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Mavrovo earthquake, experience and dynamic structural response

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Abstract

Aseismic design of structures in seismic prone regions is a complex process consisting of structural system definition, selection of foundation depth and type, definition of external impacts – both, gravitational and seismic, proper detailing and definition of stability and vulnerability level. Stability of a structure is controlled by the structural dynamic response under real seismic loads. In the period from 11.11.2020 to 12.11.2020 in the immediate vicinity of the national park "Mavrovo", a series of earthquakes occurred, which were felt by the local population. The main shock occurred on 11.11.2020 at 04:54 local time, with a moment magnitude MW = 5.0, and was followed by a series of aftershocks with a local magnitude in the range of 1.5 to 4.9. As a result of the seismic activity in this period, the instruments, which are part of the strong motion network in Republic of North Macedonia were activated. Strong motion data were recorded at fourteen different locations of instruments installed on bedrock. In the affected region, ground floor wooden structures are prevailing and therefore the damages due to the earthquake were very light. In this paper, comprehensive investigations regarding recorded time histories and different structural types are presented. Three structures of different geometry, structural system, different number of stories subjected to real accelerograms from Mavrovo earthquake have been analysed. Comparison and comments in respect to the results are made. Finally, based on the analysis results, a recommendation of the most appropriate time histories records from Mavrovo earthquake for specific types of structures have been defined.

Key words: aseismic design, seismic design parameters, real accelerogram selection

1 Introduction

Republic of North Macedonia is a seismic prone region and seismic safety of the buildins and protection of people and goods are of major concern. Therefore continuos research in the field of earthquake engineering and engineering seismology is of utmost importance.

In the period from 11.11.2020 to 12.11.2020 in the immediate vicinity of the national park "Mavrovo", a series of earthquakes occurred, which were felt by the local population. The main shock occurred on 11.11.2020 at 04:54 local time, with a local Richter magnitude M_W = 5.0, and it was followed by a series of aftershocks with a local magnitude in the range of 1.5 to 4.9.

According to the tectonic regionalization of R. N. Macedonia, the location of the occurred earthquake was in the Western Macedonian tectonic zone. The surrounding seismic sources of strong earthquakes are associated with an area where intensive geological transformation occurs, with the formation of neotectonic depressions in tectonic nodes, where the processes that condition the high lability of rock masses continue today. This is especially characteristic for Elbasan-Debar, Skopje, Urosevac and Pehchevo-Kresna areas, whose impact on the Mavrovo area is manifested with intensity up to I_0 = 6.0 - 7.0 on the MCS scale, while other seismic sources have a weaker impact.

Three structures of different number of stories subjected to real accelerograms from Mavrovo earthquake have been analysed. As an input parameter for the dynamic analysis the component with maximum acceleration was taken. A comparison was made of the relative displacement and acceleration amplification along the building's height depending on the distance and maximum acceleration obtained from the record.

2 Earthquake information

On 11th November 2020, an earthquake with M_w = 5.0 (EMSC) at 03 h 54 min (GMT) struck Republic of North Macedonia, more precisely the immediate vicinity of the national park "Mavrovo". The epicentre was located near Mavrovo lake (41.63 N 20.82E) with focal depth estimated at 10 km (EMSC). Its seismic intensity was VII degrees on EMS-98 scale and it was estimated based on the general panic associated with the stress in population.

The epicentre of the earthquake was in a so-called Drim seismic zone. This zone is seismically active since 1901 and it is characterized by several epicenter areas, for which there are data of occurred earthquakes. The largest earthquake evidenced in this area was in 1967 with local Richter magnitude of M_L=6.5.

The earthquake happened near a region where ground floor wooden structures are prevailing and the damages due to the earthquake were light.

Mavrovo earthquake was associated with a long aftershock sequence with a local magnitude of 1.5 to 4.9.

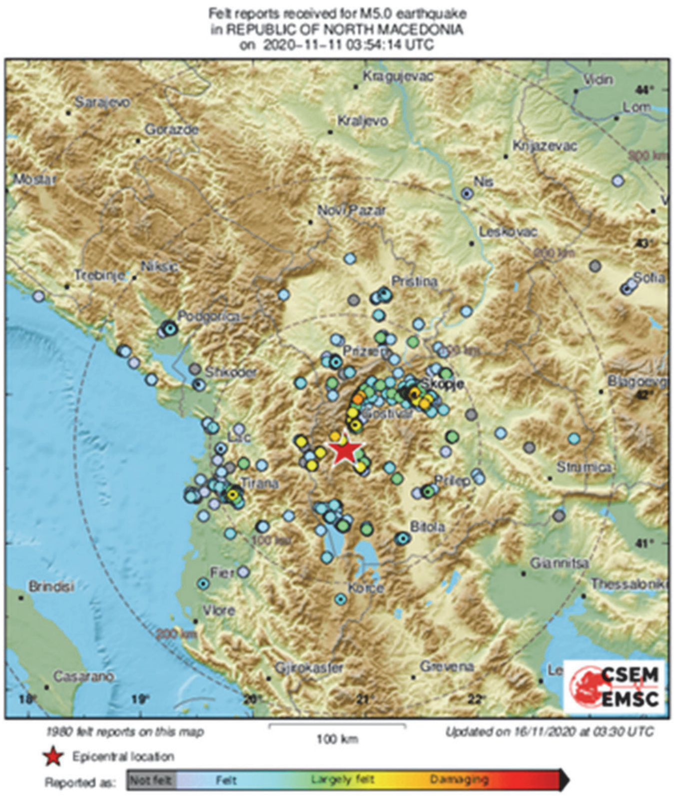

Figure 1. Regional map of the earthquake from 11.11.2020 at 03:54:14 (UTC) marked with red star (EMSC-CSEM, 2020)

3 Strong motion instruments location

Due to the above-mentioned earthquake that occurred on November 11, accelerometers type Episensor ES-T that are part of the strong motion network in the Republic of North Macedonia were activated. Strong motion data were recorded at ten different locations of instruments installed on bedrock. In figure 1 the stations' locations and the epicenter of the earthquake are presented.

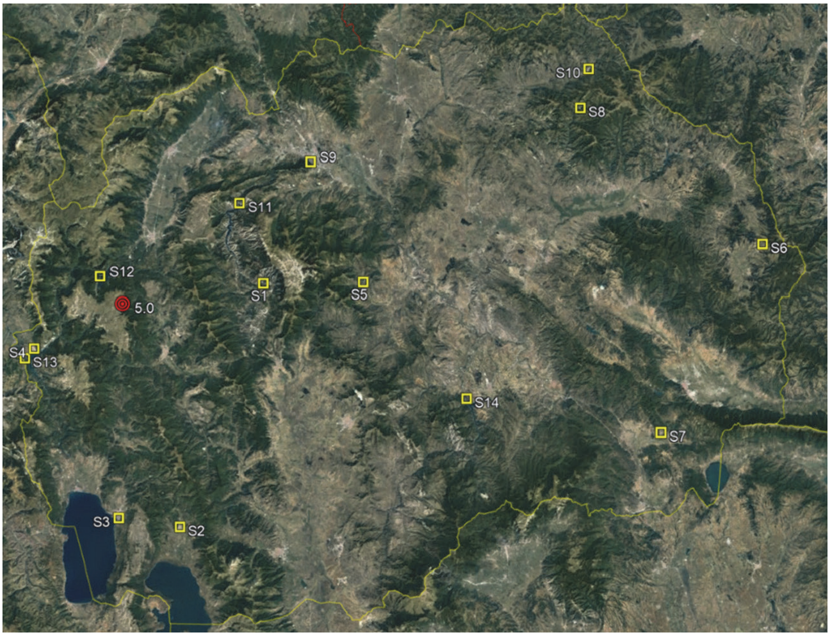

Figure 2. Strong motion instruments location

Table 1. Strong motion instruments network information

Station	**Max. acc.** [m/s²]	**Distance** [km]
S1 - Belica E-W	0.102104	38.2
S2 – Resen E-W	0.029380	62.1
S3 – Ohrid E-W	0.012049	57.9
S4 – Debar N-S	0.187309	27.2
S5 – Lisice N-S	0.137293	65.1
S6 – Pehcevo E-W	0.008479	173.6
S7 – Valandovo N-S	0.003522	149.3
S8 – Zletovica E-W	0.002758	136.9
S9 – Skopje IZIIS N-S	0.066572	63.5
S10 – Kriva Palanka N-S	0.008066	140.8
S11 – Kozjak N-S	0.068227	41.6
S12 – Mavrovo Z	1.057843	9.6
S13 – Spilje N-S	0.071858	30.7
S14 – Tikves Z	0.009048	96.2

The closest station was at 9.6 km from the occurred earthquake with a maximum recorded acceleration of 1.05784 m/s^2. The farthest station was located 173.6 km from the epicentre with a maximum recorded acceleration of 0.008479 m/s^2.

4 Analysed structures

4.1 Structure geometry

Structural dynamic response analysis of low-rise (GF+2), mid-rise (GF+8) and high-rise (GF+13) buildings was conducted. Structural systems have been adopted as regular and irregular at the base, as well as along the height of the building. The floor height is 2.90m for all regular structures, while for the irregular ones a floor height of 4.20m at the ground floor has been adopted, and the other floors had a floor height of 2.90m. The low-rise building was consisted only in terms of frame elements whereas, the mid-rise and high-rise structures consisted of frame and wall elements along the height. In figures 3 and 4 mathematical 3D models and plans of different storeys are shown.

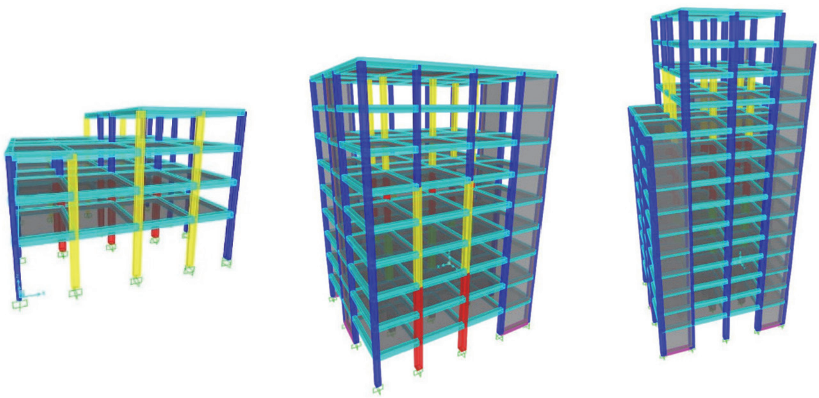

Figure 3. 3D model of irregular low-rise (GF+2), regular mid-rise (GF+8) and irregular high-rise (GF+13) building

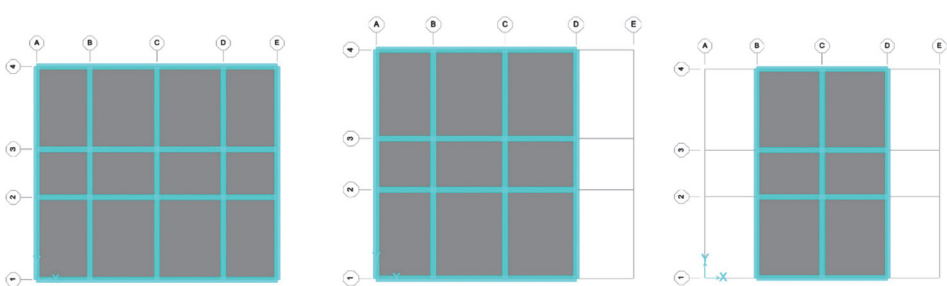

Figure 4. Building plan on different storey for irregular high-rise (GF+13) building

4.2 Applied loads – static and dynamic

Gravitational loads acting on the structure were divided into permanent (dead) loads "g" and variable (live) loads "p". Self-weight of the structural elements was automatically considered in the mathematical model depending on the dimensions of the elements and volumetric weight of concrete. Additional permanent loads with constant intensity of 4.0 kN/m^2 are applied as uniformly distributed load on all platforms, except for the roof where additional permanent load was with an intensity of 1.5 kN/m^2. The exterior beams with exception of the roof were loaded with additional linear loads with an intensity of 8 kN/m', representing the impact of the exterior walls. The intensity of the variable load was adopted in accordance with the regulation as for residential buildings with values of 1.50 kN/m^2 for all the platforms except for the roof with value of 1.0 kN/m^2. The dynamic loads were applied as a time-histoy accelerograms in SAP 2000 using the direct integration method. The original, filtered accelerograms were used, without scaling. These accelerograms are presented in figure 5 with different colours.

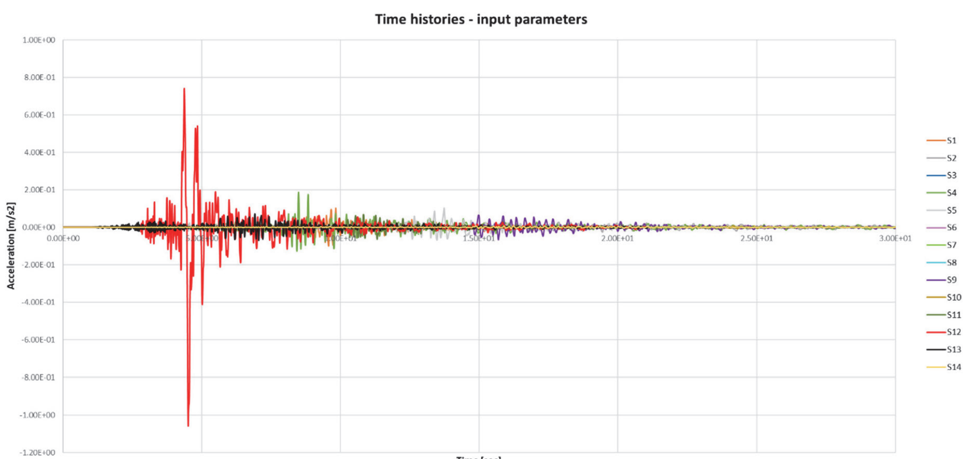

Figure 5. Input parameters for dynamic analysis – time histories recorded at different locations

5 Analysis and results

Dynamic non-linear analysis of the selected structural systems subjected to obtained earthquake records was performed. For a proper overview of the results, floor-interstorey drift and floor – acceleration diagrams are presented. Diagrams are shown in scale so that the values can be compared according to structural type and storeys. Figure 6 presents the deformed shapes in terms of absolute displacements of the structures subjected to Mavrovo accelerogram recorded on the station nearest to the earthquake epicentre. In figures 7-9 are presented the acceleration amplifications at different storeys whereas the interstorey drifts diagrams of the structures are presented on the figures 10-12, respectively.

5.1 Deformed shape of the structure

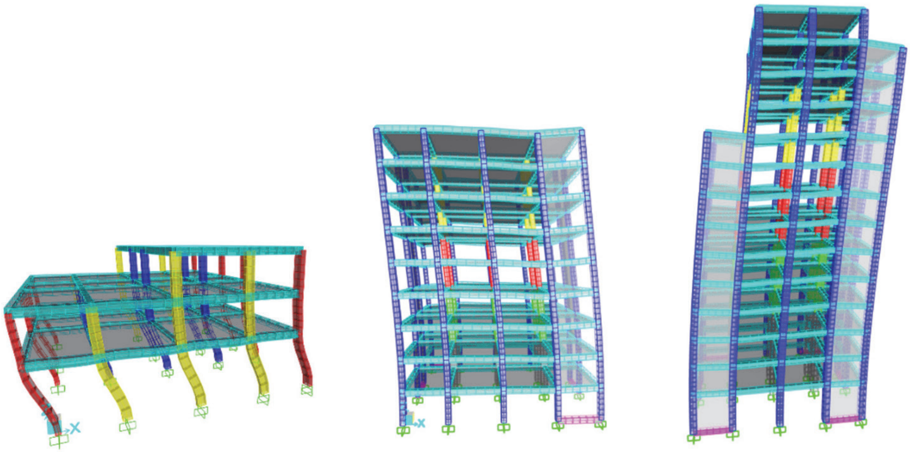

Figure 6. Deformed shape in terms of absolute displacements from Mavrovo earthquake

5.2 Acceleration results

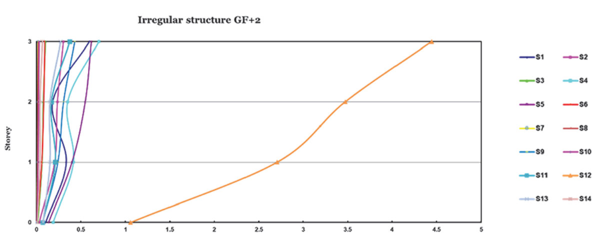

Figure 7. Acceleration amplification of irregular low-rise (GF+2) building along height subjected on different earthquake records

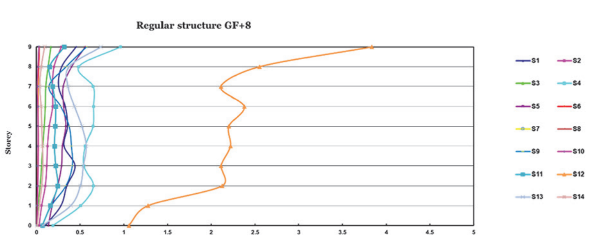

Figure 8. Acceleration amplification of regular mid-rise (GF+8) building along height subjected on different earthquake records

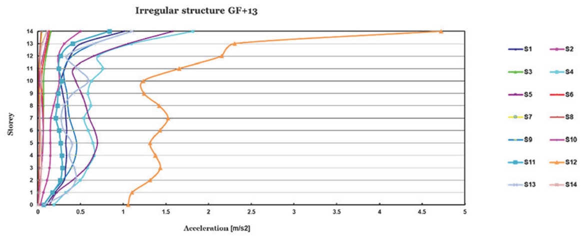

Figure 9. Acceleration amplification of regular high-rise (GF+13) building along height subjected on different earthquake records

5.3 Displacement results

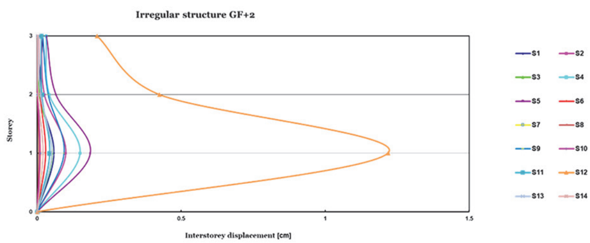

Figure 10. Interstorey drift of irregular low-rise (GF+2) building subjected on different earthquakes records

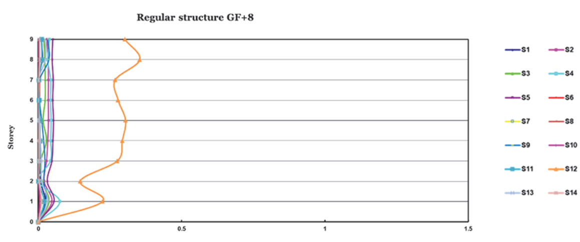

Figure 11. Interstorey drift of regular mid-rise (GF+8) building subjected on different earthquakes records

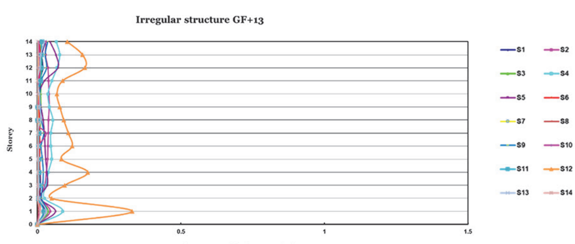

Figure 12. Interstorey drift of irregular high-rise (GF+13) building subjected on different earthquakes records

6 Conclusion

Three different buildings are analyzed in terms of number of storeys and regularity. The analysis is performed using maximum horizontal components of the obtained earthquakes recordings, except for the one obtained closest to the epicentre (d=9.6km), since the vertical component has the highest value.

From the presented results it is shown that the values of the relative floor displacements of the structures vary for different type of structure and different input time histories.

For the irregular low-rise structure in which there is a higher floor height, and no reinforced concrete walls are provided along the height, displacements are the biggest. Input motions have low acceleration values, so the maximum allowed drifts are not exceeded.

For the structure that has irregularities along the height, and in plan the distribution of the relative floor displacements depends on the variation in stiffness from one floor to another. Degradation of stiffness leads to larger observed displacements.

The biggest acceleration amplification is noticed for the irregular high-rise structure, and for accelerograms with lower acceleration values recorded at distant stations. Acceleration amplification of 10 to 16 times is noticed for input acceleration of 0.003 to 0.0072 m/s^2 recorded on stations 62-173 km from the earthquake epicenter.

For the low-rise building, the biggest acceleration amplification for the low-rise building is noticed for input records of 0.029 and 0.008 m/s^2 recorded on stations 62 km and 173 km from the earthquake epicenter, while the mid-rise building has amplification of 12 and 14 times from the input acceleration of 0.012 and 0.003 m/s2, recorded on stations 57 and 137 km from the epicenter.

Regarding the recorded acceleration of the closest station, acceleration amplifications of 3-4 times the input acceleration are observed.

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