ЕКСПЕРИМЕНТАЛНИ ИЗСЛЕДВАНИЯ НА ТРИЕТАЖНА СТОМАНОБЕТОННА СГРАДА С ПЪЛНЕЖНА ЗИДАРИЯ ОТ КУХИ И ПЛЪТНИ ГЛИНЕНИ БЛОКОВЕ

Голубка Нечевска-Цветановска[1], Роберта Апостолска[2], Йордан Бояджиев[3]

EXPERIMENTAL INVESTIGATIONS OF THREE-STOREY RC BUILDING WITH HOLLOW AND SOLID MASONRY INFILL

Golubka Necevska-Cvetanovska[1], Roberta Apostolska[2], Jordan Bojadjiev[3]

Abstract:
The design and construction of RC buildings with different types of masonry infill walls is one of the most common practices in structural engineering. In order to deepen the understanding of the behaviour of this kind of structures, a research project "Frame – Masonry Composites for Modelling and Standardizations (FRAmed-MAsonry)" was started at the Faculty of Civil Engineering in Osijek, Croatia (2014-2017). The principal investigator on this part was Prof. Dr. Vladimir Sigmund. The main objective was to investigate the safety and behavior of buildings with masonry-infilled RC frames through near full-scale dynamic earthquake-simulation tests accompanied by supporting pseudo-dynamic tests of structural assemblies and components and by calibrated analytical solutions. The Institute of Earthquake Engineering and Engineering Seismology, UKIM-IZIIS from Skopje was partner in the realization of the experimental investigations, which were carried out at the IZIIS Dynamic Testing Laboratory in the period June 2015-August 2015. The principal investigator on the part of UKIM-IZIIS was Prof. Dr. Golubka Necevska-Cvetanovska.
This paper presents the observations from a series of shaking-table tests done on a 1:2.5 scaled three story RC building with masonry infill walls. Two building models (MODEL 1 with hollow-clay infill walls and MODEL 2 with solid-clay infill walls) were designed and subjected to a tailor-made testing protocol to experience performance states between minor damage and near collapse.

Keywords:
Masonry Infills; Shaking Table Tests; RC Buildings; Damage.

1. INTRODUCTION

The Institute of Earthquake Engineering and Engineering Seismology, UKIM-IZIIS from Skopje following previous investigation in the area given in [2], [3], [7] and [9], was partner in

[1] Golubka Necevska-Cvetanovska, PhD/Professor, Institute of Earthquake Engineering and Ingeneering Seismology (IZIIS)/ University "Ss. Cyril and Methodius", Skopje, Republic of Macedonia, *e-mail*: golubka@pluto.iziis.ukim.edu.mk.
[2] Roberta Aposotlska, PhD/Professor, Institute of Earthquake Engineering and Ingeneering Seismology (IZIIS)/ University "Ss. Cyril and Methodius", Skopje, Republic of Macedonia, *e-mail*: beti@pluto.iziis.ukim.edu.mk.
[3] Jordan Bojadjiev, MSc/Teaching Assistant, International Balkan University (IBU), Skopje, Republic of Macedonia, *e-mail*: bojadziev@gmail.com.

the realization of the experimental investigations, which were carried out at the IZIIS Dynamic Testing Laboratory in the period June 2015-August 2015. The principal investigator from IZIIS side was Prof. Dr. Golubka Necevska-Cvetanovska.

The complete experimental programme consisted of:

- Laboratory tests of concrete, steel, masonry unit (bricks) and mortar specimens for definition of their strength characteristics;
- Quasi-static tests of 2 series (each consisting of 6 elements) of masonry wall samples in cement-lime mortar; the first one of hollow-clay masonry and the second one of solid-clay masonry bricks, for definition of their mechanical characteristics and failure mechanism *and*
- Shaking-table tests of the three models of three story RC building with hollow-clay masonry infill (MODEL 1), solid-clay masonry infill (MODEL 2) and innovative method for construction of infill walls (MODEL 3) to a scale 1:2.5.

This paper presents the observations from these series of shaking-table tests on a three story RC building with masonry infill walls carried out in the Dynamic Testing Laboratory of IZIIS in Skopje in the frames of the above mentioned research project FRAMA. The tests were expected to contribute to overcoming the contradictions within the research community regarding the influence of masonry infill on the seismic performance of such mixed structures. The three building models (MODEL 1, MODEL 2 and MODEL 3) were designed and subjected to tailor-made testing protocol to experience performance states between minor damage and near collapse.

2.1. Test Units

Definition of the test structures was governed by the aim to determine the failure mechanism of the column in shear. Studies of existing laboratory and field evidence highlighted five important constraints in development of proper experimental structure. It is essential: 1) to test the specimens in a dynamic (earthquake simulation) environment, 2) to have multiple stories in order to approach the fluctuations of axial force that a structural system which involves interactions of an RC frame with masonry infill walls would experience, 3) to use near full-scale materials and dimensions (masonry units, concrete aggregates, reinforcement, and mortar joints), 4) to include an intermediate column (a column between two walls) in the test structure, 5) to limit the building footprint to approximately 5 by 5 m and its weight to 45 tons because of the limits of the IZIIS shaking table.

The constraints have resulted in the choice of a three-story test structure with two bays in the assumed N-S direction and one bay in the E-W direction (Fig. 1). The height of the model was 3.9m. MODEL 1 structure had hollow-clay infill walls. MODEL 2 structure had solid-clay infill walls and for MODEL 3, an innovative method was applied in construction of the infill walls.

This paper shows the results from the experimental investigations carried out only for MODEL 1 and MODEL 2. The design of the two models was performed at the Faculty of Civil Engineering in Osijek, while building of the models and testing on the seismic shaking table were carried out in the Dynamic Testing Laboratory of IZIIS in Skopje. The artificial mass simulation law was applied to account for the scaling. Presented in the paper are selected observations only from the design, construction and shaking-table tests of the two models. Detailed information regarding the complete experimental programme is given in Necevska-Cvetanovska et al., (2015) [1].

The experimental programme for MODEL 3 is in the phase of realization and the obtained results will be published in the near future.

Figure 1. 3D view of MODEL 1, MODEL 2 and MODEL 3

The same bare RC frame structure was used for construction of MODEL 2. First, the damaged infill from the first and second story was demolished and removed from the structure. The next step was insertion of solid-clay masonry infill and vertical RC ties around the openings, (Fig. 2).

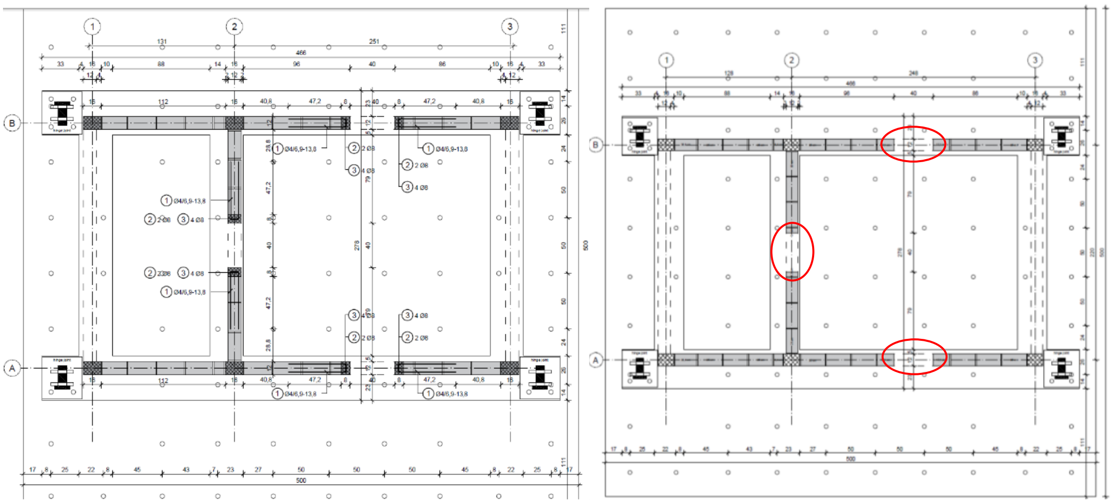

Figure 2. Layout of the models over the shaking table - MODEL 1 (left) & MODEL 2 (right)

3. SHAKING TABLE TESTS ON 1:2.5 SCALED MODELS

The shaking-table test were designed to address broader open issues within the FRAMA project as: 1) the relationship between the drift capacity and the properties of the frame-masonry system controlling the drift capacity, 2) the stability of the masonry infill walls subjected to out-of-plane inertia forces, 3) the effect of the openings in the masonry walls on the response of the frame-wall system, 4) the development and calibration of a new sensor to detect crack development and enable remote sensing of the safety state of a building after an earthquake.

The models were subjected to several runs of increasing intensity, covering performance levels between minor damage and near collapse. The damage propagation with an increasing shaking intensity is discussed and selected test results - acceleration time histories, relative displacement time histories and shift in measured frequencies due to damage propagation are presented.

4.1. Test observation regarding Model 1

Definition of the dynamic properties of MODEL 1 was the first step of the experimental testing, which enabled acquiring of important information about the achieved stiffness (natural frequencies) of the model. The natural frequency was defined in the Y direction of the model, by applying resonant frequency search tests. The frequencies obtained before the start of the seismic response tests (tests 01 and 02) and during the testing sequences after reaching PGA = 0.4 g (test 08) are presented in Figure 3. The first frequency of the undamaged model was 8.785Hz, while after performing a series of five seismic response tests, the frequency was 3.047Hz. This emphasizes the reduction of the initial stiffness of the model due to the occurrence of damages, especially in the masonry infill.

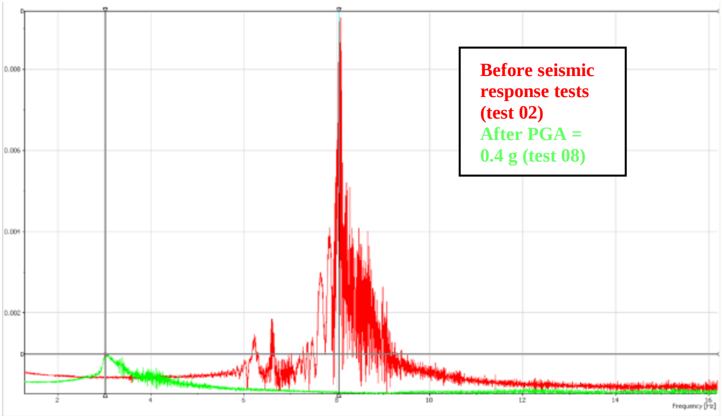

Figure 3. Obtained frequencies for MODEL 1

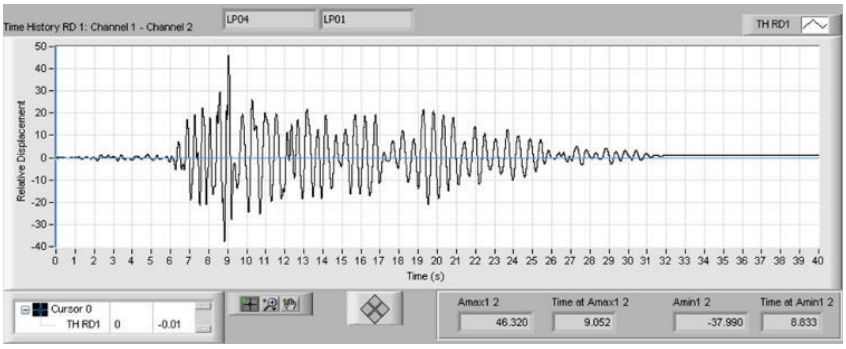

Figure 4. Relative displacement at the top of MODEL 1

The relative displacement of MODEL 1 defined as a difference between the recorded displacement at the top (linear potentiometer LP4) and at the bottom (LP1), at PGA = 1.2 g, is given in Figure 4. Selected photos showing the damage distribution on the model at PGA=1.2 g is presented in Figure 5.

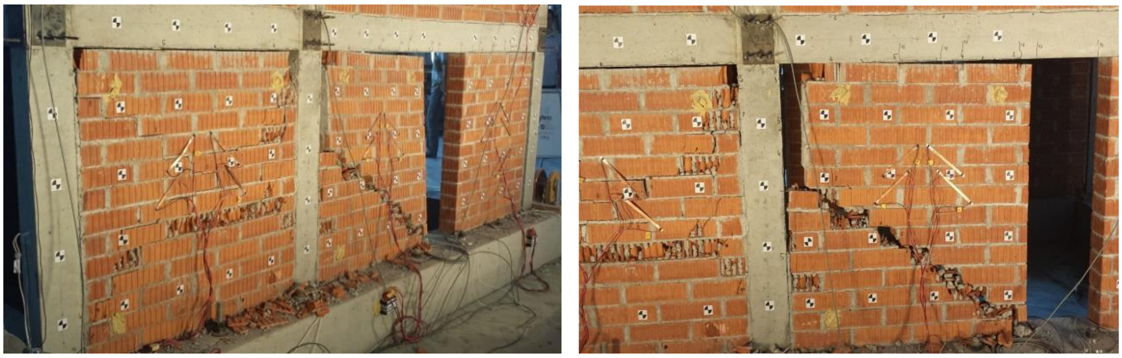

Figure 5. Damage to the infill of MODEL 1

4.2. Test Observation Regarding MODEL 2

Definition of dynamic properties of MODEL 2 was the first step of the experimental testing, which enabled acquiring of important information about the achieved stiffness (natural frequencies) of the model. The natural frequency was defined in the Y direction of the model by applying resonant frequency search tests. The frequencies obtained before the start of the seismic response tests (tests 01) and at the end of the testing (test 13) are presented in Figure 6. The other selected results obtained from the experimental testing will be presented further. The first frequency of the undamaged model was 7.51Hz, while at the end of the testing, the frequency was 3.11Hz. This emphasizes the reduction of the initial stiffness of the model due to the occurrence of damages, especially in the masonry infill.

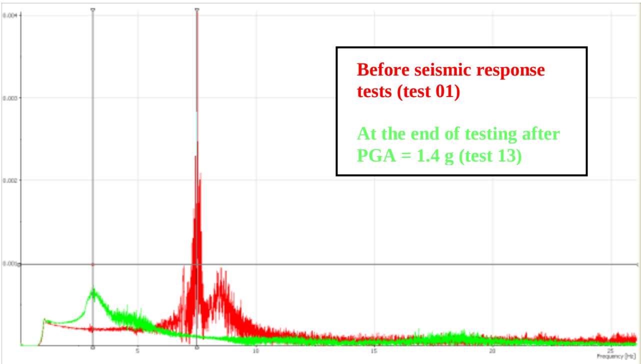

Figure 6. Obtained frequencies for MODEL 2

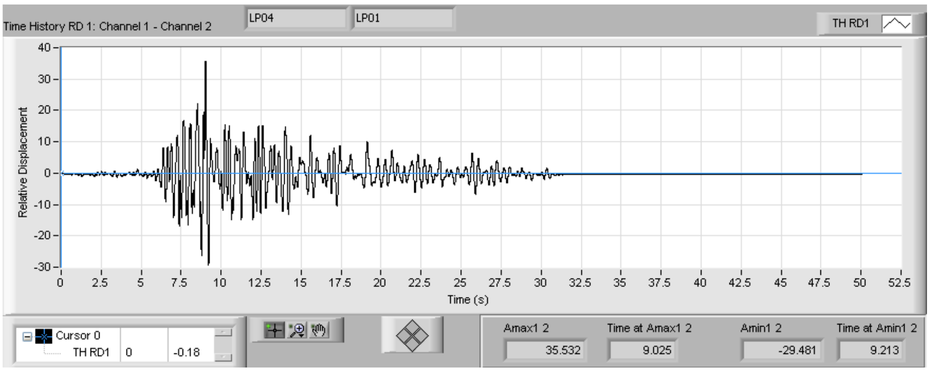

Figure 7. Relative displacement at the top of MODEL 2

The relative displacement of the MODEL 1 defined as a difference between the recorded displacement at the top (linear potentiometer LP4) and at the bottom (LP1), at PGA = 1.4g is given in Figure 7. Selected photos showing the damage distribution on the model at PGA=1.4g are presented in the Figure 8.

Figure 8. Damage to the infill of MODEL 2

5. CONCLUSIONS

The aim of the FRAMA project was to investigate, through dynamic earthquake-simulation tests, the safety and behaviour of the RC frame system containing different types of infill masonry walls since these systems serve both architectural and structural demands efficiently.

It should be pointed out that both models were subjected to the same experimental programme. However due to the higher resistance of the second model, the tests continued under higher intensities of input excitation. As a general observation from the performed tests, it can be said that MODEL 2 with solid-clay bricks and vertical RC ties around the openings has shown better performance compared to MODEL 1. The damage that appeared in the infill of MODEL 2 was considerably smaller than that of MODEL 1, even under a higher input acceleration.

6. ACKNOWLEDGMENTS

The authors would like to express their deepest appreciation to the exceptional academician Prof. Dr. Vladimir Sigmund for his leading role in the FRAMA project. Sadly, he was not able to complete this study because he passed away suddenly during the realization of the project. This paper is dedicated to his cherished memory.

The authors would also like to thank all participants who contributed to the realization of the experimental tests and to the staff of the Dynamic Testing Laboratory at IZIIS, Skopje.

REFERENCES

[1] Necevska-Cvetanovska G., Apostolska R., Shendova V., Stojanoski B., Zurovski A. (2015). Frame-Masonry Composites for Modelling and Standardizations (FRAmed-Masonry). *Report IZIIS* 2015-31.

[2] Apostolska R., Necevska-Cvetanovska G., Cvetanovska J., Gjorgjievska E. (2010). Influence of Masonry Infill on Seismic Performance of RC Frame Buildings. *Proc. of 14 European Conference on Earthquake Engineering*, Ohrid, 2010.

[3] Apostolska R., Golubka Necevska-Cvetanovska, Julijana Cvetanovska. (2010). Analytical Investigations of Seismic Behaviour of RC Frame Buildings with Masonry Infill. Structural Engineer, *Journal of MASE*, ISBN 9989-9785-3-0 (No.9/2010).

[4] Dolšek M, Fajfar P (2008). The Effect of Masonry Infills on the Seismic Response of a Four-Storey Reinforced Concrete Frame—a Deterministic Assessment. Eng Struct 30(7):1991–2001.

[5] EN 1998: (2004). Eurocode 8: Design of Structures for Earthquake Resistance. Part 1: General Rules, Seismic Actions and Rules for Buildings, 2004.

[6] Fardis M. (2006). Seismic Design Issues for Masonry – infilled RC Frames, *Proc. of the 13ECEE*, Geneva.

[7] Necevska-Cvetanovska, R. Apostolska. (2012). Methodology for Seismic Assessment and Retrofitting of RC Building Structures. *Proc. of 15 World Conference on Earthquake Engineering*, Lisboa, September 24-28, 2012, (Paper ID 2149).

[8] Shahram Taghavi, Eduardo Miranda (2003). Response Assessment of Nonstructural Building Elements, *PEER Report 2003/05*.

[9] Sendova et al. (2013). Experimental Verification of Innovative Technique for Seismic Retrofitting of Traditional Masonry Buildings, *Report IZIIS* 2013-44.