EXPERIMENTAL TESTS ON BEAM-COLUMN CONNECTIONS OF PRECAST BUILDINGS

V.Capozzi[1], G. Magliulo[2], G. Fabbrocino[3] and G. Manfredi[4]

[1] *PhD Student, Dept. of Structural Engineering , University of Naples "Federico II", Naples, Italy*
[2] *Assistent professor, Dept. of Structural Engineering, University of Naples "Federico II", Naples, Italy*
[3] *Associate professor, Dept. SAVA Engineering & Environment Division, University of Molise, Campobasso, Italy*
[4] *Full professor, Dept. of Structural Engineering, University of Naples "Federico II", Naples, Italy*

Email: vittorio.capozzi@unina.it, gmagliul@unina.it, giovanni.fabbrocino@unimol.it, gamanfre@unina.it

ABSTRACT :

The main goal of this research is to quantify through an experimental approach the parameters of ductility, strength and stiffness, which characterise the seismic behaviour of beam-column connections currently employed in precast structures; these connections are typically made by pairs of steel bars passing through the joint or other devices able to guarantee a hinge behaviour in the vertical plane of the beam and a fixed behaviour in the vertical plane orthogonal to the beam. In the paper a detailed description of the test protocol is reported; it is initially established with the definition of the test set-up, the load path and the data to be measured, in order to obtain results as much general as possible and consistent with the models of structural analysis. The test specimens are characterized by the typical dowels drowned in the column either without or with the working slab, the latter case typical of intermediate floors of multi-storey precast buildings. Shear and bending tests along the transversal beam axis direction are designed. Both monotonic and cyclic load paths are programmed; the former ones are performed until the ultimate displacement, in order to determine the skeleton curve and the levels of displacement characterising the cyclic tests. The results of the tests may have a direct industrial relevance, since they will be used for the development of guidelines for a reliable seismic design of precast structures.

KEYWORDS: Experimental tests, beam-column connections, precast concrete buildings, seismic behaviour

1. INTRODUCTION

The hierarchy of resistance is one of the innovative principles of the new seismic codes and it is fully assumed even by recent Italian seismic codes, the OPCM 3431 (OPCM 3431, 2005) and the Norme Tecniche per le Costruzioni (Norme Tecniche per le Costruzioni, 2008). It is finalised to guarantee the development of ductile mechanisms responsible of the energetic dissipation and the protection against the fragile mechanisms, which suddenly lead to the collapse.

The particular nature of the frame structures made by concrete cast in situ has leaded to the development of consolidated design rules, which seem to answer to the above quoted necessities. Different is the case of the reinforced concrete precast structures, which, due to their own nature, are close to the metallic ones, being made by assembling different components. Indeed, in addition to the general indications concerning elements and floors, the new design code provisions (Norme Tecniche per le Costruzioni, 2008; CEN, 2003a) refer to the connections, which play a central role in the seismic design. Three connection typologies are considered: connections placed far from the sections where the plastic demand is expected and connections placed in such zones; in the latter case, either an overstrength with respect to the adjacent elements or a high ductility behaviour is assigned to the connection. The high ductility behaviour is only allowed in the case of humid connections (characterised by a cast in situ).

It is evident that the application of the hierarchy of strength to precast industrial buildings cannot set aside the knowledge of connections monotonic and cyclic mechanical characteristics. The studies on such characteristics, referred to the connections most spread in Italy, are few (Tsoukantas e Tassios, 1989; Gaiotti and Smith, 1992; Ersoy and Tankut, 1993; Nakaki *et al.*, 1994; Restrepo *et al.*, 1995; Osanai *et al.*, 1996; Pampanin, 2001; Shaikh e Feile, 2004).

Obviously, the study of the beam-column connection is particularly important, because it connects two elements which are “primary” for the building seismic strength. Different typologies characterise the Italian building stock, even though they can be generally represented by a connection made by a rubber support and steel dowels (Figure 1); they are drowned both in the beam and in the column and they have the main function of absorbing the horizontal forces, avoiding differential displacements between connected elements and, consequently, the support failure. Nowadays such connection strength is computed by simplified formulas (CNR 10025, 1984), which do not consider many parameters, such as, for example, the cover, the action direction and the distance between the two dowels. Furthermore, the connection ductility and stiffness are not well known.

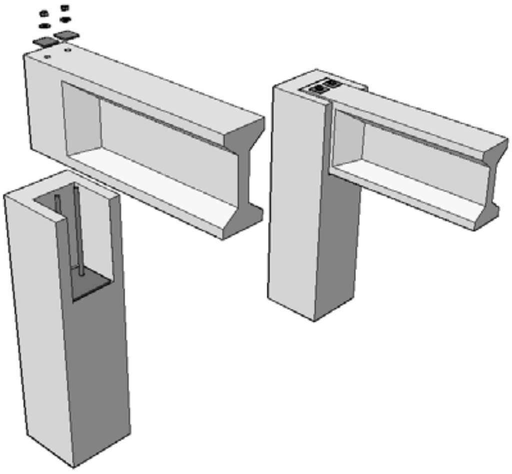


Figure 1 Connection with dowels

It is important to underline that, even though in the last years some studies on the beam-column connection mechanical behaviour have been carried out (Alcocer *et al.*, 2002; Khaloo and Parastesh,2003; Vintzeleou and Tassios, 1987, El Debs *et al.*, 2006), very few of them concern the above quoted typology, which is mostly adopted in Italy.

Definitely, nowadays specific studies, which allow to define beam-column connections with dowels and rubber design methodologies, in particular in seismic zone, and structural details for assuring the demanded performances, do not exist.
For this reason, the presented research has as principal purpose the experimental study of mechanical characteristics of some typologies of beam – column connections with dowels adopted in one-story and multi-stories precast buildings relatively. The acquired knowledge will be used in order to develop numerical procedures for the analysis of complex structural organisms and in order to provide guidelines for the design of such connections according to the hierarchy of strength principle.
The Italian precast industries association (ASSOBETON) cooperates to the experimental campaign also supplying components and sub-assemblages.

2. EXPERIMENTAL TESTS

The tests programmed at the laboratory of Structural Engineering Department of University of Naples Federico II are aimed to define the principal parameters (strength, stiffness, ductility, dissipative energy, deformability, degradation, damage) that characterize the seismic behaviour of two beam-column connections with dowels typologies (Figure 2): 1) connection with metallic dowels without working slab (top joint); 2) connection with metallic dowels, corbel and working slab (intermediate joint).

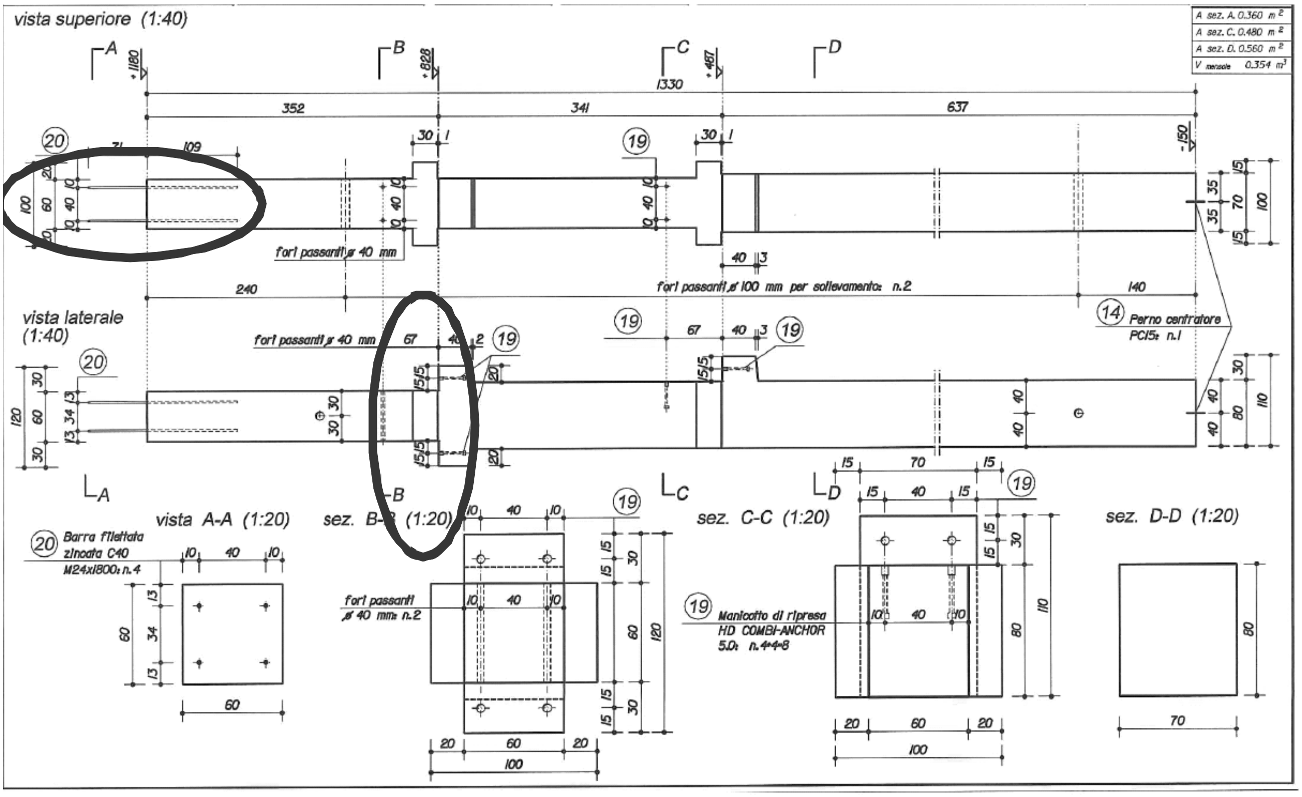
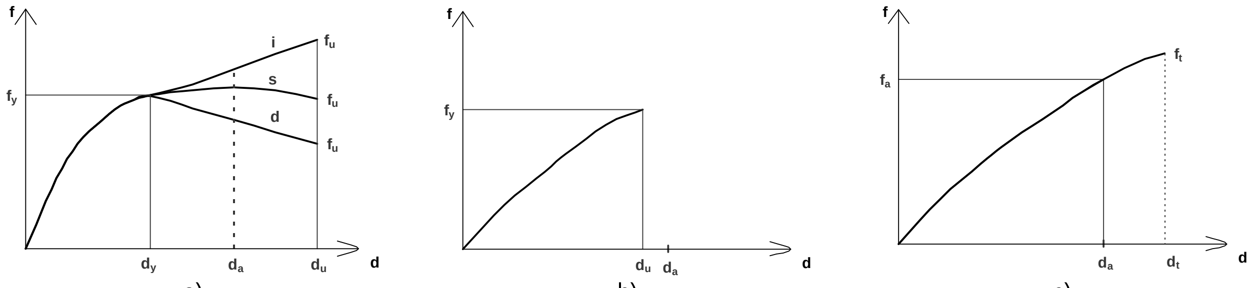


Figure 2 Connections to be tested

For each specimen, a monotonic test is performed in order to determine the constitutive force-displacement curve (Figure 3(a),(b),(c)) and, consequently, its principal points, useful for the calibration of cyclic tests, such as the first yielding (d_y-f_y), the maximum strength (d_t-f_t), the collapse (d_u-f_u) and the ductility factor of the system (d_a-f_a). The tests are performed according to the displacement control methodology in order to also plot the softening part of the capacity curve.



a) b) c)

Figure 3 Force-displacement constitutive diagrams (a) ductile; (b) brittle; (c) with overstrength

Cyclic tests are characterised by cycles of alternate displacements at increasing levels, which are determined on the base of monotonic tests; they are aimed to determine the cyclic degradation of the connections. Groups of tree cycles of equal amplitude Δd are programmed (Figure 4). The amplitude of the initial group of cycles is equal the lowest among $d_1=\pm d_y/4$, $d_1=\pm d_a/4$, $d_1=\pm d_t/4$ e $d_1=\pm d_u/4$; the following increments of the amplitude are assumed equal to $\Delta d=d_1$, until the attainment of the collapse displacement.

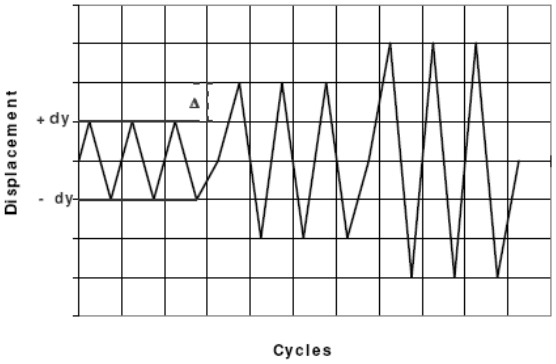


Figure 4 Load path of cyclic tests

The tests will provide the force-displacement relationship of the connections and, consequently, their ductility and dissipative capacity in terms of hysteretic energy.

All concrete elements are designed according to Eurocode 2 (CEN, 2004), Eurocode 8 (CEN, 2003a) and CNR 10025 (CNR 10025, 1984); provisions for the design of precast structures and, in particular, the spacing of column transverse reinforcement are provided by the last one. Steel elements are designed according to Eurocode 3 (CEN 2003b, CEN 2003c) and CNR 10011 (CNR 10011, 1988), while the neoprene support verifications are performed according to CNR 10018 (CNR 10018, 1999).

LVDT transducers are opportunely set in order to precisely measure the total displacements of the connections during the test; local strain and, consequently, stress are measured using strain gages placed on some steel bars and concrete surfaces.

All the measured data are collected by a data acquisition system type Spide 8 and elaborated by Catman release 3.0 software.

The tests programmed on connection with dowels without working slab are: 1) shear tests performed in the plane of the beam longitudinal axis; 2) bending tests.

The established number of first typology tests is one monotonic test and one pseudo-static cyclic test; two monotonic tests, for the two opposite signs of rotations, and one pseudo-static cyclic test are programmed for the second typology.

Only bending tests are programmed for connection with dowels and working slab: two monotonic one, for the two opposite signs of rotations, and one pseudo-static cyclic test

3.1. Shear test on connection without working slab

The specimen (Figure 5) is characterized by three principal elements: two vertical blocks (representing the columns) with section dimensions 60 cm x 60 cm, height equal to 100 cm and a T shape at the base in order to fix them at the laboratory slab; an horizontal element, representing the beam, with section dimensions 60 cm x 60 cm and length 210 cm. The beam-column connection is realized on the left block and it is made by two Φ 26 dowels and a 1 cm thickness neoprene support; the right side column only represents a support for the beam, consequently two teflon layers are placed on it, in order to avoid undesirable frictions.
The beam is loaded by a shear force provided by an horizontal hydraulic actuator, which has a maximum capacity of 500 kN and by a vertical force provided by a vertical jack restrained to a prestressed metallic bar; this bar crosses the beam through a special hole. A sleigh anchorage system is placed at the other side of the metallic prestressed bar, which avoids undesirable restraints to the beam horizontal displacement. The vertical force simulates the weight loads acting on real beam; they activate the neoprene – concrete friction force, which condition the initial seismic strength of the connection.
Both the vertical elements are restrained in order to avoid slips and oscillations which could invalidate the test results. The restrain system is characterized by opportunely designed rectangular tube steel sections, which are linked to the laboratory slab by prestressed steel bars; this connection is designed to be based on friction forces in order to avoid even minimum displacements of the bar in the slab hole.

3.2. Bending test on connection without working slab

The specimen (Figure 6(a)) is characterised by two principal elements: a vertical block (representing the column) with section dimensions equal to 60 cm x 60 cm, height equal to 280 cm, a T shape at the base and a corbel; the other element (representing the beam) is connected on this corbel, its section dimension are 60 cm x 60 cm and its length equal to 190 cm. The connection is made by two dowels M26 and a neoprene support whose thickness is equal to 1 cm; the two bars differ by the previously described connection because they are not drowned in the column concrete cast but they are screwed in a bushing prearranged in the corbel cast. The dowels are threaded at the head and the anchorage is improved by a steel plate with nut and washer. The bending moment on the connection derives by the vertical load provided by the hydraulic actuator at the beam free side.
The column is restrained at the laboratory slab by the same system adopted for the shear test in order to minimize the tests costs. The actuator is restrained at the laboratory slab, eliminating the costs of an expensive contrast frame.

3.3. Bending test on connection with working slab

The specimen (Figure 6(b)) is the same one of the above described bending test unless the presence of a working concrete slab and four horizontal dowels M12 drowned in the slab cast. The dowels are screwed in bushings (HD combi-anchor) prearranged in the column cast.

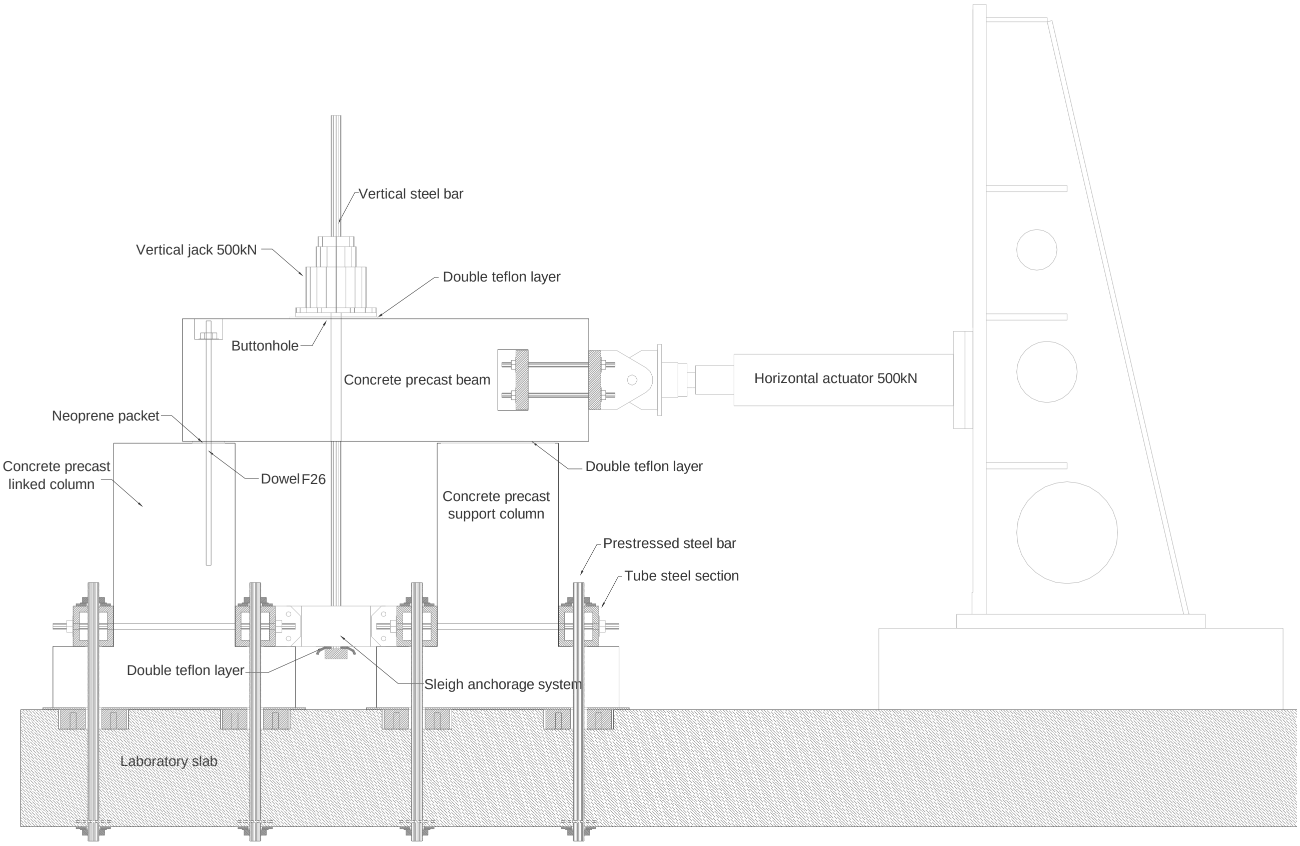
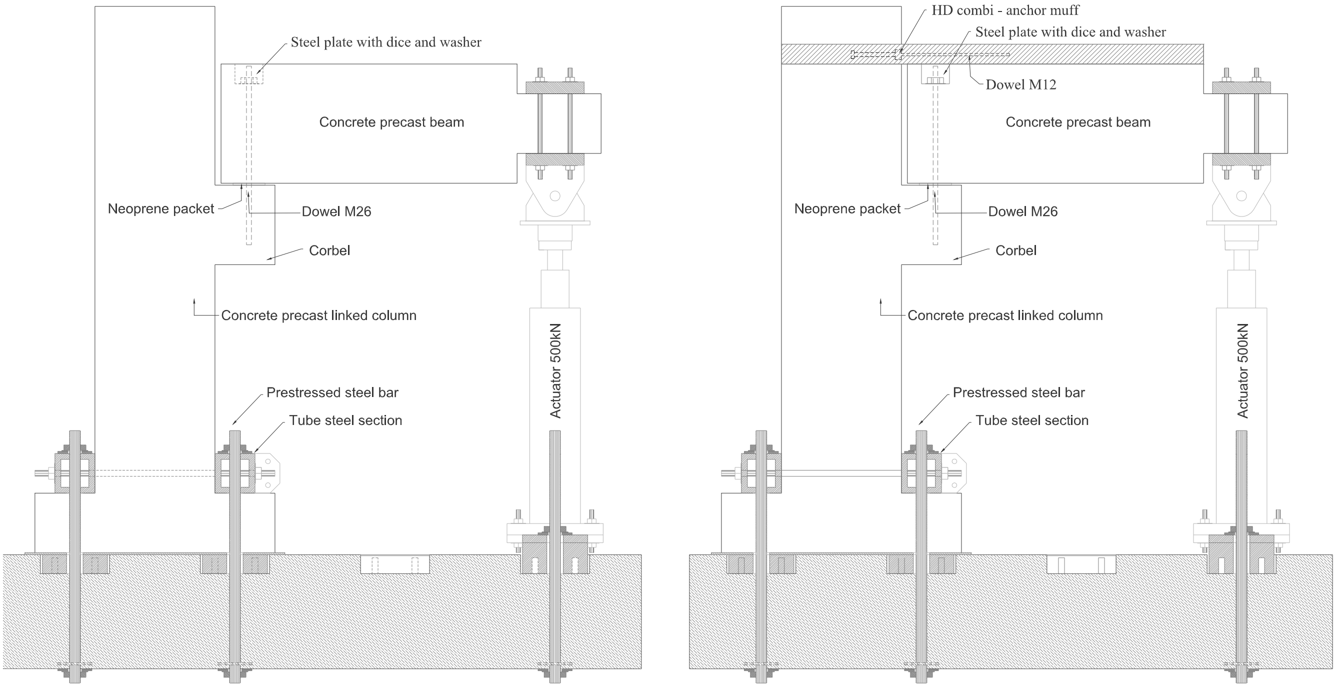


Figure 5 Shear test



(a) (b)

Figure 6 (a)Bending test without working slab; (b)Bending test with working slab;

4. CONCLUSIONS

The detailed performed bibliographic research has shown weaknesses in the theoretical and experimental knowledge concerning the mechanical characteristics, in particular in terms of hysteretic behavior, of beam – column connections with dowels commonly used in Italy and in other parts of the world for precast structures.
Consequently, the most spread typologies in Italy of such connections are pointed out, also in collaboration with the Italian precast industries association (ASSOBETON), and different groups of tests are designed in order to investigate, for each of them, the mechanic behaviour of the connections subject either to shear force in longitudinal direction of the beam or bending one.
Difficulties in theoretical prevision of test results are met, due to the lack of suitable formulations.
From an experimental point of view, the main met difficulties are represented by the application of the vertical load in shear tests and by the restrain of the column to the slab, in order to avoid even little displacements.
At the moment the tests design phase is concluded and the tests set up preparation is started.

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