# Numerical Investigations of the Seismic Response of Precast Buildings with Beam-to-Column Connections with Steel Dowels

Marco Valente

***Abstract*—This study was developed within a research project concerning the seismic performance assessment of new or existing precast structures and reports some relevant results of numerical analyses performed on precast industrial buildings subjected to earthquake excitation. Analytical models based on results of experimental tests carried out within the research project were developed to reproduce the behaviour of beam-to-column connections with steel dowels. The models were extended to consider the effects of different parameters and correlated well with experimental results. The influence of numerical modelling of beam-to-column connections was investigated analyzing the seismic performance of a reference precast industrial building and comparisons with models with simple pinned beam-to-column connections were performed. Results of the numerical investigations showed that the plastic demand on columns decreased due to the energy dissipation contribution of beam-to-column connections, especially for medium-high seismic intensity levels. The building was able to withstand stronger seismic excitations, beyond the design earthquake, dissipating significant amount of energy through inelastic behaviour.**

***Index Terms*—Beam-to-column connections, numerical models, precast industrial buildings, seismic response.**

## I. Introduction

Precast reinforced concrete structures are widely used for industrial buildings in seismic regions. The type and the response of the connections are crucial for the behaviour of the entire system, mainly under seismic actions. This study reports some relevant results of numerical analyses performed on a precast industrial building subjected to earthquake excitations. Accurate numerical models were created in order to simulate the seismic response of the reference precast industrial building and nonlinear dynamic analyses with different seismic intensity levels were performed. Analytical models based on results of experimental tests carried out at the National Technical University of Athens (NTUA) were developed for beam-to-column connections with steel dowels. The models were used for global analyses of precast industrial buildings to evaluate the effects of numerical modelling of beam-to-column connections on the seismic response. Global and local behaviour of the building was investigated and comparisons with models with simple pinned beam-to-column connections were performed. In detail, the main aims of this study were: a) the development and calibration of analytical models for beam-to-column connections with steel dowels; b) the evaluation of the influence of numerical modelling of beam-to-column connections on the seismic response of precast industrial buildings; c) the seismic response assessment of precast industrial buildings when subjected to stronger seismic excitation, beyond the earthquake design, investigating the behaviour of beam-to-column connections and the damage level at the columns base.

## II. Experimental Tests and Analytical Model

Within the Safecast research project, experimental tests were carried out on beam-to-column subassemblages at the Laboratory for Earthquake Engineering of the National Technical University of Athens (NTUA), [1]. The specimens consisted of a beam and a column element and the mechanical connection was provided by steel dowels. The dowels were grouted at the beam side with non-shrinking concrete and were fastened on top. The beam was sitting on the column through a rubber pad. The general layout of a test specimen is shown in Fig. 1.

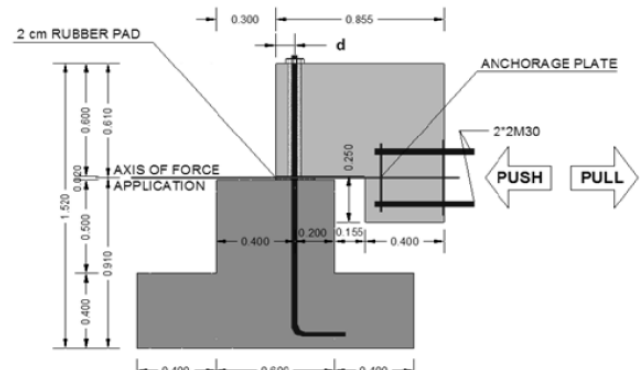


Fig. 1. General layout of a specimen tested at the national technical university of Athens, [1].

The main objective of the tests was to investigate the behaviour of several improvements of the beam-to-column connections under monotonic and cyclic purely shear loading. In the test specimens considered in this study the connection consisted of 2Ø25 dowels and the concrete cover of the dowels was 10 cm. The specimens were tested in monotonic push, monotonic pull and cyclic loadings. On the basis of the results of the experimental tests, an analytical model was proposed in order to describe the behaviour of

Manuscript received May 20, 2012; revised August 28, 2012.
Marco Valente is with the Department of Structural Engineering, Politecnico di Milano, Milan, Italy (e-mail: valente@stru.polimi.it).

DOI: 10.7763/IJET.2012.V4.465

beam-to-column connections with steel dowels for global analyses of precast buildings. The analytical model was developed on the basis of the expressions and the results reported by [2]-[5]. The model allows to define the behaviour of beam-to-column connections by means of bilinear force-displacement curve for monotonic loading and trilinear force-displacement curve for cyclic loading. The model was calibrated and verified on the basis of the experimental results and considers the effects of different parameters (dowel diameter, geometry of connection, material properties).

Fig. 2 shows the analytical bilinear curve for the two monotonic tests, push and pull, in case of connection with 2Φ25 dowels. The theoretical curve approximates well the experimental results in the elastic and plastic ranges. The maximum force in the pull-direction was significantly smaller than in the push-direction due to the failure of the concrete cover in the front side of the beam.

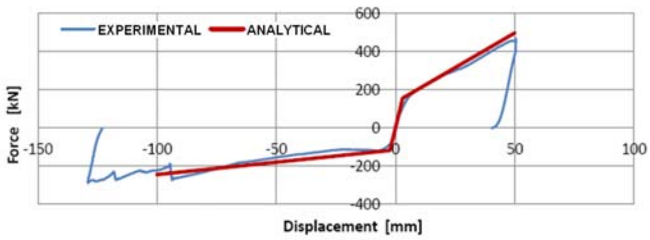


Fig. 2. Force - displacement relationship: Comparison of analytical and experimental results for monotonic test.

Fig. 3 shows the analytical trilinear curve compared to the experimental results of the cyclic tests. A good agreement can be observed in terms of stiffness, maximum load and softening branch up to collapse. As expected, the response was not symmetric in the push- and the pull-direction, because the resistance in the pull-direction was reduced due to the small cover of the dowels.

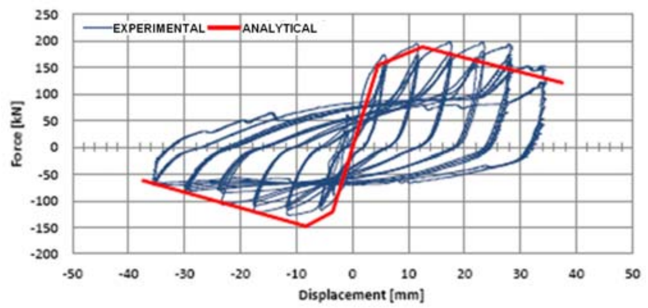


Fig. 3. Force - displacement relationship: Comparison of analytical and experimental results for cyclic test.

The models were extended and validated considering other types of specimens with different characteristics (number, diameter and cover of the dowels). Good correlation with experimental results was obtained, confirming the effectiveness of the model.

## III. Case Study Building

Some reference existing buildings, representative of typical structural solutions for precast industrial buildings built in Italy, were modelled and analyzed under earthquake loading. This study presents and discusses the relevant results of numerical analyses performed on a precast industrial building, designed according to Italian Standard (2008) for a peak ground acceleration $a_g$=0.16g and soil class B. Concrete C45/55 and steel B450C were used for the design. The building presents a regular structural scheme with a rectangular plan: the longitudinal side is equal to 33.1m and the transverse one is equal to 39.5m. The square columns (60cm x 60cm), whose height is equal to 6.7m, are connected by prestressed RC beams, parallel to the longitudinal direction, with I-shaped constant section. The length of the prestressed beams is 8.1m. Elements with length equal to 19.5m and V-shaped constant section are located on the main beams and represent the roof of the building. The connections between the main beams and the columns consist of 2Φ25 steel dowels.

The case study building was numerically modelled using both the general purpose finite element code Straus and the nonlinear dynamic analysis software Ruaumoko, widespread used in academic research. Two different modelling approaches were employed and two complementary models were developed by using the two codes. A schematic view of the numerical model developed for the case study building with notation of some reference columns is presented in Fig. 4. Two variants of the model of the building were developed, hereafter named as model M1 and model M2. The first model M1 presented simple pinned beam-to-column connections. In the second model the beam-to-column connections were modelled using spring elements. The force-displacement relationships adopted to model the behaviour of the beam-to-column connections were derived from the analytical models calibrated and validated with the results of the experimental tests. The Takeda hysteresis rule, implemented in the computer codes Straus and Ruaumoko, was adopted to reproduce the cyclic behaviour of the beam-to-column connections.

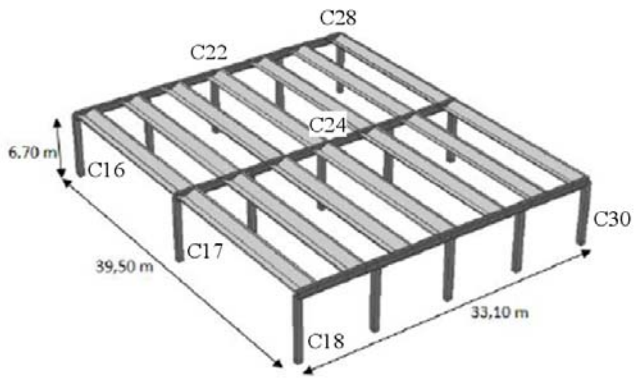


Fig. 4. Numerical model of the building and notation of columns.

## IV. Nonlinear Dynamic Analyses

Bidirectional nonlinear dynamic analyses with increasing intensity levels were performed on the two models M1 and M2. Artificial ground motion records with 20s duration were generated by using the code SIMQKE in order to match the

Eurocode 8 response spectrum (type 1, subsoil class B).

Fig. 5 shows the maximum top displacement in the longitudinal direction (direction y) for the two models at different seismic intensity levels ranging from 0.1g to 0.4g. In case of low seismic intensity level larger displacements are observed for the model M2; on the contrary, a reduction of 11% is registered for the model M2 at 0.4g seismic intensity level.

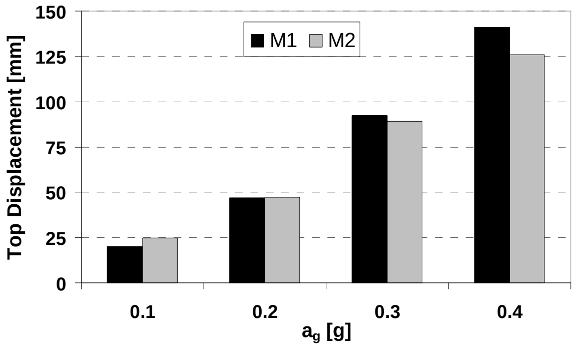


Fig. 5. Maximum top displacement for the models M1 and M2 at different seismic intensity levels.

The maximum axial forces acting on some reference columns of the two models at 0.4g seismic intensity level are presented in Fig. 6. The maximum value of the axial force is registered for the internal column C24. A maximum reduction equal to 13% is computed for the external columns C16 and C28 of the model M2.

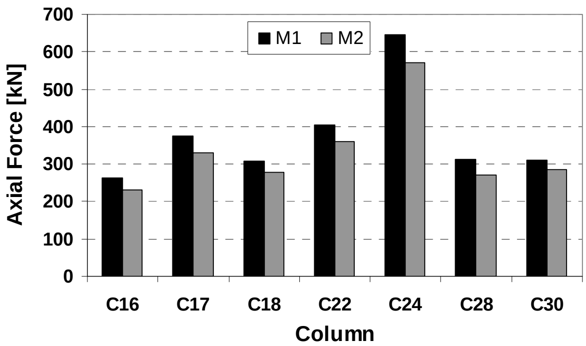


Fig. 6. Maximum axial force for the columns of the models M1 and M2 at 0.4g seismic intensity level.

The Demand-to-Capacity Ratio (DCR), i.e. the ratio between the chord rotation demand and chord rotation capacity, was used to evaluate the damage level of columns. The maximum rotation demand was obtained by numerical analyses and the rotation capacity was computed according to Eurocode 8 Part 3. Fig. 7 shows the maximum DCR values for some reference columns of the two models at 0.4g seismic intensity level. High DCR values close to 0.8 can be observed for some columns of the model M1. Significant decreases of the DCR values are registered for all the columns of the model M2, with maximum reductions of 30% for the external columns C18 and C30. Numerical results suggest that the building under study exhibits high levels of ductility, dissipating significant amount of energy through inelastic behaviour. The maximum DCR values confirm that the building is able to withstand stronger seismic excitations, beyond the design earthquake.

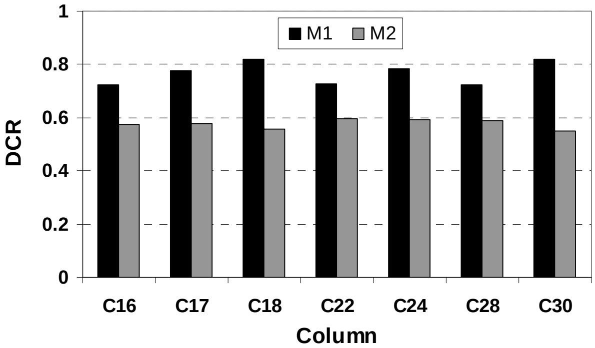


Fig. 7. Maximum DCR values for the columns of the models M1 and M2 at 0.4g seismic intensity level.

Fig. 8 shows the energy dissipated by the models M1 and M2 (columns and beam-to-column connections) for different seismic intensity levels. The total energy dissipated by the structure is larger for the model M2, but the plastic demand on columns is higher for the model M1. A considerable reduction (equal to 20%) of the energy dissipated by the columns of the model M2 is observed at 0.4g seismic intensity level due to the energy dissipation contribution of the beam-to-column connections. The difference of plastic demands on the columns of the two models increases as the seismic intensity level increases.

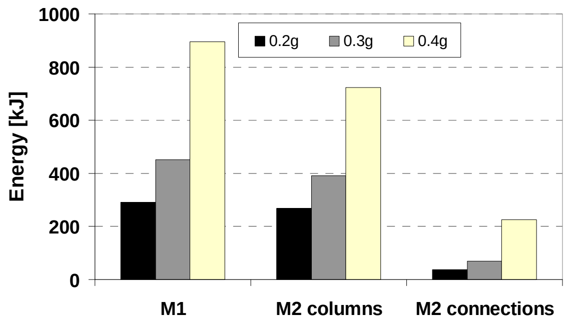


Fig. 8. Energy dissipated by the models M1 and M2 (columns and connections) at different seismic intensity levels.

The behaviour of the beam-to-column connections of the model M2 was examined at 0.4g seismic intensity level. Fig. 9 reports the maximum displacement and force values achieved in some relevant connections of the model during seismic excitation, for push and pull directions. Numerical results show that the contribution of the connections is mainly influenced by their position in the model. The external connections significantly entered into the plastic range, while a large part of the internal connections remained in the elastic range.

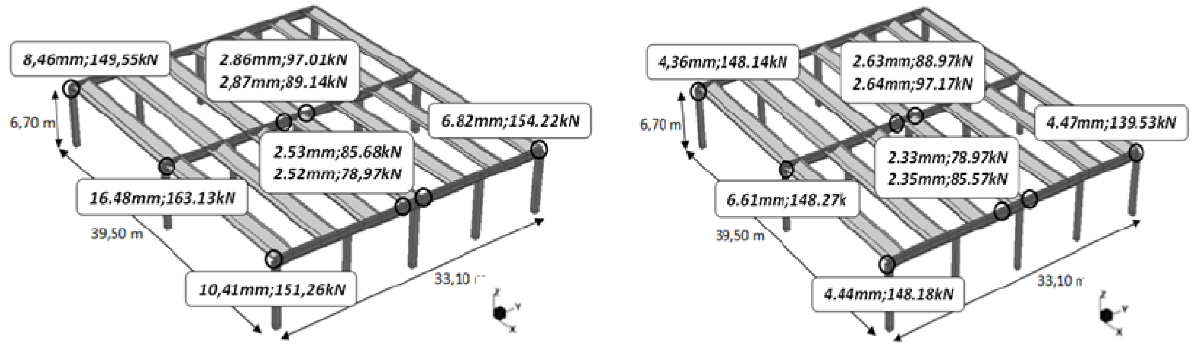


Fig. 9. Maximum displacement and force values for some springs of the model M2 at 0.4g seismic intensity level: push (left) and pull (right) direction.

It can be noted that all the connections didn't achieve failure, even for 0.4g seismic intensity level.

In the model M2 the formation of the first plastic hinge at the column base was delayed compared to the model M1. During time-history analysis with artificial accelerogram with 20 seconds duration, the first plastic hinge occurred at the column base after 3.9 seconds in the model M1 and after 4.2 seconds in the model M2. Moreover, after 5 seconds all the columns of the model M1 presented plastic hinges at the base, while in the model M2 some columns were still in the elastic range.

## V. Conclusion

The main results of a numerical study on the seismic response of a precast industrial building subjected to earthquake excitation were presented. Analytical models developed on the basis of experimental tests were used to simulate the behaviour of beam-to-column connections with steel dowels for nonlinear dynamic analyses of precast buildings. The models were extended to consider the effects of different parameters and correlated well with experimental results. The effects of numerical modelling of beam-to-column connections on the seismic response of a precast industrial building were investigated and comparisons with the model with simple pinned beam-to-column connections were performed. The use of refined models of beam-to-column connections significantly decreased plastic strain demands at the column base and a reduction of the damage level was observed for the columns of the building compared to the case of model with simple pinned beam-to-column connections. The formation of the first plastic hinge at the column base was delayed. The building exhibited high levels of ductility, dissipating significant amount of energy through inelastic behaviour. The DCR values showed that the building was able to withstand stronger seismic excitations, beyond the design earthquake. The energy dissipation contribution of the connections was mainly influenced by their position in the model. The external connections presented significant inelastic deformations, while a large part of internal connections remained in the elastic range. It can be noted that all the connections didn't achieve failure, even for 0.4g seismic intensity level.

## Acknowledgment

The Author is grateful to Dr. Antonella Colombo (Assobeton) for her valuable support and for providing experimental data.

## References

[1] S. Report, "Experimental behaviour of new/improved connections," *Part 2: Contribution of NTUA*, 2011.

[2] P. Soroushian, K. Obaseky, M. C. Rojas, and J. Sim, "Analysis of dowel bars acting against concrete core," *ACI Structural Journal*, vol. 83, pp. 642-649, 1986.

[3] P. Soroushian, "Behavior of bars in dowel action against concrete cover," *ACI Structural Journal*, vol. 84, pp. 170-176, 1987.

[4] S. G. Tsoukantas and T. P. Tassios, "Shear resistance of connections between reinforced concrete linear precast elements," *ACI Structural Journal*, vol. 86, pp. 242-249, 1989.

[5] E. N. Vintzeleou and T. P. Tassios, "Behavior of dowels under cyclic deformations," *ACI Structural Journal*, vol. 84, pp. 18-30, 1987.

[6] CEN European Standard EN 1998-3. Eurocode 8: Design of structures for earthquake resistance. Part 3: Assessment and retrofitting of buildings. *European Committee for Standardization*, Brussels, 2005.