Spain during the seventies, eighties and nineties of the XX century.
To this end, two 3/5 scale test models representative of interior subassemblages in a prototype six-storey building were subjected to gravity-load levels typical of those acting during an earthquake, and to quasi-static cyclic lateral loads until failure. The specimens exhibited a “strong column-weak beam” type yielding mechanism. The average drift ratios at first yielding of the wide beam longitudinal reinforcement and at failure were 2.9% and 6.1%, respectively. This study is part of a larger research project aimed at evaluating the vulnerability of existing RCMRF (Reinforced Concrete Moment-Resisting Frames) with wide beam-column connections, so as to develop innovative seismic upgrading strategies based on the use of hysteretic energy dissipators.

KEYWORDS: interior connection, wide beam, seismic performance, cyclic test.

1. INTRODUCTION

The reinforced concrete moment-resisting frame (RCMRF) with wide beam-column connections and one-way joist slabs has been a common structural system in countries of the moderate-seismicity Mediterranean area, such as Spain or Italy. It is still extensively used despite the lack of sufficient information on how it behaves under severe earthquake loading. Recent research has unveiled that this type of system is particularly vulnerable to earthquakes due to its large lateral flexibility, low energy dissipation capacity and the deficient transmission of bending moments from beams to columns. However, many buildings were constructed before these drawbacks became evident, and their safety in case of a severe earthquake is a real matter of concern.

This experimental study looks into the seismic performance of two interior wide beam-column connections subjected to lateral cyclic loading until collapse. The specimens represent critical parts of a prototype structure with six storeys and four bays, typical of a residential building built during the 1970s, 1980s or 1990s in the southern part of Spain (Granada region). This is a moderate seismicity region where the design peak ground acceleration according to current seismic code is 0.24*g* (*g*: gravity acceleration). This paper presents the preliminary results of the test aimed at clarifying the mechanics developed in the connection to transfer the moments from beam to column, the displacement ductility, and the ultimate energy dissipation capacity.
This work is part of a major research project funded by the Spanish Government, aimed at evaluating the vulnerability of RCMRF with wide beam-column connections, in order to develop innovative seismic upgrading strategies based on the use of hysteretic energy dissipators.

2. DESCRIPTION OF THE EXPERIMENTS

2.1. Prototype building

A prototype structure with six-storeys, four bays and four spans was designed following construction practices common in Spain during the 1970s, 1980s and 1990s. It reproduces the usual features of this type of structure in Spain at that time: (a) the width of transverse beams is approximately equal to that of the columns; (b) the slab is constructed with one-way joists carried by the wide beams, non-structural clay elements are placed between the joists, and a concrete topping 4cm thick is added; and (c) all members have the same depth (typically 25-30cm). Figure 1 shows the elevation and plan of the prototype building.

The prototype structure was located in the highest earthquake-prone area of Spain (the province of Granada, southern Spain). The design gravity loading consisted of the plate self-weight, plus 1kN/m^2 superimposed dead load and 3kN/m^2 live load. The design earthquake entailed a triangular distribution of lateral forces. The base shear normalized by the total building weight was 0.14, as prescribed by earlier Spanish seismic code (PDS-1, 1974). The design yield stress of the reinforcement was 400MPa, and the concrete compressive strength 17.5MPa. The prototype was designed as an ordinary moment-resisting frame, following former Spanish Concrete Code (EH-90, 1990). Non-ductile details and common construction practices used over ten years ago in Spain were employed. Accordingly, the transverse beams were not designed for carrying torsion, but only for sustaining their self-weight plus relatively small lateral earthquake forces in the direction perpendicular to the wide beams.

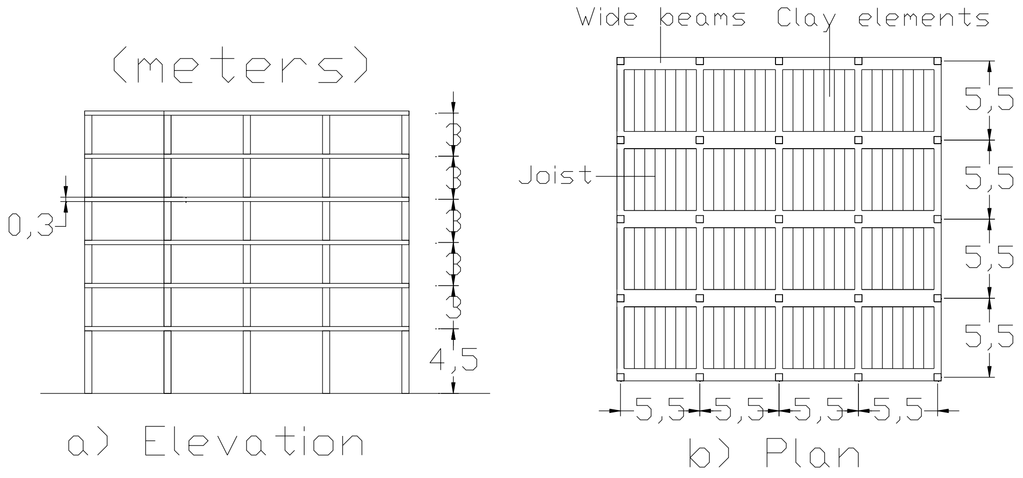

Fig. 1: Prototype building

2.2. Test specimen

From the prototype structure, two exterior wide beam-column connections were selected: one from the second storey and the other from the fifth storey of the building. Points of inflection in the prototype structure under lateral loading were assumed to be located at mid span and mid-storey height. From the selected connections, the corresponding test models, herein designated as IL and IU, were derived by applying a scaling factor of 3/5 for geometry. The test models were prepared in the laboratory. The average yield stress of the steel was 404MPa, and the concrete compressive strength 24.9MPa. The overall geometry and reinforcing details are shown in Figs. 2 and 3, respectively. The widths of the beams in specimens IL and IU are at the limits set by the current Spanish seismic code (NCSE, 2002). The spandrel beams (also referred to as transverse beams or torsional members in the literature) of specimens IL and IU had the same depth as the beam (18 cm), and were lightly reinforced.

2.3. Loading apparatus and loading history

Figure 4 shows the test setup. Gravity loading was simulated by the combination of wide beam self-weight, two sand bags of weight 40 kN each placed on the beams, and an axial force applied to the columns by means of two post-tensioned rods, whose value was 296 kN on specimen IL and 74 kN on specimen IU. The sand bags were positioned so that scaled shear and moments in the beam at the column face were similar to those acting in the prototype building for the combined gravity and earthquake load.

The load history consisted of several sets of three cycles of forced horizontal displacements at the top of the column. The amplitude of the cycles was made constant within each set, but increased with every consecutive set of cycles following the sequence $0.5\delta_y$, $0.75\delta_y$, $1.0\delta_y$, $2\delta_y$, $3\delta_y$ and so on, until the maximum available stroke of the actuator was attained. Here, δ_y denotes the yield displacement predicted with a model proposed in the literature (Benavent-Climent, 2002), which gave δ_y =3.3% for specimen IL and δ_y=1.9% for IU.

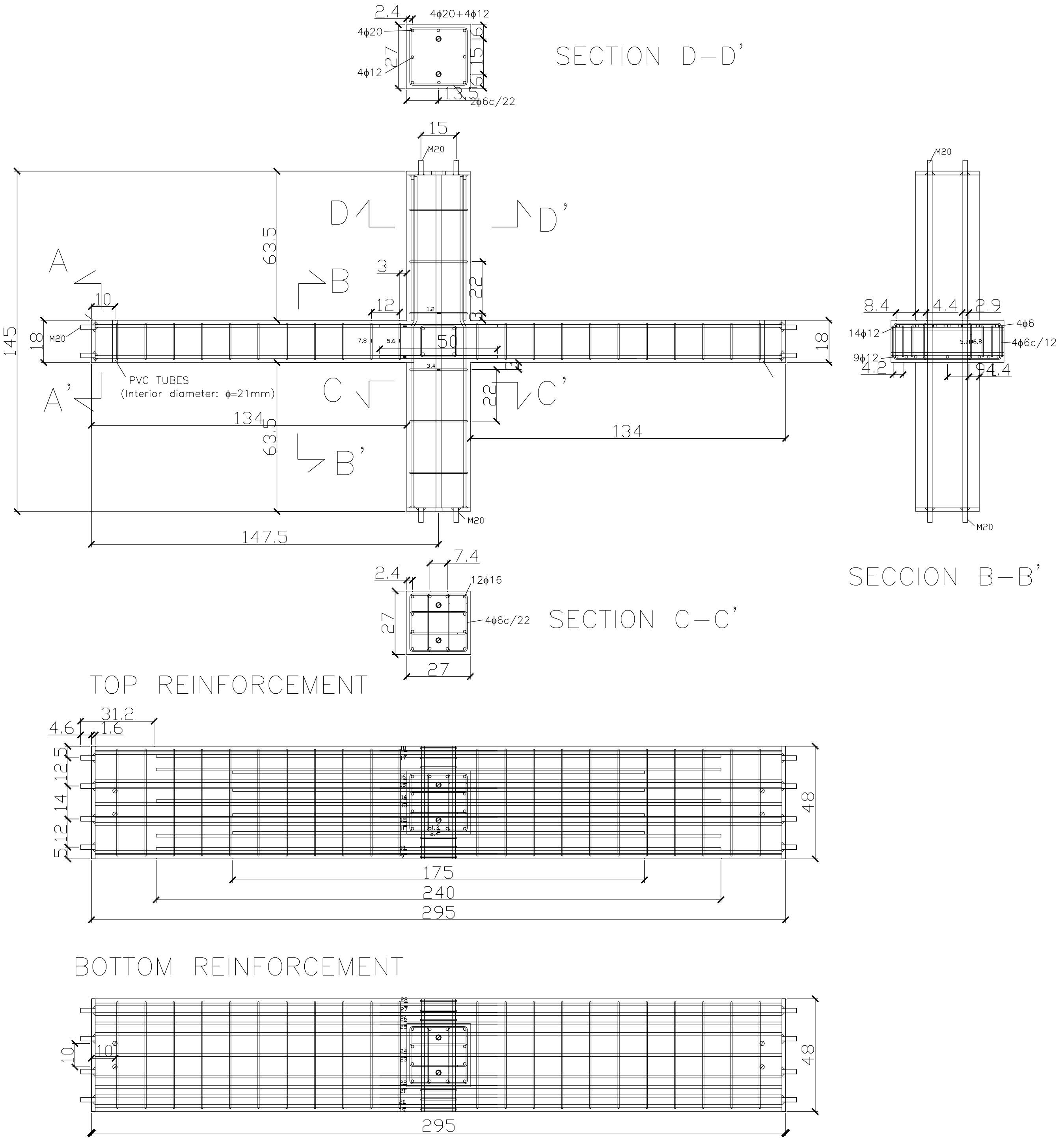

Fig. 2: Test specimen IL

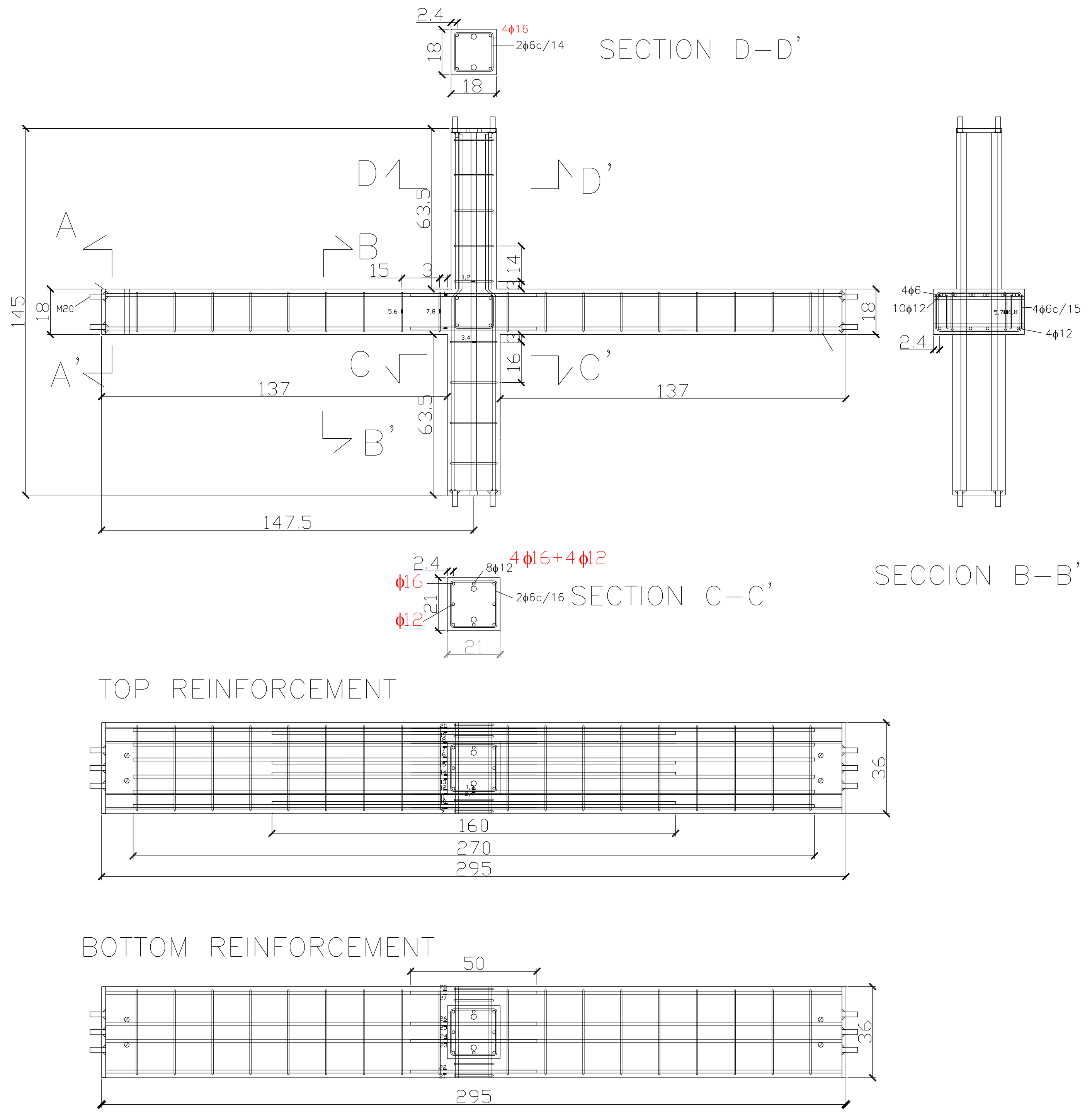

Fig. 3: Test specimen IU

2.4. Instrumentation

A load cell and displacement transducers were installed on the actuator to measure the overall horizontal force Q applied to the top of the upper column and the corresponding overall horizontal displacement, δ. The strain in the reinforcing steel was measured with gauges prior to casting the concrete. Photographs were taken and detailed visual inspections and drawings were made of the concrete cracks.

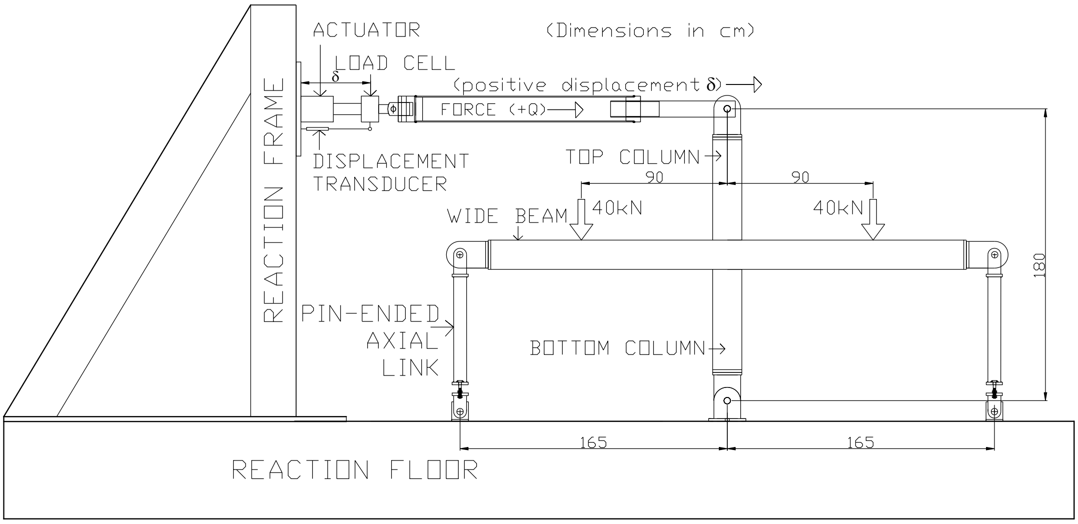

Fig. 4: Test set up

3. TEST RESULTS

3.1. Overall response

The overall response in terms of the load displacement curve, Q-δ, is shown in Figs. 5 and 6. Both specimens exhibited severe pinching of the hysteretic loops and early degradation of the overall lateral strength. No sign of joint shear failure was observed. Columns remained in the elastic range with minor cracking; thus a “strong column-weak beam” mechanism developed.

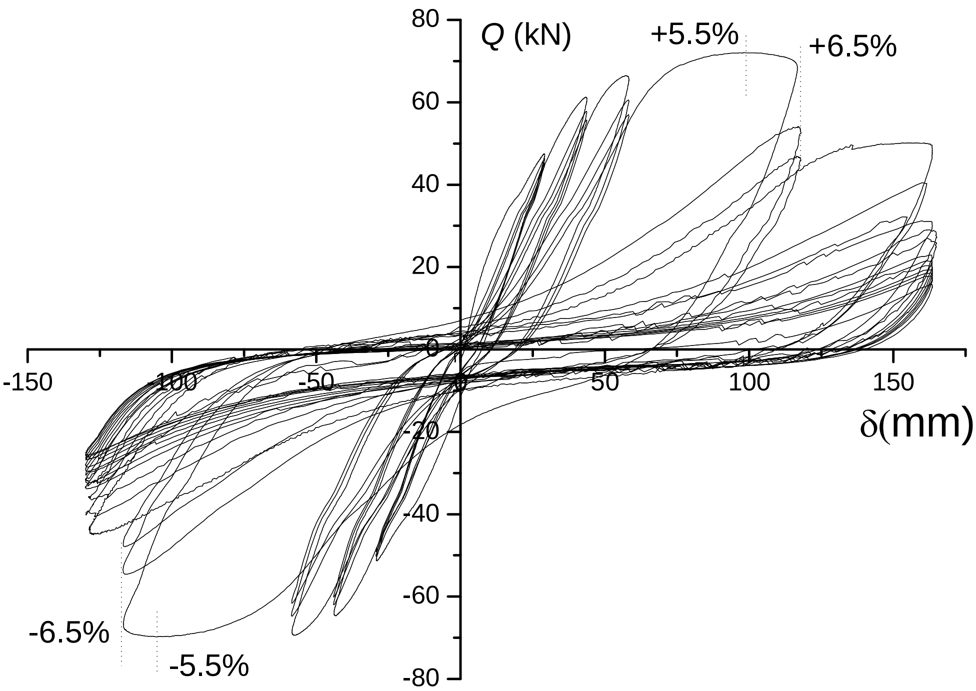

Fig. 5: Load-displacement curve of specimen IL

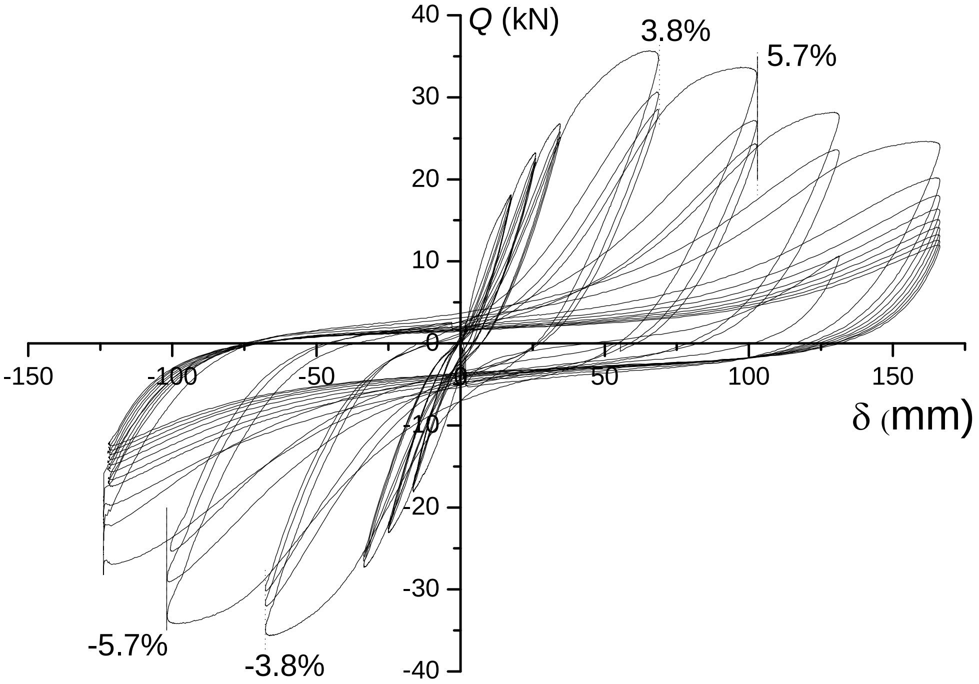

Fig. 6: Load-displacement curve of specimen IU

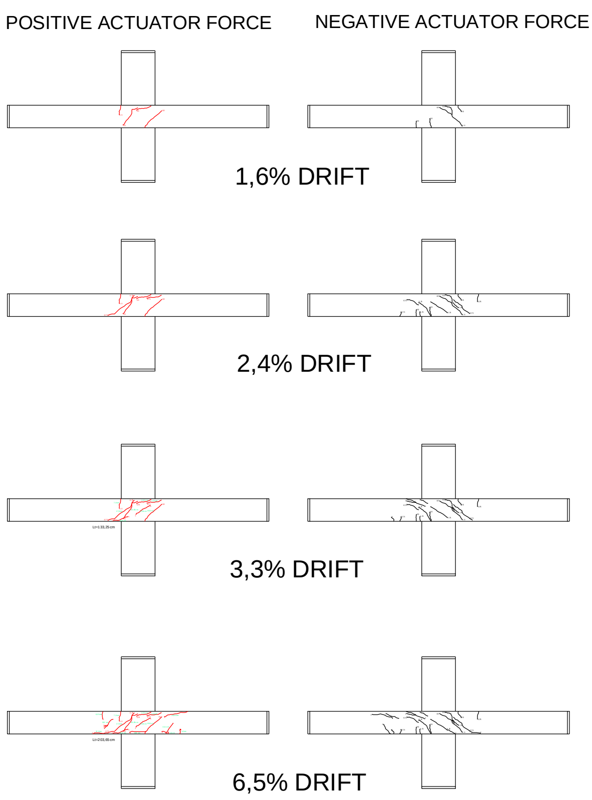

Fig. 7: Cracking pattern of specimen IL for different drifts

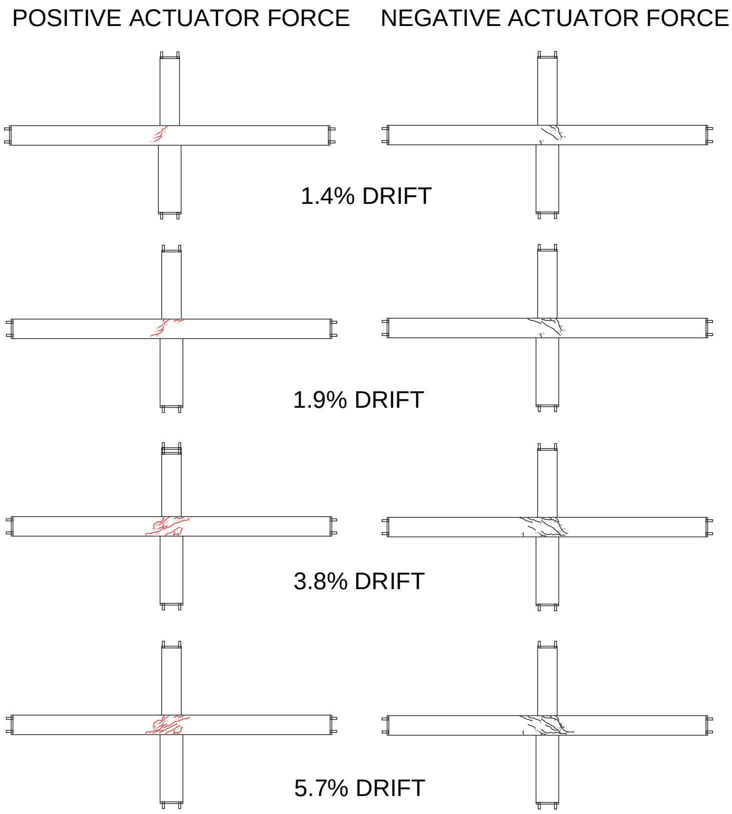

Fig. 8: Cracking pattern of specimen IU for different drifts

Yielding of the beam longitudinal bars started from the central part of the column and extended progressively to the outer bars. First yielding of the wide beam longitudinal bars was observed at drift ratios of about 2.1% and 3.6% for specimen IL and IU, respectively. The maximum lateral load, Q_{max}, was attained at drift-ratios of about 5.5% in specimen IL and 3.8% in specimen IU. Failure was assumed to occur when the strength dropped below $0.75Q_{max}$, which is considered in the literature (Scribner and Wight, 1980) as the limit of "usable" capacity of the member. The corresponding ultimate drift capacities were 6.5% for specimen IL, and 5.7% for specimen IU.

3.2. Cracking process

Flexural cracks formed in both specimens across the full width of the beam when the drift ratio was below 0.5%. Torsion shear cracks in the spandrel beans (torsional members) and its vicinity dominated the cracking patterns during the tests, and lead to the failure of the specimens, as shown in Figs. 7 and 8.

4. CONCLUSIONS

This paper presents the preliminary results of an experimental study conducted to investigate the seismic behavior of existing interior RC wide beam-column connections designed according to the usual construction practice in Spain during the 1970s, 1980s and 1990s. Two specimens were subjected to moderate levels of gravity loading and quasi-static lateral cyclic loads until failure. First yielding of the wide beam longitudinal bars was observed at an average drift of about 2.9% of the storey height, and the ultimate drift ratio was approximately 6.1%. The failure of the connection was associated with the development of severe torsion cracks in the spandrel beams (torsion members).

ACKNOWLEDGEMENTS

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