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SHAKE TABLE TESTS FOR SEISMIC QUALIFICATION OF PARTITION WALLS

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Abstract

Nonstructural components and systems represent more than 80 percent of the total investment in building construction and they are more vulnerable to earthquake shaking-induced damage than the primary structural system. This damage may result in loss of functionality, economic loss due to damage and even life safety hazards. Since they are not amenable to traditional structural analysis, full-scale experimental testing is crucial to understand their behaviour under earthquake. For this reason, shake table tests are performed to investigate the seismic behaviour of partition wall systems. A steel cube structure was properly designed in order to simulate the seismic effects at a generic building storey. Different types of panels, divided in two different layouts were tested. The first layout consisted of 10 different types of panels (unit1-10), whereas 14 type of partition walls (unit11-24) were taken into consideration in the second layout. All partition walls were supported on steel profiles set in a steel cube. Four different configurations were tested.

In this paper, will be presented results of the experimental testing performed at the Dynamic Testing Laboratory in the Institute of Earthquake Engineering and Engineering Seismology - IZIIS, Skopje, Republic of North Macedonia. Seismic certification of this systems has been conducted according to the standard AC-156 - Acceptance criteria for seismic qualification by shake table testing for nonstructural components. A lot of results have been obtained in terms of accelerations, displacements and strains in characteristic points. The systems showed good performance and it was confirmed that all acceptance criteria have been fulfilled during and after the seismic tests. Based on the complex experimental research it was observed that most of the tested nonstructural elements successfully passed the seismic acceptance criteria for shake table testing of non-structural components and systems according ICC AC-156.

Keywords: partition walls, shake table test, non-structural elements, standard AC-156

1. Introduction

Nonstructural components account for the majority of direct property losses due to earthquake damage. Although significant structural damage to modern buildings has generally been rare in moderately strong earthquakes, costly and disruptive nonstructural damage is much more widespread, and can result in additional economic losses from functionality and business interruptions. The loss related to the failure of nonstructural components may easily exceed the total cost of the building, if breakdown and loss of inventory are considered [1], [2].

These elements are housed or attached to the floors, roof, and walls of a building or industrial facility that are not part of the main or intended loadbearing structural system for the building or industrial facility, but may also be subjected to large seismic forces and must depend on their own structural characteristics to resist these forces (Villaverde 1997). Their behaviour is critical especially for strategic buildings that have to be operative immediately after an earthquake, also considering that these components usually exhibit damage even for low-intensity earthquakes. Their damage may cause the obstruction of the ways in or out of buildings, which can cause human suffocation.

The limited data collected during past events are not satisfactory to completely describe the seismic behaviour of nonstructural components and develop effective mitigation methods. Moreover, given the complexity of various typologies of nonstructural components subjected to seismic excitations, methodical experimental testing is necessary for a better understanding of their seismic behaviour. Different research studies can be found in the literature concerning the seismic and experimental assessment of nonstructural elements for the seismic performance. [3-7].

Based on the aforesaid causes, shake table testing according AC-156 standard of partition wall systems was conducted at the Dynamic Testing Laboratory at the Institute of Earthquake Engineering and Engineering Seismology, Skopje, Republic of North Macedonia. The representative specimens of partitions have been tested according to the aforementioned standard and have successfully met the requirements for their use in seismically active areas. The results will be presented in this paper.

2. Experimental facilities, Description of the Partition Walls and Testing protocol

2.1 Experimental facilities

The shake table tests were carried out at the laboratory for dynamic testing in IZIIS, Skopje, R. N. Macedonia in order to investigate the seismic behaviour of the partition walls. Two component 5x5m shake table (fig.1,left) was used characterized with 5 degrees of freedom with two lateral in one direction (Y1-2) and four vertical (V1-4) actuator(fig.1, right) The maximum payload is 400kN with a frequency range of 0.1–50Hz, peak acceleration equal to 3.0 g in horizontal direction and 1.5g in vertical direction. Maximum stroke in horizontal direction +/- 125mm and +/-60mm in vertical direction.

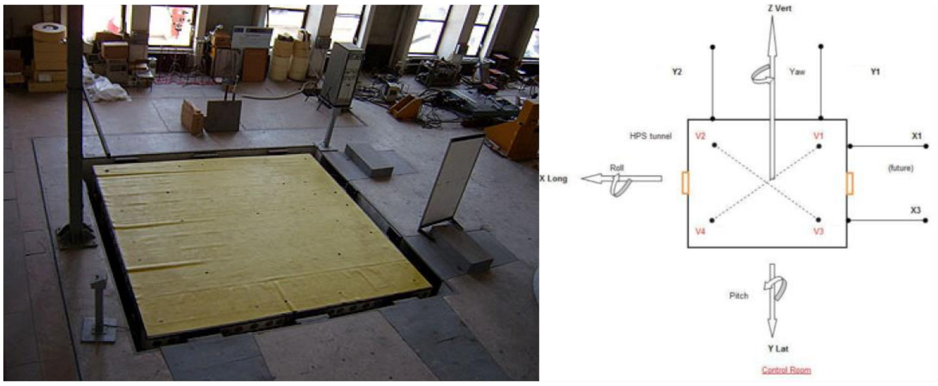
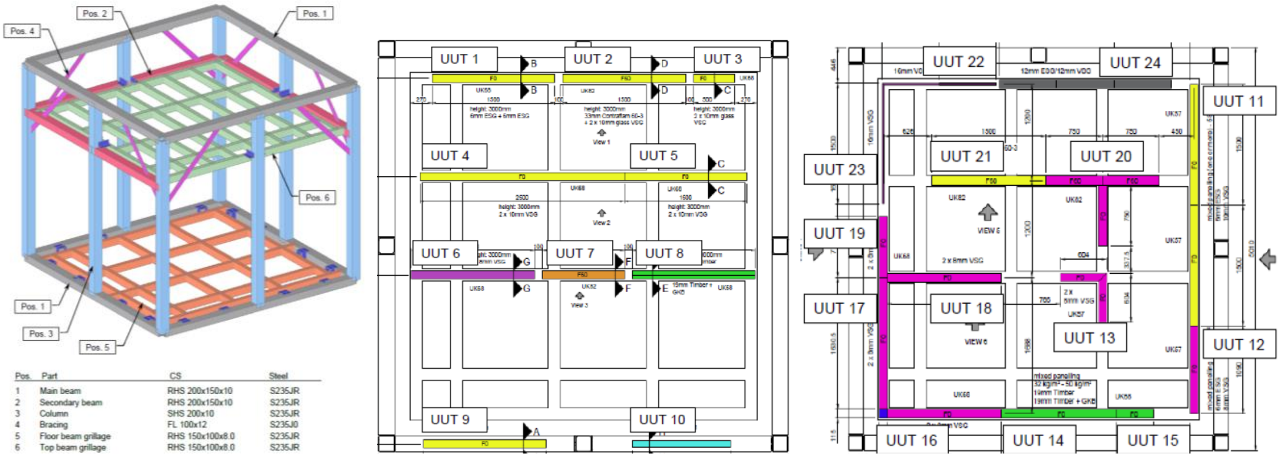


Fig. 1 IZIIS shake table (left), degrees of freedom (right)

2.2 Description of the partition walls

For the seismic certification of the partition walls according to AC156, 24 different types of panels, distributed in two different layouts were tested. The first layout consisted of 10 different types of panels (unit 1-10), whereas 14 type of partition walls (unit 11-24) were taken into consideration in the second layout. All partition walls were supported on steel profiles set in a steel cube. Inside the cube there were steel frames mounted at two different levels. The outer structure of the steel cube was welded on site. All profiles of the frame were connected to each other and to the steel cube by bolts. Details of the steel cube are given on fig.2



Pos.	Part	CS	Steel
1	Main beam	RHS 200x150x10	S235JR
2	Secondary beam	RHS 200x150x10	S235JR
3	Column	SHS 200x10	S235JR
4	Bracing	FL 100x12	S235J0
5	Floor beam grillage	RHS 150x100x8.0	S235JR
6	Top beam grillage	RHS 150x100x8.0	S235JR

Fig. 2 Details of the cube structure(left) and units in layot1 and layout2(right)

Four different configurations were tested. The first two configuration refer to the partition walls of layout 1, tested biaxial in both orthogonal directions (Y-Z and X-Z). The other two configurations, three and four, were related to layout 2, tested also biaxial in both orthogonal directions (Y-Z and X-Z).

Table 1: Characteristics of the tested partition walls in layout 1

UUT No.	Type	Height [mm]	Panelling	Weight [kg/m^2]
1	Life 137 – F0	3000	6mm ESG 6mm ESG	41
2	Life 137 – F60	3000	10mm VSG 10mm VSG	128
3	Life 137 – F0	3000	10mm VSG 10mm VSG	58
4	Life 137 – F0	3000	10mm VSG 10mm VSG	58
5	Life 137 – F0	3000	10mm VSG 10mm VSG	58
6	Life 125 – F0	3000	8mm VSG 8mm VSG	48
7	Life 110 – “F60”	3000	Contraflam 60-3 33mm	83
8	Logic timber	3000	19mm timber 19mm timber +GKB	41
9	Life 137 – F0	4000	10mm VSG 10mm VSG	58
10	Pharma 80C	4000	8mm VSG 8mm VSG	55

Table 2: Characteristics of the tested partition walls in layout 2

UUT No.	*Type*	*Height [mm]*	*Panelling*	*Weight [kg/m^2]*
11	Life 137 – F0 (2x)	3000	10mm VSG	41
			6mm ESG	
12	Life 125 – F0	3000	8mm VSG	128
			6mm ESG	
13	Life 125 – F0 (2x)	3000	8mm VSG	58
			8mm ESG	
14	Logic timber	3000	19mm timber	58
			19mm timber +GKB	
15	Logic timber	3000	19mm timber	58
			19mm timber +GKB	
16	Life 125 – F0	3000	8mm VSG	48
			8mm VSG	
17	Life 125 – F0	3000	8mm VSG	83
			8mm VSG	
18	Life 125 – F0	3000	8mm VSG	41
			8mm VSG	
19	Life 125 – F0	3000	8mm VSG	58
			8mm VSG	
20	Life 125 – F60 (2x) and F0 (1x)	3000	33mm Contraflam 60-3	55
			2 x 8mm VSG	
21	Life 137 – F60	3000	33mm Contraflam 60-3	/
			2 x 10mm VSG	
22	Life 620 – (2x)	3000	16mm VSG	/
23	Life 620	3000	16mm VSG	/
24	Life 622	3000	12mm ESG	/
			12mm ESG	

2.3 Instrumentation scheme of the tested configurations of partition walls

The response of the models was monitored by high speed data acquisition system and sensors consisting of 17 accelerometers (ACC), 15 linear variable differential transducers (LVDT) and 4 strain gages (SG), providing information about accelerations, displacement and deformation at different points (figure 3 to figure 6).

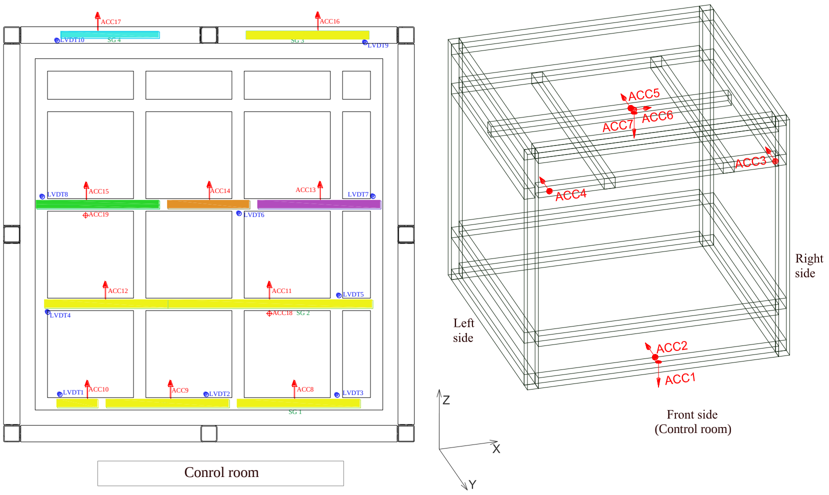


Fig. 3 Complete model instrumentation for the first configuration and the steel cube

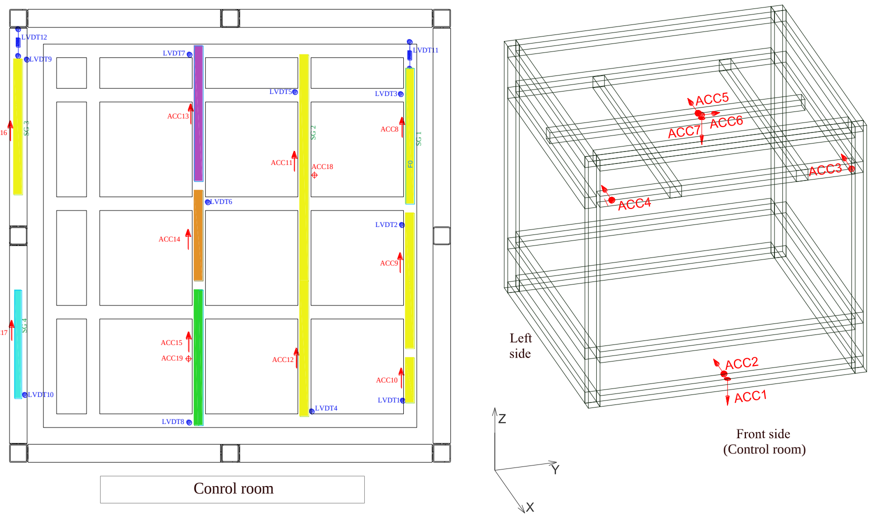


Fig. 4 Complete model instrumentation for the second configuration and the steel cube

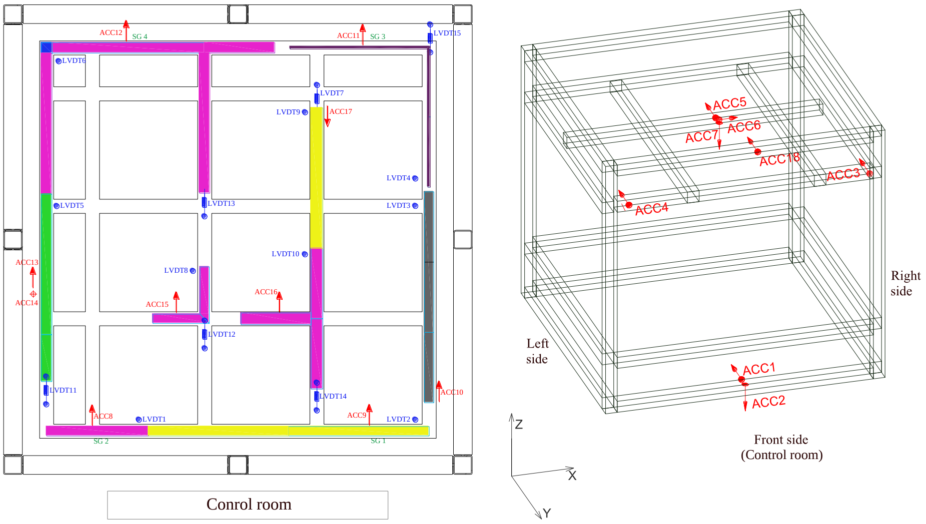


Fig. 5 Complete model instrumentation for the third configuration and the steel cube

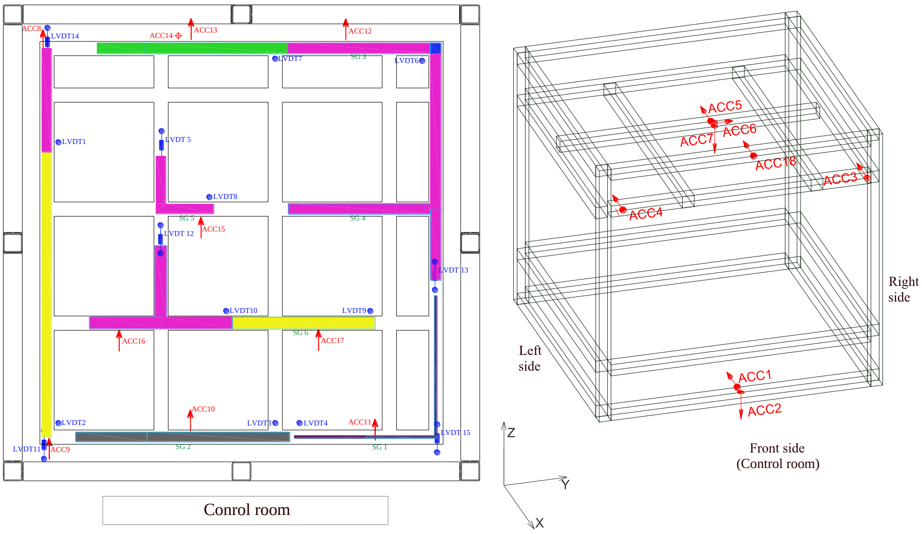


Fig.6 Complete model instrumentation for the fourth configuration and the steel cube

Fig. 7 Partition wall systems on the shake table (configurations 1 and 2)

Fig. 8 Partition wall systems on the shake table (configurations 3 and 4)

2.4 Input and testing protocol

The input to the shake table consists of two 40-s time histories representative of a target ground motion and acting biaxial along the horizontal and vertical directions; the time histories are artificially defined so as their response spectra match a target response spectrum derived using Equation 13.3-1 of ASCE 7 for the force formulation for non-structural components [8]:

$$F_p = \frac{0.4 a_p S_{DS}}{(R_p / I_p)} \left(1 + 2\frac{z}{h}\right) W_p \tag{1}$$

where a_p is the floor-to-component amplification factor, S_{DS} is the design spectral acceleration at short periods, W_p is the weight of the component, R_p is the component force reduction factor, I_p is the importance factor, and z/h is the relative height ratio where the component is installed.

The required response spectrum is defined by two spectral accelerations, A_{FLX} and A_{RIG}, which assume that the component amplification factor a_p is equal to 2.5 and 1, respectively, and R_p and I_p are equal to 1:

$$A_{FLX-H} = S_{DS}\left(1+2\frac{z}{h}\right) \quad A_{RIG-H} = 0.4\,S_{DS}\left(1+2\frac{z}{h}\right) \tag{2}$$

And for vertical response:

$$A_{FLX-V} = 0.67 * S_{DS} \qquad A_{RIG-V} = 0.27 * S_{DS} \tag{3}$$

A_{FLX} is the spectral acceleration acting on flexible components, characterized by a natural frequency ranging from 1.3 to 8.3 Hz, whereas A_{RIG} is representative of rigid components, that is, with natural frequency larger than 33.3 Hz. The defined response spectra envelop the target spectrum in the frequency range between 1.3 and 33.3 Hz and assumes a damping value equal to 5% of critical damping. In this range, they do not exceed the target spectrum by more than 30%. Furthermore, in cases where it can be shown that no resonance response phenomena exist below 5 Hz, the input spectrum is required to envelop the target spectrum only down to 3.5 Hz. When resonance phenomena exist below 5Hz, the input spectrum is required to envelop target spectrum only down to 75% of the lowest frequency of resonance [8]. The obtained input acceleration time history plots and the corresponding Test Response Spectra (TRS) that match the Required Response Spectra given in AC 156 are shown in figure 9.

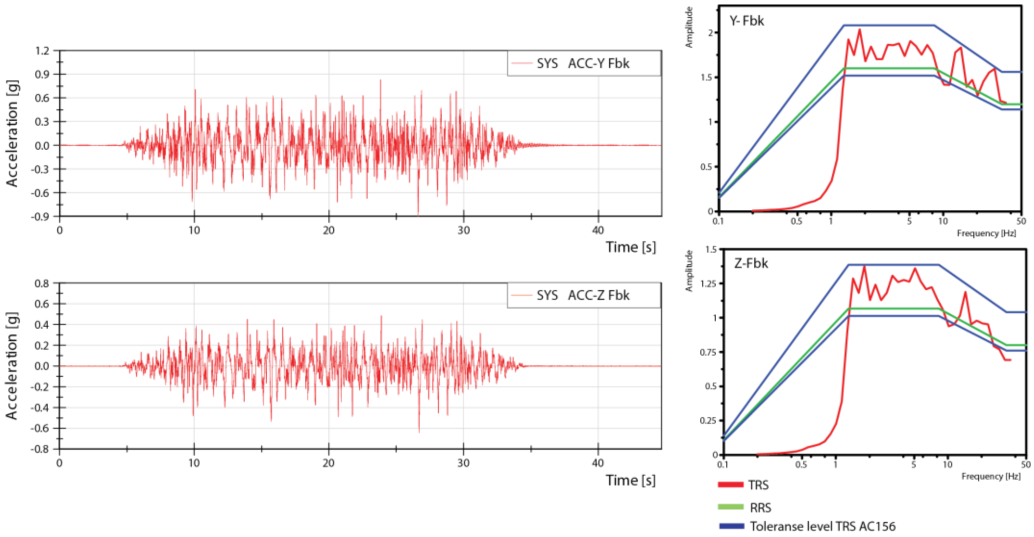


Fig. 9: Input time history and TRS (red) vs RRS in horizontal (Y Fbk) and in vertical direction (Z Fbk)

3. Discussions and results

The test method consisted of the following activities:

- Resonant frequency search tests
- Bi-axial time history shake table testing in Y – Z principal axis simultaneously
- Bi-axial time history shake table testing in X – Z principal axis simultaneously

According to the 6.4.1.2 of AC156, Bi-axial time history testing method has been chosen to conduct the time history tests (table 3). Bi-axial time history tests, in accordance with 6.5 Multi-frequency Seismic Simulation Tests of AC156, were carried out with simultaneous inputs in the horizontal and vertical axes, each producing the Required Response Spectrum (RRS) along the respective reference axis calculated with 1/6 octave of frequency bandwidth and 5% damping and prescriptions reported in AC156.

Table 3: Performed tests for all configurations

Test No.	Direction	Type of excitation	Input acc. [g]	
			Hor.	Ver.
Configuration 1-4 – layout 1,2, 0°/90°				
1	Horizontal	Sine sweep, Y/X-dir.	0.05	/
2	Vertical	Sine sweep, Z-dir.	/	0.05
3	Biaxial	AC 156, Y/X-Z, 25%	0.19	0.13
4	Biaxial	AC 156, Y/X-Z, 50%	0.36	0.25
5	Biaxial	AC 156, Y/X-Z, 100%	0.80	0.60
6	Horizontal	Sine sweep, Y/X-dir.	0.05	/
7	Vertical	Sine sweep, Z-dir.	/	0.05

For resonant frequency search sine sweep tests have been applied in horizontal and vertical direction independently, in the range of 1.0 to 35.0Hz with peak excitation level of 0.05g. Resonant frequency search tests were performed at the beginning (initials) and after final time history test.
Based on the obtained results it can be seen that there is a decrease in frequencies starting from 5% up to 55% for different units presented in table 4, which results to degradation of stiffness and damages with collapse of Unit 8 and Unit 9 (layout 1, configuration 2) (figure 10).

Table 4: Measured frequencies for the partition walls before and after seismic test

Configuration 1 – layout 1, 0° Y-dir			Configuration 2 – layout 1, 90° X-dir		
Type	Initial test frequency [Hz]	Final test frequency [Hz]	Type	Initial test frequency [Hz]	Final test frequency [Hz]
UUT 1	6.66	6.5	UUT 1	11.17	10.7
UUT 2	4.45	3.1	UUT 2	11.50	10.4
UUT 3	10.0	9.5	UUT 3	11.7	10.2
UUT 4	3.8	3.5	UUT 4	11.71	9.2
UUT 5	3.7	3.5	UUT 5	11.8	9.6
UUT 6	6.13	6.0	UUT 6	5.6	3.3
UUT 7	5.12	4.3	UUT 7	11.2	10.7
UUT 8	6.0	5.8	UUT 8	6.1	3.3
UUT 9	3.7	3.5	UUT 9	11.4	5.2
UUT 10	3.8	3.7	UUT 10	6.6	3.2
Configuration 3 – layout 1, 0° Y-dir			**Configuration 4 – layout 1, 90° X-dir**		
UUT 11	5.7	5.0	UUT 11	9.8	9.3
UUT 12	5.6	5.1	UUT 12	9.8	9.3
UUT 13	9.5	9.2	UUT 13	9.9	9.6
UUT 14	9.6	9.3	UUT 14	9.5	4.8
UUT 15	N/A	N/A	UUT 15	N/A	N/A
UUT 16	N/A	N/A	UUT 16	5.4	4.8
UUT 17	8.3	7.2	UUT 17	N/A	N/A
UUT 18	N/A	N/A	UUT 18	N/A	N/A
UUT 19	N/A	N/A	UUT 19	N/A	N/A
UUT 20	9.5	9.0	UUT 20	8.4	7.0
UUT 21	9.0	8.9	UUT 21	4.9	2.7
UUT 22	N/A	N/A	UUT 22	N/A	N/A
UUT 23	7.2	7.2	UUT 23	6.6	6.4
UUT 24	8.4	8.3	UUT 24	6.0	5.7

Fig.10: Photos showing damages of partition walls

For the maximum intensity of bi-axial tests (input intensity a_y=0.8g and a_z=0.7g), the response of partition walls is presented in terms of accelerations, displacements and strains. Some of response time histories are given on figure 11, while maximal accelerations, displacements and strains are presented in the tables 9, 10 and 11, respectively.

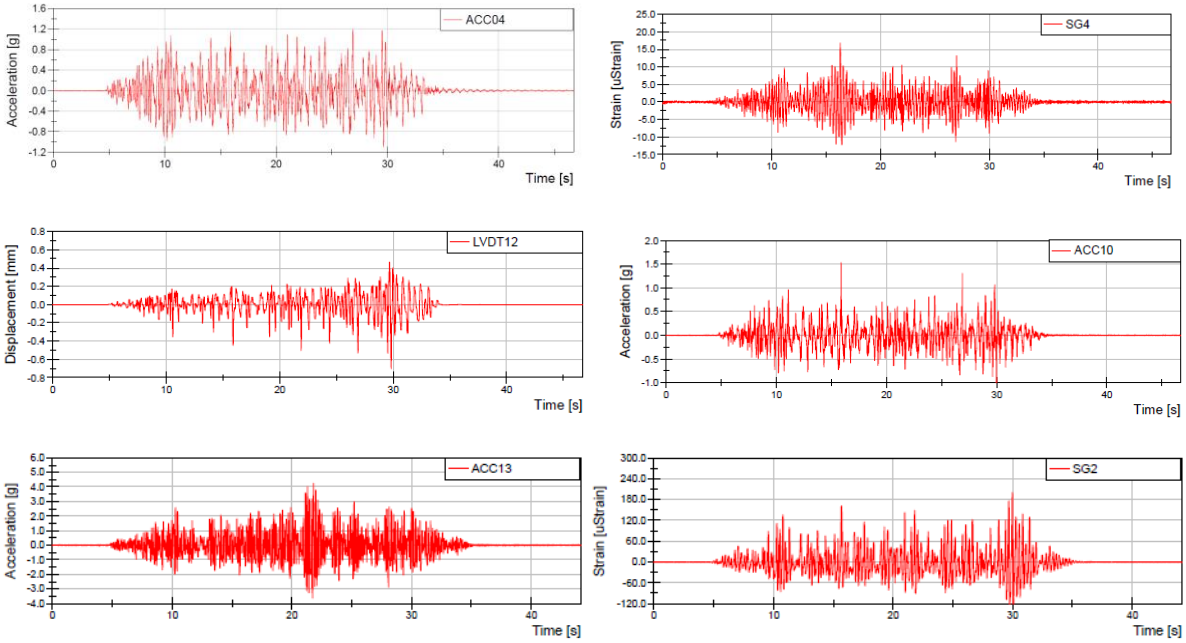


Fig. 11. Response time histories for the partition walls system

The maximum amplification factor of acceleration was obtained with value of 8.5, according to the measured acceleration of 6.8g in the first configuration, while for the other three configurations the amplifications were 7.8, 5.3 and 10.6 according to the measured acceleration of 6.3g, 4.3g and 8.5g, respectively. The maximum displacement was obtained of 13.2mm for configuration 1, while for the second, third and fourth configurations the displacements were 9mm, 8.4mm, 10mm respectively. The maximum measured strain were obtained for the first configuration of 200 µstrain. All the commented results are given in the tables bellow.

Table 5: List of maximum accelerations – layout 1 and layout 2

ACC 1 (g)	ACC 2 (g)	ACC 3 (g)	ACC 4 (g)	ACC 5 (g)	ACC 6 (g)	ACC 7 (g)	ACC 8 (g)	ACC 9 (g)	ACC 10 (g)	ACC 11 (g)	ACC 12 (g)	ACC 13 (g)	ACC 14 (g)	ACC 15 (g)	ACC 16 (g)	ACC 17 (g)	ACC 18 (g)	ACC 19 (g)	
0.8	0.8	1.1	1	1.2	0.5	0.9	5.5	5.8	2.9	6.8	2.6	4.2	3.9	4.6	3.6	5.2	3.3	1.4	**C1**
0.8	/	1.1	1.2	1.1	0.5	1.5	1.2	1.5	1.5	1.7	2	1.4	1.9	1.1	0.4	6.3	3.1	1.7	**C2**
/	/	1.1	0.9	0.9	0.2	1	3.2	4.3	1.3	2.6	/	1.1	0.6	1.1	1.5	1.3	1.1	/	**C3**
0.8	0.8	1	2.1	1	0.3	0.9	1.3	1.5	5	2.5	4.5	8.5	5.6	1.4	2.2	5.6	1.2	/	**C4**

Table 6: List of maximum displacement – layout 1 and layout 2

LVDT1 (mm)	LVDT2 (mm)	LVDT3 (mm)	LVDT4 (mm)	LVDT5 (mm)	LVDT6 (mm)	LVDT7 (mm)	LVDT8 (mm)	LVDT9 (mm)	LVDT10 (mm)	LVDT11 (mm)	LVDT12 (mm)	LVDT13 (mm)	LVDT14 (mm)	LVDT15 (mm)	
0.5	13.2	1.2	0.9	2.6	0.1	1.4	1.2	0.4	1.4	/	/	/	/	/	**C1**
2.7	2.2	0.7	3.7	1.9	0.2	3.4	9	/	5	2.8	0.7	/	/	/	**C2**
0.8	1.6	0.7	0.7	0.8	0.7	2.8	0.8	2.4	0.3	2.5	2.4	4	8.4	/	**C3**
/	1	0.8	3	2.2	1	/	0.6	1.5	1.3	5.6	10	4.5	5	0.6	**C4**

Table 7: List of maximum strains – layout 1 and layout 2

SG1 (µstrain)	SG2 (µstrain)	SG3 (µstrain)	SG4 (µstrain)	
78	200	115	136	**C1**
19	13	/	16	**C2**
175	91	81	171	**C3**
157	190	137	72	**C4**

4. Conclusions

Nonstructural elements comprise a large portion of building inventory. During an earthquakes, it is evident that these elements have sustained damage in moderate events and in well-designed buildings, resulting in loss of operation and extensive repair costs. For their use, it is necessary to verify their seismic performance according the prescribed standards. The testing was performed at the Dynamic testing laboratory of the Institute of Earthquake Engineering and Engineering Seismology, “University of St. Cyril and Methodius” Skopje, Republic of N. Macedonia.

According to the AC156 acceptance criteria for seismic qualification by shake table testing of non-structural components and system terminology, the type of seismic qualification of the partition walls was “qualification by biaxial testing”, in horizontal and vertical direction simultaneously, with maximum acceleration a_y=0.8g and a_z=0.6g.

Different types of panels, divided in two different layouts were tested. The first layout consisted of 10 different types of partition walls (unit1-10), whereas 14 type of partition walls (unit11-24) were taken into consideration in the second layout. It has to be point out that only two types of partition walls suffered a damages with collapse, while the other partitions resisted all the applied excitations, without any significant and visible damages.

Based on the complex experimental research realized in DYNLAB-IZIIS it was observed that most of the tested partition walls successfully passed the seismic acceptance criteria for shake table testing of non-structural components and systems according ICC AC-156.

6. References

[1] Taghavi S, Miranda E. (2003): Response assessment of nonstructural building elements, PEER report 2003/05. College of Engineering, University of California Berkeley, USA

[2] Earthquake Engineering Research Institute (EERI) (1984): Nonstructural Issues of Seismic Design and Construction, Publication 84-04. Berkeley, CA, USA.

[3] Lee TH, Kato M, Matsumiya T, Suita K, Nakashima M. (2007): Seismic performance evaluation of non-structural components: Drywall partitions. Earthquake Engineering & Structural 561 Dynamics; 36(3):367-382. DOI:10.1002/Eqe.638.

[4] Restrepo JI, Lang AF. (2011): Study of Loading Protocols in Light-Gauge Stud Partition Walls. Earthquake Spectra; 27 (4): 1169-1185. DOI:10.1193/1.3651608.

[5] Magliulo G, Petrone C, Capozzi V, Maddaloni G, Lopez P, Manfredi G. (2014): Seismic performance evaluation of plasterboard partitions via shake table tests. Bulletin of Earthquake Engineering; 12 (4): 1657-1677. DOI: 10.1007/s10518-013-9567-8.

[6] Cosenza E, Di Sarno L, Maddaloni G, Magliulo G, Petrone C, Prota A. (2014): Shake table tests for the seismic fragility evaluation of hospital rooms. Earthquake Engineering and Structural Dynamics; 44(1):23-40. DOI:10.1002/eqe.2456.

[7] Soroushian S, Maragakis EM, Ryan KL, Sato E, Sasaki T, Okazaki T, Mosqueda G. (2016) Seismic Simulation of an Integrated Ceiling-Partition Wall-Piping System at E-Defence. II: Evaluation of Nonstructural Damage and Fragilities. Journal of Structural Engineering; 142 (2): 04015131. DOI: 10.1061/ (ASCE) ST.1943-541X.0001385.

[8] ACCEPTANCE CRITERIA FOR SEISMIC CERTIFICATION BY SHAKE-TABLE TESTING OF NONSTRUCTURAL COMPONENTS - AC156, Approved October 2010 (Editorially revised May 2015).

[9] Krstevsks L., Bogdanovic A., Markovski I., Poposka A., Filipovski D., Shoklarovski A.(2019), Seismic Certification of Partition Walls According to AC156 Report IZIIS 2019-51, Institute of Earthquake Engineering and Engineering Seismology, Macedonia.