Infill Precast Panels as Retrofit System of Reinforced Concrete Frames

L. R. Terec & C. Enyedi
National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development URBAN-INCERC, Cluj-Napoca Branch, Romania

SUMMARY
This paper present an important experimental and theoretic research program, conducted in order to study the strengthening technique of low or moderate damaged reinforced concrete frame structures, one of the existing construction types susceptible to damage. In order to accomplish the actual requirements for earthquake design, this work discusses a retrofit solution that provide minimal disturbance during installation to the function of critical building. The results of non-linear analysis demonstrated the effectiveness of this strengthening method. Using results of analytical study, in the experimental program precast panels were tested, consisting of eight precast elements connected to the beams of reinforced concrete frame with mechanical systems, partial reusable. The principal objective of experimental program was to analyze the behavior under seismic loads of single infill precast panels subjected to vertical constant load and to lateral loads under reversed cyclic loading.

Keywords: Reinforced concrete frame, precast panels, retrofit system, test

1. INTRODUCTION

Reinforced concrete frames built prior the advent of the Romanian seismic design code represent one type of existing construction susceptible to damage. Insufficient lateral resistance along with poor detailing of reinforcement is the main reasons for inadequate seismic performance of these structures. Strengthening of such frames has been accomplished by infilling frames with precast reinforced concrete walls.

The proposed retrofit system consists of a series of precast reinforced concrete panels, which behave as deep beams (Douglas and all, 2004), (Muto and all, 1974), (Kahn and Hanson, 1979), connected to the beams of reinforced concrete frame with mechanical systems, partial reusable.

The connection systems between the infill precast panel and the structure are designed as strong connections, intended to force all inelastic deformations to occur in the adjoining precast elements rather than in the connection. This is arranged by ensuring that the ratio of induced force/available strength is smaller at the connection than elsewhere. The connections are composed into three component parts: an insert in the precast concrete panel; an insert in the beam; the connector body. There is considerable variation in the design of each of the three major components depending upon the type of connecton, bolted or welded. The connections were designed to be removable and reusable. The studies were conducted on two types of systems, one inserted centrical on the beam and the other inserted eccentrical to the beam, on the lateral side of this.

Four full scale models consisting of two beams and the single infill precast panel were tested. During the tests the lateral displacements, the interstory drifts and the stress in the longitudinal reinforcement of the infill panels were determined. The hysteretic behaviour and the crack patterns in the infill presented the great energy disipation capacity of precast panels.

The building selected for study, an existing 11-story reinforced concrete frame, damaged in the 1977 and 1986 Vrancea earthquakes, presents important structural inadequacies regarding the actual seismic design provisions.

In order to increase the lateral stiffness and resistance of the structure (Figure 1), in the retrofit scheme, infill walls were added to the two transverse marginal frames, on the entire height of the structure. The columns adjacent to the walls were assumed to remain un strengthened.

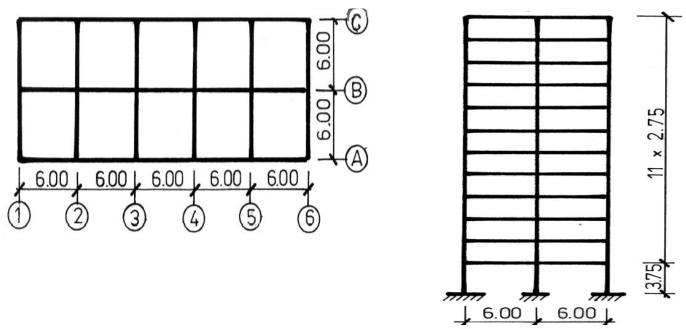
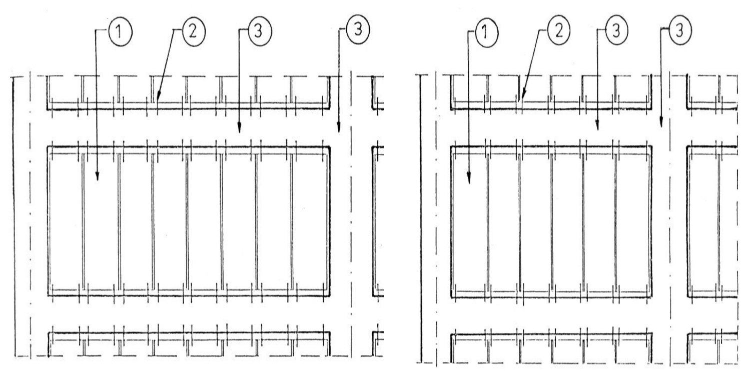


Figure 1. Analyzed substructure

Analysis of a retrofitted building was performed using a finite element program. One transverse frame, strengthened on the entire height of the structure with infill panels consisting of eight, respectively six precast elements (Figure 2), was tested by applying the gravitational loads and the lateral code load. The infill precast panels, the adjacent columns and the beams were modeled as non-linear finite-elements.



a. Retrofit panel of 8 deep beams b. Retrofit panel of 6 deep beams

Figure 2. Retrofit precast panels

The results of the non-linear analysis demonstrated the effectiveness of this strengthening method. On the base of results of analytical study, we considered for the experimental program (Terec, Enyedi and all, 1994) precast panels consisting of eight precast elements connected to the beams of reinforced concrete frame with mechanical systems, partial reusable.

2. EXPERIMENTAL MODELS. OBJECTIVES

Four full scale models consisting of two beams and the single infill precast panel (Figure 3) were tested. During the tests the lateral displacements, the interstory drifts and the stress in the longitudinal reinforcement of the infill panels were determined. The hysteretic behaviour and the crack patterns in the infill presented the great energy disipation capacity of precast panels.

The shape ratio H/B > 3 ensured a very good behavior under shear forces. The thickness of panels was 120 mm. The reinforcement of panels resulted considering the seismic force distributed between the initial columns and the eight panels, proportional with their stiffness. The reinforcement ratio was 0,31%. Stirrups of OB 37 steel at distance of 15d, respectively 27 were provided, conducting to transverse reinforcement ratio of 0,26% respectively 0,14%. The dimensions and reinforcement of initial beams of frames were in conformity with the building project.

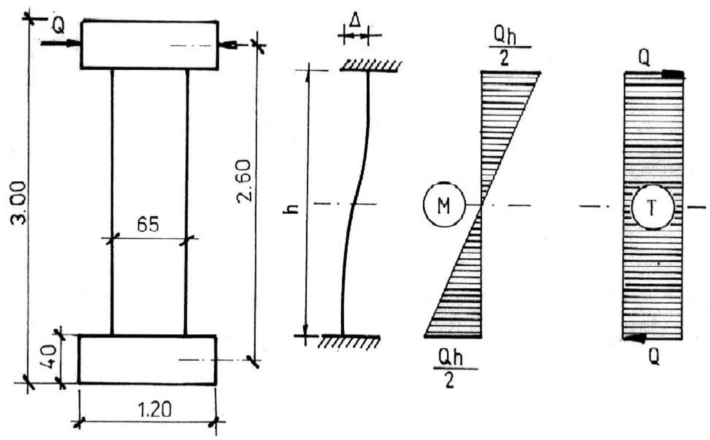


Figure 3. Experimental element

Four full scale models (Inukai and all, 1991), (Katori and all, 1992), (Stanton and all, 2000), consisting of two beams and the single infill precast panel were tested.

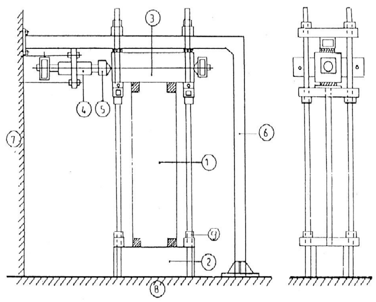
The connection systems between the infill precast panel and the structure are designed as strong connections, intended to force all inelastic deformations to occur in the adjoining precast elements rather than in the connection. This is arranged by ensuring that the ratio of induced force / available strength is smaller at the connection than elsewhere.

The connections are composed into three component parts: an insert in the precast concrete panel; an insert in the beam; the connector body. There is considerable variation in the design of each of the three major components depending of connecton type; welded or bolted. The connections were designed to be removable and reusable. The studies were conducted on two types of systems, one inserted centrical on the beam and the other inserted eccentrical to the beam, on its lateral side.
Two systems of connection were designed, one eccentric system on the lateral side of the beam (PE) and a centric system in the axis of beam (PI).

For each of them we have studied the solution of reusable connection, realized with high resistance screws (bolts) and the solution of un reusable connection, realized by welding. For both, centric and eccentric systems, the inserts in the beam were provided from their realization. The objectives of experimental program were to evaluate the influence of position and type connection on the behavior of models under lateral forces.

3. EXPERIMENTAL PROGRAM

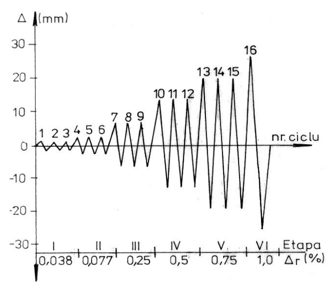
Experimental models were tested under reversed cyclic forces (see Figure 4).



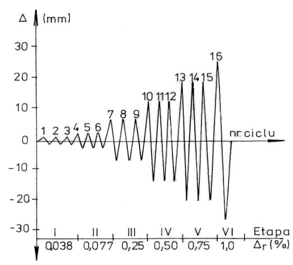
1	Precast panel
2	Bottom beam
3	Top beam
4	Hydraulic jack
5	Strain gauge
6	Rigid Frame
7	Reaction wall
8	Reaction plate
9	Loading equipment

Figure 4. Test set-up

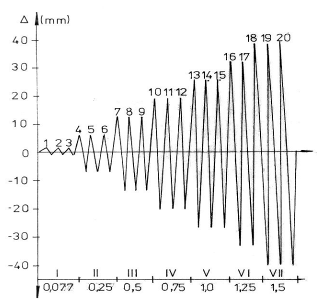
During the tests for each element, the lateral displacements, translations, rotations and stresses in longitudinal reinforcement bars of panels were determined. The test history of each panel, the imposed displacements stages and cycles number for each stage are presented in Figure 5. An instrumentation detail is presented in Figure 13.



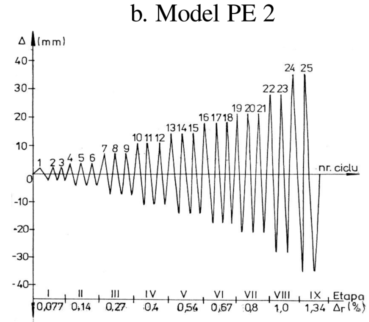
a. Model PE 1



b. Model PE 2



c. Model PI 1



d. Model PI 2

Figure 5. History of tests

4. EXPERIMENTAL RESULTS

The concrete compressive strength was f_c= 27 N/mm^2 in panels and f_c= 32 N/mm^2 in beams. The cracking process started usually at relative displacement of 0,09% in corners (see Figure 6, Figure 7, Figure 9 and Figure 10). After that, the normal cracks appeared, with opening up to 0,2 mm, under yielding loads. At displacement $\Delta=\Delta_y$ (Δ_y = displacement corresponding to yielding of tensioned reinforcement bars), the openings of cracks in the corners reached 0,6 – 1,1 mm.

For model PE1, with transverse reinforcement ratio of 0,14%, most of the cracks were shear cracks and the initial normal cracks changed their direction at displacement $\Delta=\Delta_y$ and became shear cracks.

Under displacements $\Delta=2\Delta_c$, the corner cracks in panels reached openings of 2,5 – 3 mm. The model PI 2 was an exception, because of the influence of a crack occurred by installing of model in test-up. At models with stirrups disposed at 180 mm (PE 2, PI 1, PI 2), the normal cracks appeared also until displacements $\Delta=3\Delta_y$. At displacements $\Delta=3\Delta_y$, cracks in corner zones reached openings of 3-4 mm and developed on the entire thickness of panels PE 1, PE 2 and PI 1. In stage $\Delta=4\Delta_y$, normal cracks remain constant or closed, but new shear cracks developed. Before failure, the corner cracks developed very much, while the other cracks reduced their openings or closed.

Regarding the yielding, the P-Δ diagrams determined on OB 37 steel, used as reinforcement op panels did not evidenced a good yielding segment. Therefore, yielding stress was considered R_{eH}=283,5 N/mm^2. Yielding deformation was attaint at displacement of 6,5 mm. Because of a crack occurred at installing, model PI2 was an exception and yielding deformation was attaint at displacement of 3,5 mm.

Regarding hysteretic behavior and failure mode, the P-Δ diagrams (see Figure 8 and Figure 11) and the development of cracking process proved in the first stages a behavior under bending moment. Once the cracks developed, the pinching proved the slips under shear forces.

It is to note the very good behavior of models PI with centric connection, where the forces were transmitted more directly. Also under great values of displacements, close to maximum values, the shear forces remain constant.

The failure occurred through crushing of concrete in compressed zone, respectively through reinforcement buckling and yielding in the tensioned zone (see Figure 12, Figure 13 and Figure 15).

The analysis of test results evidenced the followings:

- the decrease of transverse reinforcement ratio in panels did not significantly influenced the behavior of panels under lateral loads;

- under reversed loads, the panels presented great capacity of energy dissipation and post-elastic deformations;

- both types of connection systems, inserted centrical, respectively eccentrical to the beam, on the lateral side of this, ensured the good transmission of gravitational and seismic forces to the structure and behaved in the elastic range of the connectors;

- no relative displacements between the elements of connection systems were evidenced.

For frames structures with infill walls, failure of infill can produce a severe shear loading for the columns. Such shear deterioration of existing columns may be a problem for strengthened structures with infill walls. The increase in strength and stiffness does not necessarily result an increased seismic resistance of the entire structure. In particular, we must note the lack of ductility of some existing columns.

In order to avoid a premature failure of the frame elements, the columns / beams must be strengthened by jacketing in several manners before the strengthening of the entire structure.

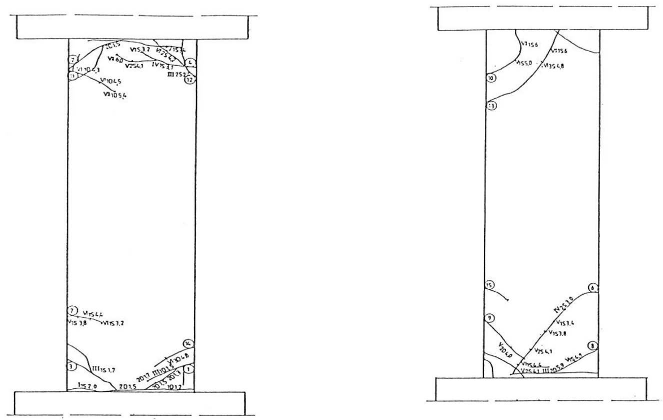


Figure 6. Model PE 1. Cracks pattern

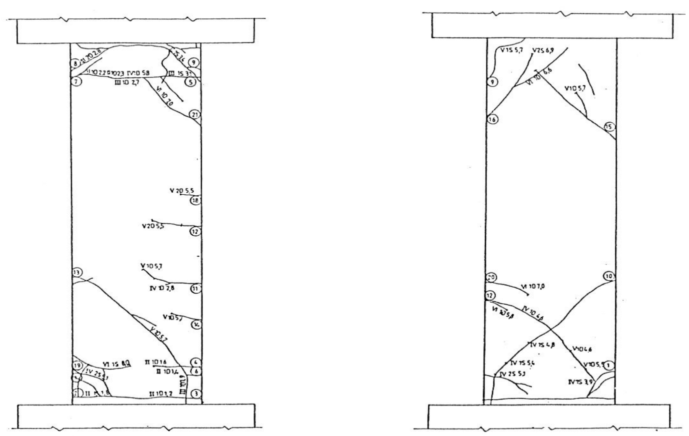
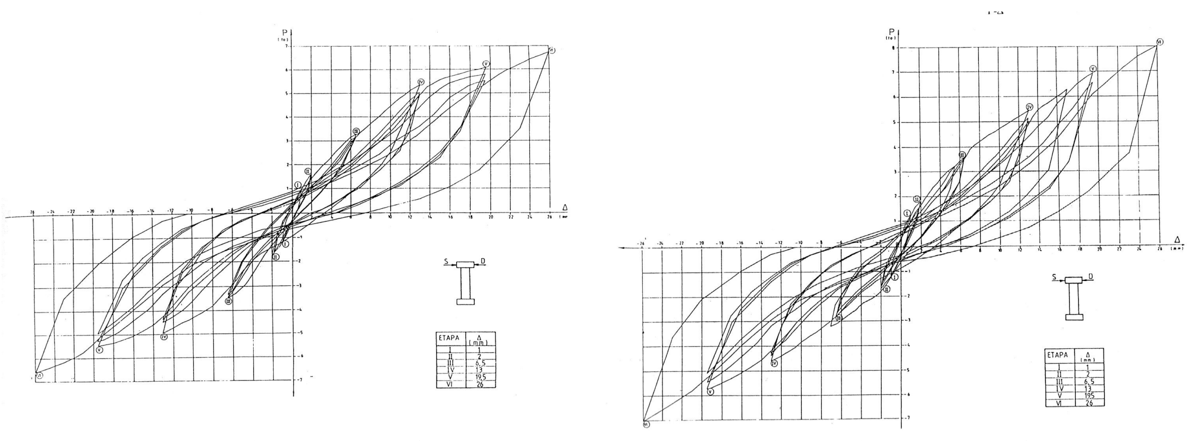


Figure 7. Model PE 2. Cracks pattern



a) Model PE 1 (eccentrical) b) Model PE 2 (eccentrical)

Figure 8. Hysteresis loops

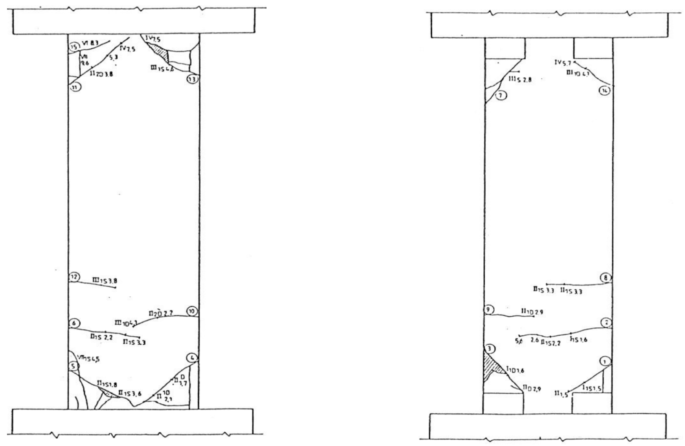


Figure 9. Model PI 1. Cracks pattern

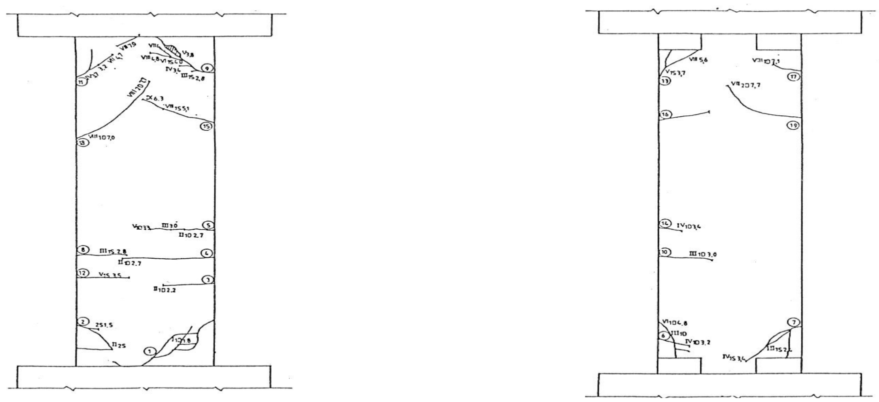
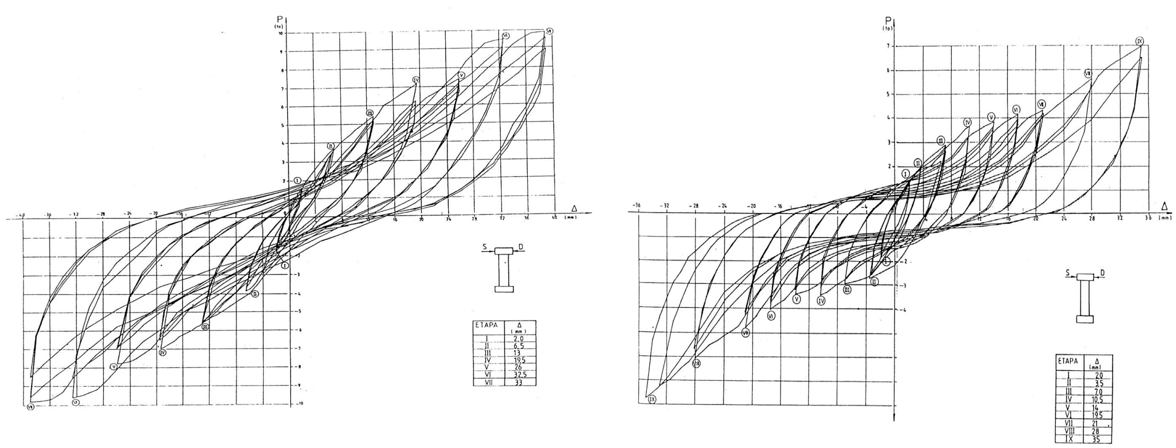


Figure 10. Model PI 2. Cracks pattern



a) Model PI 1 (centrical) b) Model PI 2 (centrical)

Figure 11. Hysteresis loops

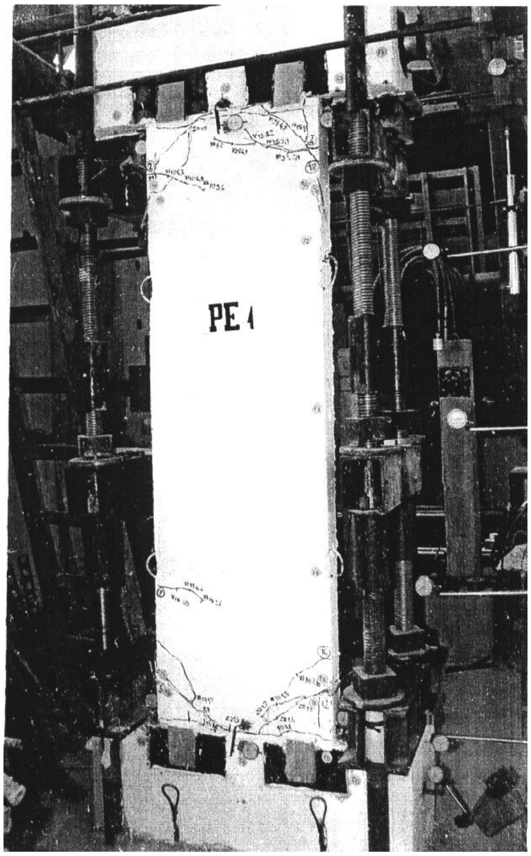


Figure 12. Model PE 1 after failure

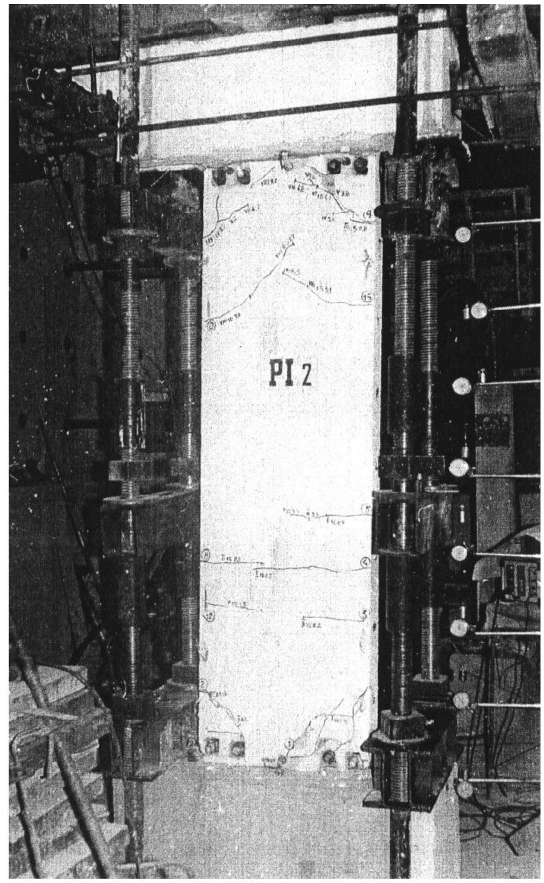


Figure 13. Model PI 2 after failure

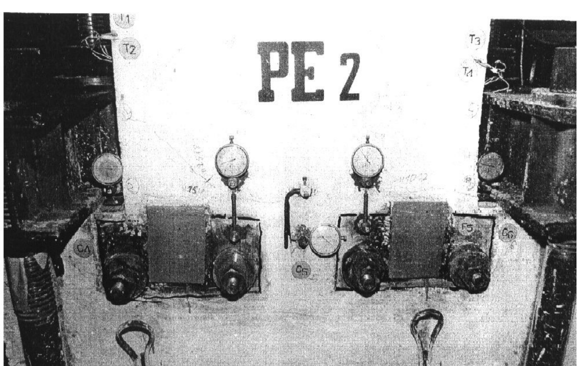


Figure 14. Instrumentation detail of model PE 2

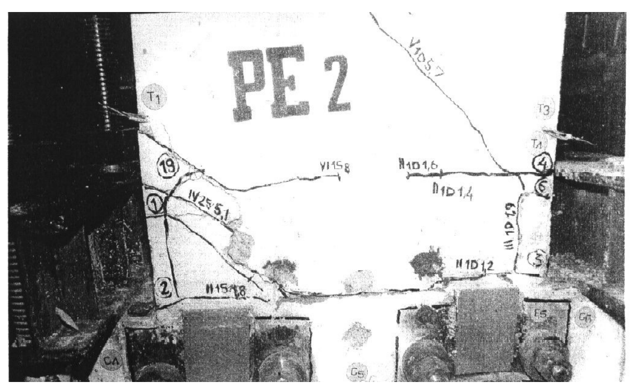


Figure 15. Detail after failure of model PE 2

5. CONCLUSIONS

This paper discusses a retrofit solution of concrete frames for accomplishing the actual requirements for earthquake design. The proposed solution was precast panels, consisting of eight precast elements, that behave as deep beams, connected to the beams of reinforced concrete frame with mechanical systems, partial reusable. In order to evaluate the behavior under seismic loads of single infill precast panels were tested.

The decrease of transverse reinforcement ratio in panels did not significantly influenced the behavior of panels under lateral loads. Under reversed loads, the panels presented great capacity of energy dissipation and postelastic deformations. Both types of connection systems, inserted centrical, respectively eccentrical to the beam, on the lateral side of this ensured good transmission of gravitational and seismic forces to the structure and behaved in the elastic range of the connectors for all types of infill walls studied. No relative displacements between the elements of connection systems were evidenced. It is to evidence the very good behavior of models PI with centric connection, where the forces were transmitted more directly.

REFERENCES

Douglas, K., Billington, S.L. and Kesner, K.E. (2004). Simplified modeling techniques for a proposed retrofit system using high-performance fiber-reinforced cementitious composites. *Proceedings 13th World Conference on Earthquake Engineering, Vancouver, Paper nr. 1712.*

Inukai, M., Kaminosono, T., Nakata, S., Miura, Y. and Yasuda, Y. (1992). Experimental study on seismic performances of precast reinforced – concrete shear walls. *Proceedings 10 WCEE, Madrid, 9: 5699-5702.*

Kahn, L.F. and Hanson, R.D. (1979). Infilled walls for earthquake strengthening, *Journal of the Structural Division, 105 (2): 283-297.*

Kahn, L.F. (2008). ACI Code Requirements for Repair of Buildings, *Concrete International*, Vol. 30, No.4: 51-54.

Katori, K., Hayashi, S., Ohta, M., Yoshida, H. and Higashibata, Y. (1992). Experimental studies on shear behavior of shear-wall used precast concrete. *Proceedings 10 WCEE, Madrid, 9: 3257-3262.*

Muto, K., Ohmori, N. and Takahashi, T. (1974). A study of reinforced concrete slitted shear walls for high-rise buildings. *Proceedings 5 WCEE, Rome: 1135-1138.*

Stanton, J.F., Collins, R. I., Galusha, J., Sugata, M. and Nakaki, S.D. (2000). A five story precast concrete test building for seismic conditions design details. *Proceedings 12th World Conference on Earthquake Engineering, Austin, New Zeeland, Paper nr. 1387.*

Terec, L., Enyedi, C., Pop, I. and Bia, C. (1994). Absorband panels of energy at frame structures in seismic zones. *Proceedings of the Second International Conference of Earthquake Resistant Construction and Design, Berlin*, 15 – 17 June 1994, A.A. Balkema Publishers, Rotterdam.

Terec, L. (1998). Ph. D. Thesis, Seismic protection through passive systems placed in the structure, Technical University of Cluj, Civil Engineering Faculty.

Terec, L. (2009). Reinforced concrete retrofit walls for frame structures, Napoca Star Publisher, Cluj-Napoca, Romania.