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THE FLORINA M5.5 EARTHQUAKE OF JANUARY 9, 2022

BRIEF REPORT ON ACCELERATION TIME HISTORIES ANALYSIS AND DAMAGE EVALUATION IN THE BUILDING STOCK

THESSALONIKI
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ACKNOWLEDGEMENTS

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1. INTRODUCTION

On January 9, 2022 21:43 GMT, a strong earthquake of magnitude **M** 5.5 (USGS, GFZ) stroke Northern Greece close to the city of Florina. According to the National Unified Seismological Network announcement, it was a shallow crustal earthquake (depth h~3 km) and its epicenter was located Northwest of the city of Florina with geographical coordinates 40.800°N 21.405°E. The highest observed Macroseismic Intesity in Florina with value IMM=VI+.

The earthquake was strongly felt in the wider area of Florina due to the short distance from the epicenter (< 10 km). It was also considerably felt in the region of Western Macedonia and in North Macedonia. From residents' information, it was also felt from southern Thessaly to Podgorica and Pristine (North), throughout Albania (West) to Thessaloniki (East). The map in **Figure 1.1** gives the distribution of Felt reports issued for the earthquake according to CSEM/EMSC.

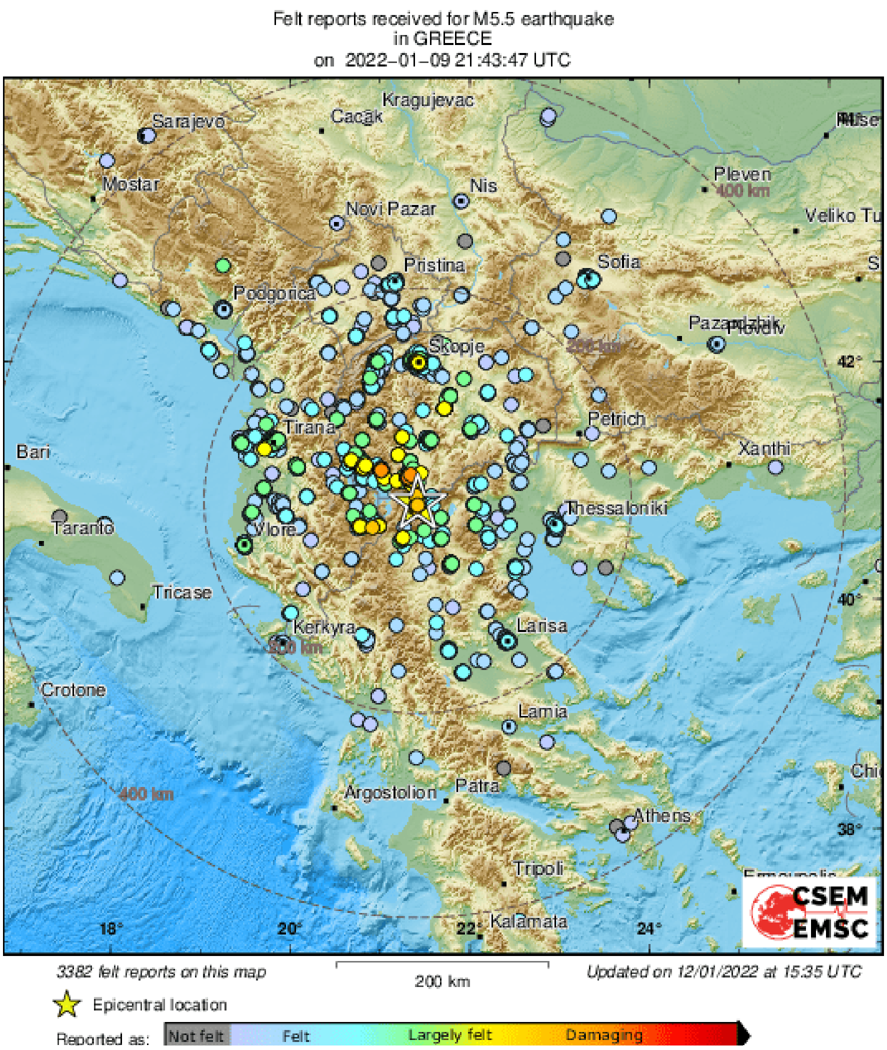


Figure 1.1. *Distribution of felt reports issued for the earthquake according to CSEM/EMSC.(https://static2.emsc.eu/Images/FELTREPORTS/108/1085365/IntensityMap.png). The star depicts the epicenter.*

The epicentral area is located in a moderate seismicity region of Greece with the last burst of moderate seismicity having occurred during the period February 2013-January 2014. During that period, more than 2,000 events were occurred with the main event with magnitude **M** 4.1 occurred on February 17, 2013, almost at the same area with the January 9, 2022 event.

2. SEISMOLOGICAL DATA

The spatial distribution of the epicenters of the main earthquake and aftershocks with magnitude **M**≥1.0 until 19.01.2022 is given in the map of **Figure 2.1.** Data in **Figure 2.1** were retrieved from the website of the Seismological Station of AUTH (www.geophysics. geo.auth.gr\ss). The star represents the epicenter of the mainshock while cycles the aftershocks with **M** ≥ 1.0. Red lines represent the faults in the area from HELPOS database (Ganas et al., ESC. 2021).

There was no surface trace of the seismogenic fault. Its rupture zone, however, could be determined by the spatial distribution of aftershocks which defines a zone about 9 km long (**Figure 2.1)** corresponding to an earthquake with magnitude **M** 5.5 (Papazachos, 1989). This zone shows a similar strike as that of the neighboring faults. From these observation as well as from the focal mechanism of the mainshock it results that the earthquake was caused by a normal fault rupture with a NE-SW direction.

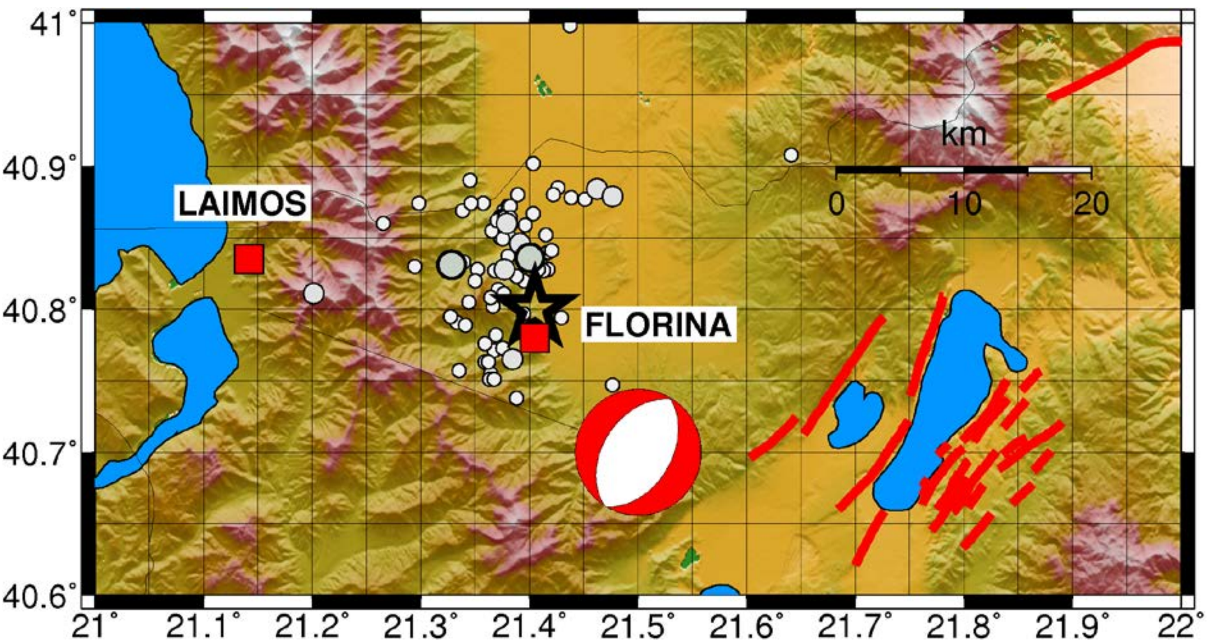


Figure 2.1. Spatial distribution of the epicenters of the mainshock and aftershocks with magnitude **M** ≥ 1.0 until 19.01.2022 and location of the ITSAK network accelerographs. The focal mechanism (after GFZ) and the mapped known faults in the area are also shown.

The map of **Figure 2.1** also shows the locations of the GURALP CMG5TD-EAM strong motion stations near the rupture zone. These are equipped with 24 bits resolution digitizers and broadband accelerometers, operating in continuous mode, transferring the data to the premises of ITSAK at Thessaloniki.

The closest ITSAK accelerograph is installed in the city of Florina, at a distance of about 5km from the epicenter, within the rupture zone and recorded a Peak Ground Acceleration (PGA) value ~15%g in the horizontal and ~23%g in the vertical component. This station is installed at a site of soil class B according to EC8 as described in Section 3. Moreover, a second instrument installed also at a site of soil class B in Laimos village, nearby Prespes lakes, recorded a PGA ~13%g in the horizontal and ~8% in the vertical component. **Figure 2.2** shows the acceleration time histories at these two sites and **Table 2.1** gives information on the analysis of the recorded accelerograms.

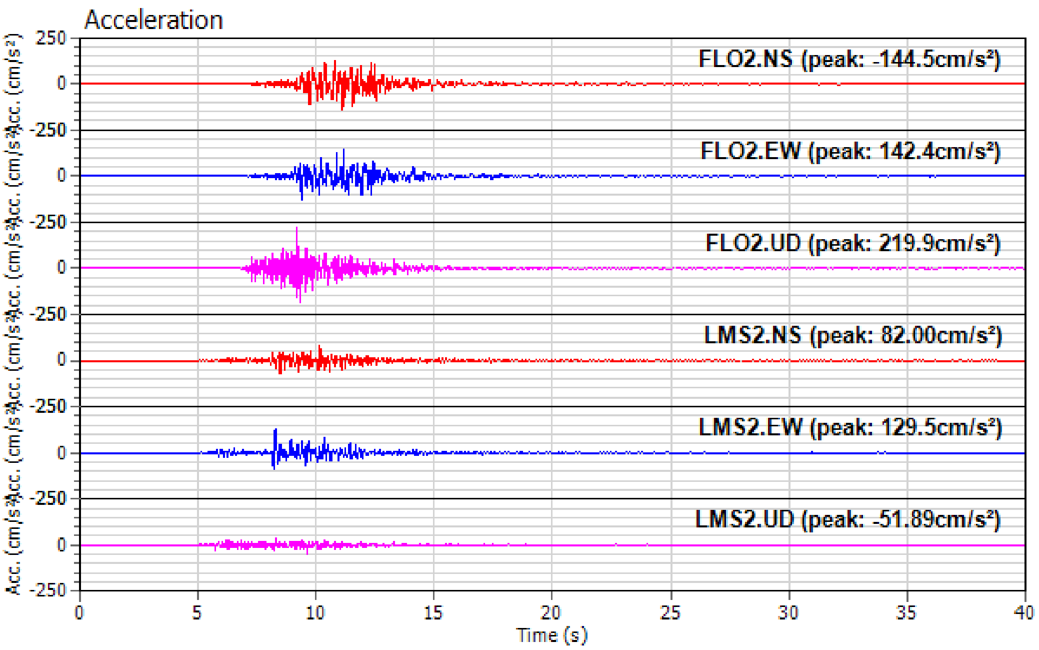
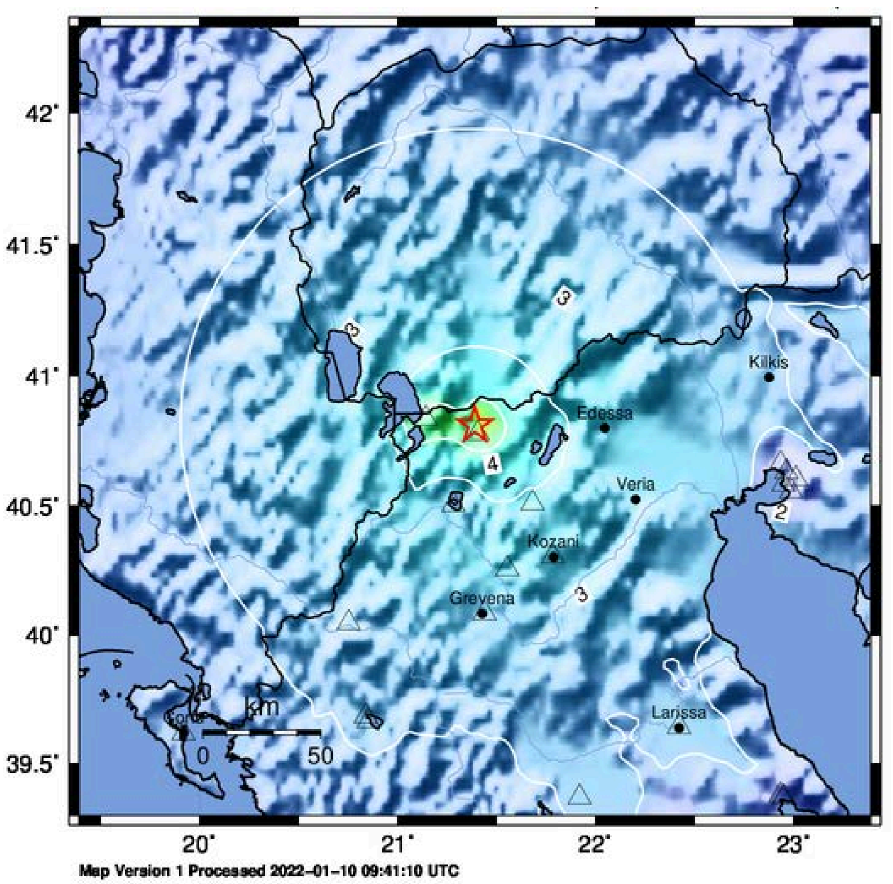


Figure 2.2. Acceleration time histories of the two closest stations FLO2 and LMS2 after the **M**5.5 January 9, 2022 event. The peak values for every component are shown and the amplitudes are at the same scale.

Table 2.1. Results of the analysis of the recorded accelerograms at the two closest sites.

STATION	Epicentral Distance (km)	Peak Ground Acceleration (cm/s/s)			Peak Ground Velocity (cm/s)			Peak Ground Displacement (cm)		
		NS	EW	UD	NS	EW	UD	NS	EW	UD
Florina (FLO2)	4	144	142	249	5.1	5.2	2.4	0.33	0.52	0.15
Laimos (LMS2)	20	82	129	52	2.2	5.4	1.6	0.15	0.38	0.24

Figure 2.3 shows instrumental macroseismic intensity (MMI) estimated in the epicentral area about 5.0-6.0 that is gradually attenuates to 3.0-4.0 in the city of Edessa. These results are in satisfactory agreement with the first published information on the level of damage caused by the main earthquake in the built environment in the area of Florina. Upon completion of the autopsies, the aforementioned correlation is likely to be reassessed.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Figure 2.3. Instrumental Macroseismic Intesity (MMI) shakemaps of January 9, 2022 earthquake.

Figure 2.4 illustrate Shakemaps in terms of PGA, based on ground motion prediction equation of Skarlatoudis et al. (2003) as well as on recorded PGA values in the wider region of Western Macedonia, Thessaly and Epirus. Peak ground acceleration in the meizoseismal area of Florina reached values of 8-13%g. The curves of equal accelerations on the left map are from 1% g (external) to 11%g. This observation is consistent with the fact that the earthquake was strongly felt in the region of NW Greece, North Macedonia and Albania.

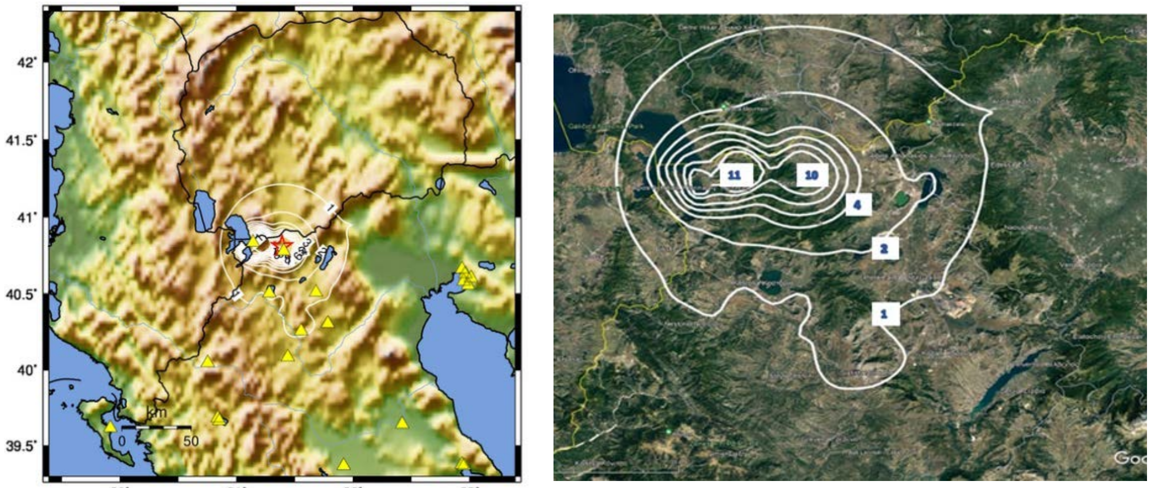


Figure 2.4. Peak ground acceleration shakemaps of January 9, 2022 earthquake (left panel) The map on the right panel focuses on the meizoseismal area.

3. RECORDED ACCELERATION ELASTIC RESPONSE SPECTRA AND COMPARISON WITH DESIGN SPECTRA

Figure 3.1 compares the absolute acceleration elastic response spectra of the January 9, 2022 M5.5 earthquake recordings at the FLO2 station with the elastic design spectra (5% critical damping) specified in the Greek seismic code (EAK2003) and the EC8. According to EAK2003, the city of Florina belongs to the Seismic Hazard Zone (SHZ) I, which corresponds to a design peak ground acceleration at A=a_g=0.16g. FLO2 station is installed at the basement of a public building of the Municipality of Florina. Taking into account as a first approximation the V_{s30} criterion, which is estimated at ~490 m/s for the FLO2 station documentation (Stewart et al. 2014), the soil type is classified as class B, according to EC8. The above soil class was also considered for the elastic design spectra of EAK2003 shown in **Figure 3.1**. In the same figure, the corresponding elastic design spectrum provided by a former version of the Greek Seismic Code (NEAK1995), which was valid until 2003, is also illustrated. It is noted that NEAK1995 specified a lower design value of the peak ground acceleration (A = a_g = 0.12g) for SHZ I. The period-independent seismic coefficients provided by the Greek Seismic codes of 1959 and 1985 (valid till 1995), for SHZ I are also shown in **Figure 3.1** for two soil classes, referring to stiff and medium-stiff soils, as defined in the above regulations. These are presented in **Figure 3.1** with their modified values ε'=0.07 and 0.10, which take into account a safety factor of 1.75, a 20% increase in allowable stress for seismic design and a pertinent correction for MDOF systems through a factor of 0.85 (Anagnostopoulos et al. 1987).

It is observed that the absolute horizontal acceleration spectral ordinates of the records (mainly the NS one) exceed those of the EAK2003 design spectrum in a relatively narrow range of periods between 0.15sec and 0.25sec, while the recorded spectral values are better captured by the EC8 design spectrum. Regarding NEAK1995, the exceedance of the design values by the recorded motion is greater for periods up to 0.3sec. The maximum spectral accelerations in the order of 0.65g and 0.45g in the EW and NS components, respectively, are observed close to 0.15sec. The comparatively larger value of the vertical component is worthy of note, which, however, appears at a small period value (~0.05 sec).

Again, the spectral ordinates of the vertical component are more adequately captured by the EC8 design spectrum. In general, modern regulations (EAK2003, EC8) seem to adequately address the ductility requirements imposed by the specific earthquake. For older structures (designed with the 1959 – 1985 code), the particular earthquake action imposed relatively moderate ductility demands (in the order of 3- 4) for structures with periods in the range of 0.15-0.35 sec, and smaller for structures with different periods than those mentioned before.

The corresponding comparisons for the recordings at station LMS2 are given in **Figure 3.2** for soil class B, taking into account the same criterion of $V_{s,30}$ (Stewart et al. 2014). At LMS2 station site, $V_{s,30}$ is estimated at ~430 m/s. Station LMS2 is installed at the Town Hall building in Lemos, Prespa. Note the similar peak ground acceleration of the EW component recorded at stations FLO2 and LMS2. However, the absolute spectral values of both the horizontal components and the vertical component are generally lower than the design spectra of EAK2003, NEAK1995 and EC8.

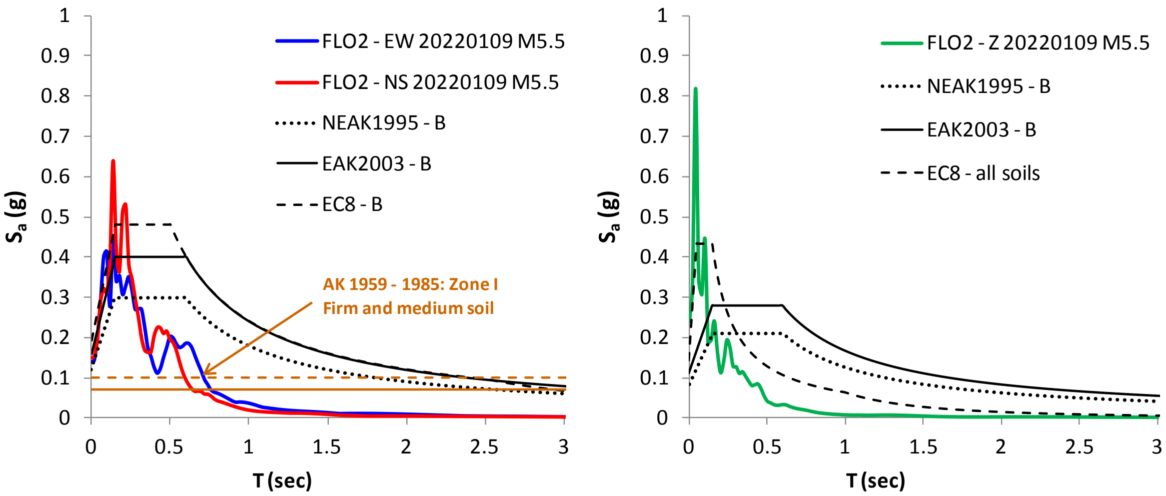


Figure 3.1 Comparison of absolute acceleration elastic response spectra of the January 9, 2022 M5.5 earthquake recordings at the FLO2 station (V_{s30} ~490 m/s) with the elastic design spectra of 5% critical damping: Horizontal components (left) and vertical (right)

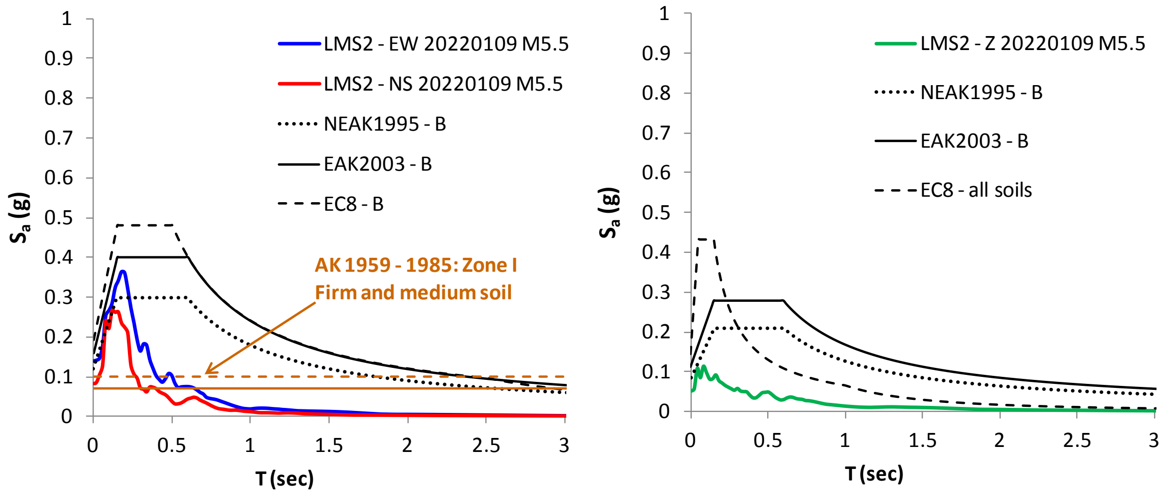


Figure 3.2 Comparison of absolute acceleration elastic response spectra of the January 9, 2022 M5.5 earthquake recordings at the LMS2 station (V_{s30} ~430 m/s) with the elastic design spectra of 5% critical damping: Horizontal components (left) and vertical (right)

4. PRELIMINARY OBSERVATIONS ON STRUCTURAL RESPONSE

In the city of Florina there are structures of various dates, typologies and structural systems. There is a significant number of old houses, of neoclassical and Macedonian architecture, usually up to two floors, which have not been constructed according to any seismic code provisions, with a significant number of them dating back to the Ottoman era. The buildings of the Ottoman era are usually two-storey, with the lower floor made of masonry, while on the upper floor usually lighter materials are used. After the liberation of Florina in 1912, masonry buildings of neoclassical and eclecticism architecture were constructed, which typically consist of a semi-basement, an elevated ground floor and a first floor. These older houses were typically constructed with wooden horizontal diaphragms (floors and ceilings). At the same time, as in every urban area in Greece, there are also R/C structures, several being multi-storey (up to 7 floors), designed in accordance with the Greek seismic codes in effect at the time of their construction.

In the villages near and around the epicenter of the main earthquake, there are single- or two-storey masonry structures as well. Several buildings have mainly an auxiliary use and the masonry typically consists of two or three layers. On the other hand, buildings of residential use, usually have a good building quality of the load-bearing masonry and a better seismic response is expected in relation to buildings of auxiliary use. It is a fact that in auxiliary buildings there was no elaborate construction (use of irregular stones and mortar of low strength), as no human presence was expected in them for long periods. This practice was also confirmed during the on-site autopsies performed by researchers from the Institute of Engineering Seismology and Earthquake Engineering in damaged buildings during the recent earthquakes of Tirnavos – Elassona in Thessaly and Arkalochori in Crete. An analogous philosophy is also introduced into modern seismic codes, where, through use of appropriate coefficients (coefficients of importance), a reduction of seismic design loads (in the order of 20% relative to those for an ordinary residential building) is considered for auxiliary buildings, while a corresponding increase (of up to 40%) is prescribed for buildings of great importance. It is therefore observed that this construction practice also pre-existed in buildings that were constructed before the enactment of the first seismic code in 1959. A similar logic applies to most modern seismic codes internationally.

Based on the reports to date, damage to structures was rather limited in the city of Florina, given the magnitude and the proximity to the epicenter of the main earthquake. There were mainly falls of external plasters and marble claddings in old buildings and in multistorey apartment buildings as well (**Figure 4.1a**), local failure of stone walls (**Figure 4.1b**), damage to balconies, as well as crackings at interior walls of houses (**Figure 4.1c,d**). A collapse of an uninhabited old house in the village of Agia Paraskevi, north of Florina was also reported. In the city of Florina, the neoclassical building of the Folklore Museum of the Florina Cultural Club, of cultural heritage importance, presented limited damage, namely falls of external plasters and a failure of a decorative element on the roof of the building (**Figure 4.2**). After the completion of autopsies by the authorities in the wider earthquake-stricken area, damage to various categories of structures will be recorded in more detail, in order to draw more conclusions about the vulnerability of the structures in the Greece.

Fall of plasters from masonry buildings in case of an earthquake is rather common and is one of the first forms of "failure" that occurs. This is justified in two ways: (i) Plasters are made of low-strength materials which are particularly brittle. In many cases, they are already worn and weakened due to environmental factors, and due to the seismic excitation, they detach and fall. ii) Detachment and fall of plasters are also due to in- and out- of plane deformation of the masonry walls. The strength of masonry (of stones or bricks and building mortar) as proposed by the Code for Assessment and Structural Interventions in Masonry Buildings (KADET 2021 - draft) is at least three times the plaster strength. Masonry walls deform and develop cracks during the seismic excitation, resulting in the cracking and detachment of plaster, with a possible simultaneous fall of smaller infill stones (**Figure 4.1a,b, 4.2b,c**).

(a) (b)

Figure 4.1. Observed failures from the earthquake of 09/01/2022 Photo sources: (a) Twitter (b) www.skai.gr

(c) (d)

Figure 4.1. (continued) Observed failures from the earthquake of 09/01/2022. Photo sources: https://neaflorina.gr

Another form of cracking which is also first to appear in R/C buildings is the detachment of infill walls from the surrounding RC frames. It is a common form of failure which is among the first to appear in R/C buildings (and sometimes the only observed). This is due to the different response of masonry and reinforced concrete elements for two reasons: i) The drift ratio for which cracks develop in the two materials is very different, with that for reinforced concrete elements being about three times the respective one for infill walls. Thus, in several cases cracks appear in infill walls, while the surrounding reinforced concrete frames experience no damage. Typically, these cracks initially appear at the interface between the infill walls and the surrounding R/C frames. ii) Cracks in reinforced concrete elements with no significant yield of the longitudinal reinforcement (reinforcement elongation in the order of 2-4 ‰) close after the seismic event and are not perceived during the on-site macroscopic autopsies. On the contrary, cracks in infill walls leave a trace on the plaster, and are easily observed (**Figure 4.1.d**).

After the earthquake, some villages were left without power for several hours, with the damage gradually being restored. Problems were reported even on railways, with a train reported to be immobilized between the cities of Skydra and Florina.

(a)

(b)

(c)

Figure 4.2. Folklore Museum of Florina (a) before and (b), (c) after the earthquake of 09/01/2022. Photo sources: (a) Google Earth (b) https://neaflorina.gr (c) www.skai.gr

5. CONCLUDING REMARKS

On January 9, 2022 21:43 GMT, a strong earthquake of magnitude **M** 5.5 (USGS, GFZ) (40.800°N 21.405°E, depth h~3 km) stroke Northern Greece close to the city of Florina (IMM=VI+). The closest ITSAK accelerograph installed in the city of Florina, at a distance of about 5km from the epicenter, recorded a Peak Ground Acceleration (PGA) value ~15%g in the horizontal and ~23%g in the vertical component. A second instrument in Laimos village, nearby Prespes lakes, recorded a PGA ~13%g in the horizontal and ~8% in the vertical component.

With reference to the elastic response spectra recorded at FLO2 station, modern seismic design codes (EAK2003, EC8) cover the loading demands imposed by this earthquake, except for a narrow period band (0.15 - 0.25 sec), where the spectral ordinates of the horizontal records exceed the design values. These codes seem to adequately address the ductility requirements imposed by the specific earthquake. Regarding the provisions of the older (NEAK1995) Greek seismic code, relatively small (in the order of 1.5-2) ductility demands arise for periods up to around 0.3 sec. For older structures (designed with the 1959 – 1985 code), this earthquake action imposed relatively moderate ductility demands (in the order of 3- 4) for structures with periods in the range of 0.15-0.35 sec, and smaller for structures with different periods. The large spectral values (up to 0.8g) of the vertical component of motion recorded from FLO2 station at quite low periods (~0.05 sec) (due to near-source effects), as well as the comparable value (on the order of 0.13g) of the horizontal peak ground acceleration between the FLO2 and the LMS2 stations, recorded along the EW direction, are also noteworthy. The observed damage to structures in the city of Florina (as reported by the time of the present report), was not significant from a structural point of view. More complete conclusions on the vulnerability and seismic behavior of the building stock will be able to be drawn after the completion of detailed inspections within the meizoseismal area.

Acknowledgements

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