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NEW SEISMO-SAFE SYSTEM OF PREFABRICATED INDUSTRIAL HALLS WITH TEST-PROVED MODELS OF CRITICAL CONNECTIONS

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Abstract. *Heavy damages and total collapses of prefabricated industrial halls was observed in past earthquakes widely in the world. Regarding the present need, conducted was specific large-scale research project leaded by the first author, "Development of optimal prefabricated system of industrial halls applicable in seismic zones with higher intensity, including seismic intensity IX", supported by well-known Serbian PUT INZENEERING construction company. Based on conducted intensive testing in Skopje RESIN laboratory of constructed large-scale prototype models of critical connections, the advanced novel seismically resistant (NSR) prefabricated system of industrial halls has been successfully developed. Improved seismic safety of the system was achieved by combined application of new concepts of critical connections along with added new integrating segments of the global structural units.*

Keywords: *Industrial hall; prefabricated structure; nonlinear response; seismic safety; critical connections.*

1. INTRODUCTION

Industrial facilities representing large industrial halls are, in recent years, rapidly constructed in the region of South East Europe (SEE) and wider, applying various precast RC systems. High seismic risk of precast industrial halls, including heavy damages and total collapses, was commonly observed in past earthquakes widely in the world, [2-4], [6], [8-11]. It clearly points out the urgent need to seriously treat this problem in regard of providing essential structural safety, sustainable economic and social development and general seismic security in seismically active regions. The created specific seismic risk of this type has not been well quantified to this date and sound seismic risk mitigation concepts are not available. Considering the above stated, led by the first author, conducted was extensive experimental and theoretical research in the frame of initiated large-scale research project "Development of optimal prefabricated system of industrial halls applicable in seismic zones with higher intensity, including seismic intensity IX", supported by known Serbian PUT INZENJERING construction company, [13-18]. The advanced novel seismically resistant (NSR) prefabricated system of industrial halls has been successfully developed based on combined intensive testing of constructed large-scale prototype models of critical connections in Skopje RESIN laboratory and conducted specific nonlinear seismic behavior studies of integral structures, [1], [7], [12]. The proposed seismically resistant prefabricated system of industrial halls was developed through application of advanced concepts for detailing of critical connections and incorporated steel truss segments as integrating systems of the global structural units, [19], [20]. Beside obtained original experimental results from conducted experimental tests, in the paper are also presented some fundamental innovative end-products which are highly important for the creation of the presently proposed novel seismically resistant (NSR) prefabricated system of industrial halls, including: (D1) Basic design concept of structurally sound connection of precast RC column with precast RC footing and representative experimentaly proved nonlinear behaviour model; (D2) Experimentally proved design concept of solid prefabricated joint between RC column and RC corbel (short cantilever) and corbel's safety margins; (D3) Experimentally proved design concept and nonlinear behavior modeling approach of both, original and improved original connection between precast longitudinal RC beam and RC column; (D4) Experimentally proved design concept and nonlinear behavior modeling approach of both, original and improved original connection between precast roof RC beam and RC column; (D5) Advanced experimentally proved nonlinear analysis procedure providing its wide application for design of novel seismically resistant prefabricated system (*NSR-prefabricated system*) of industrial halls in seismic zones characterized with expected significant and/ orvery high seismic intensity.

2. PROTOTYPE COLUMN-FOOTING CONNECTION TEST: MODELM1

Providing safety and controlled behaviour of connection between precast RC column and precast RC footing is very important condition for assuring seismic stability of the integral precast structural system. To get full evidence in real nonlinear behaviour characteristics of this critical connection type, performed was detailed test model design, common production and laboratory testing up-to failure of representative prototype model–M1 in the scale M=1:2. Experimental test was realized on existing laboratory testing frame under simulated constant vertical load and horizontal cyclic displacement with increasing amplitude up-to deep nonlinearity. Model test set-up is shown in Figure 1. Experimental model–M1 is composed of precast RC footing and precast RC column with cross-section dimensions 30x30cm and its total length of L=165.0cm. Column length l_1=50cm was installed in footing box and the remaining column`s length of l_2=115cm was used for application of simultaneous vertical and horizontal cyclic load. Longitudinal reinforcement consisted of 12ϕ10mm steel bars and special confining ties of ϕ= 6mm spaced at distance of e=10cm. Footing RC base plate dimensions are d=25 cm and a/b=120x100cm, reinforced with steel bars ± 9ϕ12mm and ± 7ϕ12mm in both sides directions, was fixed to the frame base with 6 bolts with diameter of ϕ32mm.

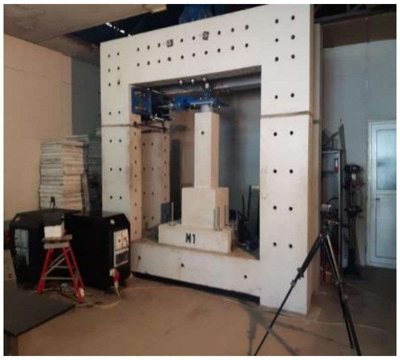

Fig. 1. Set-up of 1/2 scaled model M1 in laboratory testing frame

Fig. 2. Initiated damage at PC column

Fig. 3. Heavy damage at PC column (footing safe)

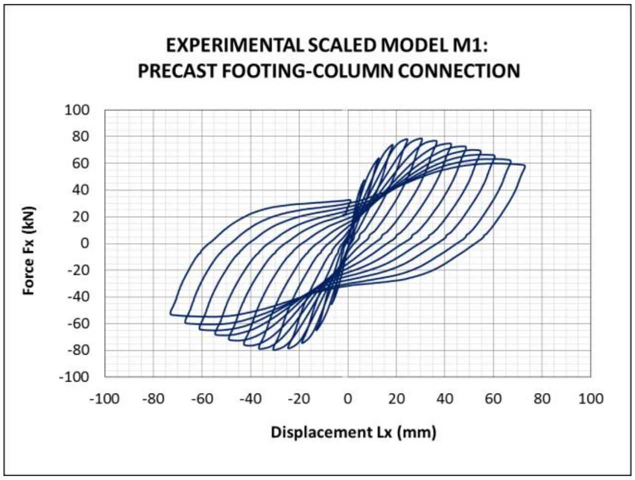

Fig. 1a. Force-displacement hysteretic response recorded from the test of prototype model M1

The RC footing box is with outer dimensions of 60x60cm and bottom inner dimensions of 35x35cm were used to fix RC column applying standard putinzenjering technology. The four side-walls of RC box were reinforced at both faces using 16+16=32ϕ8 steel bars as vertical reinforcement and the horizontal reinforcement existed of 6ϕ8 and 6ϕ8 steel bars at outer and inner wall faces, respectively. The recorded hysteretic curve from the performed experimental test, Figure 1a, showed very stable nonlinear behaviour resulting from induced plastic hinge only in column's critical section. RC footing box was fully safe and damage was observed only in critical section zone of RC column, Figure 2 and Figure 3. Maximum horizontal restoring force of F_{max}=±80.0kN was recorded for displacement of d=±25mm. However, for induced maximum displacement of D_{max}=±74.0mm, the recorded horizontal force amounted to F=±55.0kN. So, obtained is small reduction of only 25.7% along with the recorded very stable hysteretic relation without any visible cracks in the foundation box. The test results have clearly shown perfect and controlled nonlinear behaviour of the assembled precast column-footing connection, confirming full validity of the developed production technology.

3. TESTING OF PROTOTYPE BEAM SUPPORT ON RC CORBEL: MODELM2

In the cases of construction of two-story structures, longitudinal precast RC beams are supported on RC corbel (short cantilever) constructed during production of precast RC column.

Fig. 4. Set-up of 1/2 scaled prototype model M2 in laboratory testing frame

Fig. 5. Reinforcement ofcolumn with corbel

Fig. 6. Loading of RC corbel using rubber pad

Safety state of short cantilever under maximum design load was, in the frame of the present project, experimentally tested using specifically designed experimental model–M2. In Figure 4 shown is test set-up of experimental model-M2 in the laboratory testing frame along with the applied vertical loading system composed of hydraulic actuator. Model base fixation support was constructed in the form of RC footing with dimensions 60x71cm and thickness of t=30cm. The footing was reinforced in both directions and equal in bottom and top zone with ±6ϕ12mm and ±8ϕ12mm steel bars, respectively. For fixing the model footing to the frame base, fours steel bolts of ϕ32mm were used. Above the footing constructed was segment of precast column with corbel. Considered cross section of the column was 30x30cm and its total length above footing was L=135cm, being 30cm below corbel, then corbel height 30cm and 75cm above the corbel. Longitudinal reinforcement of the column consisted of 12ϕ10mm longitudinal steel bars and steel tiesϕ6mm installed at distance of 10cm, Figure 5. Corbel contact face with column was 30cmx30cm, its span was L=20cm and free face was reduced to 30x20cm adapting linear variation of corbel height. Reinforcement of corbel consisted of4ϕ10mm bars in upper and 4ϕ10mm bars in lower zone, respectively. Confinement was assured using specially formed tiesϕ6mm installed in two directions. To increase safety of corbel added are inclined three steel anchors ϕ6mm in the shape of letter U. Corbel loading was provided with steel plate being above neoprene layer with d=10mm and by vertical steel component with hollow section 180x260x10mm, directed vertically by two steel belts with cross section 100x20mm, Figure 6. During experimental test, even under maximum vertical load of N=300.0kN, the precast model corbel showed perfect stability, pure linear behaviour without any visible cracks. Based on conducted experimental test, it was concluded that the developed precast corbel construction method provides reliable and safe supporting system of precast RC longitudinal beams under respective design loads.

4. PC L-BEAM WITH COLUMN CONNECTION TEST: MODELSM3-A& M3-B

Controlled safety level of the adopted connection between precast RC column and RC longitudinal beam, which is supported by RC corbel produced during construction of prefabricated RC column, is highly important connection property providing conditions to efficiently prevent severe damages during seismic loading of related structural segments. Beside provided seismic safety of prefabricated RC column and prefabricated longitudinal RC beam, as individual structural members, their connection should also sustain required safety level for induced real seismic action under strong future earthquakes. To experimentally confirm actual nonlinear behaviour characteristics of this important connection and to provide valid design parameters assuring required and controlled seismic safety, two developed longitudinal beam-column connection options have been experimentally tested using constructed scaled (1:2) experimental models. The first tested model M3-A represent commonly used original connection (item 4.1), while the second model M3-B is recently developed and proposed, representing improved original connection option (item 4.2).

4.1. Testing of original connection of PC longitudinal beam & column: Model M3-A

Standard or original experimental model M3-A of connection between longitudinal precast beam and column was designed to include segment of precast column with corbel, segment of precast longitudinal beam and constructed connection segment applying original connection system. The column segment with corbel positioned horizontally, was used for model fixing to the base of laboratory test frame with eight bolts d=32mm, installed in constructed column supporting RC footing placed under the column segment. Footing was constructed with dimensions a/b=140x60cm and thickness t=20cm. Reinforcement of column with section 30x30 cm consisted of 12ϕ10mm longitudinal bars and ties of ϕ6mm spaced at 10cm distance. Column supporting RC footing was reinforced in both faces with longitudinal reinforcement of 6ϕ12mm, respectively and ties of ϕ6mm spaced at distance of e=10cm. Corbel dimensions and reinforcement arrangement were adapted based on standardized method described before (item 3). Longitudinal PC beam segment with cross section in the form of inverted T was reinforced with standard longitudinal reinforcement and ties. Dimensions of base wider cross-section part were b_1/h_1=30x20cm, for vertical part b2/h2=15x20cm, resulting in total section height $h=h_1+h_2$=40cm.Standard connection system existed of two pin anchors ϕ12mm and l=350mm installed in the existing holes ϕ24mm made along the total precast beam height of 40cm. Two pin anchors were additionally fixed by inserted standard connecting emulsion. The head of precast longitudinal beam was strengthened with U shaped horizontal anchoring ties. Three anchoring ties ϕ8mm were applied in vertical section part having b_2=15cm and three anchoring ties ϕ8mm were applied in lower wider section segment having b_1=30cm. The test model M3-A set-up in laboratory testing frame is shown in Figure 7, along with vertical loading system with hydraulic actuator.

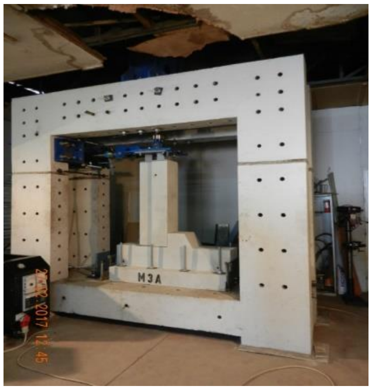

Fig. 7. Set-up of 1/2 scaled prototype model M3-A

Fig. 8. Original connection PC column and L-beam

Fig. 9. Final failure state of original connection M3-A

Table 1. Experimentally defined parameters representing nonlinear behavior of the tested original connection of prefabricated RC longitudinal beam with RC column: Model M3-A

Original M3-A connection type: L beam-column					
No.	Scaled-model/full-scale	DY(m)	FY(kN)	DU(m)	FU(kN)
1	Tested scaled modelM3-A	0.0155	62.00	0.0540	100.00
2	Full-scale connection M3-A	0.0310	248.00	0.1080	400.00

Applying tension force on the vertical model segment representing longitudinal precast beam, nonlinear behaviour characteristics of original connection of precast L-beam with column have been defined and presented in Tab.1, for the tested scaled model and for full-scale connections converted values. The obtained experimentally proved bilinear model parameters represent highly valuable representative nonlinear modelling data of the original connection. The presented data can be used in the process of detailed seismic behaviour modelling and seismic response study of the integral precast structural system. The performed experimental test of prototype model connection M3-A has clearly shown all its specific behaviour phases including initial linear behaviour, crack and damage propagation and finally total failure, Fig. 8 and Fig. 9.

4.2. Test of improved original connection of PC L-beam with column: Model M3-B

To investigate possibility of upgrading of standard or original connection system M3-A, constructed was and experimentally tested experimental model M3-B, representing improved original connection system of PC longitudinal beam with column. The model components, including RC fixation footing, RC column with corbel and vertical segment representing PC longitudinal beam were constructed with the same dimensions and the same reinforcement.

The improved original connection system–2 represents structural modification of the original connection system-1 in the following two parts: (1) The basic pin anchors were produced applying 2ϕ16mm steel bars (instead of 2ϕ12mm steel bars) and (2) The three U shaped horizontal anchors in the vertical section part and three U shaped horizontal anchors in the lower wider section part were applied with larger diameter of ϕ16mm, instead of ϕ12mm used in the case of model M3-A.

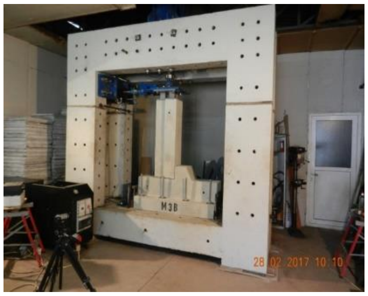

Fig. 10. Set-up of 1/2 scaled model M3-B in referent testing frame

Fig. 11. Improved M3-B connection: C & L-beam

Fig, 12. Damage of M3-B improved connection

Table 2. Experimentally defined nonlinear behavior parameters of the tested improved original connection of prefabricated RC longitudinal beam with RC column: Model M3-B

Improved **o**riginal M3-B connection type: L beam-column					
No.	Scaled-model/full-scale	DY(m)	FY(kN)	DU(m)	FU(kN)
1	Tested scaled model M3-B	0.0030	44.00	0.0480	120.00
2	Full-scale connection M3-B	0.0060	176.00	0.0960	480.00

Experimental model set-up as well as loading system of experimental model M3-B are considered the same, Figure 10. From conducted experimental test defined were actual nonlinear behaviour characteristics of the proposed improved original connection system M3-B, including linear stage, damage propagation stage and total failure, Figure 11 and Figure 12. Nonlinear behaviour characteristics of the tested improved original connection M3-B of PC beam-PC column, respectively for scaled model and full-scale connection are presented in Table 2. The presented parameters of bilinear models for M3-A & M3-B show some differences. For M3-B recorded is enlargement of failure force for 20% because FU=100N and FU=120kN, respectively for original and improved connection, Table 1&Table 2.

5. PC ROOF-BEAM & COLUMN CONNECTION TEST: MODELSM4-A&M4-B

Without any exception, connection between precast RC roof beam and precast RC concrete column exists in every PUTINZENGERING industrial hall structure. It is located in the highest structural zone and commonly is exposed to not very well-defined forces under strong earthquake excitations. The safety of the implemented connection system between precast heavy roof beam and column is one the basic requirements to assure seismic resistance of the integral structural system. To obtain full evidence in real nonlinear behaviour characteristics of this important connection system performed was extensive experimental laboratory study including experimental tests of constructed related large-scale testing models with two options. Experimental test model M4-A, representing the developed original connection system and experimental test model M4-B, representing improved original connection system between precast roof beam and precast column. The experimental test models have been originally assembled using specific parts of structural components that will provide its successful testing on existing laboratory test frame. Significant structural part of the column, with cross-section 30x30cm, was considered as horizontal and its top part (left in Figure 13) with height of hc=44cm was constructed in the form of twin RC walls. Both end column walls with thickness of $t_1=t_2=9$cm were constructed with free distance of d=12cm between them to provide resting of end vertical part of T-type roof beam. Bellow the precast column, constructed was RC footing part with thickness t=20cm and with dimensions in plane 150x60cm, providing model fixation to the base of the testing frame with eight bolts with diameter of 32mm.The end part of the typical T-type roof beam was considered vertical. Its lower part, resting on the PC column, was used to apply related connection system, while the upper part of the roof beam was appropriately equipped with connecting steel device used for application of prescribed tension loading. Two types of roof beam-column connection systems have been tested. The first, representing original connection system was tested using model M4-A (item 5.1), while experimental model M4-B was constructed and used to test connection system-2, representing improved original connection system between precast roof beam and column (item 5.2).

5.1. Testing of original connection of PC roof beam with column: Model M4-A

Experimental test model M4-A was constructed considering reinforcement of the footing part and the column part the same as in the case of tested models M3-A and M3-B. Similarly, the implemented T-type roof beam is constructed with common reinforcement in its regular part out of the zone of connection. The applied connection in experimental model M4-A, representing original connection system-1 was developed based on application of the following four specific structural detailing measures as follows: (1) At both side walls of RC column installed were special pin anchors with diameter ϕ12mm entering in the hole at both sides of precast roof T-beam. Both anchors were properly fixed by injection of connecting emulsion; (2) To provide safe transmit of load from both applied pin anchors, adopted were regular (original) arrangements of additional reinforcement at both upper sides of roof beam and at both RC walls of column; (3) To increase connection safety, adopted was central bolt of ϕ15mm through column side walls and vertical part of roof T-beam and (4) All connection contacts are finalized with commonly applied standard filling emulsion. The test set-up of experimental model M4-A is shown in Figure 13. The experimental test was completed with gradual application of increased upward vertical force up-to connection failure. Actual nonlinear characteristics of the original roof beam-column connection M4-A have been very successfully defined along with damage propagation for different displacement stages, Figure 14 and 15. The representative bilinear model properties of the tested scaled model M4-A and for full-scale connection are presented in Table 3. The presented experimentally confirmed nonlinear model properties of original connection M4-A between precast roof beam and column can be successfully applied in the process of analytical model formulation of the integral precast structural system.

Fig. 13. Set-up of 1/2 scaled prototype model M4-A

Fig. 14. Original connection: PC column-roof beam-M4-A

Fig. 15. Final failure state of original connection M4-A

Table 3. Experimentally defined parameters representing nonlinear behavior of the tested original connection of prefabricated RC roof beam with RC column: Model M4-A

Original M4-A connection type: roof beam-column					
No.	Scaled-model/full-scale	DY(m)	FY(kN)	DU(m)	FU(kN)
1	Tested scaled model M4-A	0.0020	60.00	0.0380	108.00
2	Full-scale connection M4-A	0.0040	240.00	0.0760	432.00

5.2. Testing of improved connection of PC roof beam & column: Model M4-B

The experimental test model M4-B, representing the improved original connection of precast roof beam and column was constructed applying the same model components as in the case of experimental model M4-A. However, to investigate possible upgrading level of connection system-1, applied is modified, i.e. improved connection system-2 which is characterized with the following structural measures: (1) Increased is the diameter of special pin anchors, in this case to d=16mm. They were located in the same positions at both RC side walls of the column. The anchors were fixed to the roof T-beam applying the same connecting concept; (2) In this case, to provide safer load transition from both stronger pin anchors, adopted was improved original arrangement of additional confining and anchoring reinforcement at both upper sides of roof beam and at both side RC walls of the column; (3) In this case adopted was central bolt with d=18mm passing through the same elements and spaced on the same location; and (4) The connection contact faces were finalized applying the same method as in the case of experimental model M4-A.
Experimental model set-up of the tested connection model M4-B is presented in Figure 16. Details of crack propagation during the model testing are shown in Figure 17 and Figure 18. From experimental test of improved original connection model M4-B, representing connection between roof beam and column, defined were related nonlinear characteristics of analytical bilinear model for both, scaled connection model and full-scale connection, Table 4.

Fig. 16. Set-up of 1/2 scaled model M4-B in testing frame

Fig. 17. Improved column & roof beam connection

Fig. 18. Failure of improved original connection M4-B

Table 4. Experimentally defined parameters representing nonlinear behavior of the tested improved original connection of prefabricated RCroof beam with RC column: Model M4-B

Improved original M4-B connection type: roof beam-column					
No.	Scaled-model/full-scale	DY(m)	FY(kN)	DU(m)	FU(kN)
1	Tested scaled model M4-B	0.0030	70.00	0.0600	190.00
2	Full-scale connection M4-B	0.0060	280.00	0.1200	760.00

Comparing ultimate force obtained from the tested original connection model M4-A ranging to FU=108kN, with ultimate force recorded for improved original model connection M4-B ranging to FU=190kN, significant increase of ultimate strength of 75.9% has been achieved. The obtained original experimental data represents highly important experimental evidence providing proved conditions for detailed modelling and seismic safety analysis of the integral systems of precast structures having various geometrical and global shape properties.

6. MODELING OF NSR SYSTEM WITH TESTED CONNECTIONS

Using experimentally proved nonlinear behaviour characteristics of the implemented structural connections, in SAP2000 formulated was nonlinear analytical model of integral full-scale prototype precast industrial hall structure and used to study its seismic response performances under the effect of strong earthquakes, Figure 21. The structure represents precast frame system, formed by installed seven frames parallel to x axis, integrating in total 27 columns supported by 27 individual precast foundations with variable dimensions 400x400cm, 300x300cm and 250x250cm, depending on actual vertical load and column cross-sections. In x and y direction, the structure dimensions in plan are L_x=44.0m and L_y=63.75m. The columns are designed with three different cross-sections, first 80x80cm (cast with concrete C40), second 70x70cm (C50) and last 60x60cm (C50), reinforced respectively with longitudinal bars 20ϕ28mm, 16ϕ25mm and 8ϕ25mm and with tiesϕ6/15cm. The height of central and side columns are, H_c=14.2m and H_s=11.94m, respectively.

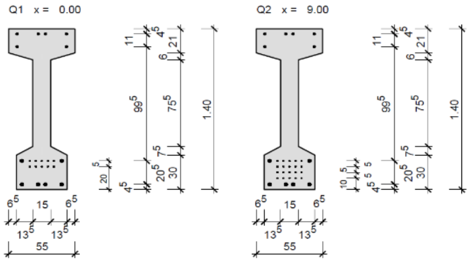

Fig. 19. Main prestressed beam I140 used in prefabricated NSR structure

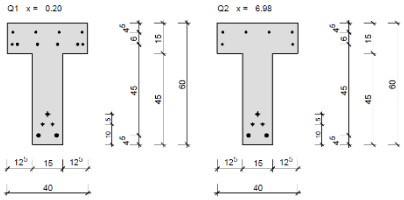

Fig. 20. Longitudinal prestressed beam T60 used in prefabricated NSR structure

The roof structure is formed with precast roof I-beams with h=140cm and span L=22m, Fig. 19, precast T-beams with h=90cm and L=11.0m; longitudinal precast T-beams with h=60cm and L=15.0m, Fig. 19 and longitudinal precast T-beams with h=45.0cm and L=8.75m. Steel trusses integrating the structure consist of hollow rectangular braces 160x160x4 mm, 100x100x4mm and 80x80x4mm and brace filling rebar d=25mm. Nonlinear behaviour of columns above foundations were simulated by hysteretic Takeda model based on previously performed detailed analysis of moment-curvature relations for all respective sections of columns. Nonlinear behaviour of the existing connections of precast roof-beams with precast columns and longitudinal precast beams with precast columns were realistically modelled based on experimentally proved nonlinear model parameters from conducted experimental laboratory tests, Figure 22 and Figure 23.

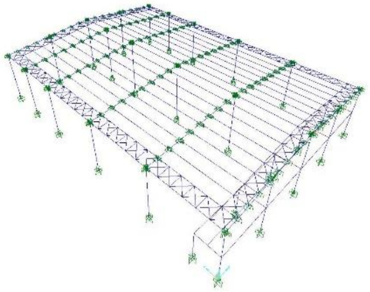

Fig. 21. Nonlinear 3D model of full scale prefabricated NSR structure

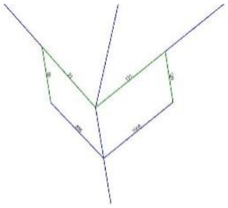

Fig. 22. Connection model above corner column

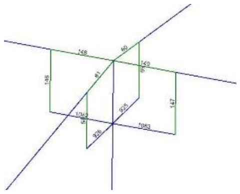

Fig. 23. Connect. model above central column

From the analysis of the dynamic characteristics for the initial state of the structure defined were the following vibration periods of the first three modes: T_1=1.526s, T_2=1.445s and T_3=1.305 s, dominantly exposed in x-direction, y-direction and in torsion mode, respectively. Seismic response of the integral structure has been analysed for earthquake action simultaneously in both x and y direction, considering seismic ground motion to act under the angle of 45^o in respect to the global x-axis. In this paper included are results obtained for simulated Ulcinj-Albatros earthquake record scaled to very high intensity represented by peak ground acceleration PGA=0.60g.

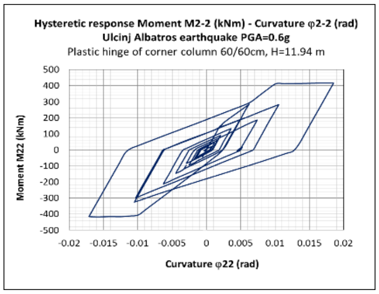

Fig. 24. Hysteretic response M22-ϕ of corner column under strong seismic load: PGA=0.6g

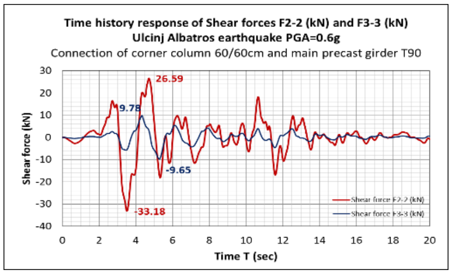

Fig. 25. Time-history response of connection forces above corner column under strong seismic load

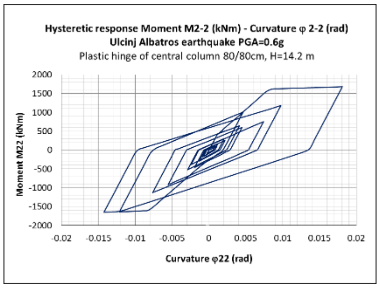

Fig. 26. Hysteretic response M22-ϕ of central column under strong seismic load: PGA=0.6g

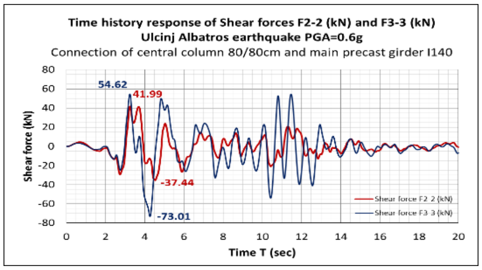

Fig. 27. Time-history response of connection forces above central column under strong seismic load

Structural response of the integral structure was generally characterized by the following important observations: (1) During the lower intensity level, specifically during the first 2-3 sec, structural response was completely linear and all critical column sections and all modelled connections were not cracked; (2) During the increased earthquake intensity, time segment t=3-6sec, critical sections of the columns in both directions were exposed to intensive nonlinear response represented by opened hysteretic curves, Figure 24, Figure 26, Figure 28 and Figure 29.

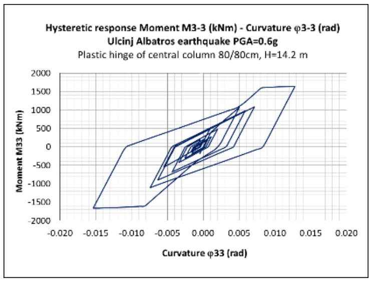

Fig. 28. Hysteretic response M33-ϕ of central column under strong seismic load: PGA=0.6g

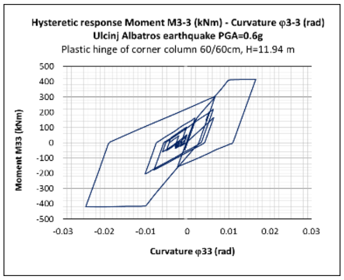

Fig. 29. Hysteretic response M33-ϕ of corner column under strong seismic load: PGA=0.6g

During this time segment, in all horizontal connections recorded was increased level of induced forces, Figure 25 and Figure 27; (3) The increased level of forces in these connections are not higher than yield forces and the connections are remaining safe and undisturbed and (4) If input earthquake intensity will be further increased, the failure of the structure is expected to be produced due to failure of the columns; (5) Column`s controlled failure is in this case advanced strategy and can be avoided during the advanced design process and (6) During the third time segment, t=6-20s, the structure was vibrating around new very little changed deformed state, but the system remained integrally safe. The observed global seismic response of NSR prefabricated structure, characterized by controlled and favorable behavior, actually represents advanced strategy to minimize seismic risk and to assure full seismic stability of this specific and other important structural types.

7. CONCLUSIONS

From the conducted extensive experimental testing of various developed and implemented connection types of the novel seismically resistant NSR PUTINZENJERING prefabricated system the following conclusions are summarized: (1) Prefabricated standard footing showed full safety for seismic loads in the case of installation of columns with standard respective cross sections and reinforcement; (2) Prefabricated RC columns showed stable nonlinear hysteretic behavior under cyclic loads along with expressed ductility for the case of implemented ties spaced in prescribed small distances; (3) The implemented RC corbels supporting L-beams possess high safety for the prescribed design loads; (4) From experimental tests confirmed was that nonlinear behavior characteristics of the developed L beam-column connection types and roof beam–column connection types possess stable and favorable behavior properties with opened possibility for their application in seismic regions and (5) The proposed nonlinear analytical model parameters of connections represent highly valuable modeling data which can be successfully considered during the final seismic design process of NSR PUTINZENJERING prefabricated structures in seismic regions. In addition, from conducted nonlinear seismic response analysis of the integral NSR prototype structure, the following main conclusions are summarized: (1) Novel siesmo-resistant NSR PUTINZENJERING prefabricated system can be successfully applied in seismic zones with high seismic intensity based on application of the developed design principles; (2) Nonlinear response of the integral structure should be generally controlled by hysteretic ductile behavior of prefabricated columns; (3) For the case of design earthquake, the behavior of structural connections should be basically linear while for the case of maximum expected earthquake intensity, the behavior of structural connections may be in controlled nonlinear range. To efficiently define and satisfy both design stages, potential use of advanced structural analysis procedures during the design process is recommended.

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REFERENCES

1. Ristic D., 1988, *Nonlinear Behavior and Stress-Strain Based Modeling of Reinforced Concrete Structures Under Earthquake Induced Bending and Varying Axial Loads, (Doctoral Dissertation),* School of Civil Engineering, Kyoto University, Kyoto, Japan.
2. EERI, 1994, Northridge Earthquake January 17, 1994, *EERI Preliminary Reconnaissance Report,* Earthquake Engineering Research Institute, 104pp, 1994.
3. Muguruma H., Nishiyama M., Watanabe F., 1995, *Lessons learned from Kobe earthquake, A Japanese perspective*, PCI Journal, V40, N4, July/August, pp.28-42, 1995.
4. EERI, 2000, Kocaeli, Turkey, Earthquake of August 17, 1999, *EERI Reconnaissance Report*, Earthquake Spectra, Supplement to Vol. 16. 2000.
5. Wilson L. Edward, 2002, *Three-Dimensional Static and Dynamic Analysis of Structures: A Physical Approach With Emphasis on Earthquake Eng.,* Berkeley, California: Third Ed., 2002.
6. Posada M., Wood S.L., 2002, *Seismic performance of precast industrial buildings in Turkey.* Proc. of the 7th U.S. National Conference on Earthquake Engineering, July 21-25, 2002, Boston, MA, USA, EERI publications.
7. Doneux C., Hausoul N., Plumier A., 2006, Deliverable 55 "Analysis of 3 precast RC structures with dissipative connections", LESSLOSS Sub-Project 7 – Techniques and methods for vulnerability reduction.
8. Myiamoto, 2009, *2009 M6.3 L'Aquila, Italy, Earthquake Investigation Report*, Global Risk Myiamoto, 2009.
9. Zhaoa B., Taucera F., Rossetto T., 2009, *Field investigation on the performance of building structures during the 12 May 2008 Wenchuan earthquake in China,* Engineering Structures, 31 (2009) 1707–1723, 2009.
10. Senel S.M., and Kayhan A.H. 2010, *Fragility based damage assessment in existing precast industrial buildings: A case study for Turkey,* Structural Engineering and Mechanics, Vol. 34, No. 1 (2010) 39-60, 2010.
11. Decanini L. D., Liberatore L., Sorrentino L., 2012, *Preliminary Report on the 2012, May 20 Emilia Earthquake,* May 2012, v.1, Univ. "La Sapienza" of Rome, Department of Structural Engineering and Geotechnics, Italy, 2012.
12. Ristik J., 2016, *Modern technology for seismic protection of bridges with application of new seismic response modification system,* Doctoral dissertation, Institute of earthquake engineering and engineering seismology (IZIIS), University Ss. Cyril and Methodius, Skopje, Macedonia, 2016.
13. Ristik J., Pavlov S., Pavlov P., Ristic D., 2017, *Laboratory Testing of Constructed Prototype Models of Typical Connections Used in Prefabricated RC Construction System of Industrial Halls Implemented by PUT Inzenering, Serbia: Experimental Laboratory Testing of Prototype Model-M1 Representing Connection Between Prefabricated Column and Prefabricated Footing,* RESIN Lab. of Industrial Sciences and Technology, Report: RESIN-011-2017.
14. Ristik J., Pavlov S., Pavlov P., Ristic D., 2017, *Laboratory Testing of Constructed Prototype Models of Typical Connections Used in Prefabricated RC Construction System of Industrial Halls Implemented by PUT Inzenering, Serbia: Experimental Laboratory Testing of Prototype Model-M2 Representing Beam Support Fromed as RC Column-Short Cantilever (Corbel),* RESIN Laboratory of Industrial Sciences and Technology, Report: RESIN-012-2017.
15. Ristik J., Pavlov S., Pavlov P., Ristic D., 2017, *Laboratory Testing of Constructed Prototype Models of Typical Connections Used in Prefabricated RC Construction System of Industrial Halls Implemented by PUT Inzenering, Serbia: Experimental Laboratory Testing of Prototype Model-M3a Representing Original Connection of Prefabricated Longitudinal Beam with Column,* RESIN Lab. of Industrial Sciences and Technology, Report: RESIN-013-2017.
16. Ristik J., Pavlov S., Pavlov P., Ristic D., 2017, *Laboratory Testing of Constructed Prototype Models of Typical Connections Used in Prefabricated RC Construction System of Industrial Halls Implemented by PUT Inzenering, Serbia: Experimental Laboratory Testing of Prototype Model-M3b Representing Improved Original Connection of Prefabricated Longitudinal Beam With Column,* RESIN Laboratory of Industrial Sciences and Technology, Report: RESIN-014-2017.
17. Ristik J., Pavlov S., Pavlov P., Ristic D., 2017, *Laboratory Testing of Constructed Prototype Models of Typical Connections Used in Prefabricated RC Construction System of Industrial Halls Implemented by PUT Inzenering, Serbia: Experimental Laboratory Testing of Prototype Model-M4a Representing Original Connection of Prefabricated Roof Beam With Column,* RESIN Lab. of Industrial Sciences and Technology, Report: RESIN-015-2017.
18. Ristik J., Pavlov S., Pavlov P., Ristic D., 2017, *Laboratory Testing of Constructed Prototype Models of Typical Connections Used in Prefabricated RC Construction System of Industrial Halls Implemented by PUT Inzenering, Serbia: Experimental Laboratory Testing of Prototype Model-M4b Representing Improved Original Connection of Prefabricated Roof Beam With Column,* RESIN Lab. of Industrial Sciences and Technology, Report: RESIN-016-2017.
19. Fangfang Geng, Youliang Ding, Honglei Wu, Xiaoning Cai, Yun Zhang., 2021, *Experimental investigation and seismic response behavior of a self-centering precast concrete frame with hysteretic dampers,* Engineering Structures, Volume 240, 2021,
20. Marco Breccolotti, Luca Brocchi, Annibale Luigi Materazzi, 2021, *Ductility evaluation of precast RC shear walls in Italian existing buildings,* Engineering Structures, Volume 240, 2021.