Analytical Investigations of Beam-Column Connections in Precast Buildings under Seismic Loads

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SUMMARY:
The critical point which defines behavior of precast buildings under cyclic loading is connections. The experience gathered from the past earthquakes together with existing analytical and experimental investigations are not sufficient enough to explain their seismic behavior. Therefore, experimental investigations of existing beam-column dowel connections were carried out by Slovenian researchers at the University of Ljubljana, (Fischinger at al, 2011). In parallel, analytical investigations of nonlinear behavior of the above beam-column connections under earthquake loading were realized at UKIM-IZIIS, Skopje (Apostolska, Necevska-Cvetanovska at al, 2011). Based on the above investigations, the numerical model for connection behavior is proposed. Presented in the paper are selected results from experimental and analytical research of the obtained response parameters for different types of beam-column connections under seismic action.

Keywords: precast, beam-column connections, dowel, cyclic loading

1. INTRODUCTION

The seismic safety of precast structural systems represents a subject for investigation which is very much of a current interest worldwide. There are two main reasons for the unfavorable behaviour of precast systems: (1) in many structures, some of the structural elements are designed as seismically resistant, whereat the remaining ones sustain only gravitational loads. In such cases, it is of vital importance that the latter elements keep their capacity for sustaining vertical loads also in conditions of being exposed to deformations under seismic effect; (2) inappropriate floor structures that don't have the capacity to transfer inertial forces to the seismically resistant vertical elements.

Predominant type of the precast (industrial) building in Europe consists of columns tied together with beams. Among many types of different connections between precast elements, the connection using steel dowel is most common. The existing analytical and experimental investigations as well as the experience gathered from the occurred earthquakes are not sufficient enough for throwing light on their seismic behaviour. This can partially be explained by the fact that modeling of the mechanisms of seismic response of connections (i.e. dowel action at large relative rotations, gap opening and closing, shear-flexure interaction) are complex and very difficult to model. In practice, connections are predominantly designed by engineering feeling and numerical verification are seldom done. There is an urgent need first to verify the existing practice and then to improve and optimize detailing and technological solution for the typical connections in the precast buildings.

In Macedonia, according to the Rulebook on Technical Norms for Construction of High Rises in Seismic Areas (PIOVS-81), the stability of the structural system of precast structures should be verified (proved) experimentally and analytically and the connections of the precast elements should enable a monolith system. This means that additional investigations are necessary to verify the seismic performance of the connections and the entire system and to generalize the obtained results in design rules and procedures.

The above stated was motivation for initiation of bilateral project between Institute of Earthquake Engineering and Engineering Seismology, IZIIS, Skopje and University of Ljubljana in the area of seismic performance of precast industrial buildings. The Slovenian partner performed experimental investigations of connections (*the research leading to these results has received funding from the European Community's 7^{th} Framework Programme under grant agreement n^{o} 218417 (SAFECAST project)*) and at Macedonian side, numerical modeling of behaviour of connections were done.

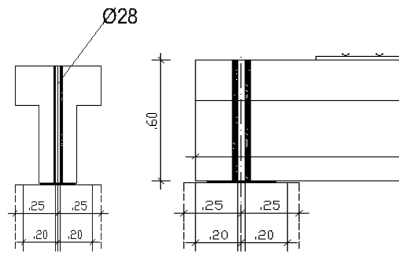
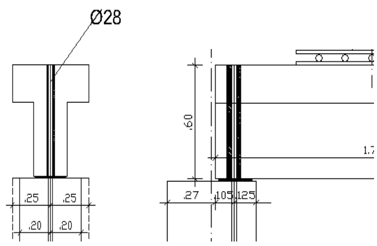
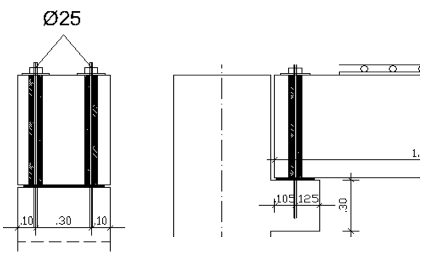
In the paper briefly are addresses experimental investigations of existing beam-column dowel connections carried out by Slovenian researchers at the University of Ljubljana, (Fischinger at al, 2011), as well as analytical investigations of nonlinear behavior of the above beam-column connections in plane frame models under cyclic loading, realized at UKIM-IZIIS, Skopje (Apostolska, Necevska-Cvetanovska at al, 2011).

2. EXPERIMENTAL INVESTIGATIONS OF EXISTING BEAM-COLUMN DOWEL CONNECTIONS

The quantified knowledge of the inelastic response of the beam-column connections in precast structures to earthquakes is very poor. This is partly due to the fact that the predominant mechanisms of the seismic response of the connections are complex and very difficult to model.

The objective of the research carried out at University of Ljubljana was full-scale experimental investigations of the complex nonlinear behavior of beam-column connections at small and large relative rotation between columns and beams, (Fischinger at al, 2010). The following existing beam-to-column connections have been tested, (table 2.1):

Table 2.1 Type of the existing beam-column connections

Type of the existing connection	Scheme
(1) **A pinned connection with a single centric dowel** Consequently, the dowel was surrounded by a thick layer of concrete from all sides. Such connections are usually employed at the roof level on the edge of a structure (for columns that are supporting only one beam)	
(2) **A pinned connection with a single eccentric dowel** Eccentric position of the dowel is exposing a beam to a greater risk of fracture. Such connections are usually employed at the roof level in the middle of the structure (for columns that are supporting two beams simultaneously)	
(3) **An intermediate story connection with two eccentric dowels** This connection comprises of a column corbel in which two vertical dowels are anchored. Usually, the corbel is made on each side of the column, allowing the column to support two beams on opposite sides. Here, an isolated connection between a single column corbel and the beam was tested.	

The columns and the beams were constructed of high strength self-compacting concrete C45/55, and the reinforcing steel S500 B. The horizontal connection between the beam and the column at the first two types of connections were established by means of the vertical steel dowels of diameter ϕ28 mm and at the third type of connections with two steel dowels with diameter ϕ25 mm.

In order to obtain different rotations at the top of the columns, as well as different relative beam-column rotation, two main types of columns were designed: (1) **strong columns** – should remain elastic during the experiment. The tests should provide the capacity of the connection at small rotations; (2) **weak columns** – should permit large relative rotation between beam and column and allow formation of plastic hinges at the column base prior to the failure of the connection.

All the specimens were designed and constructed at the Slovenian construction company Primorje. The experiments were performed at the Slovenian National Building and Civil Engineering Institute (ZAG). In total, 13 experiments of the existing beam-column connections have been performed and the test programme is given in table 2.2.

Table 2.2 Test programme for three types of existing beam-column connections

Position	Beam type	Column type	Column – cross-section	Column – long. reinforcement	Test type	Label
Top Centric	T-beam	strong	50x50cm	16ϕ22	push-pull	S1-1
					cyclic	S1-2
		weak	40x40cm	8ϕ16	cyclic	S2
				8ϕ14	push-pull	S3-1
					cyclic	S3-2
				8ϕ12	cyclic	S4
				8ϕ20	cyclic	S5-1
				4ϕ18 + 4ϕ20	cyclic	S5-2
Top Eccentric	T-beam	strong	50x50cm	14ϕ22	push-pull	S6-1
					cyclic	S6-2
Inter-mediate story	omega beam	strong	50x50cm	14ϕ22	cyclic	S7-1
						S7-2
		weak	40x50cm	6ϕ18 + 2ϕ14	cyclic	S8

The selected test results in the form of relation between force (Fh) and relative displacement of the connection (Li) are given in figure 2.1

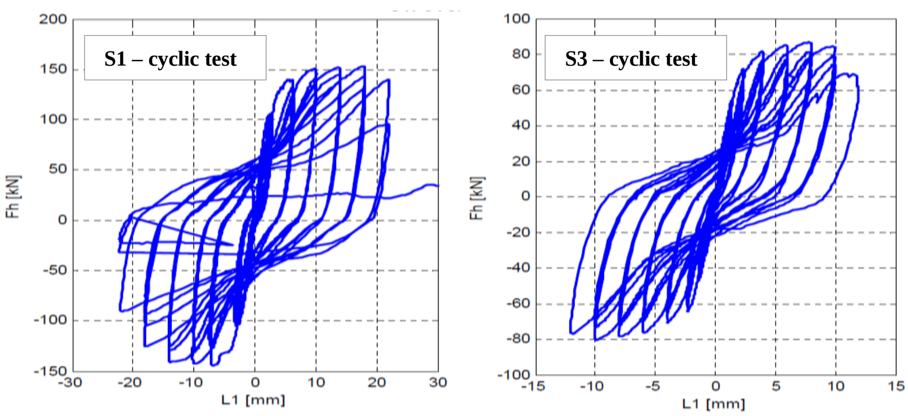


Figure 2.1 Cyclic tests of the specimens

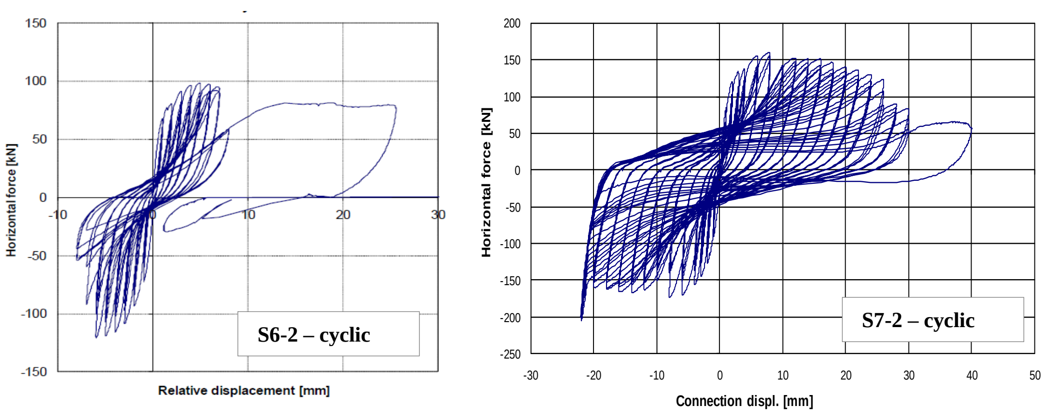


Figure 2.1 Cyclic tests of the specimens (*cont.*)

3. ANALYTICAL INVESTIGATIONS OF NONLINEAR BEHAVIOUR OF THE EXISTING BEAM-COLUMN DOWEL CONNECTIONS

The analytical investigations regarding strength and deformability capacity of beam-column connections in precast buildings is very limited. From the literature, the well know is analytical expression for calculation of strength of dowel connections under monotonic and cyclic loadings, (Vintzeleou and Tassios, 1987). The results from performed experimental investigations at the University of Ljubljana show that this analytical expressions underestimate strength of the first type of connection (singe centric dowel) and overestimate the capacity of the second and third type of connections, (as they are defined in table 2.1).

In order to contribute to the knowledge of nonlinear behavior of beam-column dowel connections, analytical investigations of 2D precast frame under earthquake loading were carried out, (Apostolska, Necevska-Cvetanovska at al, 2011). The investigations are carried out in two phases:

Phase 1: Numerical modeling of the existing beam-column dowel connections and their nonlinear behavior using widely known commercial software package (SAP2000). As a results the design engineers could be provide by simple and efficient tool for practical assessment of seismic response of the connections. Difference in the strength and deformability capacity of the experimentally tested connections are investigated also. Nonlinearity is concentrated in the connections, only.

Phase 2: Extension of the analytical investigations to capture the complex seismic behavior of beam-column connections in the case of large relative rotation between column and beam. Further calibration of model with results from state-of-the art experimental and analytical investigations, especially in the area of large deformation (significant nonlinearity).

Presented further in the paper are selected results from the first phase of analytical investigations.

3.1. Description of the model frame and selected hysteretic model

The plane frame model represents a single story, one bay RC frame. The columns have a square cross-sections with dimensions 50/50cm and are designed with concrete class C45/55. The beam is designed with T-shape with 60 cm high and 22/50cm wide. The column height is 4.0m and the span of the beam is 8.0m. The modeling and analysis of the plane frame has been performed using the finite element method and **SAP2000v14** (*Structural Analysis Program - Wilson and Habibullah, CSI, Berkley University, California*). The mathematical model of the 2D frame is presented in figure 3.1.

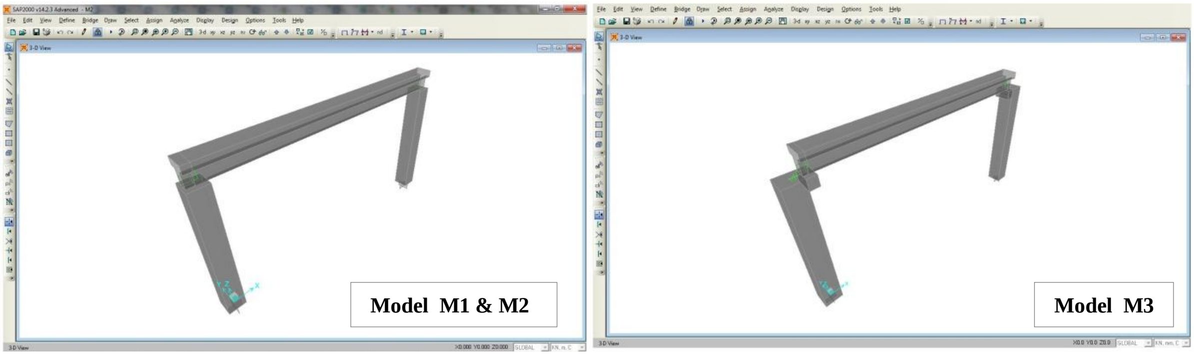


Figure 3.1 2D mathematical model of the RC frame

In presented analytical investigations the concept of strong columns is considered which means that the columns remain elastic and the nonlinearity is concentrated in the beam-column connections. For modeling beam-column connection a **Link element** from the SAP computer program elements library is used, (CSI Analysis Reference Manual for SAP2000, ETABS and SAFE). A Link element is a two-joint connecting link. Each element is assumed to be composed of six separate “springs,” one for each of six deformational degrees-of freedom (axial, shear, torsion, and pure bending). Among the types of nonlinear behavior that can be modeled with this element is Multi-linear uniaxial plasticity with several types of hysteretic behavior: kinematic, Takeda, and pivot.

In order to model nonlinear behavior of connection multi-linear pivot hysteretic plasticity property model is used, (SAP 2000 reference manual). This model is similar to the Multi-Linear Takeda model, but has additional parameters to control the degrading hysteretic loop. It is particularly well suited for reinforced concrete members, and is based on the observation that unloading and reverse loading tend to be directed toward specific points, called pivots points, in the force - deformation (or moment-rotation) plane, (fig. 3.2). The effects of unsymmetric section, cyclic axial load associated with frame action and strength degradation are included. The amount of strength degradation is controlled through α_1 and α_2 parameters and pinching of the hysteretic loop is controlled by β_1 and β_2 parameters. The primary advantage of this hysteretic model is its ability to capture the dominant nonlinear characteristics of very complicated RC members response with three simple rules. It give good results as judged by comparisons to experimentally measured results and results from the more rational fiber model.This model is fully described in Dowell, Seible, and Wilson (1998).

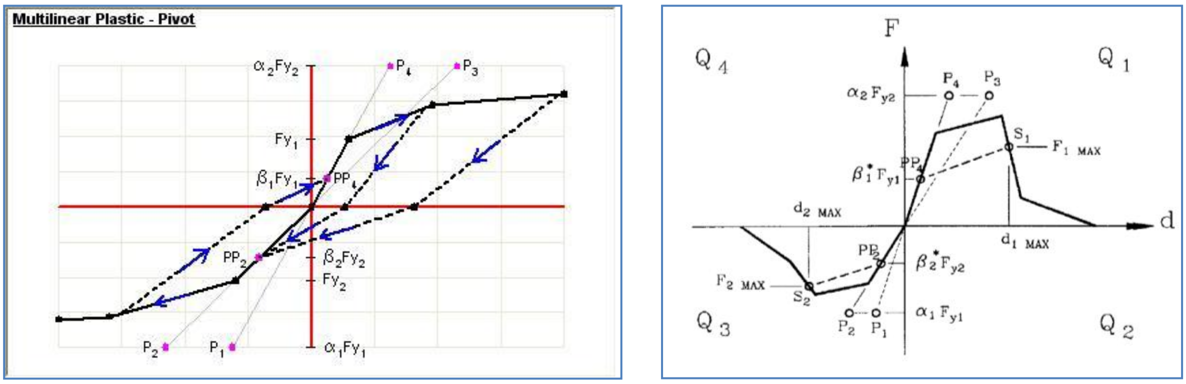


Fig.3.2 Multi-linear Takeda Plasticity Property Type for Uniaxial Deformation and pivot point designations

3.2. Nonlinear behavior of dowel beam-column connections

The analytical investigations are performed on defined mathematical model of RC frame and included three different type of above defined beam-column dowel connections, as follow:

- Model M1 – with a pinned beam-column connection with a single centric dowel
- Model M2 – with a pinned beam-column connection with a single eccentric dowel
- Model M3 – intermediate story connections with two eccentric dowels

Analysis is carried out using *El Centro N-S, USA, 1940* earthquake records scaled to two different levels of peak ground acceleration: (1) PGA=0.15g – to simulate behavior near to linear elastic and (2) PGA =0.30g – to simulate nonlinear behavior.

The results obtained from the analysis for all three models defined above are presented in the form of:

- force - relative displacement of the connections
- force - top displacement of the columns
- response-histories of displacements in the connections and columns
- response-histories of forces in the connections and columns
- response-histories of the moment at the base of the columns
- total dissipated energy during the loading history

3.2.1. Results from the analysis for the model M1

The selected results from the nonlinear time history analysis for the connection with single centric dowel, (Model M1) are presented in figures 3.3 and 3.4.

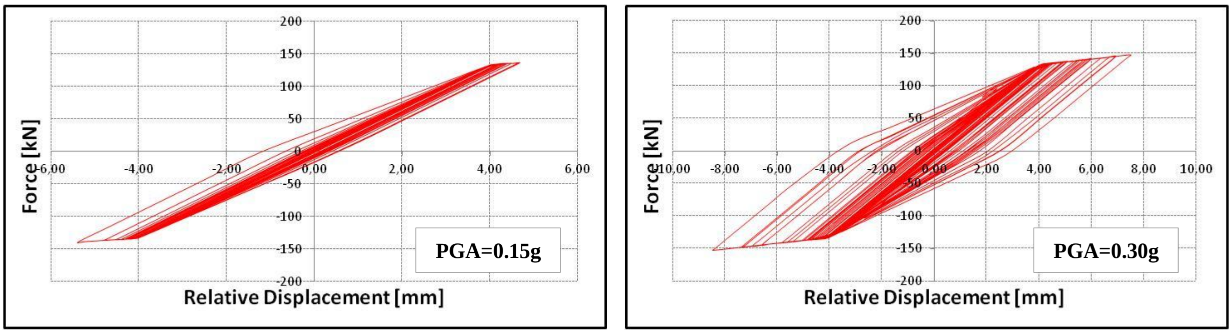


Fig.3.3 Force -displacement relationship in the connection with one single centric dowel

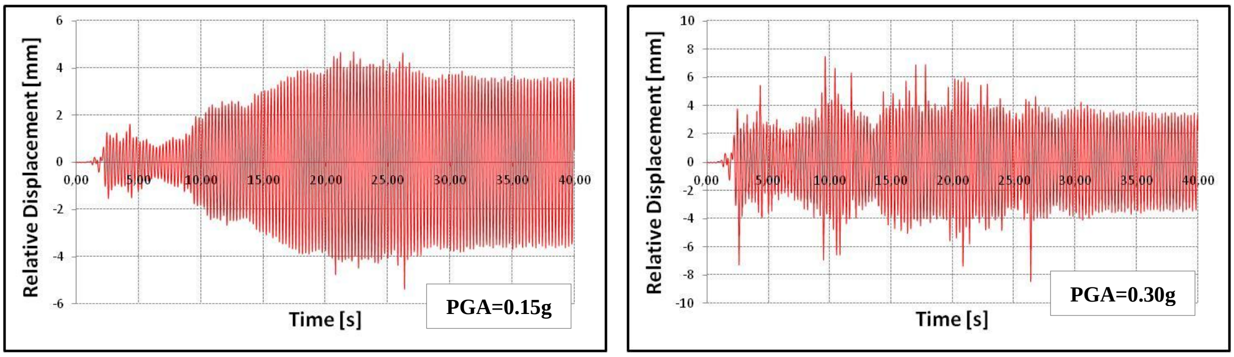


Fig.3.4 Time history of relative displacement in the connection with one single centric dowel

3.2.2. Results from the analysis for the model M2

The selected results from the nonlinear time history analysis for the connection with single eccentric dowel, (model M2) are presented in figures 3.5 and 3.6.

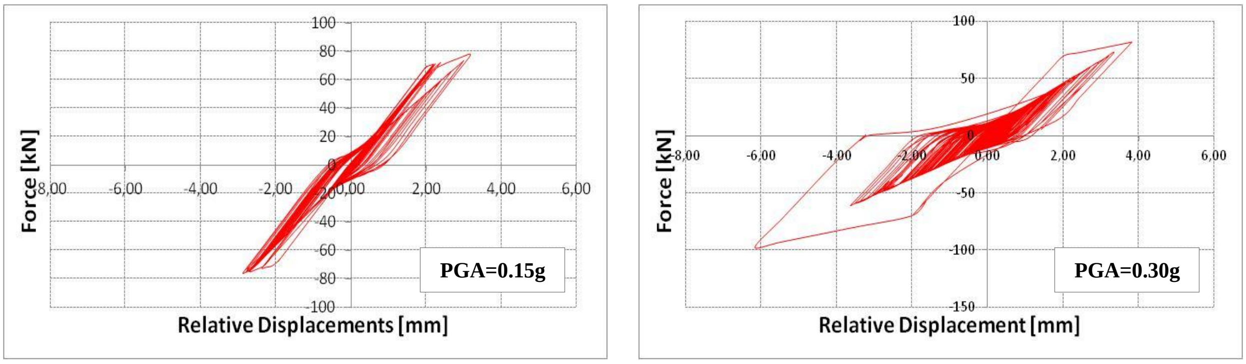


Fig.3.5 Force -displacement relationship in the connection with one single eccentric dowel

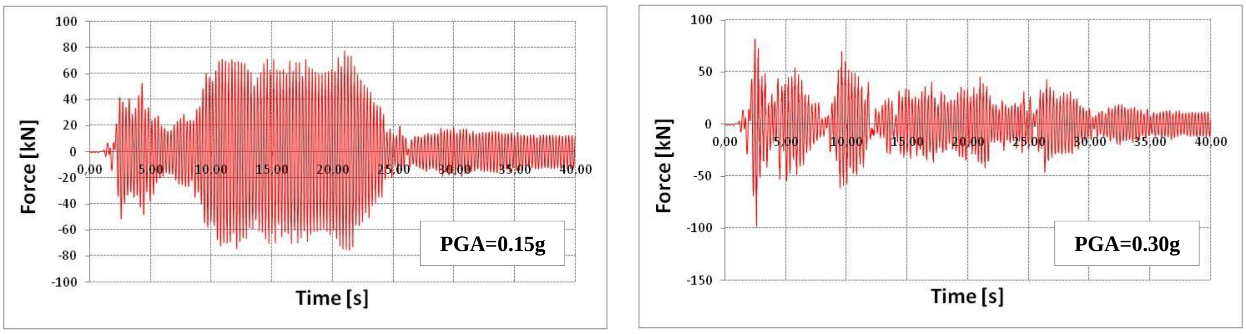


Fig.3.6 Time history of force in the connection with one single eccentric dowel

3.2.3. Results from the analysis for the model M3

The selected results from the nonlinear time history analysis for the connection with two eccentric dowels, (model M3) are given in figures 3.7 and 3.8.

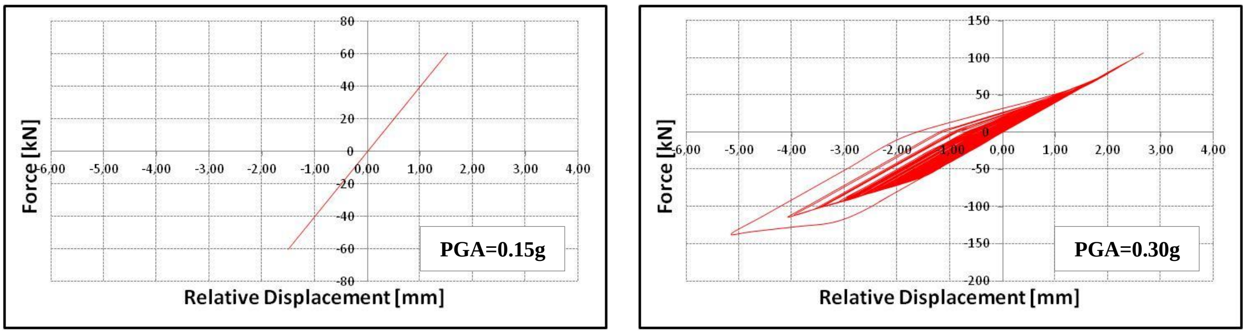


Fig.3.7 Force -displacement relationship in the connection with two eccentric dowels

4. CONCLUSIONS

Selected results from experimental and analytical investigations of existing beam-column dowel connections are addressed in the paper. The results from performed experimental investigations at the University of Ljubljana show that the analytical expressions for calculation of strength of dowel connection connections under monotonic and cyclic loadings, (Vintzeleou and Tassios, 1987), underestimate strength of the singe centric dowel connection and overestimate the capacity of the connections with one eccentric and two centric dowels.

In order to provide the design engineers with simple and efficient tool for modelling of seismic behaviour of connections, multi-linear pivot hysteresis numerical model incorporate in the widely used commercial software SAP2000 is proposed. The results from the analytical investigations carried out at UKIM-IZIIS show that this model can capture nonlinear behaviour of traditional dowel connections assuming small relative beam to column rotations.

Further investigation anticipated in the phase II are planned to include the effect of large column rotation and effects on different (near-field and far field) earthquakes on nonlinear behaviour of connections in precast building structures.

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REFERENCES

Fischinger M., Isakovic T., and Kramar M. (2011). SAFECAST Project "Performance of Innovative Mechanical Connections in Precast Builidng Structures under Seismic Conditions", (grant agreement no. 218417), FP7, European Commission, *Deliverable 2.1:Experimental behavior of existing connections*, January, 2011.

Apostolska R., Necevska-Cvetanovska G. (2011). "Seismic safety of precast industrial buildings", Joint research project between Republic of Macedonia and Republic of Slovenia, Ministry of Education and Science of Republic of Macedonia, 2010-2011.

Fischinger M., Kramar M. and Isakovic T. (2010). Seismic behavior of dowel beam-column connections in precast industrial buildings. *Proceedings of the COST C26 Final Conference, Naples, September, 2010.*

Vintezeleou E.N. and Tassios T.P. (1987). Behaviour of dowels under cyclic deformations. *ACI Structural Journal 84:1,18-30.*

Dowell R., Seible F., and Wilson E. (1998). Pivot hysteresis model for reinforced concrete members. *ACI Structural Journal 95:5,607-616.*

Necevska-Cvetanovska G. (1995). Evaluation of seismic resistance of existing RC low and medium-rise buildings", *Journal of Macedonian Assosciation of Structural Engineers-MASE*, Vol. 1, No. 1, 01/1995.

Cvetanovska-Necevska G. and Petrusevska (Apostolska), R. (1996), "Non Linear Analysis of RC Structures using Computer Program INELA with Included Bank of Hysteretic Models", *Proc. of the Third European Conference on Structural Dynamics, EURODYN '96, Florence, Italy, 1996.*