PSEUDODYNAMIC TESTS ON FULL SCALE PROTOTYPES OF PRECAST STUCTURES

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ABSTRACT

The paper presents the results of pseudodynamic and cyclic tests performed at ELSA Laboratory in Ispra on full scale prototypes of precast structures. The typical frame system used for one storey industrial buildings is treated. The results give clear indications on the behaviour of such structures in terms of seismic capacity, ductility resources related to reinforcement details and role of the different construction elements (connections, roof diaphragm, cladding panels).

KEYWORDS: precast structures, seismic design, testing

1. INTRODUCTION

The research is set in the scope of an European Growth Programme with the acronym "Precast Structures EC8" (Contract n. G6RD-CT-2002-70002). Ten partners are involved in the programme, under the coordination of prof. G. Toniolo. For Portugal: LNEC Laboratorio National de Engenharia Civil of Lisbon and Civibral Systemas de Costrucao of Sao Pedrp Fins; for Italy: Politecnico di Miano, Magnetti Buildings of Carvico and Gecofin of Verona; for Greece: NTUA National Technical University of Athens and Proet of Athens; for Slovenia: University of Ljubljana; for China: Tongji University of Shanghai; for the European Community: ELSA European Laboratory of Structural Assessment.
"Precast Structures EC8" represents one step of a series of theoretical and experimental researches started on 1994 and devoted to the investigation of the seismic behaviour of precast structural systems for one storey industrial buildings. First, a campaign of cyclic and pseudodynamic tests on prototypes of precast columns in their pocket foundations has been performed evaluating their behaviour parameters [Saisi and Toniolo 1998]. Second, using these parameters, analytical simulations of the dynamic response of some prototypes of precast and cast-in-situ structures have been elaborated comparing their seismic behaviour [Biondini et al. 2004]. The analytical models have been then verified with pseudodynamic tests performed on full scale prototypes of precast and cast-in-situ structures within an European Ecoleader Programme [Biondini et al. 2003]. Finally all the preceding results have been used for a more complete qualification of the seismic behaviour of the structures of concern, including the effects of claddings, diaphragm action and role of connections.
The present work deals with one task of the Italo-Slovenian group dedicated to the tests on full scale prototypes performed at ELSA Laboratory in Ispra. Typical arrangements of precast frame structures have been chosen, with hinged beam-to-column and roof-to-beam joints made with steel connectors, following the ordinary technology used in many European countries. Different layouts, with and without cladding panels, have been tested with pseudodynamic and cyclic methods and a relevant amount of data has been obtained. In the following sections some of these results are presented.

2. DESCRIPTION OF THE PROTOTYPES

In Figures 1 and 2 the tested prototypes are represented. Both are set in a square mesh of 8 m of side in the nodes of which six columns are placed supported on pocket foundations. Prototype *A* has 2+2 beams placed in the longitudinal direction and 6 roof elements placed in the transverse direction. In the prototype *B* the orientation of the roof elements is turned around with 3 beams placed over the columns in the transverse direction and 3+3 roof elements placed over the beams in the longitudinal direction. The testing action is applied in the transverse direction.

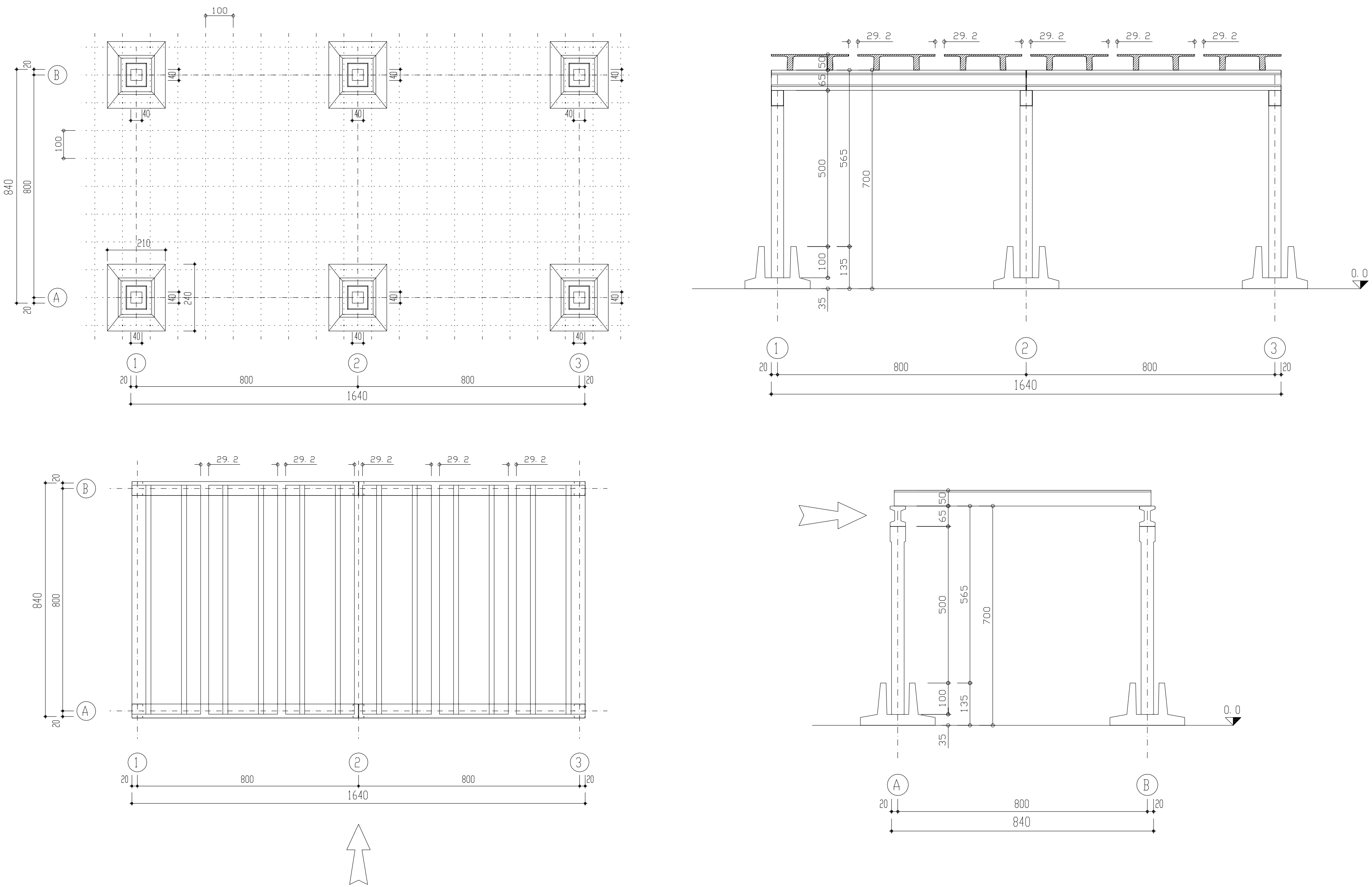


Figure 1. Prototype *A*.

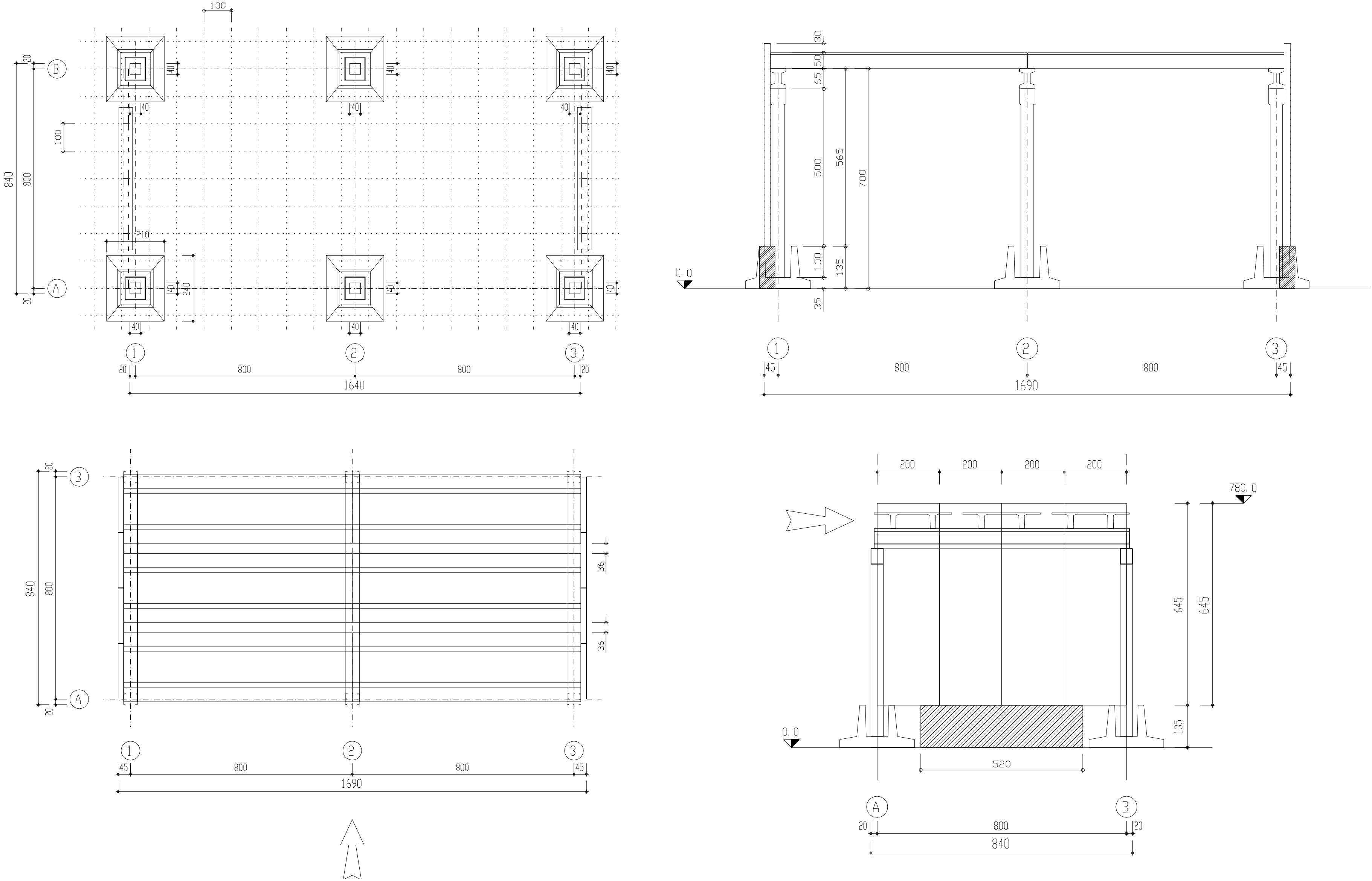


Figure 2. Prototype *B*.

Figure 3 shows the details of the cross section of the columns with their reinforcement. A concrete class C40 (f_{ck}=40 MPa) has used with a steel B500H (f_{yk}=500 MPa). Ribbed bars of diameter ϕ=16 mm are used for the longitudinal reinforcement and ϕ=8mm for the stirrups with a spacing of 75 mm (~5ϕ).

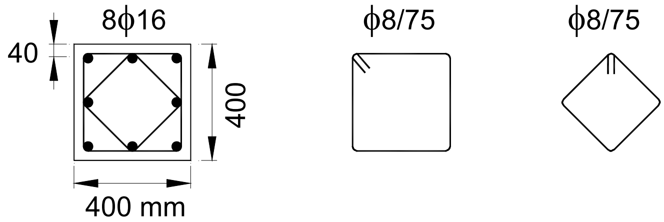


Figure 3: Details of the column cross section

Figures 4 shows a view of the two prototypes installed in the plant of ELSA Laboratory ready for testing, with the jacks applied against the reaction wall. For Prototype *A* two degree of freedom have been assumed, using four jacks with the same displacement imposed to the symmetric couples (Figure 4a), remaining their actions applied to the single internal and external elements. For Prototype *B* it has been assumed that the response is characterised by one degree of freedom and by consequence, for the control of the tests, two symmetric jacks have been used with the same imposed displacement (Figure 4a), being their action distributed on the three lines of roof elements by means of connecting beams. The main controlling quantities are the top displacements. For the details of the instrumentation see [Ferrara et al. 2006].

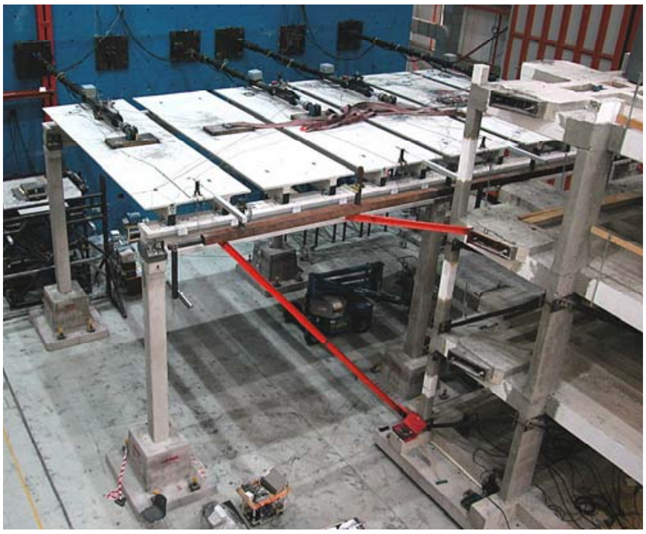


Figure 4a: View of the Prototype *A*

Figure 4b: View of the Prototype *B*

Prototype *B* has been duplicated into a Prototype *B’* of the same dimensions but with the stirrup spacing decreased down to 50 mm (~3ϕ).

3. PSEUDODYNAMIC TESTS

For pseudodynamic tests reference has been made to a registered accelerogram properly modified for a good consistency with the elastic response spectrum given by Eurocode 8 to soil of category B (Figure 5). With this accelerogram three subsequent tests have been performed for any prototype with peak ground accelerations increasing from PGA=0.14g to PGA=0.35g and to PGA=0.525g. These levels have been chosen on the basis of the seismic capacities of the prototypes evaluated in design stage as PGA=0.93g and PGA=0,86g respectively for Prototype *A* and Prototypes *B* and *B’*. The pseudodynamic test on Prototype *B* has been invalidated by a malfunctioning of the controlling system and it is not reported in this paper.

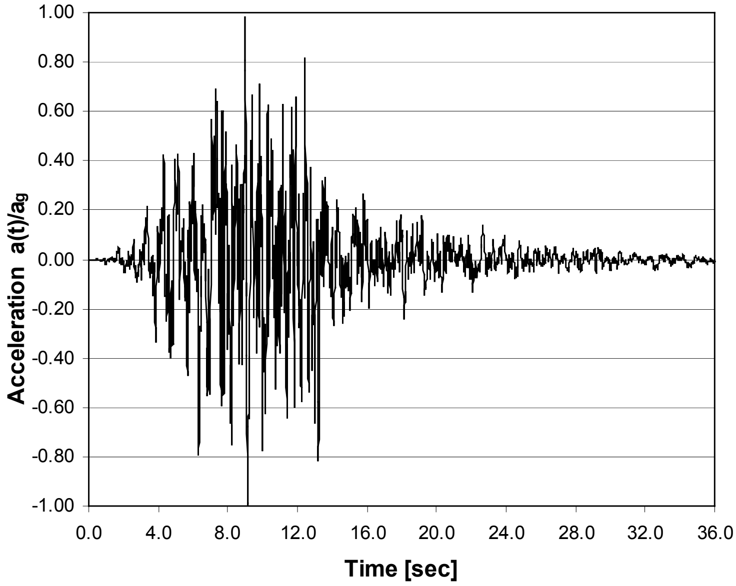


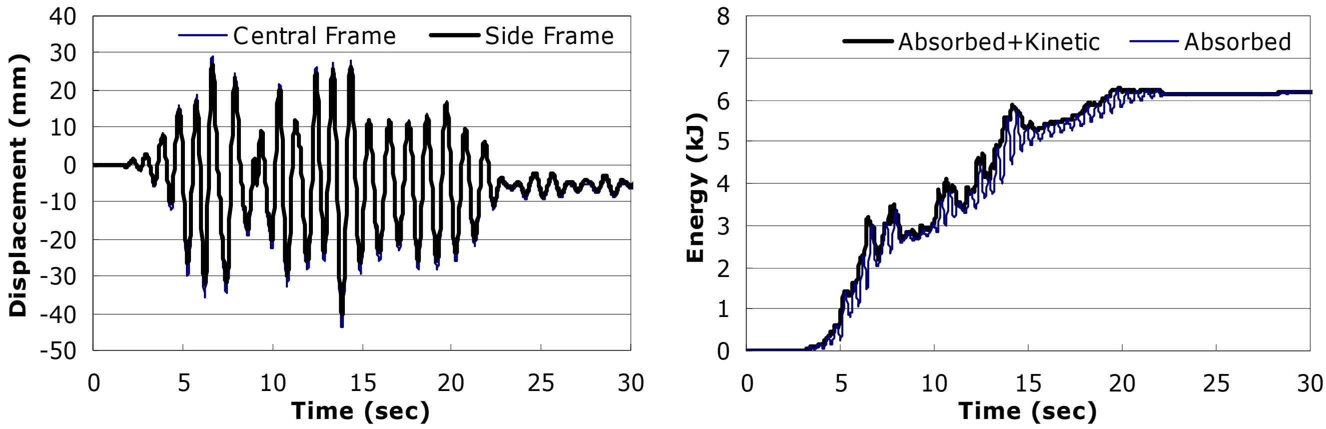
Figure 5: Accelerogram used in the tests.

Figures 6 and 7 shows the time histories of the measured top displacements and energy dissipation of the pseudodynamic tests on Prototype *A* (Figure 6) and Prototype *B'* (Figure 7). The measured top displacements of lateral and central columns resulted practically coincident. Significant differences have been found only during the pseudodynamic tests with PGA=0.525g. This result confirms that double connections between beams and roof elements give a rotational restraint which enables the activation of an effective diaphragm action, even if the roof elements are not connected among them.

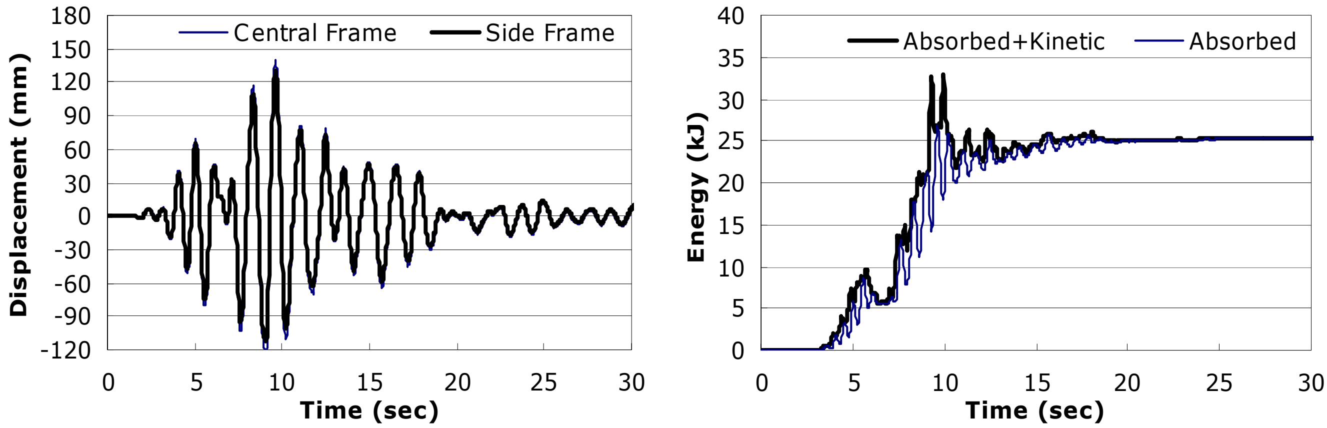
The force-displacement diagrams in Figure 8 refer to the total force recorded in the actuators, and to the displacements imposed by the actuators at the top of the roof. It is worth noting that these displacements are sensibly higher than the corresponding displacements measured at the top of the columns. The direct comparison of the cycles shown in Figure 8 highlights the overall good seismic behaviour of both prototypes, with moderate damage and small residual deformations, at least for the first two levels of pseudodynamic tests.

For the higher level, the spalling of concrete cover with buckling of the longitudinal bars placed on the same side at the base of the central columns occurred for Prototype *A*. For this Prototype, with reference to a yielding displacement $d_y \approx 80$ mm and a ultimate displacement $d_u \approx 300$ mm, as were evaluated at the top of the columns during the pseudodynamic test with PGA=0.525g, a global ductility equal 3.75 is deduced, value significantly lower than 4.5 as assumed by EC8 for the behaviour factor of frame systems. With this regards, it should be noted that a stirrup spacing equal 5ϕ, as adopted for Prototype *A* in the critical zones at the base of the columns, is not sufficient to prevent the early rupture of the buckled bars during their reloading in tension. This experimental evidence was already noted during some cyclic tests carried out on single columns [Saisi and Toniolo 1998], for which the obtained results indicated a limit spacing of stirrups equal 3.5ϕ. Based on these considerations, the stirrup spacing in the critical zones has been reduced to 3ϕ for Prototype *B'*. This allowed to avoid the early failure of the compressed bars during the third pseudodynamic test with PGA=0.525g, and to reach an ultimate displacement $d_u \approx 360$ mm with a global ductility equal 4.5.

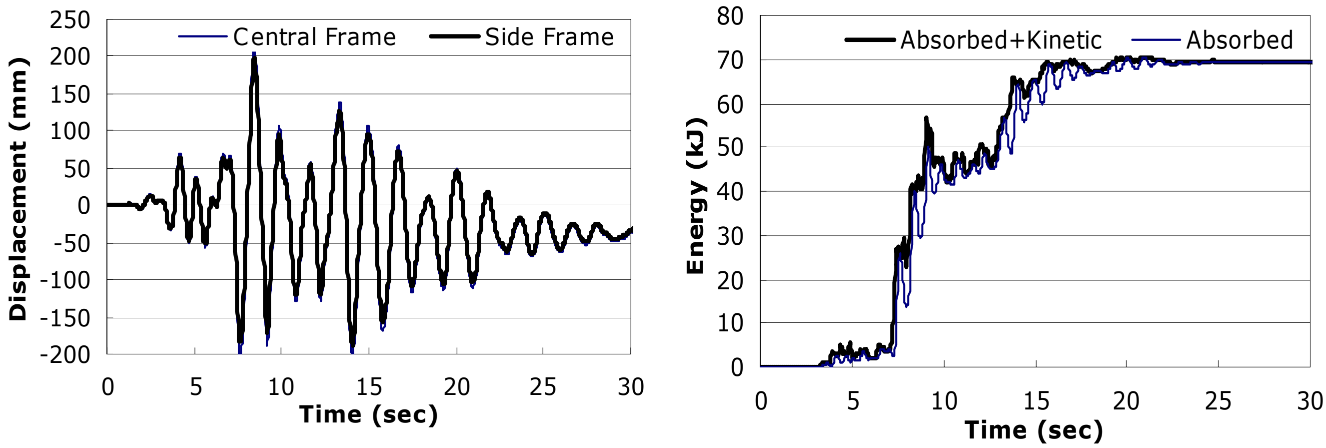
It is worth noting that preliminary pseudodynamic tests on Prototype *B*' with cladding panels were also carried out for the first two levels of peak ground acceleration. The force-displacement cycles of these pseudodynamic tests are shown in Figure 9. The results of this investigation highlighted a high cooperation between frames and panels, with very limited cracking of the columns at the end of the tests.



PGA=0.14g

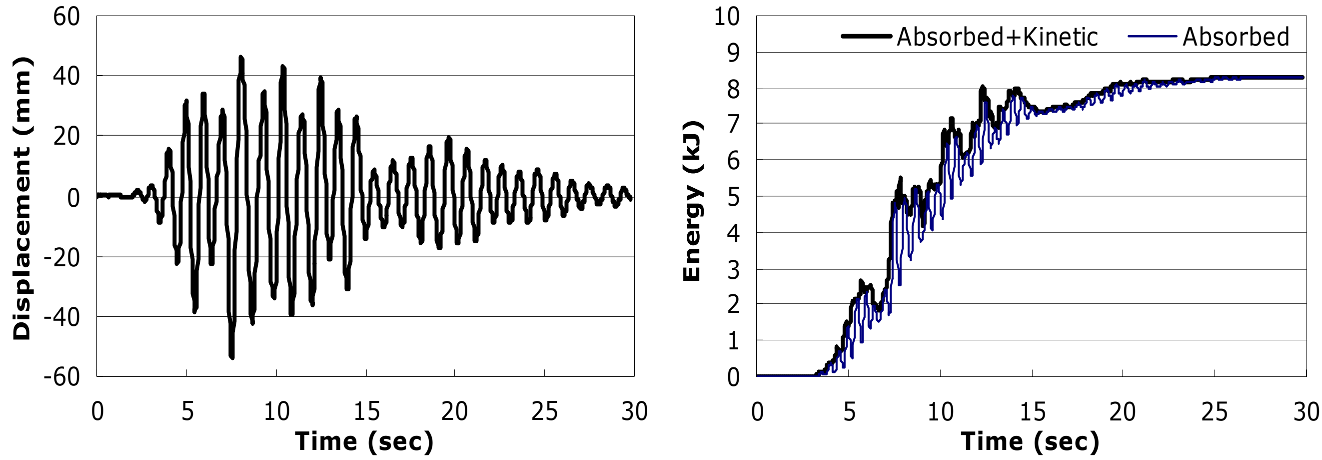


PGA=0.35g

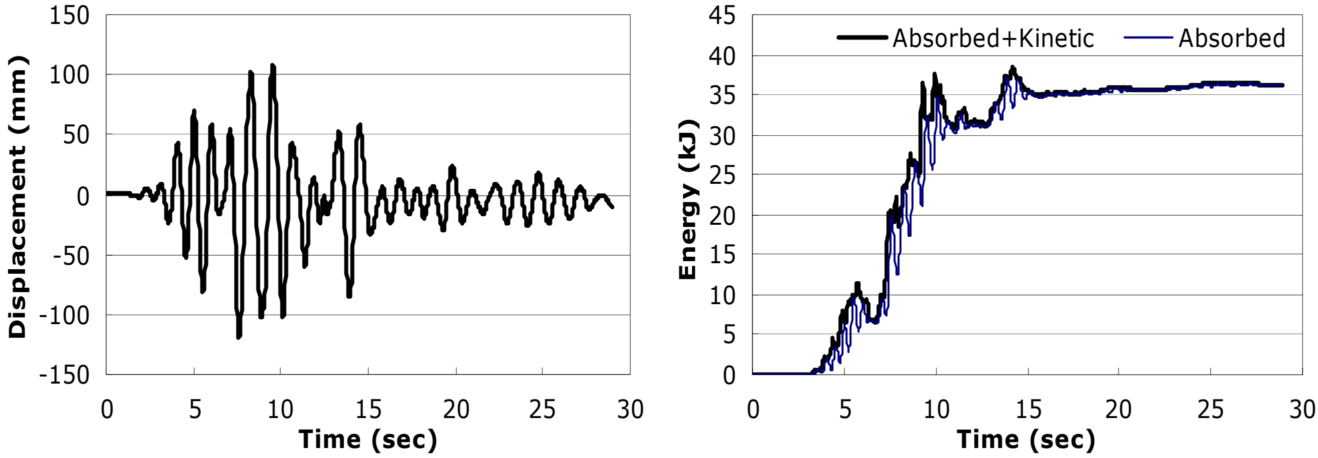


PGA=0.525g

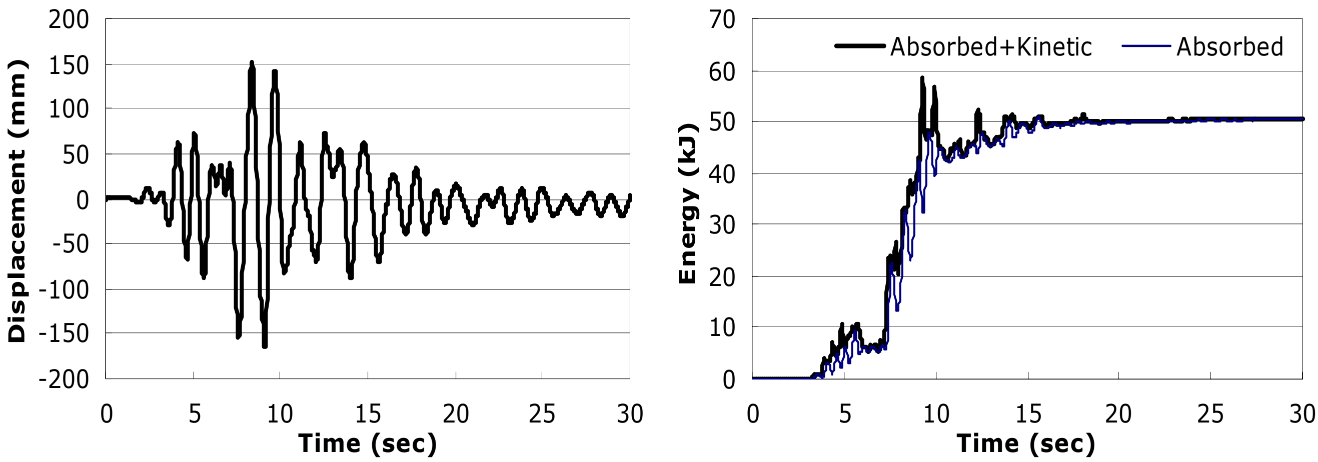
Figure 6: Time histories of the top displacement and energy dissipation of PsD tests on Prototype *A*.



PGA=0.14g

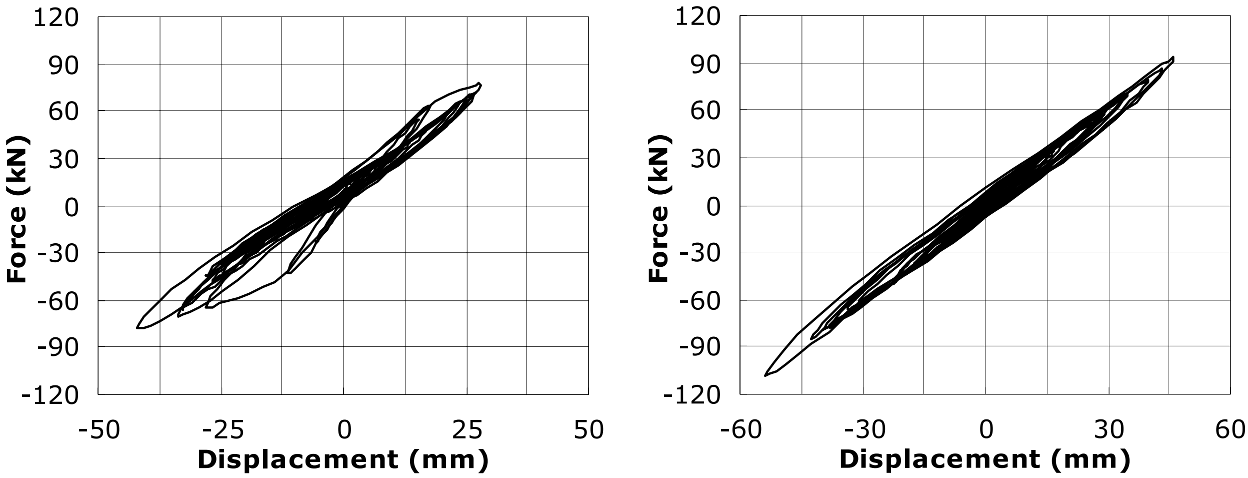


PGA=0.35g

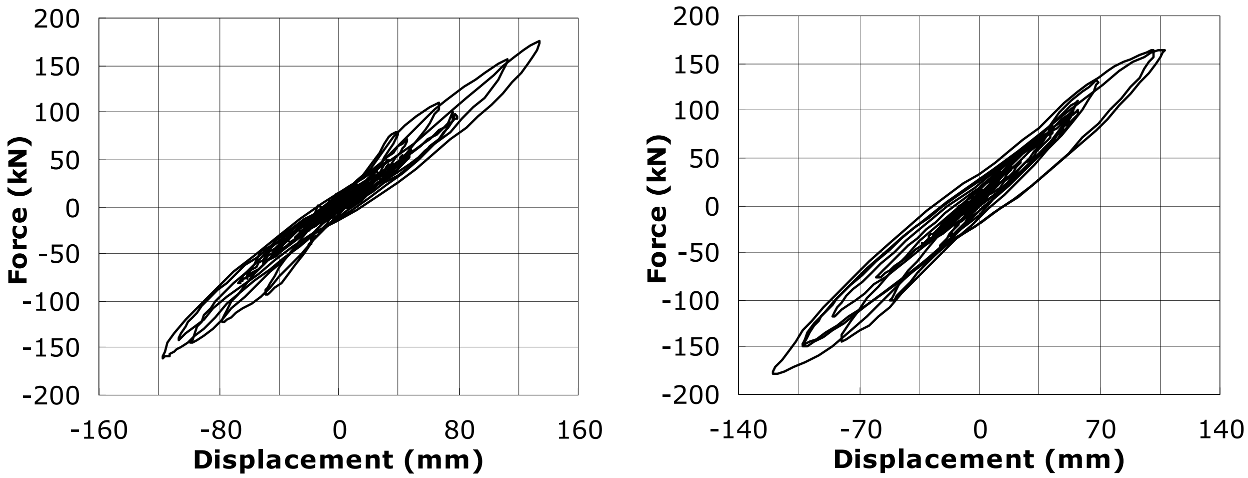


PGA=0.525g

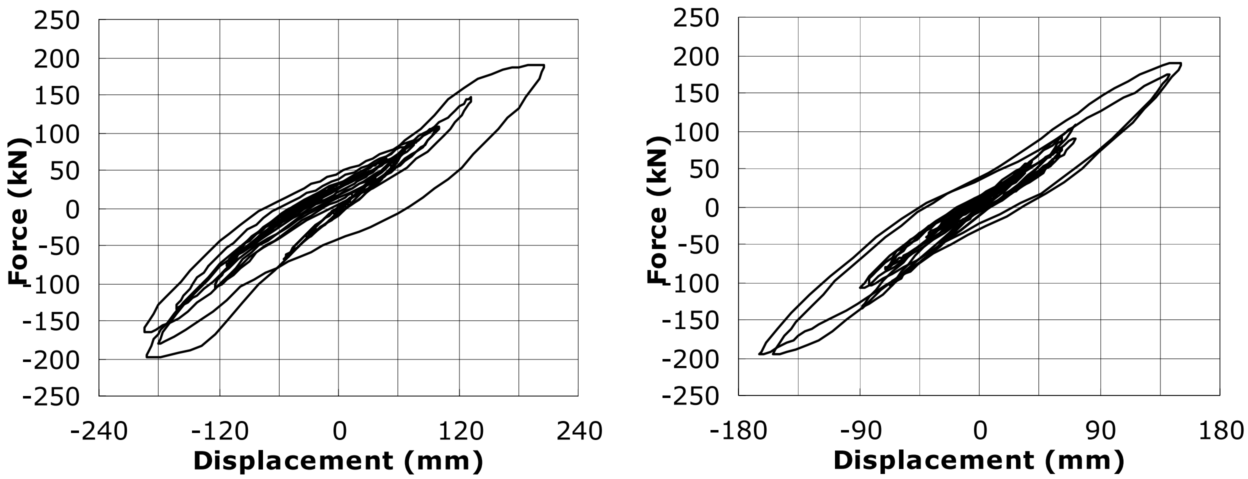
Figure 7: Time histories of the top displacement and energy dissipation of PsD tests on Prototype *B'*.



PGA=0.14g



PGA=0.35g



PGA=0.525g

(a) (b)

Figure 8: Force-displacement cycles of PsD tests on (a) Prototype *A* and (b) Prototype *B'*.

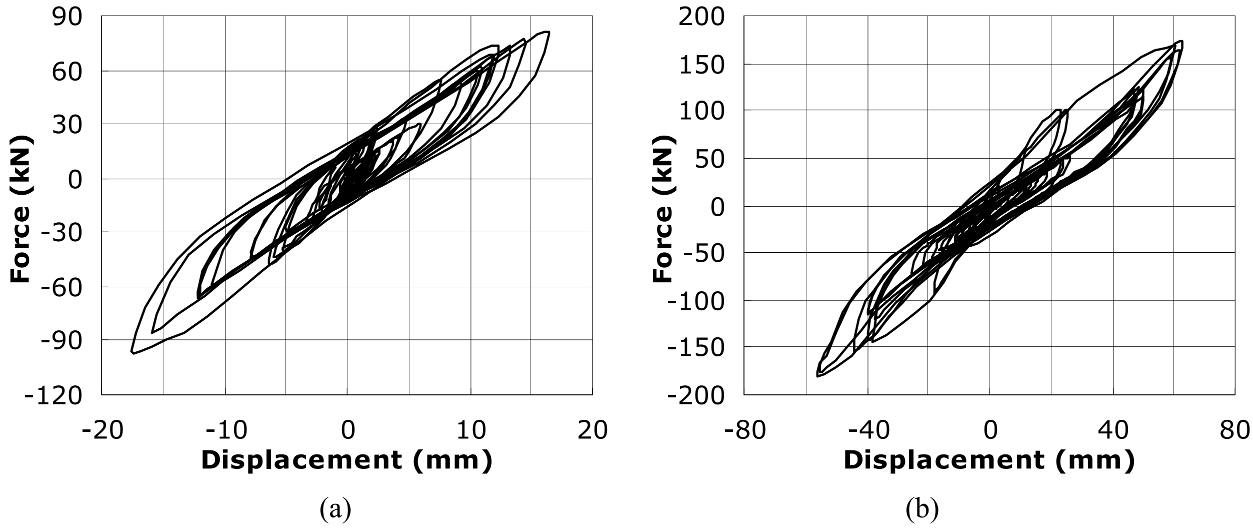


Figure 9: Force-displacement cycles of PsD tests on Prototype *B'* with panels: (a) PGA=0.14g; (b) PGA=0.35g.

4. CYCLIC TESTS

After the pseudodynamic tests the prototypes have been submitted to a cyclic test with imposed displacements of amplitude increasing up to failure. The load history consists of subsequent sets of three cycles of the same amplitude, starting from the estimated threshold of the first yielding $\pm d_y \approx 80$ mm and increasing it step by step by 40 mm. This test gives the intrinsic seismic capacities of the structure in terms of ductility and energy dissipation. In the present case the evaluation refers to the cracked state of the critical sections with little damage as resulting from the previous pseudodynamic tests.

Figure 10 shows the force-displacement diagrams of the cyclic tests carried out on Prototypes *A*, *B*, and *B'*. As already pointed out, the spalling of concrete cover with buckling of the longitudinal bars placed on the same side at the base of the central columns occurred for Prototype *A* for the pseudodynamic test with PGA=0.525g. This was due to the adoption of a stirrup spacing equal 5ϕ in the critical zones at the base of the columns, which was not sufficient to prevent the early rupture of the buckled bars during their reloading in tension. This local damage had a strong consequence also on the global seismic behaviour of the prototype during the subsequent cyclic test. In fact, the results of this test show a different strength decay associated with positive and negative displacements (Figure 10.a).

For Prototype *B'* a stirrup spacing equal 3ϕ was then adopted. This allowed to avoid the early failure of the compressed bars during the pseudodynamic tests and to obtain a subsequent cyclic response more stable and characterised by higher dissipative resources (Figure 10.c).

5. CONCLUSIONS

The seismic performance of precast reinforced concrete structures for industrial buildings has been investigated by means of pseudodynamic tests on full-scale prototypes. Typical arrangements of precast frame structures have been chosen, with hinged beam-to-column and roof-to-beam joints made with steel connectors, following the ordinary technology used in many European countries. Different layouts, with and without cladding panels, have been tested with pseudodynamic and cyclic methods and a relevant amount of data has been obtained. The main results of the experimental investigation have been presented in this paper. These results highlighted the overall good seismic performance of precast structures with roof elements placed side by side, for which an effective horizontal diaphragm action can be activated even if the roof elements are not connected among them.

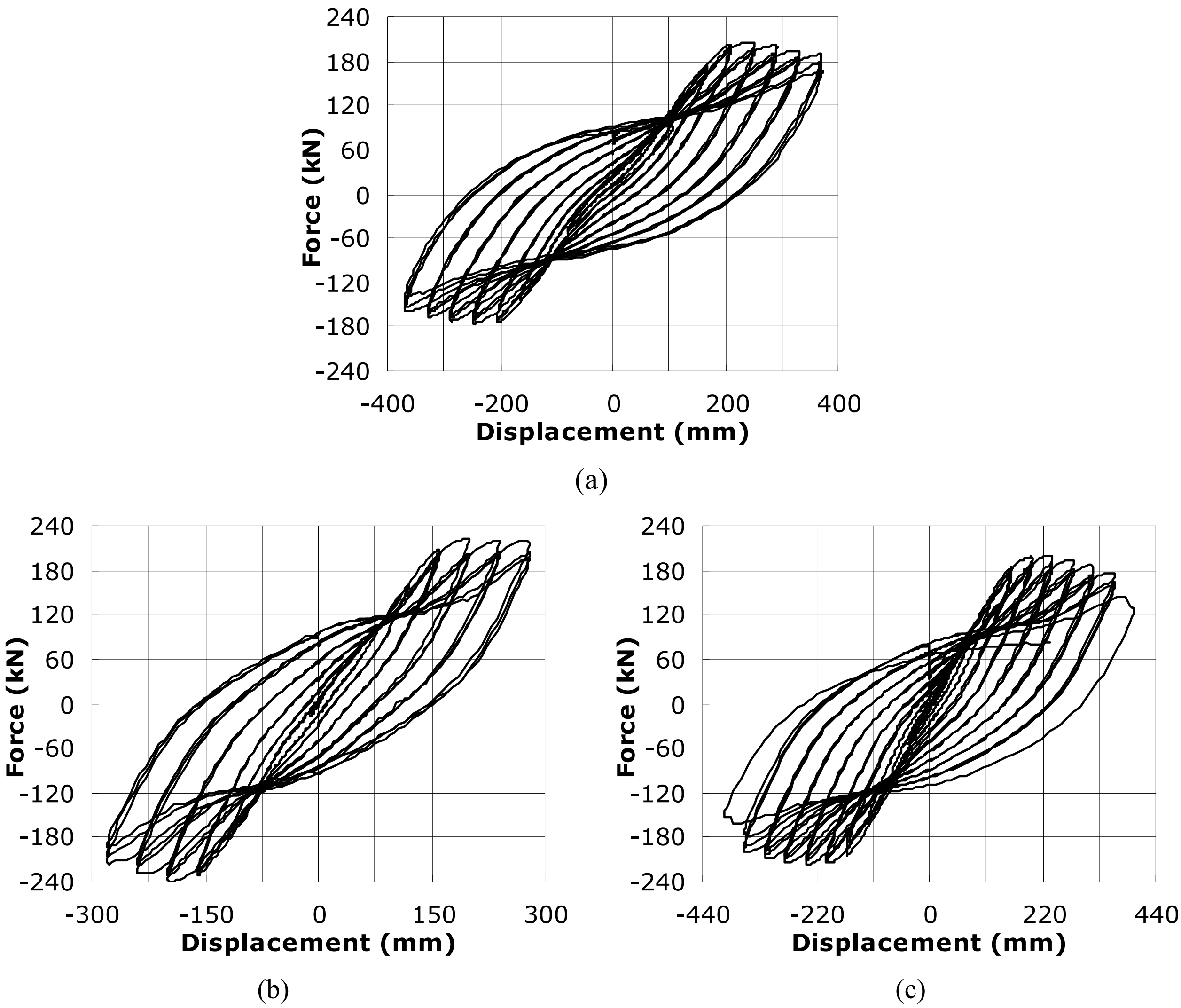


Figure 10: Force-displacement cycles of cyclic tests on (a) Prototype *A*, (b) Prototype *B*, and (c) Prototype *B'*.

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REFERENCES

Biondini F., Toniolo G. Seismic Behaviour of Concrete Frames: Experimental and Analytical Verification of Eurocode 8 Design Rules. *fib Symposium on Concrete Structures in Seismic Regions*, Athens, Greece, May 6-9, 2003.

Biondini F., Ferrara L., Negro P., and Toniolo G., Results of Pseudodynamic Test on a Prototype of Precast R.C. Frame. *International Conference on Advances in Concrete and Structures (ICACS),* Beijing-Xuzhou-Shangai, China, May 25-27, 2004.

Ferrara L., Mola E., Negro P. Cyclic test on a full scale prototype of r/c one storey industrial building, *2nd fib Congress*, Naples, June 5-8, 2006.

Saisi, A., Toniolo, G., Precast r.c. columns under cyclic loading: an experimental program oriented to EC8. Studi e Ricerche, School for Concrete Structures "F.lli Pesenti", Politecnico di Milano, **19**, 373-414, 1998.