SEISMIC TESTING OF NON-STRUCTURAL SYSTEMS

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Abstract

Non-structural elements are more vulnerable to earthquake shaking-induced damage than primary structural systems. Their failure during earthquakes can cause significant disruption and economic loss, while their good performance can save lives and eliminate costs. Since they are not compliant with traditional structural analysis, full-scale experimental testing is crucial to understand their behavior under earthquakes.

This paper presents the results obtained during the experimental testing of non-structural elements including raised floors, ceiling and cleanroom systems, performed at DYNLAB - IZIIS, Skopje, Republic of North Macedonia. The systems have been certified following the requirements of the standard AC-156 - Acceptance criteria for seismic qualification by shake table testing for nonstructural components. For this purpose, a steel cube structure was properly designed as a basic structure in order to simulate the dynamic effects. Inside the steel cube, different types and configurations of non-structural elements were implemented. The response of the systems was followed by measuring accelerations, displacements and strains at characteristic points. The systems, in general, showed good performance and it was confirmed that most of the tested nonstructural elements fulfilled the acceptance criteria of the considered standard during and after the seismic tests.

Keywords: non-structural elements,shake table, seismic testing, standard AC-156.

1. Introduction

The use of nonstructural elements in modern buildings like industrial and business centers or in laboratories and hospitals with precious equipment is increasingly gaining attention due to the intensity of their implementation as well as their value. Even though they are considered as completely nonstructural elements, in the events of earthquakes, they are more vulnerable than the primary system. Their damage may result in loss of functionality, economic loss due to damage and even life safety hazards [1,2]. Since there are many different types of products whose seismic response has not been fully experimentally investigated and there is lack of strict design standards, the investors require seismic certification by shake table testing.

For the purpose of seismic qualification of specific types of raised floors, ceilings and cleanroom systems by shake table testing in the Institute of Earthquake Engineering and Engineering Seismology in Skopje, Republic of N. Macedonia, a series of shaking table seismic tests have been performed according to the ICC AC-156 criteria [3]. Analysis of dynamic behavior has been performed and results on earthquake response of the considered elements have been obtained.

Many different configurations of products were tested based on the most frequent installation scenarios. Hence, there were 32 different raised floor configurations, varying in height, constraints, etc., 6 ceiling configurations and 11 cleanroom system configurations. All of them were subjected to biaxial, artificially produced earthquake excitation time history. Although most of these successfully fulfilled the standard requirements, valuable data in terms of accelerations, relative and absolute displacements as well as strains in selected elements have been acquired. These are briefly presented in this paper.

2. Testing Procedure

The testing program has been selected to comply with the seismic certification test procedure described in chapter 6 of AC156 - Acceptance Criteria for Seismic Certification by Shake Table Testing of Non-structural Components [3]. Specifically, the criteria require simultaneous testing in both horizontal and vertical direction. Each specimen was tested under two different types of excitations, resonant frequency search excitations and time-history seismic excitations, for determination of the natural frequencies of the specimens and the global dynamic response, respectively. All non-structural elements were tested in the Laboratory for Dynamic Testing in the Institute of Earthquake Engineering and Engineering Seismology. The IZIIS' shake table comprises a 5m by 5m platform supported by two lateral and four vertical actuators, providing 5 degrees-of-freedom (DOF). The table can carry up to 40 tons and a peak table acceleration of 3.0g with peak displacements of ±125mm in horizontal direction and acceleration of 1.5g with peak displacement of ±60mm in vertical direction. The shake table uses new, state-of-the-art digital control system produced by MTS and data acquisition system produced by National Instruments.

2.1 Resonant Frequency Test

For the resonant frequency search tests, random and sine sweep excitations have been applied in each direction, horizontally and vertically independently, before testing of each specimen (initial state), after certain biaxial tests and after all performed tests (final state). The performed random and harmonic tests were in a frequency domain of 1.0-35.0(40.0) Hz, with sweep rate of 2.0 octave/min and with peak excitation level of 0.01g-0.05g, in horizontal and vertical direction. Beside the standard resonant tests performed for each type of non-structural elements, additional sine-sweep tests were carried out for determination of the dynamic characteristics for different size and height of raised floor systems. These excitations were performed with 0.02g input acceleration in both X and Z direction, in frequency range of 1.0-40Hz and 1.0-45.0Hz for Y and Z direction, respectively.

2.2 Seismic Tests

The main purpose of the testing procedure is to generate acceleration or test spectrum time histories in accordance with the prescribed standardized spectra in vertical and horizontal directions, respectively.

Bi-axial time history tests, in accordance with the 6.5 Multi-frequency Seismic Simulation Tests of AC156 [3], were carried out by simultaneous, but independent inputs in the horizontal and vertical axes, each producing the Required Response Spectrum (RRS) along the respective reference axis calculated with 1/12 octave of frequency bandwidth, 5% damping and prescriptions reported in AC156. The non-symmetric, non-structural elements were rotated for 90° in order to test each direction. The tests were conducted by gradually increasing the intensity of the time history earthquake, starting with 0.23g and 0.17g and finishing with 0.92g and 0.64g in Y and Z direction, respectively. Figure 1 shows the maximum input acceleration time history plots in horizontal and vertical direction as well as the corresponding Test Response Spectra (TRS) that match the Required Response Spectra given in AC 156.

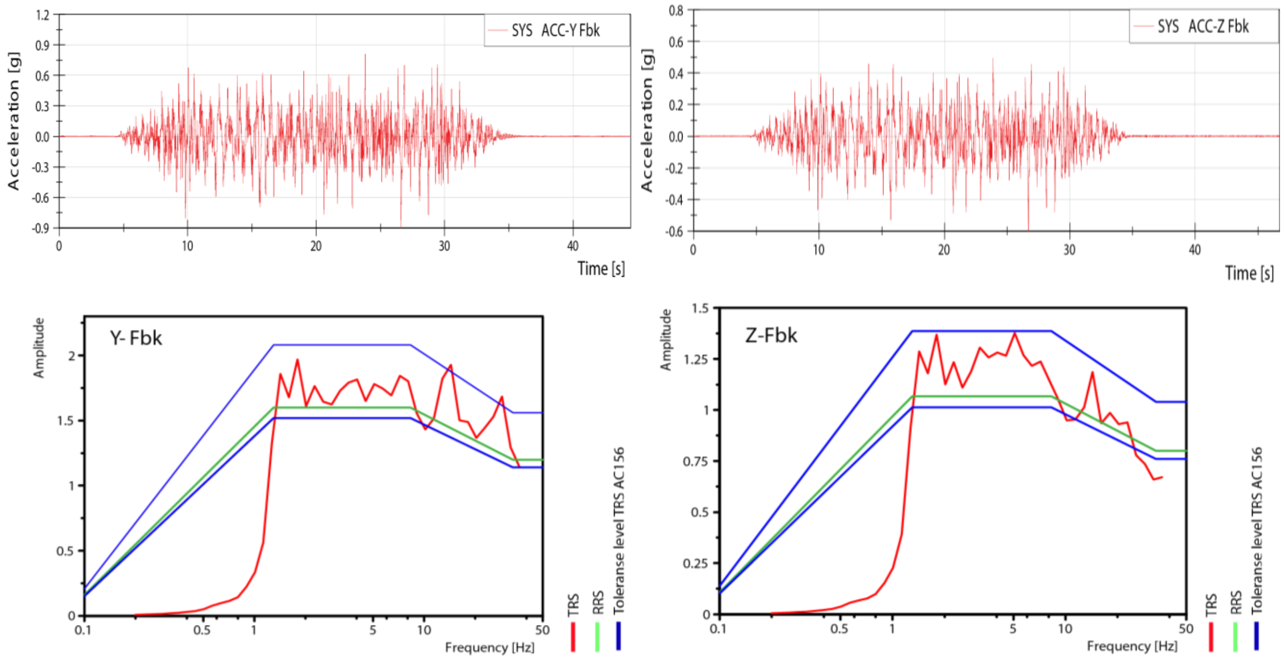

Fig. 1 – Input time histories of the test with the highest excitation and TRS vs RRS.

3. Raised Floors

Raised floors represent nonstructural system of elements designed in order to provide a clear walkable area on top and underneath. Different types of installations might be provided.

3.1 Description of the Tested Specimen

The tested units consisted of vertical bearing support elements, steel pedestals with varying heights of 0.5m, 1.0m and 1.5m, fixed on the bottom and on the top, connected by a grid of perpendicular steel beams, each one of them intersecting the longitudinal axis of the pedestals [4,5,6]. The longitudinal and transverse distance between the pedestals was 0.6m, i.e., the same as the sides of the floor panels. The only major difference between the setups were the 0.5m tall raised floors, where on the top of the pedestals, the floor panels were put directly on special shaped joints on the pedestals, without the steel beam grid substructure. Additionally, the different configurations varied in terms of bracings, i.e., they were without and with adjustable steel bracings inserted in order to limit the horizontal motions of the raised floor sub-structure. Depending on the type of the raised floor, different bracings were used.

In order to additionally explore the behavior of the increasing number of modules, a varying number of panels were tested, i.e. one panel, three by three, five by five and seven by seven panels, filling the space in the steel cube representing a real life scenario where the floor is constrained by the elements of the primary structural system, resulting in 32 different configurations.

The last variation considered in the investigation was the type and amount of additional load added to the floor panels, simulating distributed and concentrated load.

In figure 2, a five by five panel configuration without the additional load from the 1.0m tall pedestals is shown on the left and a view of a raised floor structure from the bottom is shown on the right side.

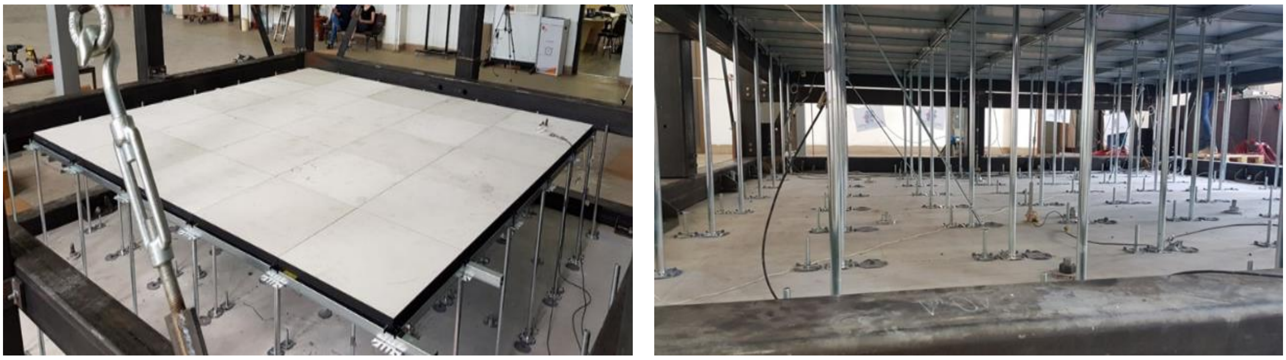

Fig. 2 – Five by five panel configuration – left. Raised floor structure – right.

3.2 Instrumentation

The specific and numerous experimentally tested raised floor configurations had a type of modular instrumentation that was easily adjustable as the number of panels was increasing. Four different types of transducers, namely, accelerometers (ACC), linear potentiometers (LP), linear variable differential transformers (LVDT) and strain gauges (SG) were installed to measure acceleration, absolute displacement and relative displacement. Their precise placement on the raised floor structure and steel cube is shown in figure 3.

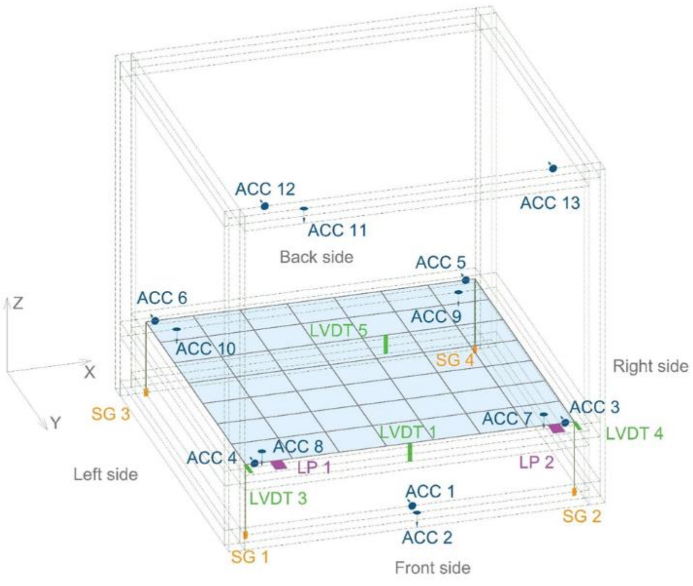

Fig. 3 – Instrumentation set up for a raised floor system

3.3 Selected Results

For the 1m high raised floor systems, based on the presented results, the following frequencies in horizontal direction were obtained: for the configuration with bracings starting from 1x1 panel, 3x3 panels, 5x5 panels and 7x7 panels, frequencies of 30.02Hz, 11.35Hz, 7.32Hz, 6.19Hz were measured, respectively (figure 4 – left). It was observed that the increase of the number of panels led to a decrease of the value of the resonant frequency. The same tendency is visible for the panels without bracings where, in the same configurations, the measured respective frequencies of 6.36Hz, 4.25Hz, 3.81Hz, 4.67Hz are significantly lower compared to the previous ones (configurations with bracings) due to the lower stiffness. If the results obtained for the frequencies are compared, it is clear that the increased number of panels and the use of bracings significantly reduce the value of the resonant frequency.

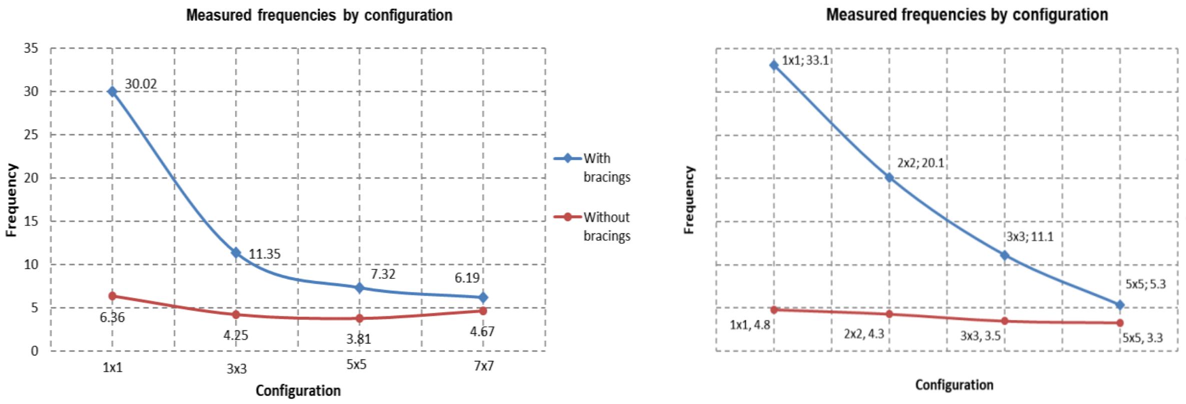

Fig. 4 – Change of dynamic characteristics of raised floors (left 1.0m high, right 1.5m high)

Analyzing the 1.5m high raised floor system, the following frequencies in horizontal direction were obtained: for the configuration with bracings starting with 1x1 panel, 2x2 panels, 3x3 panels and 5x5 panels, frequencies of 33.1Hz, 20.1Hz, 11.1Hz, 5.3Hz were measured, respectively (figure 4 – right). It can also be observed that the increase of the number of panels leads to a decrease of the value of the resonant frequency. The presence of bracings had a clear influence on the frequency value. The removal of the bracings leads to stiffness degradation of the floor and lower frequency value. A similar tendency is also visible in the case of panels without bracings where, for the same configurations, the measured frequencies of 4.8Hz, 4.3Hz, 3.5Hz, 3.3Hz, respectively, are significantly lower compared to the configurations with bracings due to the lower stiffness.

The plots in figure 5 and figure 6 show the input acceleration time history versus the acceleration time history at the level of floor panels. The maximum input acceleration is 0.85g and the top acceleration with certain amplification ranges from 3.7g to 5.1g for the specific measured points.

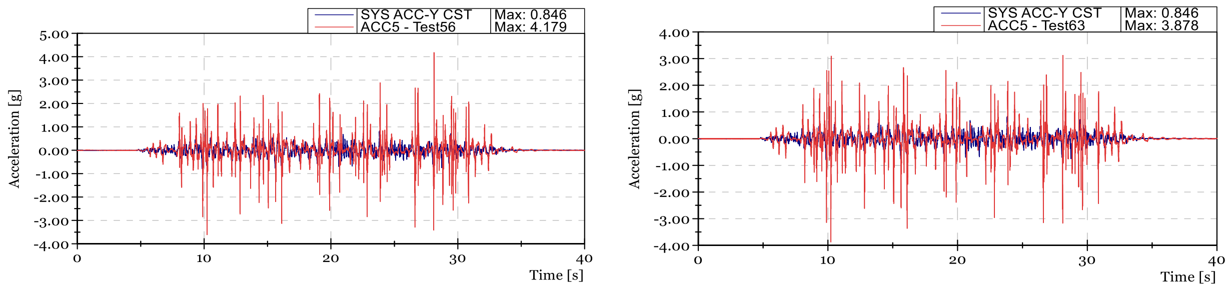

Fig. 5 – Input TH vs output TH of acceleration at point 5, left – braced, right – unbraced, 1.0m high.

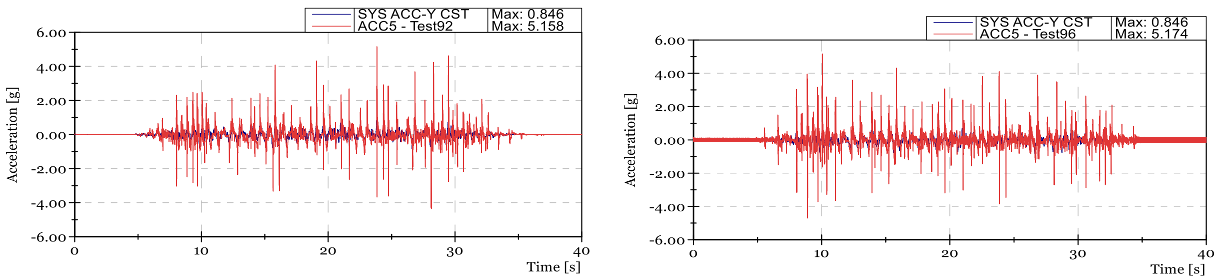

Fig. 6 – Input TH vs output TH of acceleration at point 5, left – braced, right – unbraced, 0.5m high.

Related to the dynamic behavior during the most intensive seismic tests, there was noticeable sliding and slight separation of the panels, but there was no damage of the elements of the system and no change in the stability of the tested configurations.

4. Ceiling Systems

Ceiling systems represent suspended nonstructural elements intended to architecturally form space and simultaneously provide space for the necessary air ventilation systems or other types of installations.

4.1 Description of the Tested Specimen

Testing of ceiling systems has been carried out by examining 10 different types of panels divided into two layouts [7]. Each layout consisted of 5 different types of panels, supported by steel profiles set in a basic steel cube. Both layouts were tested biaxially in both orthogonal directions (Y-Z and X-Z). For the ceilings of layout 1, some additional components as seismic clips, screws and stoppers were used, while for the ceilings of layout 2, stoppers and ropes were used. During the tests, additional load of different weight was added to some of the panels simulating real-life exploitation scenarios.

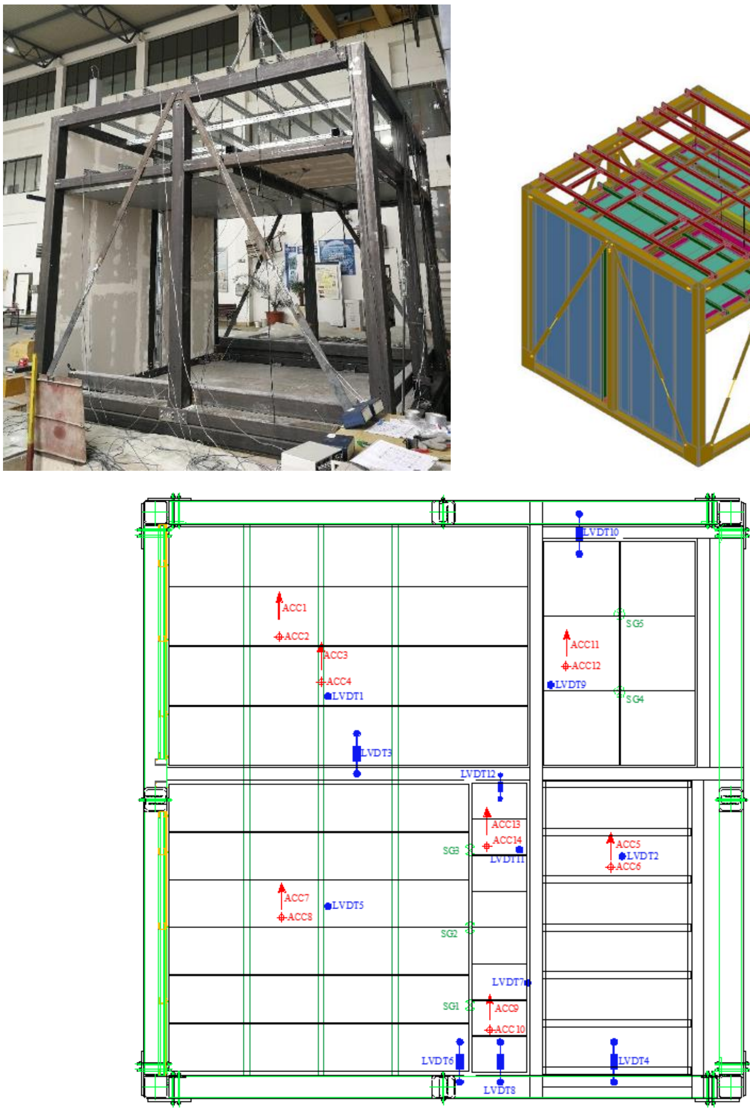

Fig. 7 – Ceiling systems - test setup and instrumentation.

4.2 Instrumentation

The testing protocol consisted of sine sweep tests and biaxial test, simultaneously in horizontal and vertical direction, according to the general testing methodology. A total number of 46 tests were performed for testing all 6 configurations. The response of the models was monitored by high speed data acquisition system and sensors consisting of 20 accelerometers (ACC), 12 linear variable differential transducers (LVDT), 1 linear potentiometer (LP) and 5 strain gages (SG), providing information about accelerations, relative and absolute displacement and deformation at different points. Graphical representation as well as photo of the test setup and instrumentation are shown in figure 7.

4.3 Selected Results

The maximum relative horizontal displacement of the most flexible ceiling panel was 13.5mm measured by LVDT 1 (Layout 1 – Configuration 1), while the maximum relative vertical displacement between the steel profile and the panel was 14.9mm as measured by LVDT1 (Layout 1 – Configuration 2), figure 8. The maximum measured acceleration in horizontal direction was 4.25g (accelerometer ACC01) and the maximum measured acceleration in vertical direction was 3.20g (accelerometer ACC02) (Layout 1 – Configuration 2). The selected time histories are shown in figure 9.

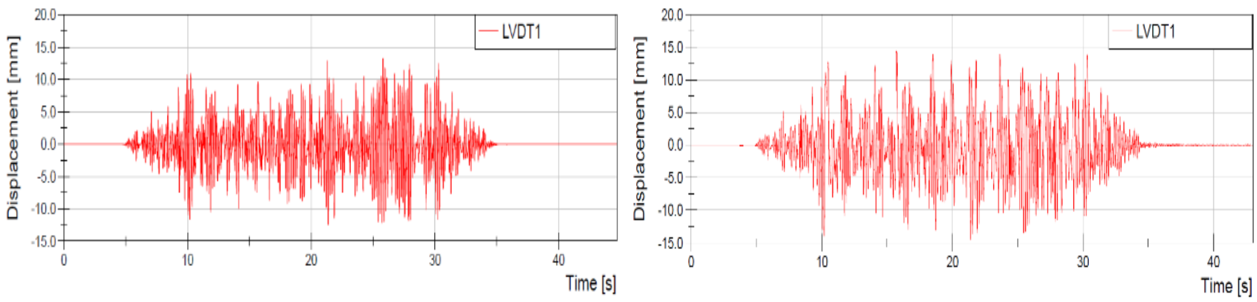

Fig. 8 – Time histories of maximum relative displacement, left – configuration 1, right – configuration 2.

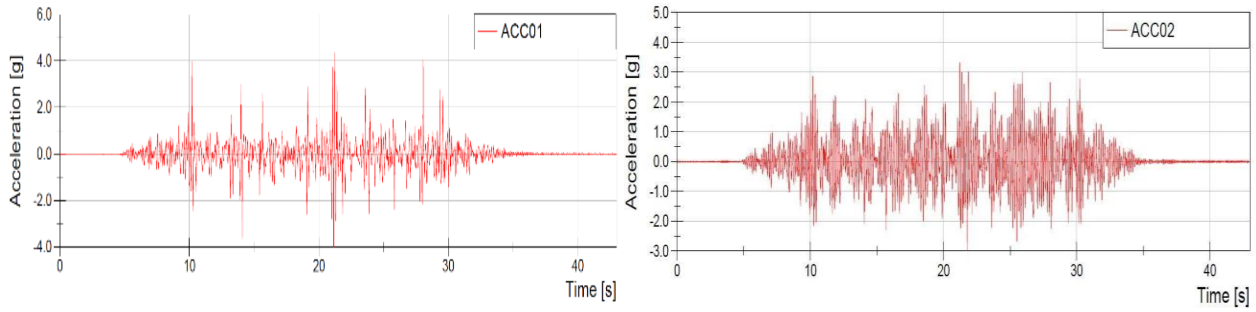

Fig. 9 – Time histories of maximum measured accelerations, left – ACC 01, right – ACC 02.

During and after the seismic test, all units of the ceiling systems and their supporting structures showed neither damage nor loss of function, except two different types of panels, which fell during the strongest tests (figure 10).

Fig. 10 – Damaged panels

5. Cleanroom Systems

Cleanroom systems are special type of closed rooms inside the main structural systems. They have specific dust-proof, humidity-proof or some other special characteristics.

5.1 Description of the Tested Specimen

Cleanroom systems are generally more complicated non-structural systems than raised floors and ceilings because they contain more non-structural elements, ceilings, partitions, raised floors, etc. The tested specimen for clean room systems were divided into two different layouts [8]. The first layout consisted of one type of a ceiling system, 15 different partition walls, 2 different types of doors and one type of installations. The second layout consisted of one type of a ceiling system, 20 different partition walls, 2 different types of doors and one type of installations. Each layout had an additional or optional component as silicone wall or bracing system. Moreover, an imposed load of 150 kg/m2 or a point load of 4x150 kg were used for testing of the systems. Since the cleanroom systems were not symmetrical, they were rotated for 90° in order to test both horizontal directions. Taking into consideration combinations of variables including non-structural element, silicone wall, bracing systems, type of load and rotation of specimens, eleven different configurations of clean-room systems were tested.

5.2 Instrumentation

Figure 11 presents a photo of one of the tested configurations as well as the specific instrumentation. Each configuration was tested biaxially, simultaneously in horizontal and vertical direction, according to the general testing methodology described in section 2. A total number of 62 tests were performed for testing all 11 configurations. To obtain valuable data, 26 different transducers were used, out of which 11 accelerometers, 4 strain gauges and 11 linear variable differential transformers.

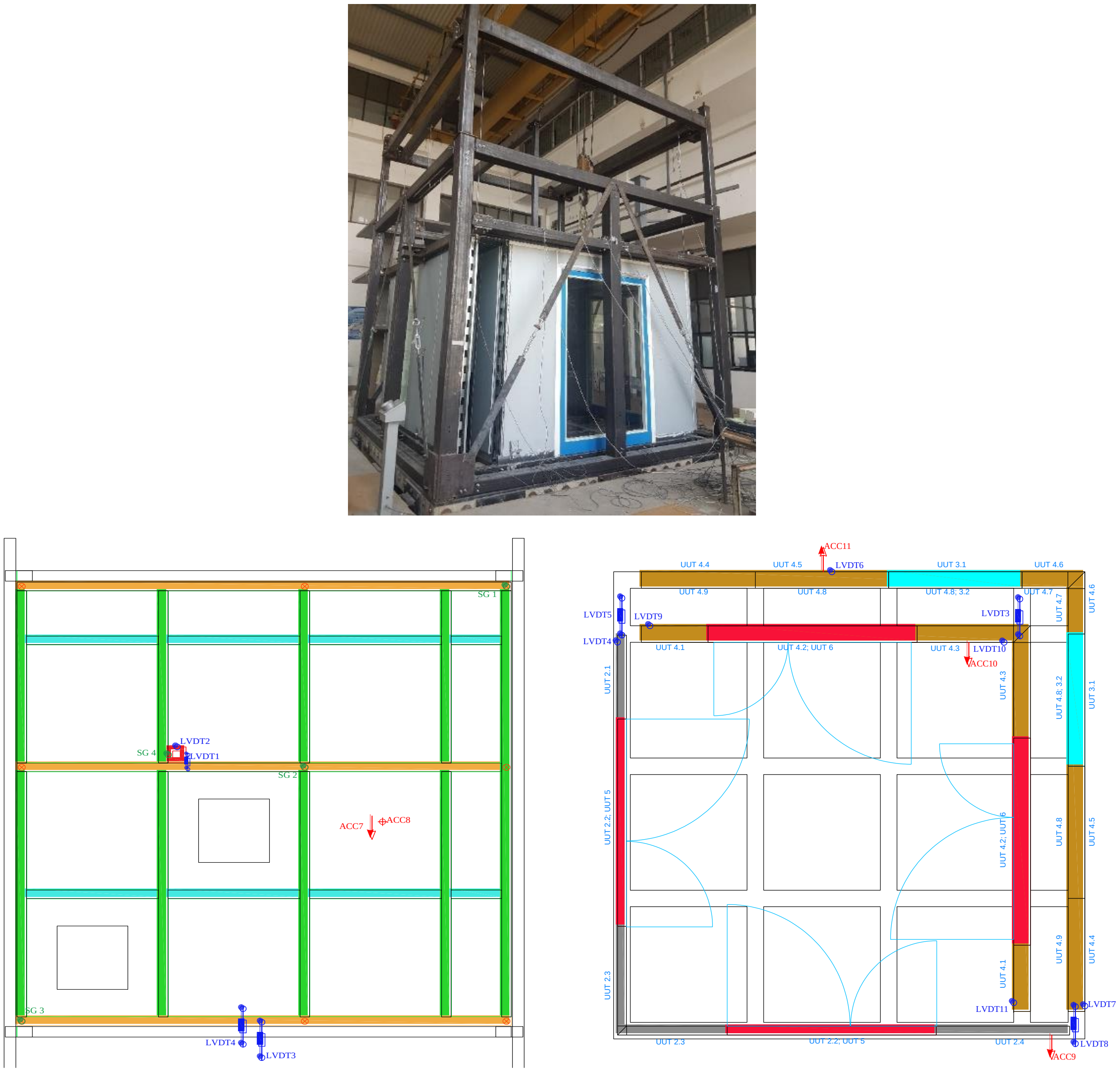

Fig. 11 – Photo of the tested clean room and instrumentation scheme.

5.3 Selected Results

Max. relative displacement of 19.6mm and maximum acceleration of 6.4g were measured during the intensive seismic tests. The corresponding time histories are presented in figure 12.

After the test performed according to the test procedure, no visible damage nor loss of function was noticed in 9 configurations. In the remaining 2 configurations, slight bending of some panels and braces of the ceiling system was observed.

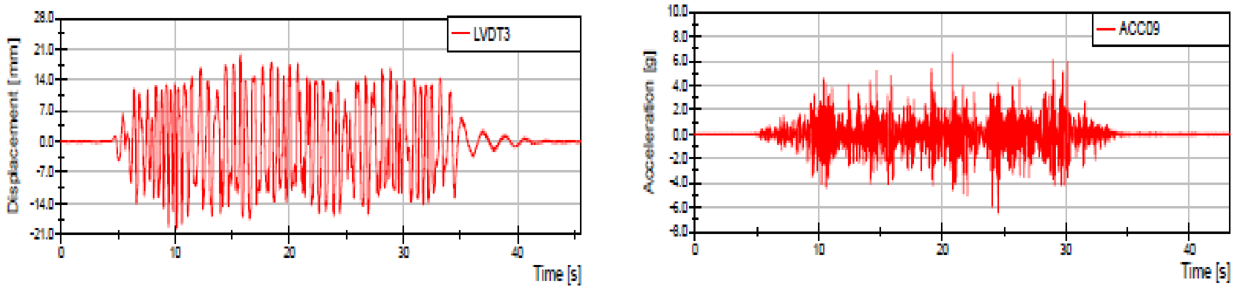

Fig. 12 – Time histories of maximum rel. displacement and acceleration during the seismic tests.

6. Conclusions

During earthquakes, non-structural components can be seriously damaged, and their failure can result in loss of human lives and extensive repair costs. Their stability and seismic performance are necessary to be verified according to the acceptance criteria in the prescribed standards.

The presented testing of different configurations and layouts of raised floors, ceilings and cleanroom systems was performed at the Dynamic Testing Laboratory of the Institute of Earthquake Engineering and Engineering Seismology, "Ss. Cyril and Methodius" University in Skopje, Republic of N. Macedonia according to the AC156 acceptance criteria for seismic qualification by shake table testing of non-structural components. Qualification by biaxial testing in horizontal and vertical direction was simultaneously performed with corresponding Test Response Spectra (TRS) that match the Required Response Spectra (RRS) given in AC156.

The obtained results of this complex experimental research showed that almost all tested systems successfully passed the seismic acceptance criteria for shake table testing of non-structural components and systems according to the applied standard.

7. References

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