16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 414

THE JANUARY-FEBRUARY 2014 CEPHALONIA (IONIAN SEA, WESTERN GREECE) EARTHQUAKE SEQUENCE: DAMAGE PATTERN ON BUILDINGS

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Abstract

The early 2014 Cephalonia earthquake sequence comprised two main shocks with almost the same magnitude (Mw 6.0) occurred successively in short time (January 26, February 3) and space (western Cephalonia, Paliki peninsula). The first event caused damage mainly in the Paliki peninsula, while the second aggravated damage induced by the first. The dominant buildings types are masonry, reinforced concrete (RC) and monumental buildings. Masonry buildings suffered the most due to their high vulnerability. RC buildings showed good performance due to their good construction quality. The monumental and cultural heritage buildings showed good performance due to their resistance and stiffness. In conclusion, the severity of the 2014 Cephalonia earthquakes was not reflected in the overall picture and the spatial distribution of damage on the building stock of western Cephalonia due to the fact that these buildings possess higher strength under earthquake effects than the expected for the affected area. Based on the application of the European Macroseismic Scale 1998 (EMS-98) for the early 2014 Cephalonia earthquakes, seismic intensities in the Paliki peninsula ranged from V to VIII. Based on the assigned EMS-98 seismic intensities and historical earthquake intensity data, it is concluded that the Paliki peninsula is the area most affected by both 2014 earthquakes and it is the part of Cephalonia usually and mostly affected by earthquake effects in its natural and built environment.

Keywords: Cephalonia, Ionian Islands, strike-slip earthquake, building damage, EMS-98

1. Introduction

Cephalonia is located only a few km east of the Hellenic Trench in the Ionian Sea, at the northwesternmost part of the Hellenic Arc (Fig. 1a). The Hellenic Trench is an active plate boundary between the subducting eastern Mediterranean lithosphere and the overriding Aegean lithosphere. This subduction zone terminates against the Cephalonia Transform Fault Zone (CTFZ in Fig. 1a) [1, 2]. The CTFZ located west of Lefkas and Cephalonia is composed by the Lefkas segment (LS in Fig. 1b) to the north and the Cephalonia segment (CS in Fig. 1b) to the south. It has a significant role in the geodynamic complexity of the region and the kinematic field in Greece as it (a) connects the subduction boundary to the continental collision between the Hellenic foreland and the Apulian microplate and (b) separates the slowly NNW-ward moving northern Ionian Islands from the rapidly SW-ward moving central Ionian Islands [3, 4, 5]. Due to its location, the Cephalonia Island is characterized by the highest seismicity in Greece. The early 2014 Cephalonia are among the largest earthquakes that have ever affected the island.

On January 26, 2014 at 15:55 (local time) a strong earthquake struck the Cephalonia Island (Ionian Sea, western Greece). It was assessed as Mw 6.0 (GINOA) or Mw 6.1 (UOA, HARV, INGV, AUTH, GFZ). Its epicenter was located onshore in the southeastern part of Paliki peninsula (Fig. 2). Based on data provided by national and international seismological institutes and observatories (GINOA, UOA, HARV, INGV, AUTH, GFZ), this shock is consistently located at depths of 10-17 km. The focal mechanism demonstrates a NNE-SSW striking dextral strike-slip seismic fault with a small reverse component that dips southeastwards at a steep angle [6] (Fig. 2). The aftershock sequence of the first earthquake comprised about 731 events from January 26 to February 3 based on the earthquake catalogues provided by the Permanent Regional Seismological Network operated by the Aristotle University of Thessaloniki, Greece [7] (Fig. 2). The spatial distribution of aftershocks with most hypocentral depths in the range of 1 to 16 km [7] extended for a total length of about 40 km in a NE-SW direction and covered the entire Paliki peninsula (Fig. 2). This distribution shows consistency with the strike of one of the two nodal planes indicated by the focal mechanisms of the main shock (Fig. 2).

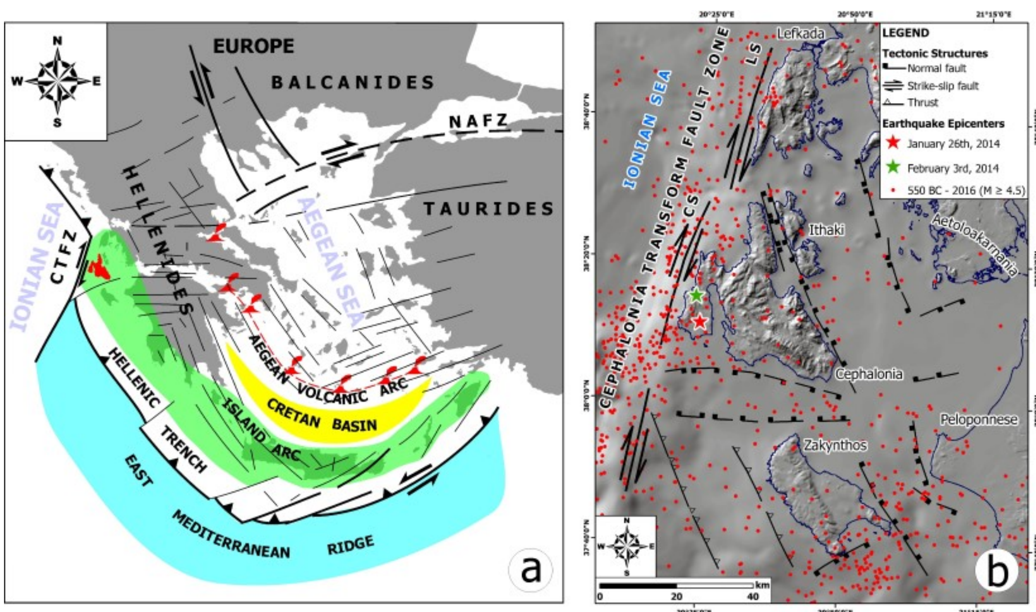

Fig. 1 – (a) Structural sketch of the Hellenic Arc showing the location of the Cephalonia Island at the northwesternmost part of the Hellenic Arc [8, 9]. (b) The central part of the Ionian Islands controlled by the Cephalonia Transform Fault Zone (CTFZ) comprising the Cephalonia segment (CS) and the Lefkas segment (LS). The epicenters of the early 2014 Cephalonia earthquakes (January 26 and February 3) and the epicenters of earthquakes with magnitude M ≥ 4.5 for the period extending from 550 BC to April 2, 2016 [7] are also shown.

A week later, on February 3 at 05:08 (local time) another strong earthquake hit Cephalonia once again. It was assessed as Mw 5.9 (UOA, NOA) or Mw 6.0 (HARV, AUTH, GFZ). Its focal depth is about 7 km and its focal mechanism is consistent with NE-SW striking dextral strike-slip [6] (Fig. 2). Its aftershock sequence comprised 427 seismic events from February 3 to February 13 with most hypocentral depths in the range of 1 to 17 km [7]. Only 14 of them had magnitude equal to or larger than ML 4.0, with the largest one occurring 10 days later [7]. The aftershocks extended for a total length of about 40 km in a NE-SW direction and covered the entire Paliki peninsula once again (Fig. 2). This direction is again consistent with the strike of one of the two nodal planes indicated by the focal mechanism of the second earthquake (Fig. 2).

The maximum peak ground acceleration (PGA) of the second shock recorded at Chavriata site (southern Paliki peninsula) was 0.77 g, larger than that recorded during the first shock (0.56 g) [10, 11]. It is significant to note that 0.77 g is the largest PGA value ever recorded in Greece since the early 1970s, when the first accelerographs were installed at large cities of Greece. A slightly smaller PGA was measured as 0.68 g at Lixouri site (eastern coastal Paliki peninsula) during the second event [11].

Both earthquakes were predominantly felt on Cephalonia and throughout the Ionian Islands, the Peloponnese and the Western Continental Greece with fortunately no fatalities or serious injuries reported. They had a major impact on the building stock generally in the western part of the island and particularly in the Paliki peninsula and the western part of the Aenos Mt. They affected the island infrastructures including road network, port and airport facilities as well as telecommunication, electricity distribution, potable water supply and wastewater networks. They also caused extensive effects on the natural environment in the aforementioned affected area.

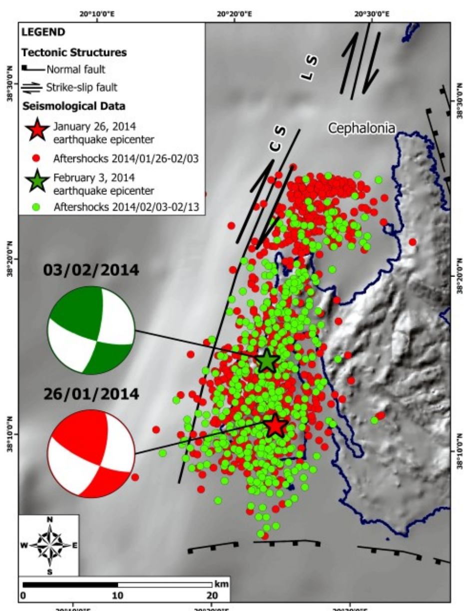

Fig. 2 – (a) Epicenters, focal mechanisms and aftershock distributions of the January 26 and February 3, 2014 Cephalonia earthquakes.

This study focuses on damage induced by the early 2014 Cephalonia earthquakes on the building stock of the affected area and the application of the European Macroseismic Scale 1998 (EMS-98) [12] for both earthquakes. It is structured as follows. An overview upon the geomorphological, geological and neotectonic setting of the wider studied and the affected areas is given in the second section. The dominant building types of the earthquake-affected area are presented in the third section, while building damage is described in the third section. The application of the EMS-98 for both earthquakes is presented in the following section along with the derived seismic intensities and the respective isoseismal maps. Finally, a brief summary of lessons learnt is found in the conclusions.

2. Geological and seismotectonic setting

Cephalonia comprises alpine formations of Paxoi (Pre-Apulian) and Ionian geotectonic units and Plio-Quaternary sediments that lie on the alpine basement [13, 14, 15, 16, 17, 18, 19, 20, 21, 22] (Fig. 3). The Paxoi unit occurs in the largest part of the island and consists mainly of neritic and locally pelagic carbonates of Triassic-Middle Miocene age and the flysch-type clay-clastic sequence of Middle Miocene-Early Pliocene age comprising alternations of marls, clays, and mudstones [21, 22] (Fig. 3). The Ionian unit is the allochthonous nappe observed along the eastern part of the island (Fig. 3) and comprises an evaporitic sequence of gypsum beds and limestone breccia of Triassic age and thick-bedded limestones, red nodular limestones, and slates of Jurassic-Cretaceous age [21, 22] (Fig. 3). The recent formations in Cephalonia comprise a Pliocene-Calabrian sequence and Middle-Late Pleistocene-Holocene formations [21, 22] (Fig. 3).

Four major fault blocks constitute the island: (a) the Aenos Mt, (b) the Erissos peninsula, (c) the Paliki peninsula and (d) the Argostoli peninsula (Fig. 3). The Aenos Mt is located in the central and eastern part of Cephalonia and bounded by the Aenos fault zone to the SW, by the Kontogourata-Agon fault to the NW, by the Agia Efimia fault to the NE and by the Paliokastro fault to the SE (AFZ, KAF, AEF, PF respectively in Fig. 3). Aenos Mt has suffered significant uplift (> 1500 meters) and considerable incision since the Early Pliocene [21, 23]. The Erissos peninsula located in the northern part of Cephalonia is bounded to the SW by the AEF and has also suffered significant uplift and erosion. It presents the same evolutional characteristics with the Aenos Mt since Pleistocene and after the deactivation of AEF. The Paliki peninsula located in the western part of the island is bounded to the west by the CTFZ and especially the CS (Fig. 3). This active fault defines the evolution of Paliki through considerable uplift movements (< 1000 meters), which are smaller than the Aenos Mt ones [21, 23]. The Argostoli peninsula located southwest and south of the Aenos Mt is bounded to the east and north by the AFZ (Fig. 3). Back-thrust faults occur exclusively in this fault block as the result of possible increased compression during Pleistocene.

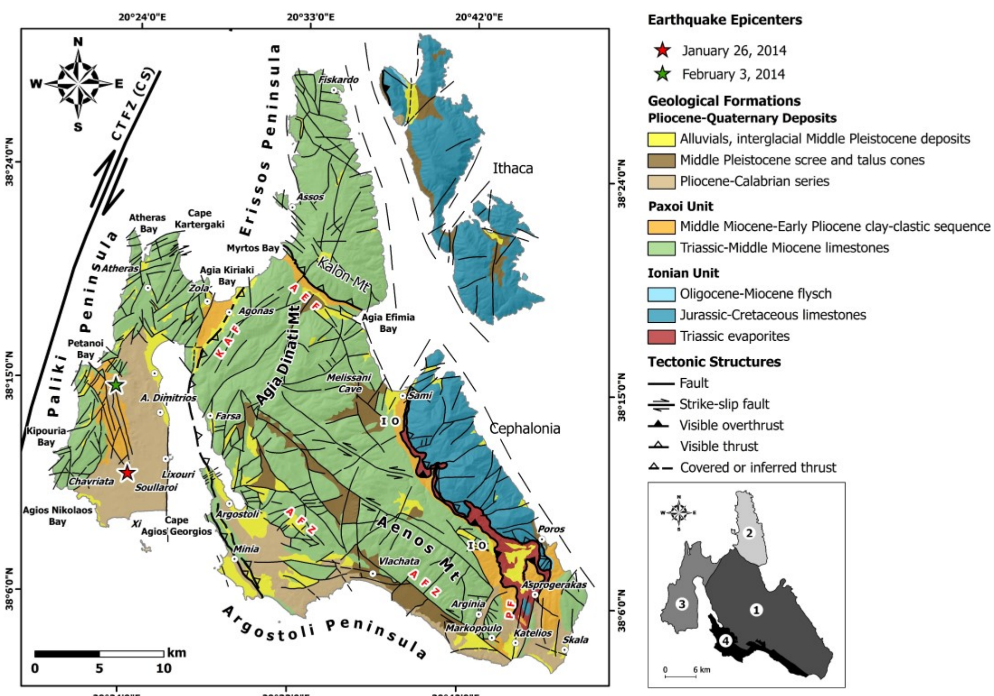

Fig. 3 – Geological map of the Cephalonia Island and its major neotectonic units. (1) Aenos Mt, (2) Erissos peninsula, (3) Paliki peninsula, (4) Argostoli peninsula.

The historical seismicity and the instrumentally recorded seismological data for the Ionian Islands show that Cephalonia has been repeatedly struck by destructive shocks with magnitudes up to 7.2 and intensity up to X+ (Fig. 4a) and earthquake sequences with more than one strong seismic event [24, 25]. Earthquake sequences analogous to the 2014 Cephalonia earthquake sequence have been also generated in 1767 (2 shocks, July 11 and

22), in 1912 (4 shocks, January 24, 25, 26 and February 10), in 1953 (3 shocks, August 9, 11 and 12) and in 1983 (3 shocks, January 17, 19 and March 23) [24] (Fig. 4a). Thus, Cephalonia falls in seismic zone III characterized by a ground acceleration coefficient of 0.36g, which corresponds to the greatest seismic strength demand according to the Greek code for Seismic Resistant Structures [26] (Fig. 4b).

Stress interaction is the most possible explanation for the occurrence mode of strong earthquakes in the Ionian Islands [27]. It is likely that the second main shock of the 2014 Cephalonia sequence was triggered by redistribution and changes of sufficient magnitude in the state of stress following the first main shock [6].

3. Dominant types of buildings in the affected area

The dominant types of buildings observed in the affected area can be broadly categorized in the following main types: (a) reinforced concrete (RC) buildings, (b) masonry buildings, (c) timber buildings, (d) monumental and cultural heritage buildings including castles, monasteries, churches, schools and libraries and (e) other structures stone and RC bridges.

The RC buildings comprise the majority of the building stock in Cephalonia. They are generally one- to four-storey buildings, constructed to strict anti-seismic specifications during the last decades following the devastating 1953 earthquakes. In this building type, an important feature playing a significant role in the earthquake structure response is the type of the ground storey. The Greek Building Code permits buildings to have an open ground storey (pilotis) to be used for various purposes (vehicle parking garage, playground, garden, shops). This practice creates a soft storey due to drastic reduction or absence of infill walls in comparison to the above storeys. In Cephalonia characterized by the highest recorded seismicity levels in Greece, the vast majority of RC buildings are characterized by the extensive use of shear walls and design of regular space frames with effective small to medium spans of beams. Carefully constructed infill walls with vertical RC elements for reduction of the distance between the columns and horizontal RC belts along the wall's height for the increase of the infill wall stiffness is a common technique for the mitigation of the undesirable consequences of the soft first storey.

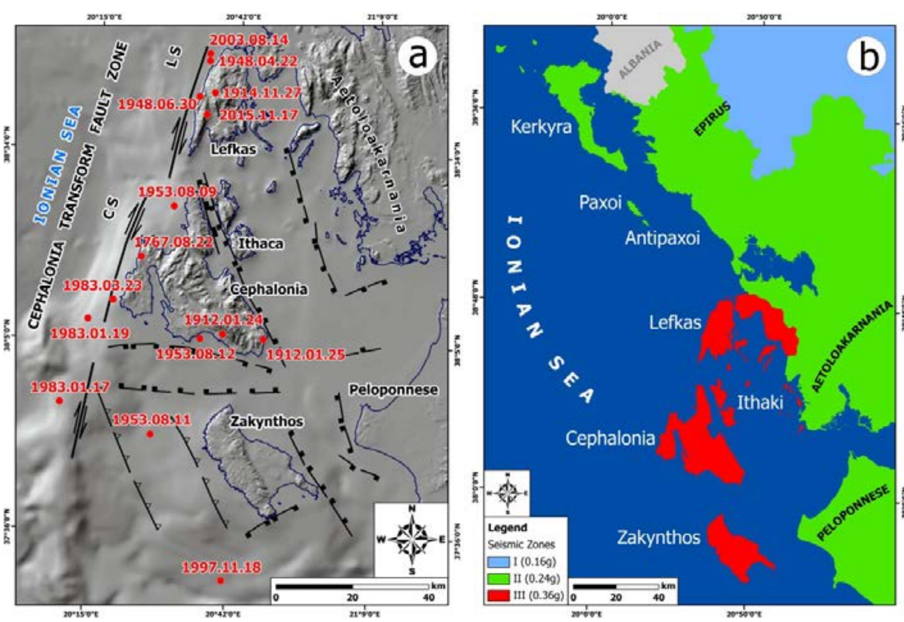

Fig. 4 – (a) Significant historical and instrumentally recorded earthquakes and epicenters that affected the geodynamic evolution of the Ionian Islands. (b) Cephalonia falls in the third seismic zone of Greece which is characterized by a ground acceleration coefficient of 0.36g corresponding to the greatest seismic strength demand according to the Greek code for Seismic Resistant Structures [26].

The one or two storey masonry buildings have a load-bearing system which includes masonry walls constructed either by clay, stone or concrete bricks with high-strength concrete mortar especially in tows or by roughly treated stones with low-strength clay mortar especially in small villages of the affected area. These buildings are not common in the island because most of them were destroyed during the devastating 1953 earthquakes.

The monumental and cultural heritage buildings are classified in RC buildings and buildings with masonry load-bearing walls. The first are located in Argostoli and Lixouri towns and include buildings with RC frame constructed after the 1953 earthquakes for administrative use and purposes and for accommodation of museums. The latter include one- to two-storey masonry churches and schools constructed with traditional seismic-resistant techniques. There are also other buildings in the meizoseismal area including timber buildings and stone or RC bridges.

4. Building damage

The building stock in the western part of Cephalonia in general and in the Paliki peninsula and the western part of Aenos Mt in particular suffered most damage by the 2014 Cephalonia earthquakes (Fig. 5). Damage was observed in unreinforced masonry buildings, RC buildings and monumental and cultural heritage structures.

The second earthquake not only aggravated damage induced by the first earthquake in Paliki peninsula, but also created new one. Such damage aggravation was not observed in Argostoli peninsula by the second earthquake. Damage due to pounding of building with different height and stiffness and damage to special structures such as bridges and monumental buildings including churches and their bell towers are only presented below and were not taken into account in the application of the EMS-98 always bearing in mind its limitations and special cases. It is significant to note that all villages and structures in the affected area were inspected after each earthquake and the classification of damage after the second earthquake was based on observations on both damaged and intact buildings after the first earthquake.

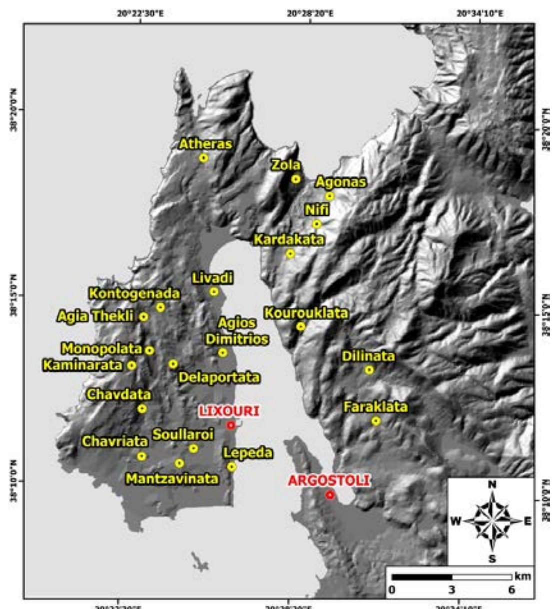

Fig. 5 – Spatial distribution of villages and towns in the western Cephalonia suffered damage by both earthquakes.

Damage in most of the RC buildings was concentrated in non-structural components. Most of the RC buildings suffer damage including roof detachment, fall of gables at the edge of double-pitched roofs, dislocation of the roof tiles due to the high accelerations involved and light cracks in the brick infill walls as well as detachment of the infill walls from the surrounding RC frame (Fig. 6). Diagonal cracking was only observed in buildings without reinforced infill walls. Damage was also observed at the connection area of adjacent buildings due to pounding.

The majority of RC buildings in the affected area showed satisfactory seismic response and structural performance during both earthquakes since none of them collapsed and no resident was killed or seriously injured. This was due to the good quality of construction materials and concrete with comprehensive strength higher than the expected, seismic detailing and presence of earthquake resistant features such as the reinforced infill walls at the ground level. This fact takes on even greater significance when considering that (a) the peak ground acceleration values recorded during both earthquakes are among the largest measured so far in Greece [10, 11] and (b) all buildings in Cephalonia must be designed and constructed on the basis of a PGA equal to 0.36 g, which corresponds to the greatest seismic strength demand according to the Greek code for Seismic Resistant Structures [27].

However, several exceptions were observed along the road extending from the Lixouri town to the villages of Agios Dimitrios and Livadi located north of Lixouri and along the southeastern coastal part of Paliki peninsula (Fig. 6). Several RC buildings designed under older anti-seismic codes and RC buildings with a soft storey at the ground level and stiffness considerably lower than the upper floors suffered severe structural damage to RC elements comprising concrete disorganization, flexural cracks and buckling of the longitudinal and transversal rods of the columns on the verge of collapse. Indicatively for this region, a two-storey RC building in the Agios Dimitrios village without infill walls in the first floor suffered soft-storey failure on the verge of collapse including buckling of steel bars and disorganization of concrete, while the second storey remained intact (Fig. 6a). Another two-storey RC building in the Agios Dimitrios village suffered diagonal cracks and detachment of infill walls of the first floor from the surrounding RC frame by the first earthquake (Fig. 6b) and failure of columns and joints by the second earthquake (Fig. 6c,6d). A three-storey building sustained severe structural and non-structural damage due to poor and inadequate construction. The structural damage include total collapse of the second floor due to absence of a column (Fig. 6e) and the non-structural damage comprised detachment of the infill walls from the surrounding RC frame due to vertically perforated bricks in the infill walls of the first floor (Fig. 6f, 6g, 6h). A three-storey building in Lixouri probably built before 1984 without infill walls in the first floor sustained soft-storey failure, while the two upper floors remained also intact (Fig. 6i-6l). Buildings in the Lixouri public housing complex sustained non-structural and structural damage including detachment of large pieces of plasters from the infill walls, extensive cracks of infill walls and failure of columns (Fig. 6m-6t). In conclusion, the abovementioned damage to RC buildings was induced due to open ground storey, asymmetric building construction, and heavy loads on the upper floors, short columns and inappropriate foundation on poor soils.

Masonry buildings suffered dislocation of several roof tiles (Fig. 7a), diagonal cracks in the masonry load-bearing walls, damage at the corners of longitudinal and transversal masonry walls (Fig. 7b) and detachment of large pieces of plaster from the masonry walls and of the roof from the rest of the building. Heavy damage included partial collapse of walls (Fig. 7c, 7d). After the second earthquake, many of these structures suffered destruction comprising total or near total collapse.

The RC churches suffered non-structural damage comprising light cracks in the brick infill walls, detachment of large pieces of plaster applied on the interior walls and damage occurred on bell towers (Fig. 7e-7h). The masonry churches suffered dislocation of several roof tiles and detachment of large pieces of plaster (Fig. 7e), light diagonal and vertical cracks in the masonry load-bearing walls (Fig. 7f) as well as fall of the church riser and gables at the edge of double-pitched roofs (Fig. 7g, 7h). Heavy damage included heavy diagonal and vertical cracks in the masonry load-carrying walls resulting in masonry disorganization and partial or total collapse of the structure. Damage in cemeteries includes partial or total collapse of retaining and perimeter walls and destruction of grave monuments. The ancient monuments of the affected area suffered no damage by the early 2014 Cephalonia earthquakes. On the contrary, the post-Byzantine monuments of the island including castles and churches suffered damage induced mainly by the first earthquake.

From the aforementioned damage, it is concluded that the seismic response, the structural performance and the observed damage of monumental and cultural heritage buildings induced by the 2014 Cephalonia earthquakes were significantly differentiated depending on their load-bearing structure and the impact of previous strong earthquakes generated in the Ionian Islands and affected Cephalonia. The monumental and cultural heritage buildings showed an overall good performance due to their resistance and stiffness.

Timber buildings and roofs performed in a satisfactory manner. No damage was also observed in stone or RC bridges.

5. EMS-98 intensities for the 2014 Cephalonia earthquakes

Based on the guidelines of EMS-98 [Grünthal, 1998], the buildings were grouped in vulnerability classes (A-E). More specifically, the RC buildings designed and constructed to strict anti-seismic specifications belong to the vulnerability classes D and E comprising reinforced concrete structures with moderate to high level of earthquake-resistant design. The unreinforced masonry buildings with load-bearing system composed of masonry walls belong to the vulnerability classes A and B and the timber buildings to the vulnerability class D.

Based on macroseismic field survey immediately after the January 26, 2014 earthquake and the guidelines of EMS-98, the following conclusions can be drawn (Fig. 8):

(a) Few unreinforced masonry structures of vulnerability classes A and B in villages located in the northern, western and southern part of the Paliki Peninsula (e.g. Atheras, Zola, Agonas, Nifi, Agia Thekli and Chavriata) suffered damage of grade 1 including negligible to slight non-structural damage, namely light cracks in very few masonry walls and detachment of small plaster pieces from the masonry walls. Thus, intensity V_{EMS-98} is assigned to the northern, western and southern part of Paliki peninsula.

Fig. 6 – Damage to RC buildings. (a) A two-storey RC building in the Agios Dimitrios village suffered soft-storey failure on the verge of collapse, while the second storey remained intact. (b – d) A two-storey RC building in the Agios Dimitrios village suffered diagonal cracks and detachment of infill walls of the first floor from the surrounding RC frame by the first earthquake (b) and failure of columns and joints by the second earthquake (c, d). (e – h) A three-storey building sustained total collapse of the second floor due to absence of columns (e) and detachment of the infill walls from the surrounding RC frame due to vertically perforated bricks in the infill walls of the first floor (f, g, h). (i – l) A three-storey building in Lixouri probably built before 1984 sustained soft-storey failure, while the two upper floors remained also intact. (m – p) A three-storey building in the Lixouri public housing complex. The first earthquake caused moderate damage (m), while the second earthquake aggravated damage (n). (o, p) The same building on the verge of collapse in July 2015 and in November 2015

immediately after the Mw 6.4 Lefkas (Ionian Sea, Western Greece) earthquake. (q – p) Another two-storey building in the Lixouri public housing complex suffered moderate damage due to the first earthquake (q) and severed damage due to the second earthquake (r, s, t).

Fig. 7 – Damage to masonry buildings included (a) detachment of roof tiles, (b) partial collapse of the load bearing wall, (c) destruction of the upper corners of the buildings and (d) near total collapse of the building. Masonry churches suffered damage including (e) detachment of roof tiles and pieces of plaster, (f) cracks in masonry load bearing walls and in the upper corners of the structure and (g, h) fall of gables at the edge of double-pitched roofs.

(b) In villages located in the western part of Aenos Mt (e.g. Kardakata, Kourouklata, Dilinata and Faraklata) and the eastern and central part of the Paliki peninsula (e.g. Livadi and Chavdata respectively), many unreinforced masonry structures of vulnerability classes A and B sustained slight damage of grade 1, while few such buildings suffered moderate damage of grade 2 comprising cracks in many walls, dislocation of roof tiles, detachment of large plaster pieces and partial collapse of chimneys. Thus, intensity VI_{EMS-98} is assigned to the western part of Aenos Mt and the eastern and central part of the Paliki peninsula.

(c) In the Lixouri town and the Agios Dimitrios village, many buildings of vulnerability classes A and B suffered substantial to heavy damage of grade 3 like large and extensive cracks in walls, detachment of roof tiles and moderate damage of grade 2 like cracks in walls and fall of small pieces of plaster respectively, while few buildings of vulnerability classes A and B suffered very heavy damage of grade 4 like partial collapse of masonry walls and substantial to heavy damage of grade 3 respectively. Moreover, reinforced buildings of vulnerability class D suffered negligible to slight damage of grade 1 like light cracks in infill walls, while reinforced buildings of vulnerability class E suffered no damage at all. Thus, the highest intensity for the first earthquake is VII_{EMS-98} and is assigned to the Lixouri town and the village of Agios Dimitrios in the eastern coastal part of Paliki peninsula.

Based on macroseismic field survey immediately after the February 3, 2014 earthquake and the guidelines of EMS-98, the following conclusions can be drawn (Fig. 8):

(a) Few unreinforced masonry structures of vulnerability classes A and B in villages located in the northern, and western part of the Paliki Peninsula (e.g. Atheras, Zola, Agonas, Nifi and Agia Thekli) suffered damage of grade 1. Thus, intensity V_{EMS-98} is assigned to the northern and western part of Paliki peninsula.

(b) In villages located in the western part of Aenos Mt (e.g. Kardakata, Kourouklata, Dilinata and Faraklata), many unreinforced masonry structures of vulnerability classes A and B sustained slight damage of grade 1, while few such buildings suffered moderate damage of grade 2. Thus, intensity VI_{EMS-98} is assigned to the western part of Aenos Mt.

(c) In villages located around the Lixouri town (e.g. Livadi located northwards, Chavdata located westwards and Lepeda located southwards), the second earthquake aggravated building damage induced by the first earthquake. Due to this aggravation, the assigned intensity for the second earthquake (VII_{EMS-98}) is one grade larger than that for the first earthquake (VI_{EMS-98}).

(d) Building damage aggravation occurred in the Lixouri town and the village of Agios Dimitrios. Thus, the assigned intensity for the second earthquake ($VIII_{EMS\text{-}98}$) is one grade larger than that for the first earthquake ($VII_{EMS\text{-}98}$).

(e) The second earthquake generally aggravated damage induced by the first earthquake in Paliki peninsula. Such damage aggravation was not observed in Argostoli peninsula.

Based on the application of the EMS-98 and the intensity assignment to the area affected by the 2014 Cephalonia earthquakes, it is concluded that the highest seismic intensities of the first event reached VII and were assigned to the Paliki peninsula, while the highest seismic intensities of the second event were bigger reaching VIII and were also assigned to the eastern part of Paliki peninsula.

6. Conclusions

The early 2014 Cephalonia earthquake sequence comprised two main shocks with almost the same magnitude (Mw 6.0) occurred successively in short time (January 26, February 3) and space (western Cephalonia, Paliki peninsula). The first event caused damage in Paliki peninsula, while the second generally aggravated damage induced by the first. Masonry buildings were most affected due to their high vulnerability. RC buildings showed good performance due to their good construction quality. The monumental and cultural heritage buildings have been repeatedly affected by strong earthquakes in recent past. However, they showed good performance due to their resistance and stiffness.

In conclusion, the severity of the 2014 Cephalonia earthquakes as expressed through the recorded accelerations, velocities and displacements was not reflected in the overall picture and spatial distribution of the damage on the building stock of western Cephalonia. However, damage was induced by both earthquakes mainly in masonry buildings, monumental and cultural heritage buildings as well as in buildings designed and constructed according to older anti-seismic codes. Damage in most of the RC buildings was concentrated in non-structural components, while damage to structural elements of RC buildings was limited and localized in the eastern coastal part of Paliki peninsula (Lixouri town, Agios Dimitrios and Livadi villages).

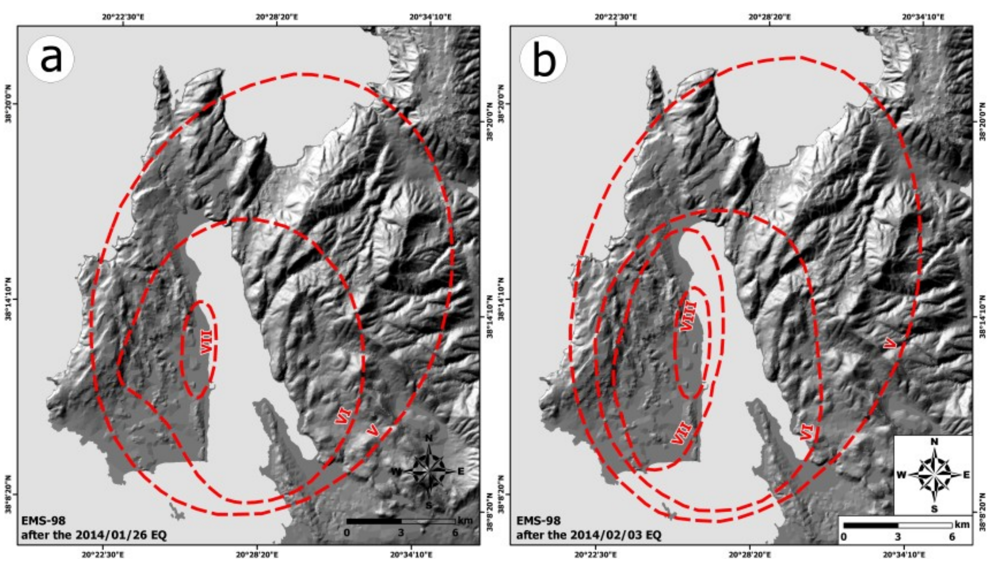

Fig. 8 – EMS-98 intensities for (a) the first earthquake on January 26, 2014 and (b) the second earthquake on February 3, 2014. The western part of Cephalonia and especially the Paliki peninsula suffered the most from both earthquakes and thus the highest seismic intensities were observed there.

This satisfactory seismic response and performance of buildings in Cephalonia during both earthquakes is attributed to the fact that these buildings possess higher strength under earthquake effects than the expected for the affected area which is characterized by the highest recorded seismicity levels in Greece. This unexpected strength reserves are due to the good quality of construction material and cement, the indeterminacy of the structures, the ductility and the overstrength of the individual structural elements and the provision of extra reinforcement by the carefully constructed infill walls with vertical and horizontal RC elements. Soil structure interaction phenomena possibly occurred because of the magnitude and the severity of both earthquakes. These phenomena may have beneficial effects on the seismic response of buildings. Thus, the overall seismic building response stresses the efficiency of the Greek code for Seismic Resistant Structures and the importance of the constructions quality.

Based on the spatial distribution and the type of building damage induced by the 2014 Cephalonia earthquakes and the seismic intensities derived from the application of the EMS-98, it is concluded that the Paliki peninsula is the area most affected by both 2014 earthquakes with seismic intensities ranging from V to VIII (Fig. 8). From the comparison of the above mentioned seismic intensity distribution with historical earthquake intensity data for Cephalonia [24, 25, 28], it becomes clear that this is not the first time such a distribution is observed on the island. The western part of the island is the area usually and mostly affected by earthquake effects in its natural and built environment. More specifically, the highest seismic intensities of historical earthquakes have undoubtedly been observed in the western part of Cephalonia in general and in Paliki peninsula in particular (IX-X+$_{MMI}$ during the 1658, 1767, 1867 and 1953 earthquakes). On the contrary, Erissos peninsula is the only neotectonic macrostructure of the island that suffered the lowest seismic intensities during these shocks (IV-VI$_{MMI}$ during the 1658, 1767, 1862, 1867, 1915 and 1953 earthquakes). This anomalous attenuation of seismic waves is generally correlated with the geodynamic complexity of the region and strongly related with the complexity of fault systems and the existence of salt layers that lie into the adjacent slipping areas of the faults [25, 28].

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