NEW METHODOLOGY FOR REINFORCED CONCRETE BEAM-COLUMN CYCLIC TEST

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Abstract:

The aim of the present communication is to present an analysis of the gravity load influence on the hysteretic behaviour of a beam-column connection. For this purpose, in the experimental campaign a new procedure for RC cyclic tests is presented in order to reproduce closer demands on the beam critical zone than the traditional procedures. The Experimental campaign included cyclic tests of the specimens according with the ECCS recommendation and an innovate procedure. The test results are presented, compared and analysed.

A numerical simulation of the tests is presented where the model for the hysteretic response of the beam was calibrated with the experimental results. Finally, the behaviour of a portal frame system under cyclic displacements up to a drift of 3.5% was analysed, assuming that the non-linearity is concentrated on the plastic hinges, considering different levels of gravity load. Thus it is intended to assess the influence of the gravity load on the behaviour of a structure subjected to cyclic loads.

1. INTRODUCTION

The requirement to improve the behaviour of structures regarding seismic actions can be related with new demands of use and new design code recommendations. A structure with good seismic behaviour must present ductility and capacity for dissipate energy. In frame systems, the plastic hinge regions have the main task of dissipate energy[1]. This fact justifies the search for new solutions with high seismic performance. The response of the beam-column connection can be optimized to improve the response of the global structure.

Admitting a seismic conception of strong-column–weak-beam[2], the experimental study stays limited to the analysis of the beam behaviour. In the present research the Reference Specimen is a RC T-beam, which has been designed to exhibit a normal ductility.

The conventional methodology of cyclic tests for structural elements is based on the imposition of a history of reverse cyclic displacement where the failure is conventionally defined and follows the ECCS[3], ACI[4] or ATC[5] recommendations. However, the present study intends to implement a new procedure for RC cyclic tests which reproduce more real demands of a beam element.

This new test procedure involves the imposition of a history of reverse cyclic displacement starting from the gravity load effects, leading to a non-symmetrical loading history where failure takes place when the connection is no longer able to sustain the gravity loads[6], and considering the asymmetry of the section geometry and reinforcement.

2. EXPERIMENTAL PROGRAMME

2.1 Specimens

The reinforced concrete Reference Specimen is a T-beam, designed to exhibit a normal ductility, which presents a cross section with a width of 250mm and a height of 500mm. The model simulates a cantilever beam with 1/3 of the clear length of the beam, where the column is modelled by a rigid block. The beam reinforcement, the location of twenty-four strain-gauges and seven displacement transducers used in the test program are shown in Fig.1.
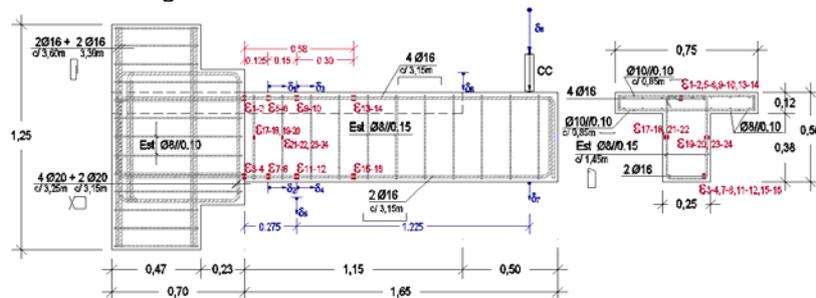

Figure 1: Detailing and instrumentation of the specimen

2.2 Test Setup

The experimental campaign was carried out in the Laboratory of Structures of UNL. This laboratory has two reaction walls and a "strong floor". The equipment used in the tests was an electric worm-screw jack with a capacity for application of horizontal loads of ±500 kN and a displacement up to 400mm (±200mm), a double-action load cell FIMEI CS-24 with a capacity of ±500kN and displacement transducers CDP100 TML of 100mm. For the acquisition of the test results, four Data logger Spider8 were used with capacity for 8 channels each.
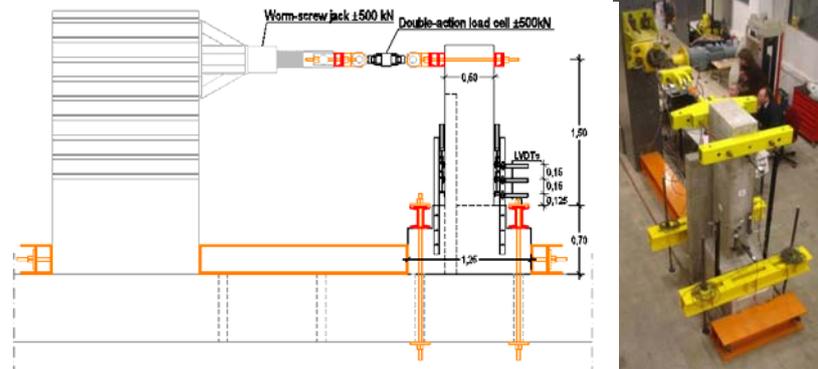

Figure 2: Test setup

2.3 Loading History

As stated above, the aim of this study is to implement a test procedure that allows the simulation of gravity loads on the beam with asymmetrical cross section geometry and reinforcement.

The test of Specimen VR1 was based on the recommendations ECCS[3] and consisted on the application of a reverse cyclic displacement history with increasing amplitude. The displacement steps were $\pm0.5d_0$, $\pm1.0d_0$, $\pm2.0d_0$, $\pm3.0d_0$, $\pm4.0d_0$, $\pm5d_0$ and $\pm6d_0$. Three cycles were performed for each step. The values of the positive and negative yielding displacement (d_y), obtained experimentally, were 6mm and 12mm, respectively. For simplification of the procedure, a base displacement (d_0) was set for to the minor value obtained, i.e., 6mm.

The procedure implemented on the test of Specimen VR2 was proposed by Proença et all[6]. This test procedure involves the imposition of a reverse cyclic displacement history starting from the gravity load effects (forces and displacements).

The performance of this procedure leads to a test under force-controlled (until the application of gravity load) and displacement-controlled (corresponding to the imposition of a reverse cyclic displacement history). The reverse cyclic displacement history is imposed starting from the time when the value of the gravity load pre-defined is restored.

During the test, the restore of the gravity load will correspond to larger displacements caused by the degradation of the stiffness of the model.

This fact leads to a different starting point from which cyclic displacement is imposed and the displacement history will not be necessarily symmetrical. The failure occurs when the connection is unable to resist the gravity forces.

For this purpose, a LabView code was developed for the necessary force and displacement control.

This procedure consisted in the following load sequence: application of a pre-established load equivalent to the gravity load effects of 90kN (corresponding to 50% of the yield force) on the beam followed by the imposition of a reverse cyclic displacement history with increasing amplitude, with displacement steps of $\pm 0.5d_y$, $\pm 1.0d_y$, $\pm 1.5d_y$, $\pm 2.0d_y$, $\pm 2.5d_y$, $\pm 3d_y$ and $\pm 3.5d_y$, at each step 3 cycles were performed. The value of the negative yielding displacement, obtained experimentally, was 12mm. As stated above, it should be noted that displacement history is not symmetrical.

In the Fig. 3, the loading and displacement history concerning the experimental cyclic test of Specimen VR1 (according ECCS[3] recommendations) and Specimen VR2 (with the Proença et all[6] procedure) are presented.
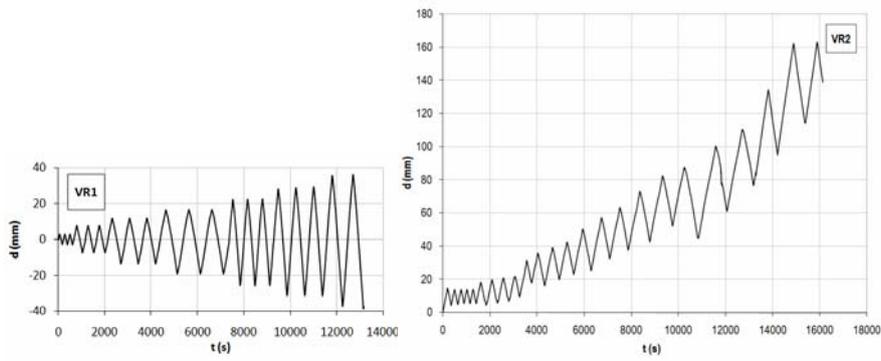

Figure 3: Displacement History of ECCS3 cyclic test - Specimen VR1 - and with the Proença et all6 procedure - Specimen VR2

3. EXPERIMENTAL RESULTS

3.1 Specimen VR1

The failure mode observed on Specimen VR1 was caused by the fracture of one longitudinal bottom bar reinforcement of the beam, preceded by the spalling of the concrete cover and the buckling of the longitudinal bottom bar. In Fig. 4, the Specimen after failure is illustrated, it should be noted that this type of test lead to a failure for positive moments with accumulation of positive deformation (clearly questionable in the case of a beam loaded with gravity load). The failure occurred in the second positive $6d_y^+$ displacement cycle, and the maximum negative displacement observed corresponded to $3d_y^-$ cycle.
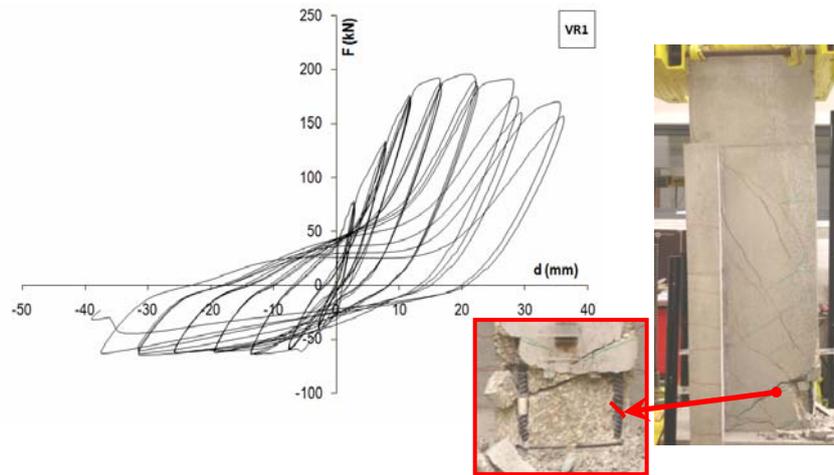
Figure 4: Failure mode and respective force-displacement hysteretic
loops of Specimen VR1

3.2 Specimen VR2

The Specimen VR2 presented a ductile failure, controlled by the gradual deterioration of the compressive zone and progressive buckling of the longitudinal bottom bars. In Fig.5 a picture of the Specimen VR2 after failure is presented, it should be noted that this test led to an accumulation of negative deflection, while for positive moments the longitudinal bottom reinforcement remained on the elastic range up to the end of the test.

The failure criterion proposed by Proença et all[6] was not attained, i.e., at the end of the test the beam resistance was larger than the corresponding pre-established gravity load effect. However, failure occurred according with ECCS[3], i.e., the force reached was lower than 85% of maximum force.
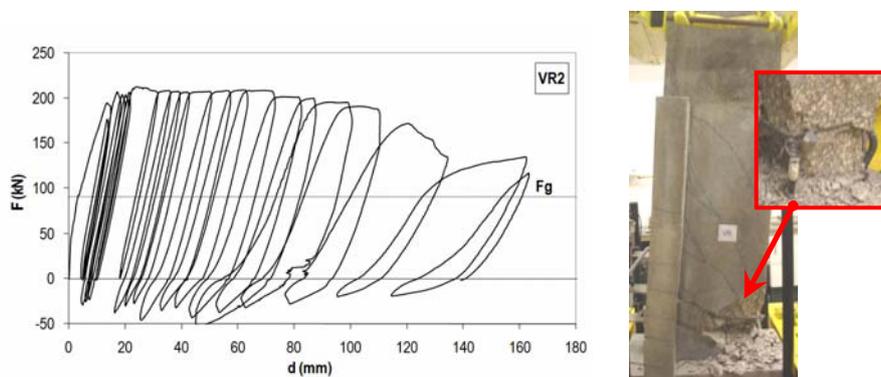

Figure 5: Force-displacement hysteretic loops of Specimen VR2

4. NUMERIC SIMULATION

The aim of the numeric simulation is to analyse the hysteretic response of a frame system subjected to a lateral displacement history up to drifts of 3.5% (ACI)[4], considering different levels of gravity load.
For this purpose non-linear structural analysis software - Sap2000[7] - was used. This software permits the simulation of the nonlinearity behaviour concentred on the plastic hinges. In this programme a non-linear element *"Link"* is available presenting several hysteretic models that can be calibrated with the loading envelope obtained from the test results.

4.1 Modelling of the Plastic Hinge

In order to simulate the plastic hinge, it is necessary to define the length and calibrate the model that simulates the hysteretic response.
There are semi-empirical expressions to estimate the length of the plastic hinge that depends on the extension of the yielding of the longitudinal reinforcement; the yield penetration and the effect of shear force. The estimation of the plastic hinge length was obtained by the following expression [Priestley and Park][10]:

$$l_p = 0,08 \; l + 0,022 \cdot d \cdot b \cdot fy = 0,08 \times 1.5 + 0.022 \times 477 \times 0.016 = 0,287 m \quad (1)$$

In *Sap2000*[7], three numerical models for the hysteretic response of reinforced concrete members are available: *Kinematic*; *Takeda and Pivot*[8]. These models are based on a few rules and parameters that can be calibrated with the loading envelope. Fig.6 shows the loading envelope M$\times\theta$ obtained from the experimental tests. It should be noted that in the second test procedure, for positive moments the longitudinal bottom reinforcement remain elastic therefore, in that case, the loading envelope assumes a development similar to the first procedure.
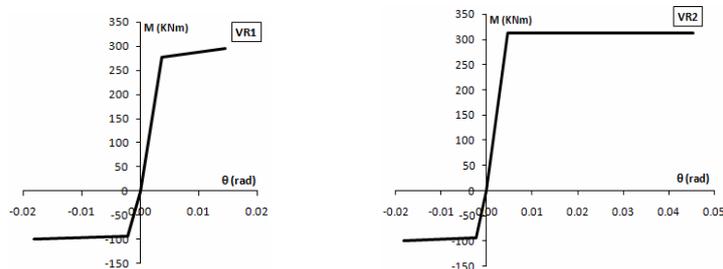

Figure 6: Experimental loading envelope for Specimens VR1 and VR2

In order to verify the capabilities of the cyclic response of the elements *"Link"* and the numerical models available, a beam cantilever subject to the displacement history similar to the experimental test was simulated. The numerical results from model *Pivot*[8] showed a better approximation to the test results: allowing a better simulation of the stiffness degradation; of the pinching effect and demonstrating to be more appropriate for non-symmetrical sections (Fig.7).
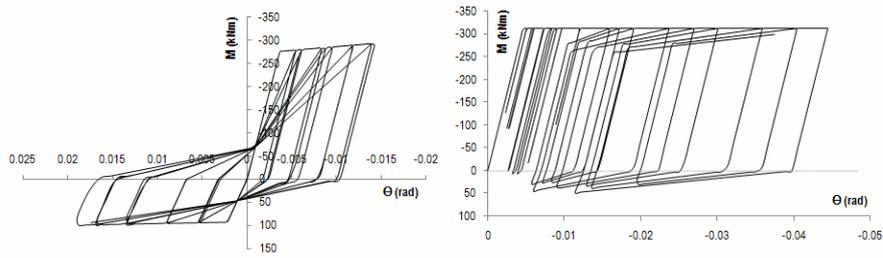
Figure 7: Response of the Pivot Model simulating the experimental test of Specimens VR1 and VR2

4.2. Analytical Model of a Portal Frame System

As stated above, for the analysis of the hysteretic response of a frame system connection, a one bay portal frame with a length of 5.0m and a single story was simulated, where the nonlinearity behaviour was concentrated on the plastic hinges (located at the extremities and at 1/4 of the length of the beam). The portal frame was subjected to a lateral displacement history up to drifts of 3.5% (ACI)[4], considering different levels of gravity linear distributed load. The Mxθ diagram is shown for plastic hinge A (plastic Hinge B is similar to A). In this figure diagrams of different levels of loads are presented. The values considered for the gravity load correspond to moments at support of 0%, 25% and 50% of the yielding moment on the plastic hinge.
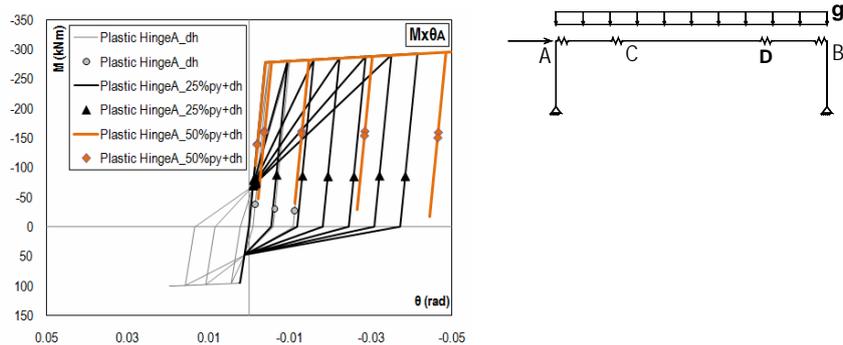

Figure 8: Hysteretic response on the plastic hinge of the Portal Frame

From the analysis of the Mxθ diagram it is interesting to observe that the imposition of gravity load leads to a progressive accumulation of deformation in the direction of the negative moments and failure in the beam-column connection has a propensity to occur for negative moments.

In order to analyse the unloaded state, when the structure is only subject to gravity loads after each cycle, the residual moments are represented in the diagram with bullets. As may be observed, although the residual moment has an evolution that corresponds to a moment redistribution, function of several parameters, its value depends meanly on the initial gravity load moment at the connection.

5. CONCLUSIONS

The proposed procedure for the cyclic test consists on the imposition of a reverse cyclic displacement history starting from the gravity load effects. The failure criterion proposed by Proença et all[6] is established as the instant when the connection is no longer able to sustain the gravity loads. However this criterion can lead to a level of deformation not acceptable. Therefore, it should also be established a failure criterion based on the drift and on the residual stiffness of the connection.

ACKNOWLEDGEMENTS

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