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TESTING OF MODELS OF ORIGINAL AND UPGRADED CONNECTION BETWEEN RC FLOOR-BEAM AND COLUMN USED IN MODERN PRECAST HALL SYSTEM

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Abstract

The design and construction of modern, globally upgraded and seismically safe industrial hall systems (SSIH Systems) is currently viewed as an activity of extraordinary importance since these structures most frequently house new advanced and robotically conceptualized industrial machines and equipment, whose value multiply exceeds the value of the integral structures. The SSIH systems are of vital importance because it is only by their practical application that efficient and continuous functioning of important production industrial systems and compounds is provided. The achieved safety margins, the actual seismic performances and the present limitations of the used pin-based floor-beam column connections of the existing precast N-system were integrally confirmed by the original results obtained from the conducted experimental tests of the constructed connection prototype models. The precast N-system is commonly used for intensive construction of large industrial structures in different regions and countries, including areas of Europe and wider characterized by high seismicity. The initial results obtained from the laboratory test of the constructed large-scale prototype model representing a common floor-beam column (CFBC) connection confirmed the actual bearing capacity of the connection, the damage propagation pattern and the specific total failure mode. To investigate possible upgrading of the connection safety, a specific supplementary test was performed using the created and constructed new experimental model, representing an upgraded floor-beam column (UFBC) connection by application of an improved concrete confinement and use of larger diameters of steel connection pins (dowels). The main conclusion regarding the safety increase was that such common upgrading concept of pin-based connections could not be considered as a basic adequate approach since it was able to provide only limited upgrading effects. The existing need for creation of a new, advanced, experimentally proved and effective innovative upgrading method was clearly pointed out.

Keywords: precast structures, connections, testing, damage propagation, seismic safety

1. Introduction

Although extensive research has been carried out during the recent period, [3-4], [6], [9-10], [12-17], [19-20], [22-24], heavy damages and total collapses of prefabricated industrial halls have been observed during past earthquakes widely in the world, [1-2], [5], [7-8], [11], [18], [21]. Creation, design and construction of a new, modern seismically safe precast system of industrial halls is presently of the highest importance since these structures most frequently house new, advanced and robotically conceptualized, industrial machines and equipment, whose value multiply exceeds the value of the integral structures. Today, such precast industrial hall structures are of vital importance. This is mainly the result of the real need for providing continuous production of important industrial products. This condition can be achieved only if high structural seismic safety level is provided in future practical applications. It is known that our region, the wider region of Europe and the World are characterized by pronounced to high seismicity. The high importance of these systems directly conditions the real need for application of an advanced, new and more successful technology for seismic protection.

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Therefore, a specific research work has been conducted for the purpose of development of suitable systems for earthquake protection of large prefabricated industrial hall structures. The conducted extensive research work was focused on development of a new upgraded seismically safe system (USS-system) of prefabricated industrial halls. The development of the USS system of prefabricated industrial halls was based on the original experimental results from the extensive innovative experimental research project realized in the RESIN Laboratory (Skopje), led by Prof. Danilo Ristic. The project included realization of laboratory testing of constructed large-scale prototype models of critical connections up to failure (Ristic J. et al. 2017), [19-20]. The important part of the original experimental research work devoted to testing of large-scale prototype models of the original and upgraded connection between a precast RC floor-beam and an RC column used in a modern precast hall system are presented and discussed in this paper.

2. Experimental Testing of Model of Original Connection Between Precast RC Floor Beam and RC Column

2.1 Prototype and Experimental Model M3-A of Original Connection-OC3

The prototype of the original connection OC3, providing connection between a precast RC floor beam and an RC column, is of a great importance since the corbels provide conditions for support of longitudinal (floor) prefabricated RC beams.

DESIGN OF TEST MODEL M3A: Page-1

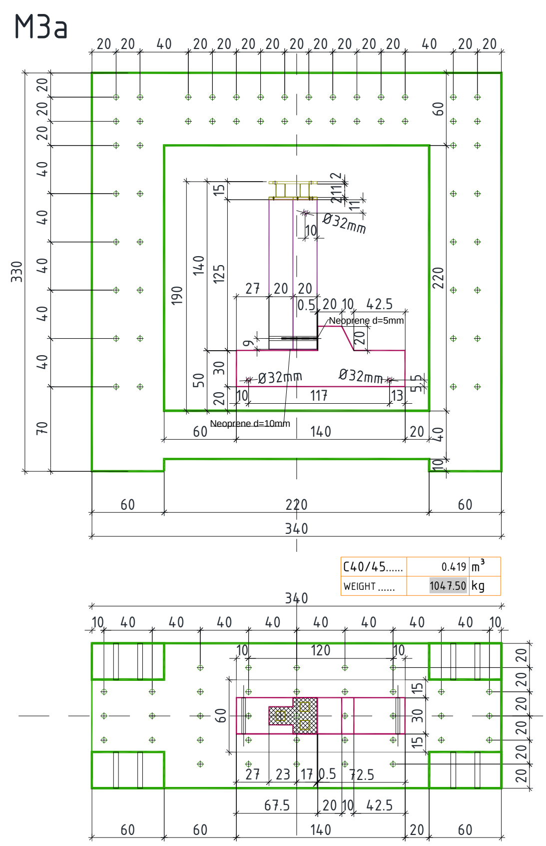

Fig. 1. Design of the prototype of model-M3A representing a connection between a precast RC floor beam and an RC column: Set-up of the test model.

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At the same time, it is very important to execute a safe connection between RC corbels and RC columns. The connection between an RC corbel and an RC beam is realized by means of two anchors ϕ 25 mm that are concreted into the short cantilever, i.e., into the RC corbel. In the RC L-floor beam, two openings ϕ 70 mm are made because of the required clearance for assemblage. Prior to mounting of the L-floor beam, a neoprene bearing with hardness of 70 shores and thickness of d = 10 mm is placed on the short element. Following the placement of the floor beam, the openings are poured with non-shrink mortar of high strength. In 24 hours, such mortar achieves strength of 45 N/mm2, while after 28 days, its strength is 70kN/mm2 and Ꞇp = 2,8 N/mm2. Isomat Megagrout 101 is used as mortar. The short RC cantilever and the RC beam are made of concrete class 50 (or C50), whereas the metal anchor is constructed of reinforcement steel B500B. For this structural connection, it is of importance to experimentally prove: (1) the vertical bearing capacity of the short RC element (corbel) and (2) the bearing capacity of the connection itself realized by application of a reinforcing anchor and pouring of mortar, which does not shrink during hardening, but is characterized by a high bearing capacity.

DESIGN OF TEST MODEL M3A: Page-3

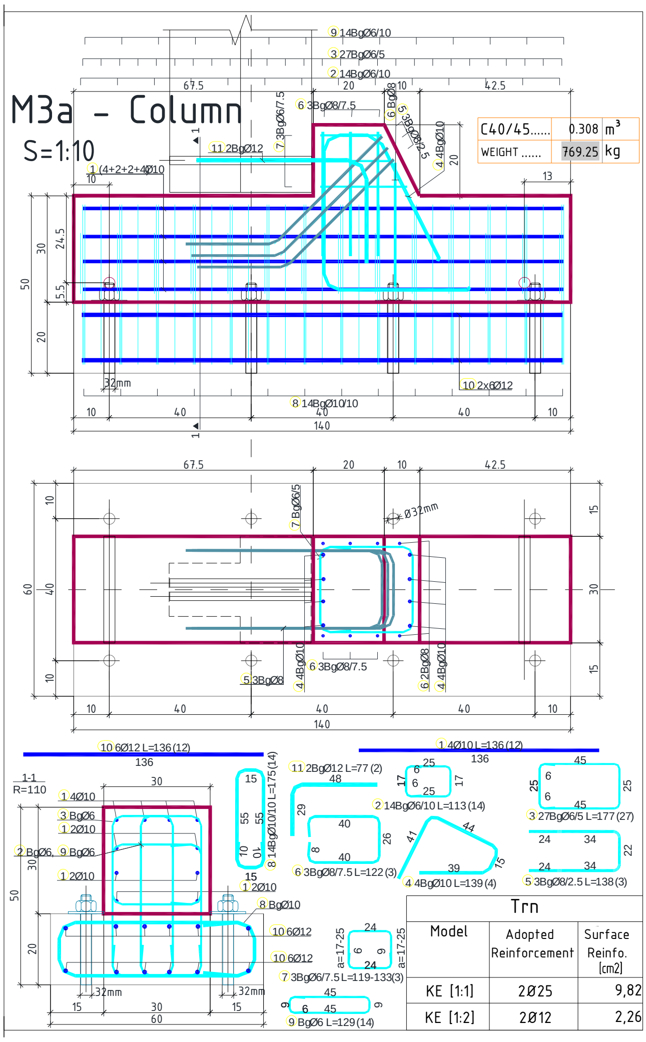

Fig. 2. Design of the prototype of model-M3A representing a connection between a precast RC floor beam and an RC column: Design of the RC column.

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The actual design of the used prototype connection OC3, representing an original connection between a precast RC longitudinal floor beam and a column through an RC corbel (short RC cantilever) was studied comprehensively. Also, the original in situ construction during assemblage of the integral structure of the prefabricated hall was fully considered. For experimental testing of the connection, a large scale experimental model M3-A was designed and constructed, Fig. 1 and Fig. 2. The test was planned for the purpose of defining the bearing capacity of the used original (O) type of a commonly used connection. The experimental test model M3-A was constructed to a large scale (M=1:2) whereat the actual characteristics of the original prototype connection were applied. With the applied large scale of the experimental model, important advantages were achieved: (1) The concrete used for the construction of the experimental model remained with the same mechanical characteristics as the concrete used for the construction of the prototype connection; (2) The reinforcement of the model was also with the same mechanical characteristics as those of the structural connection prototype; (3) In accordance with the stated advantages, the design of the model of the connection was reduced only to geometrical scaling, and (4) The physical experimental model was successfully adapted to the laboratory conditions for its successful laboratory testing, Fig. 1 and Fig. 2. The project on construction of the experimental model M3-A was initially completed. The configuration of the experimental model M3-A was very successfully adapted for its installation into the experimental rigid frame, enabling successful testing under application of the predefined loading program.

Fig. 3. Construction of model-M3A: Segment of the precast RC floor beam.

Fig. 4. Construction of model-M3A: Segment of the precast RC column.

The construction of the experimental model M3-A was done completely in factory conditions and with identically high quality as that of the prototype. Fig. 3 shows a view of the constructed RC floor beam, whereas Fig. 4 provides a view of the concreted segment of the RC column with the RC corbel. From the presented figures, it could be concluded that the applied technology of construction of the experimental model M3-A was identical to the original technology that was applied in the construction of the prototype connection. Actually, the applied procedure provided all the needed prerequisites for obtaining experimental results of high quality and reliability for specific practical or research objectives.

2.3 Principal Results from OC-3 Connection Test

The laboratory test set-up of the connection model M3-A is shown in Fig. 5. The experimental test was realized by use of two hydraulic actuators. The horizontal hydraulic actuator was used for fixation of the vertical position of the RC floor beam segment. The vertical hydraulic actuator was used for application of a continuously increased vertical tensile force (upwards) up to total failure of the structural connection. In this way, an insight into all the characteristic phases of increase of damages to the connection was gained. The whole experiment was carried out through a predefined history of deformations.

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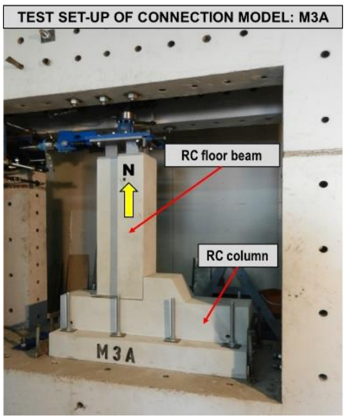

Fig. 5. Laboratory test set-up of the constructed model M3-A.

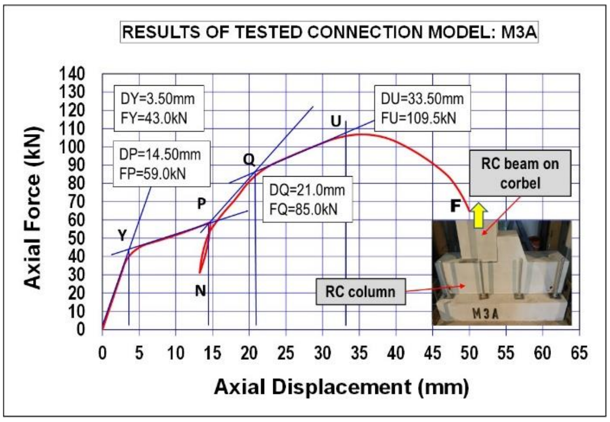

Fig. 6. Recorded nonlinear response of the constructed model M3-A.

The experimentally defined relationship between the applied vertical force and the vertical deformation is presented in Fig. 6. The recorded original force – deformation relationship was quite unusual and characteristic since it clearly reflected several phases of behavior. Phase 0-Y-P reflected the real bearing capacity of the connection. The next phase P-Q and the subsequent phase Q-U reflected the increase in force (with two inclinations of the envelope segments) due to stronger activation of the tensile anchors following larger cracks in concrete. After achievement of the maximum strength of the connection (point U), its strength decreased and total failure took place.

In the course of realization of the experimental testing of model M3-A, the development of the characteristic phases of damage to the structural connection was successfully monitored. For presentation of the damage degree, a scale for identification of the damage degree from 1 to 5 (DD = 1, 2, 3, 4, 5) was used. If there is no damage, the state is indicated by DD=1, while the state of failure is indicated by DD=5. States DD=2,3, 4 represent interim states characterized by consecutively increased damage degree. The states of occurred phases of damage are demonstrated in two characteristic figures, namely, Fig. 7 and Fig. 8 that show DD=1 and DD=5, respectively.

Fig. 7. Damage degree of model M3-A: Initial stage characterized by DD=1.

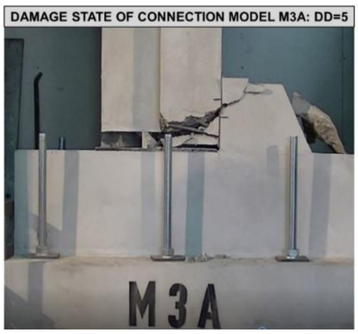

Fig. 8. Damage degree of model M3-A: Final stage characterized by DD=5.

2.4 Notes on Typical Response of OC-3 Connection

Following the obtained original results from the realized experimental testing of the behaviour of the respective structural connection using the constructed physical model M3-A, the following conclusions can be summarized: (1) The connection of this type formed with cast connecting anchors does not experience failure due to failure of the anchors themselves even in conditions of considerably increased deformations; (2) Progressive destruction of the connection accompanied by increase of damage generally takes place due to progressive cracking of concrete and propagation of concrete damage in

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the zones of the occurred larger cracks; (3) In the next phases, crushing and falling of concrete from the most critical zones exposed to high stresses takes place; (4) The real bearing capacity of the connection is characterized only by the O-Y-P envelope that shows a bearing capacity that is quite lower than the recorded maximum; (5) The envelope part of the P-Q-U relationship shows an increased strength, but with presence of severe damage to concrete and increased deformations; (6) During design of structures in practice, behavior of the connection only in the linear domain, segment O-Y, can be accepted. However, for this segment, it is also necessary to define the corresponding safety factor for the purpose of avoiding damage to the connection under strong earthquake effects, and (7) Although the connection has proved to be considerably tough, it is recommended and it will also be of interest to introduce appropriate structural advancement of the connection. Therefore, the qualitatively improved option of the same connection was experimentally tested by means of the corresponding model M3-B.

3. Experimental Testing of Model of Upgraded Connection Between Precast RC Floor Beam and RC Column

3.1 Prototype and Experimental Model M3-B of Upgraded Connection-OC3

The new prototype connection UC3, representing an upgraded (improved) original connection between a precast RC longitudinal floor beam and a column through an RC corbel (short RC cantilever) was appropriately designed. For the connection itself, two improvements were made. Considered were steel anchors with increased diameter and provided was an improved reinforcement arrangement and concrete confinement in the region of the corbels. The procedure of the in situ construction during assemblage of the integral structure of the prefabricated hall remained the same in the case of the original (O) and the upgraded (U) connection. Experimental testing of the constructed experimental model M3-B was performed for the purpose of defining the bearing capacity of the upgraded (U) connection type, connecting also a prefabricated RC corbel (fixed to a column) with an RC longitudinal floor beam. The experimental test model M3-B was analogously constructed to a large scale (M=1 : 2) whereat the actual characteristics of the original prototype connection were applied. With the applied large scale of the experimental model, important advantages were also achieved. In accordance with the stated advantages, the design of the model of connection M3-B was simplified and reduced only to geometrical scaling. The physical experimental model M3-B was also successfully adapted to the laboratory conditions providing its successful laboratory testing.

3.2 Testing of Prototype Model M3-B of Upgraded Connection OC-3

The construction of the experimental model M3-B was done completely in factory conditions assuring its high quality identical to that of the constructed prototype. It should be pointed out that the applied technology of construction of the experimental model M3-B was also identical to the original technology that was applied in the construction of the prototype connection. By assuring this, there were provided the main important prerequisites for obtaining experimental results of high reliability.

3.3 Principal Results from UC-3 Connection Test

The laboratory test set-up of the connection model M3-B is given in Fig. 9. The experimental test was realized by use of two hydraulic actuators. The horizontal hydraulic actuator was used for fixation of the vertical position of the RC floor beam segment. The vertical hydraulic actuator was used for application of a continuously increased vertical tensile force (upwards) up to total failure of the structural connection. In this way, an insight into the present characteristic phases demonstrating increase of damages to the upgraded connection M3-B was gained. The whole experiment was carried out through simulated predefined history of vertical deformations. The experimentally defined relationship between the applied vertical force and the vertical deformation is presented in Fig. 10.

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The recorded original force – deformation relationship was also quite unusual and characteristic compared with the M3-A model since it also clearly reflected several phases of behavior. Phase 0-Y-P reflected the actual initial bearing capacity of the connection.

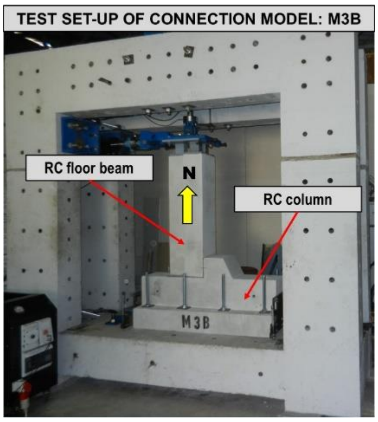

Fig. 9. Laboratory test set-up of the constructed model M3-B.

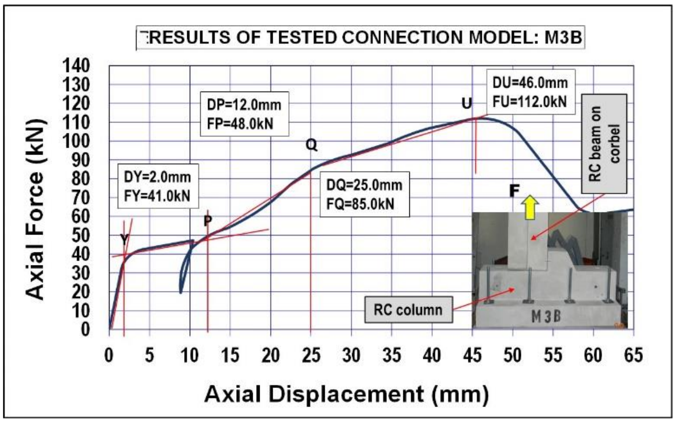

Fig. 10. Recorded nonlinear response of the constructed model M3-B.

The next phase P-Q and the subsequent phase Q-U reflected the increase in force (with two inclinations of the envelope segments) due to stronger activation of the tensile anchors following larger cracks in concrete. After achievement of the maximum strength of the connection (point U), its strength decreased and total failure took place.

Fig. 11. Damage degree of model M3-B: Initial stage characterized by DD=1.

Fig. 12. Damage degree of model M3-B: Typical stage characterized by DD=2.

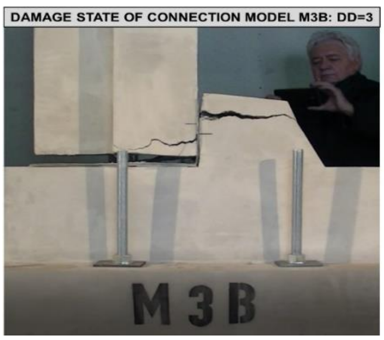

Fig. 13. Damage degree of model M3-B: Typical stage characterized by DD=3.

Fig. 14. Damage degree of model M3-B: Typical stage characterized by DD=4.

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- In the course of realization of the experimental testing of model M3-B, the development of the characteristic phases of damage to the structural connection was successfully and continuously monitored. The states of occurred phases of damage are demonstrated in four characteristic figures, namely, Fig. 11, Fig. 12, Fig. 13 and Fig. 14 that show DD=1, DD=2, DD=3 and DD=4, respectively.

3.4 Notes on Typical Response of UC-3 Connection

Based on the obtained original results from the test of the respective structural connection using the constructed physical model M3-B, the following conclusions can be summarized:

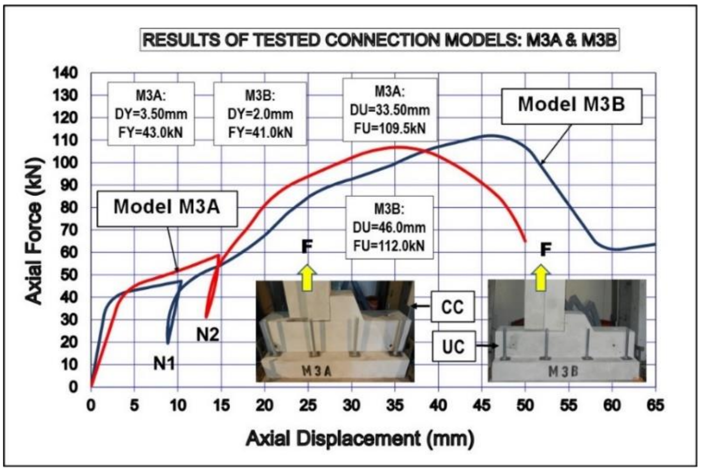

Fig. 15. Results for the experimentally tested model M3-A and M3-B representing the original and the upgraded connection between a precast RC floor beam and an RC column.

(1) The improved connection of this type formed by cast connecting anchors with increased diameter also does not experience failure due to failure of the anchors themselves even in conditions of considerably increased deformations; (2) Progressive destruction of connection M3-B accompanied by increase of damage generally takes place due to progressive cracking of concrete and propagation of concrete damage in the zones of occurred larger cracks, similar to model M3-A; (3) In the next phases, crushing and falling of concrete from the most critical zones exposed to high stresses takes place; (4) The real bearing capacity of the connection is characterized only by the O-Y-P envelope that shows bearing capacity that is quite lower than the recorded maximum; (5) The envelope part of the P-Q-U relationship shows an increased strength, but with presence of severe damage to concrete and increased deformations; (6) During design of structures in practice, behavior of the connection only in the linear domain, segment O-Y, can be accepted. However, for this segment, it is also necessary to define the corresponding safety factor for the purpose of avoiding damage to the connection under strong earthquake effects, and (7) Although the connection proves to be considerably tough, it is recommended and it will also be of interest to introduce appropriate innovative structural advancement of the connection.

5. Conclusions

Fig. 15 comparatively shows the actual nonlinear behavior characteristics of the tested original connection (OC3) and the upgraded connection (UC3) obtained from the realized experimental tests of model M3-A and M3-B, respectively. The two models represented alternative solutions for the same connection between an RC longitudinal floor beam and an RC column (using the anchors from the corbel). The following general observations can be made: (1) The original connection tested with the constructed model M3-A and the upgraded connection tested with the constructed model M3-B

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showed quite similar force – deformation relationship and similar damage generation patterns; (2) Connection M3-B was, first of all, upgraded by increasing the diameter of the applied anchors and then, by adding some steel hoops to increase the concrete confinement. However, the experimental results showed that the upgraded connection did not enable considerable qualitative improvement of the connection response; (3) The upgraded connection showed only some increase of the deformation capacity. However, the remaining parameters characterizing the safety of the connection were not significantly improved; (4) The main reason for the occurrence of damage and failure of the connection was the crushing and failure of concrete. Therefore, the increase of the diameter of the anchors and the improved confinement of concrete did not provide a considerable upgrading effect; (5) From the general knowledge gained from the experimental investigations, it is concluded that the original connection used in practice represents the "optimal maximum" that can be achieved with this technological concept of a connection, and (6) Finally, the most important knowledge arising from the experimental results clearly demonstrates the fact that significant and qualitative improvement of the connection bearing capacity and seismic safety can only be achieved by the created new, original and innovative technological solution of a connection.

6. Acknowledgements

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