KEFALONIA EARTHQUAKE 26/1/2014 AND 3/2/2014

Technical Report · May 2014

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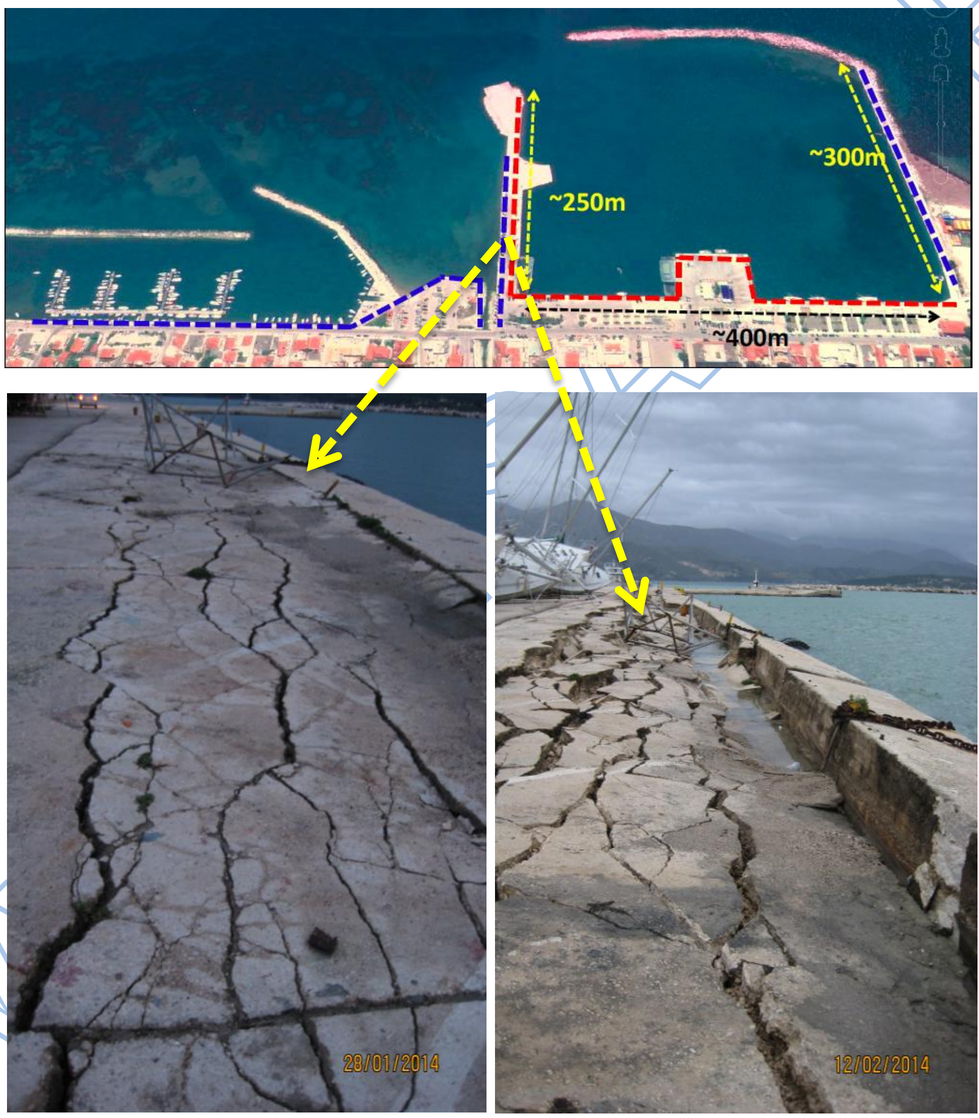
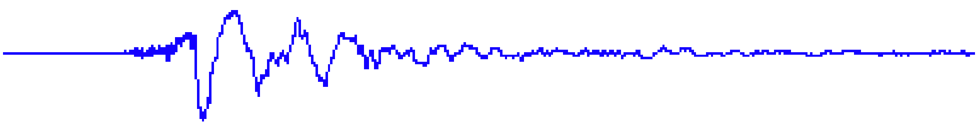
STRONG GROUND MOTION OF THE FEBRUARY 3, 2014 (M6.0)

CEPHALONIA EARTHQUAKE:

EFFECTS ON SOIL AND BUILT ENVIRONMENT IN COMBINATION WITH THE JANUARY 26, 2014 (M6.1) EVENT





THESSALONIKI

FEBRUARY 2014

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EFFECTS ON SOIL AND BUILT ENVIRONMENT IN COMBINATION WITH THE JAN. 26, 2014 (M6.1) EVENT

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Digital data of the Feb. 3, 03:08 event are open to the public at:
http://www.itsak.gr/news/news/65

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1. STRONG GROUND MOTION

1.1. INTRODUCTION

In February 3, 2014, 03:08 GMT (05:08 local time), eight days after the moment magnitude, M6.1, earthquake that hit the region of Cephalonia, another strong earthquake with a moment magnitude, M6.0, occurred at the Paliki peninsula, western coasts of the Cephalonia island, about 7km northwest of the Lixouri town. According to the Hellenic Unified Seismological Network (HUSN), it was a shallow crustal event with epicenter 38.25N, 20.39E and depth 10km.

From the epicenter and focal mechanisms of the earthquakes it is deduced that they are related to the Cephalonia Transform Fault (CTF) (Scordilis et al. 1985). This is a dextral strike-slipe fault with a thrust component (Papazachos and Papazachou 1997, 2003).

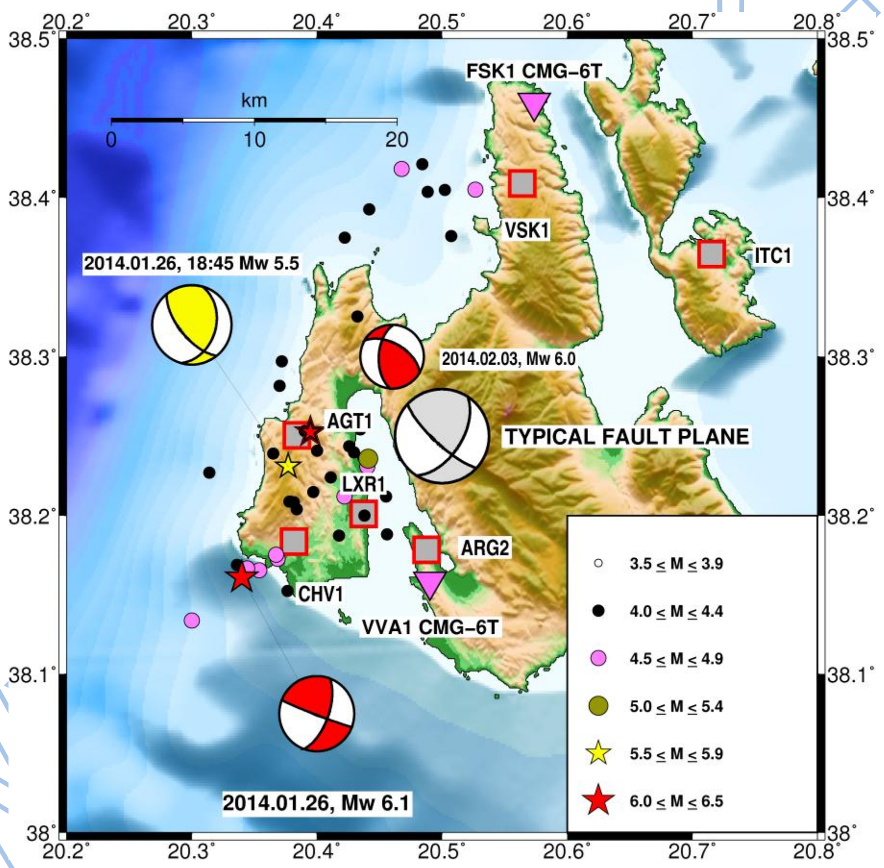


Figure 1.1 Epicenters of the 26/1/2014 and 3/2/2014 earthquake are marked with red stars. The yellow star depicts the epicenter of the 26/1/2014 !8:45 GMT with M=5.6 The aftershock distribution (with M≥4.0) of the seismic sequence in Cephalonia one month after the first event are also shown (source: HUSN). The focal mechanisms of these events (source: GCMT solutions) in respective color balloons and the typical focal mechanism for Cephalonia area (Papazchos and Papazachou, 2003) are also given. The grey squares and pink triangles denote the sites of accelerographs and seismographs.

The seismic sequence of Cephalonia is related to the Cephalonia Transform Fault (CTF) which is a strike slip fault with thrust component (Scordilis et al., 1985). In Fig. 1.1 the epicenters of the January 26 and February 4, 2014 strong events and the epicenter of the 26/1/2014, 18:45GMT (M5.5) aftershock are shown according to the legend. The focal mechanisms for all three events (source: Global CMT project) and the typical focal mechanism of the region are also provided.

Due to the source properties of the **M** 6.0, of the 3/2/2014 earthquake, the ground shaking was felt on the Cephalonia, on the islands of Ithaki, Lefkas and Zakynthos, as well as on areas of western Greece and Peloponnesos. According to the EMSC the ground motion was also felt in parts of western Greece and marginally in south Italy (Fig. 1.2).

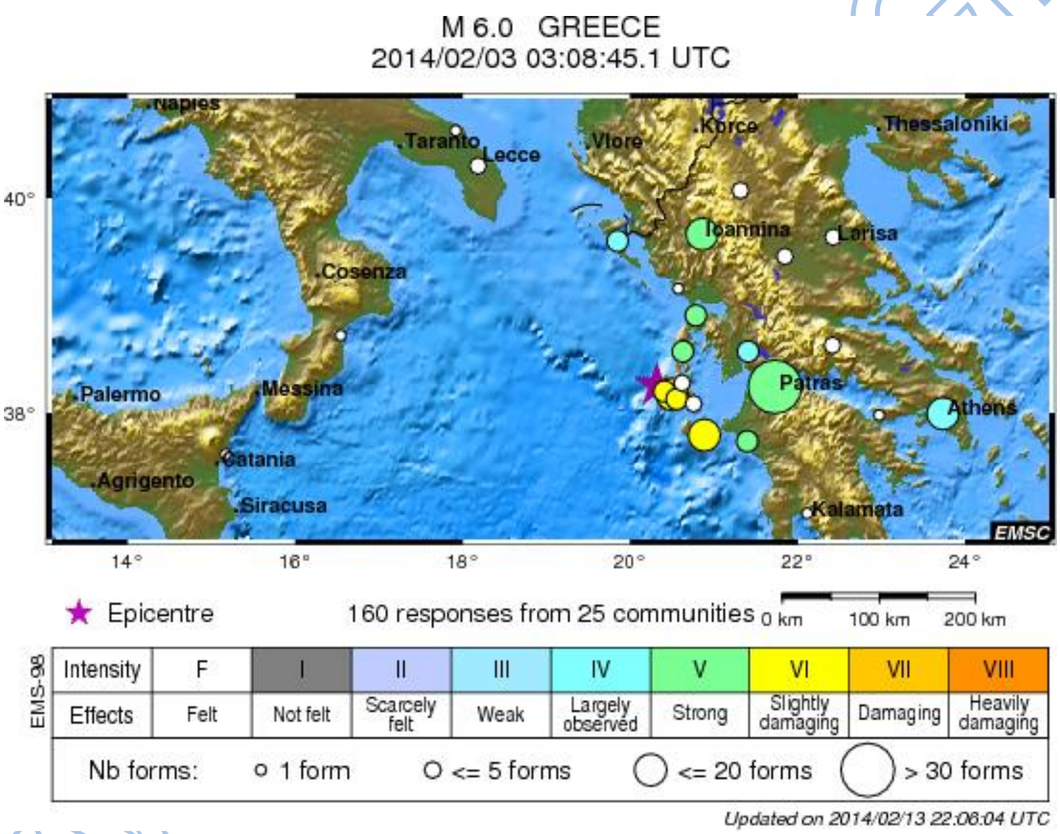


Figure 1.2. Map of observed macroseismic intensities of the 3/2/2014 mainshock in Cephalonia (EMSC, 2014).

On February 3 and 10, 2014, members of the scientific staff of EPPO-ITSAK arrived on the Cephalonia island in order to maintain accelerographs and seismographs already installed on the island just after the mainshock of 26/1/2014, download data and record cumulative effects of strong ground shaking on natural and built environment.

During the last three years the EPPO-ITSAK has installed throughout Greece a dense network of continuous recording accelerographs. They are equipped with broadband digitizers, of high resolution (24bits), and absolute GPS time. Recordings of this network are transmitting in real time at the central computing unit of the EPPO-ITSAK in Thessaloniki. Consequently, strong ground motion parameters of the mainshock recorded at the Cephalonia and Ithaki islands (peak ground acceleration, velocity, displacement and spectral values) were provided in short time in the form of a preliminary report on the web site of EPPO-ITSAK (www.itsak.gr). In addition, in less than 10 minutes (almost real time) after the earthquake origin time, the first shakemaps were generated and were available to the public (http://portal.ingeoclouds.eu/sitools/client-user/Shakemaps/project-index.html). Later the shakemaps were updated on the basis of additional manual data and revision of the earthquake source parameters.

1.2. NETWORK OF ACCELEROGRAPHS

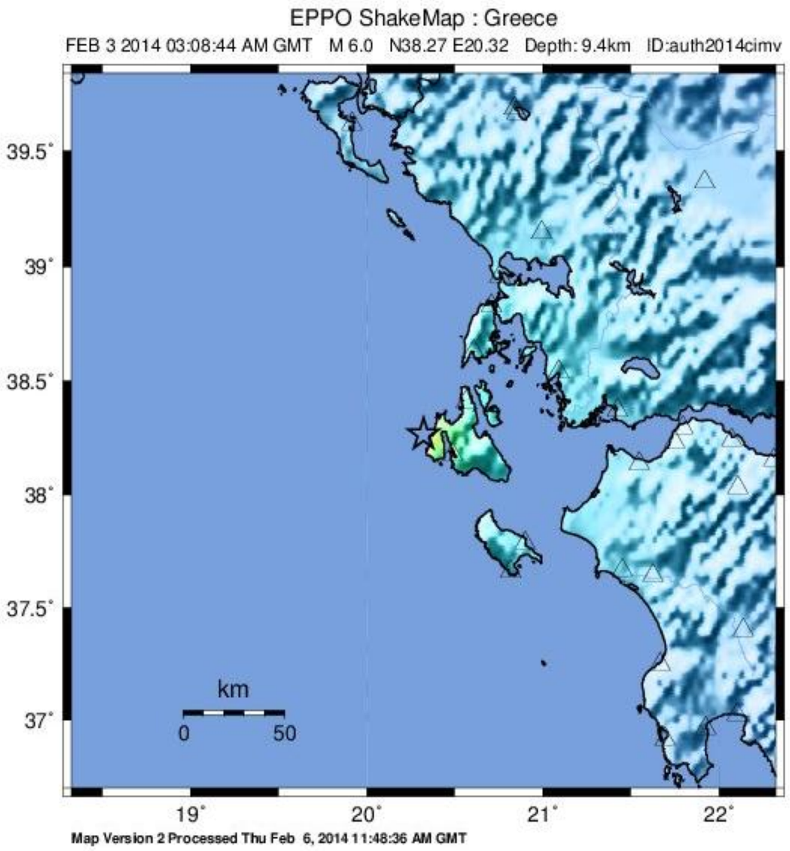
The permanent accelerographic network on the Cephalonia & Ithaki Regional Unity (digital instruments CMG-5TD-EAM) were installed in the town of Argostoli (ARG2: building of Regional Authority) and in the village of Vasilikades (VSK1: building for Sitizens' Service Center) and in the village of Vathi (ITC1: building of Municipality Technical Department). A temporary network of three accelerographs was deployed in 27 and 28 of January, 2014, mainly within the area strongly affected by the mainshock around the town of Lixouri. More specifically, three accelerographs were installed: (i) in the townhall of Lixouri (LXR1), (ii) in the old school of the village Chavriata(CHV1) and (iii) in a private house of the Ag. Thekli village (AGT1). In addition, two seismographs one in the Fiskardo village (FSK1) and another south to Argostoli (VVA1) were also installed (Fig. 1.3). All these instruments

Figure 1.3. Permanent (ARG2, VSK1, ITC1) and temporary (CHV1, LXR1, AGT1) accelerograph stations and temporary stations of seismographs (VVA, FSK1), installed by EPPO-ITSAK on the Cephalonia and Ithaki islands.

operate in continuous mode and from their data analyses significant information for the seismic source properties of the mainshock and its aftershock, ground motion prediction in the near field and influence of site conditions on ground motion may come out. Data from the stations ARG2, VSK1, CHV1, LXR1 and AGT1 are also transferred in real time to the seismological station of Thessaloniki contributing in the improvement of the hypocenter location and magnitude estimation of the aftershocks for the national seismographic network.

1.3. GROUND MOTION RECORDINGS IN CEPHALONIA DUE TO FEBRUARY 3, 2014, EARTHQUAKE

Ground motion of the mainshock was recorded by the permanent accelerographic network on the islands of Cephalonia and Ithaki as well as throughout Greece. In near real time, in about 10 minutes after the origin time, preliminary shakemaps were produced and uploaded on the web (Fig. 1.4). These maps include distribution of instrumental intensity, peak ground acceleration, velocity and spectral acceleration values for natural periods T=0.3, 1.0, 3.0 sec.



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+

Scale based upon Worden et al. (2011)

Figure 1.4. Shakemap for the February 3, 2014 (M6.0) earthquake in Cephalonia.

During the earthquake of 3/2/2014, 03:08GMT (M6.0) very high spectral values were observed, especially at the temporary accelerograph stations installed in Paliki peninsula (CHV1, LXR1). Spectral acceleration values at the CHV1 reached up to 2900 cm/s/s, in the N-S component at low periods, T≈0.25sec, while in intermediate periods, T≈0.8sec, they reached up to 1500 cm/s/s (Fig. 1.5). Spectral values at the LXR1 reached up to 1900cm/s/s, in U-D component at very low periods, T<0.1sec, while in intermediate to long periods 0.8sec≤T≤1.5sec, they reached up to 1600cm/s/s, in the E-W component (Fig. 1.6). At the ARG2 site spectral high were also observed, up to 1000cm/s/s, in U-D component at very low periods, T<0.1sec, while they reached up to 800cm/s/s, in the N-S component at intermediate periods, T≈0.5sec (Fig. 1.7). At the site of Vasilikades (VSK1) relatively low spectral acceleration values were observed, less than 200 cm/s/s/, at low periods, T<0.5sec, in both horizontal components (Fig. 1.8). The software ViewWare (Kashima, 2005) was used in the processing of the accelerograms.

In Table 1.1, recorded peak ground acceleration, velocity and displacement for the events of 3/2/2014, 03:08GMT (M6.0) are given, along with corresponding epicentral distance from the recording stations of EPPO-ITSAK. The peak ground values were observed in horizontal components. **The peak ground acceleration, PGA=0.77g, at the Chavriata site (CHV1) was the greatest value recorded to date in Greece.** Not much lower value was that recorded at Lixouri site (LXR1), PGA=0.68g. Both stations fall in the near-field at a distance of about 7km from the earthquake epicenter and also within the rupture zone of the earthquake.

Table 1.1. Ground motion parameters for the 3/2/2014 earthquake observed at Chavriata (CHV1), Lixouri (LXR1), Argostoli (ARG2) and Vasilikades (VSK1).

STATION	Epicentral Distance (km)	Peak Ground Acceleration (cm/s/s)	Peak Ground Velocity (cm/s)	Peak Ground Displacement (cm)
Chavriata (CHV1)	7	752	62	11
Lixouri (LXR1)	7	667	122	30.5
Argostoli (ARG2)	12	264	30	5.7
Vasilikades(VSK1)	23	57	5	1.4

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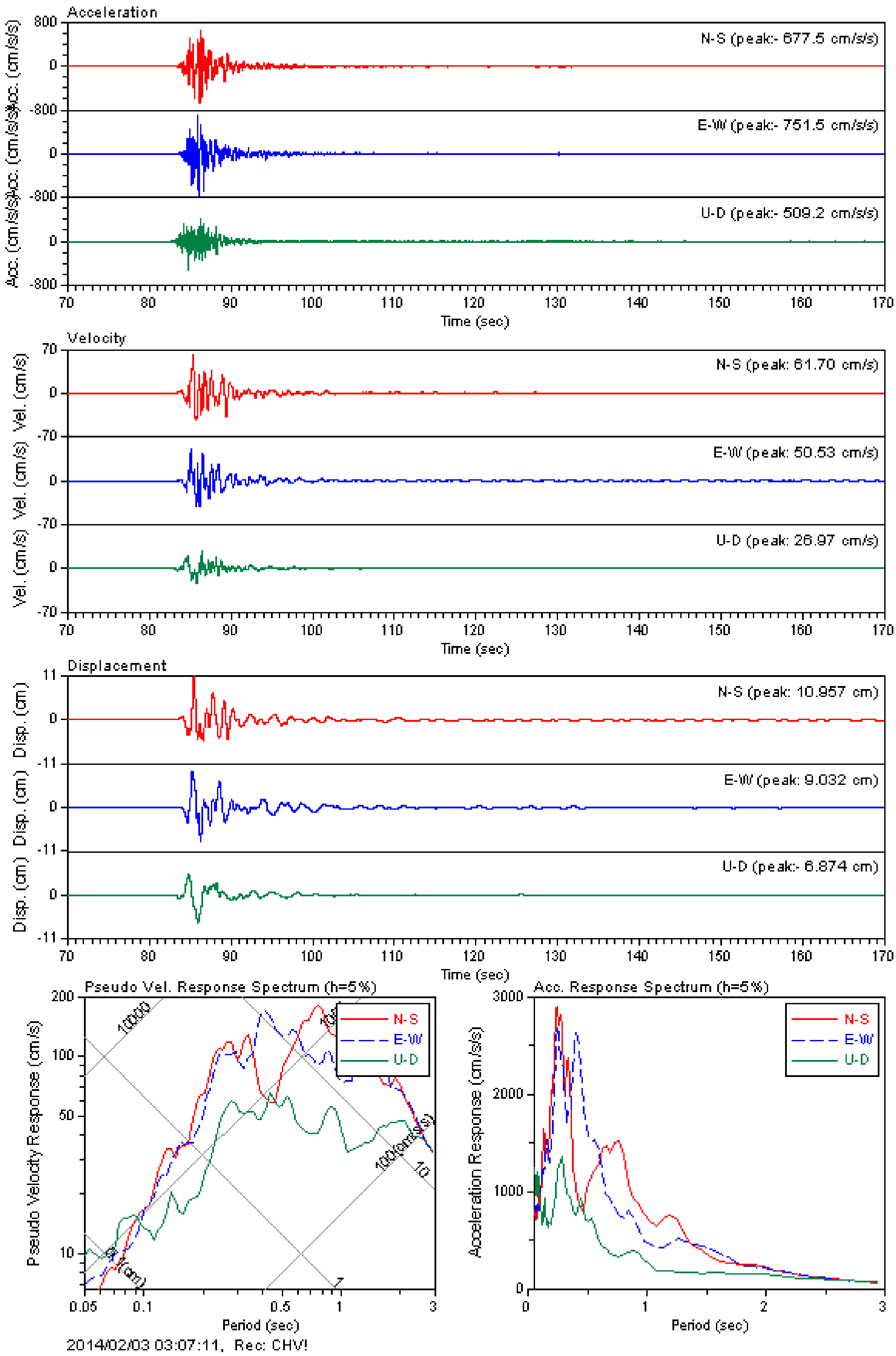

Figure 1.5. Acceleration, velocity and displacement time histories recorded at Chavriata (CHV1) station and their corresponding pseudo-velocity and acceleration response spectra for the aftershock of 3/2/2014, 03:08GMT(M6.0) and damping D=0.05.

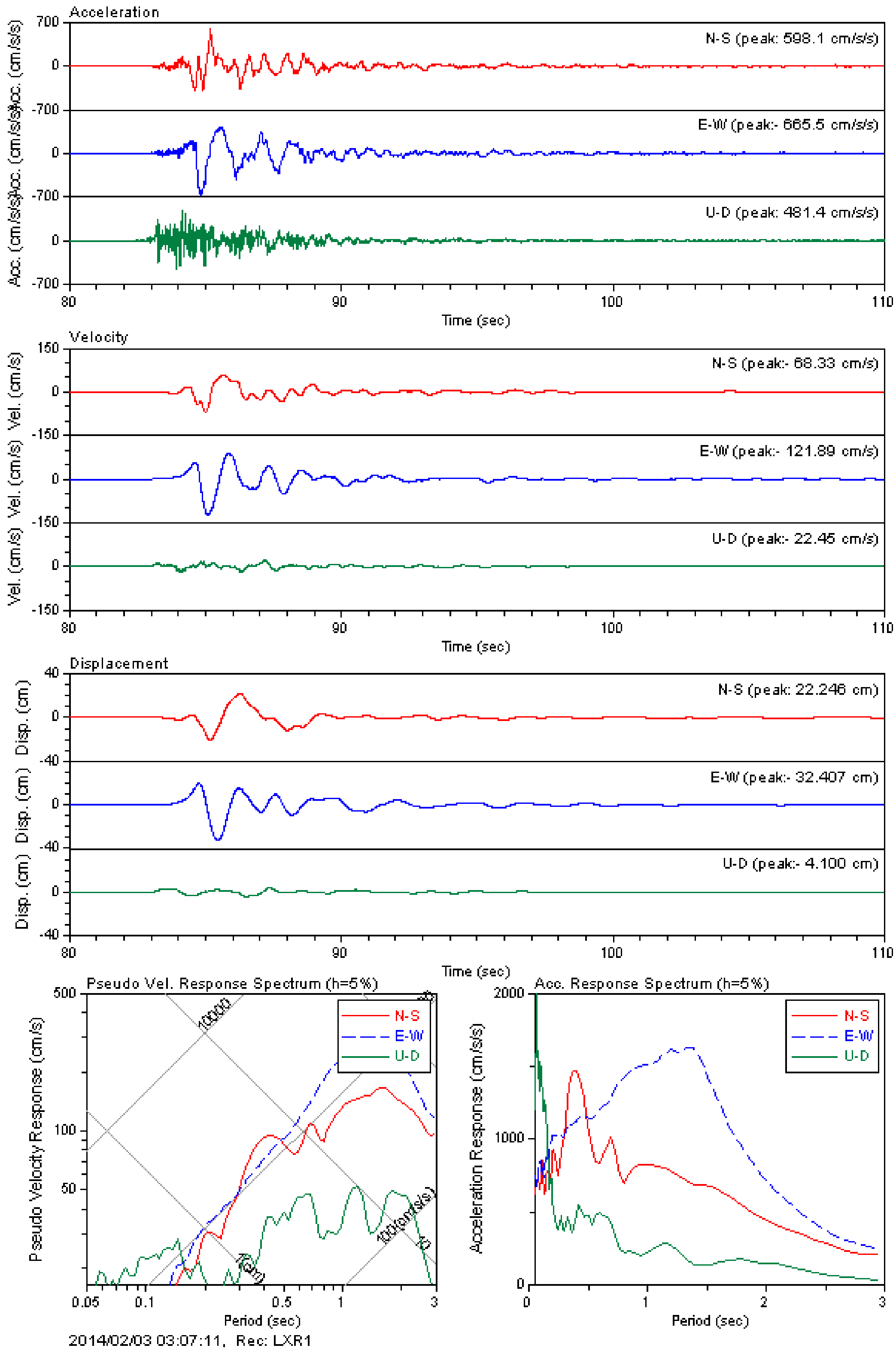

Figure 1.6. Acceleration, velocity and displacement time histories recorded at Lixouri (LXR1) station and their corresponding pseudo-velocity and acceleration response spectra for the aftershock of 3/2/2014, 03:08GMT (M6.0) and damping D=0.05.

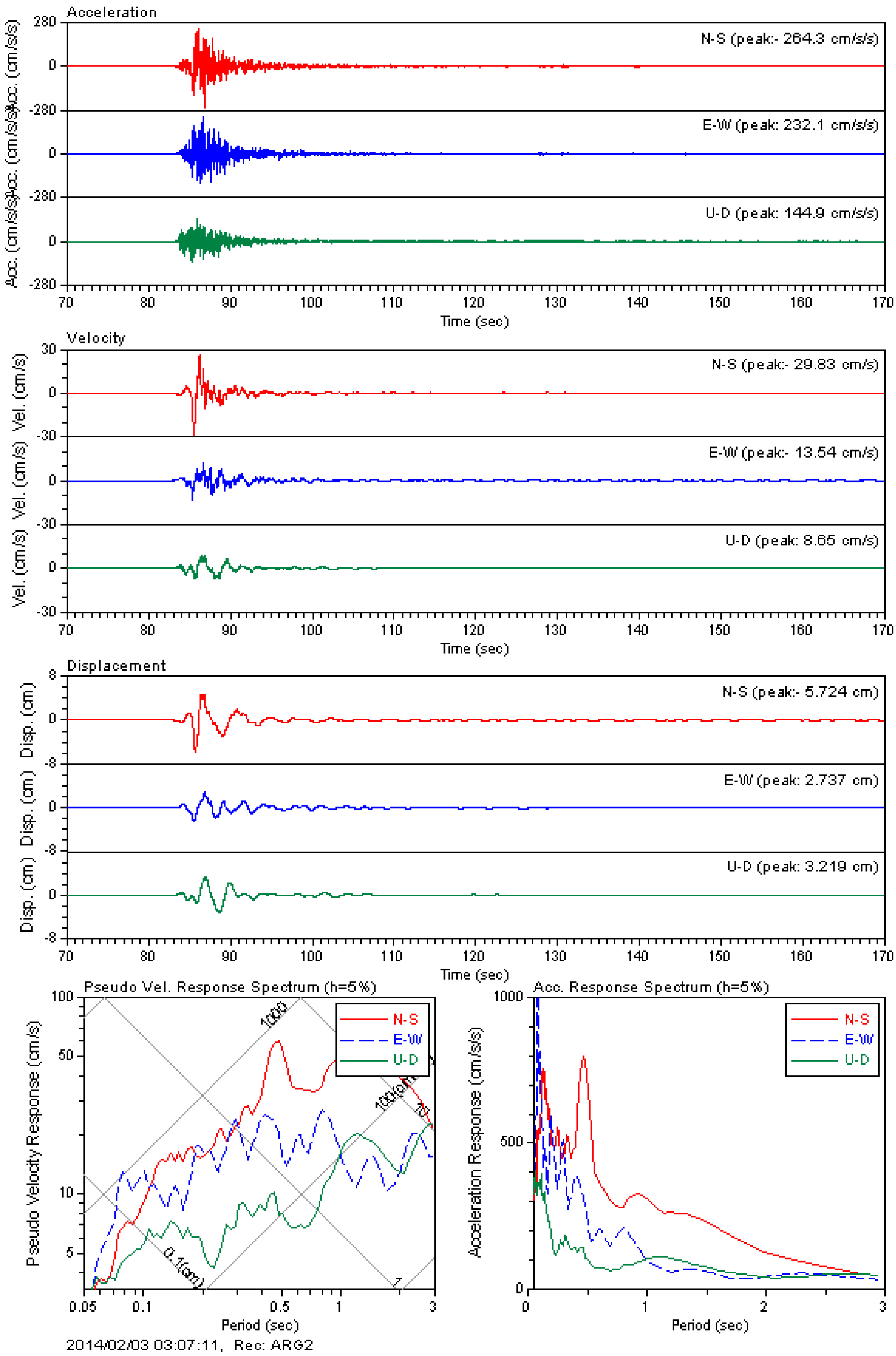

Figure 1.7. Acceleration, velocity and displacement time histories recorded at Argostoli (ARG2) station and their corresponding pseudo -velocity and acceleration response spectra for the mainshockof 3/2/2014, 03:08GMT (M6.0) and damping D=0.05.

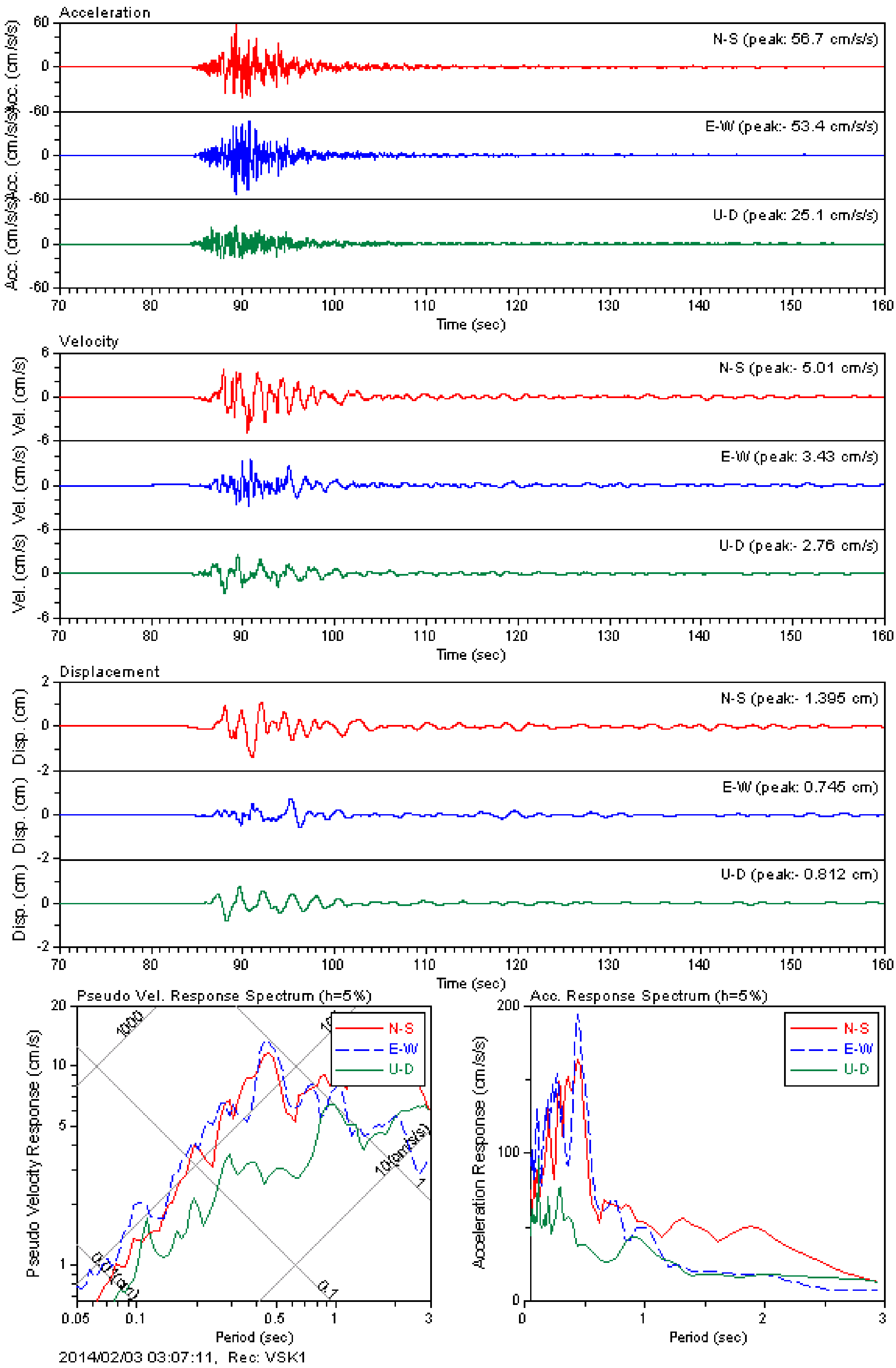

Figure 1.8. Acceleration, velocity and displacement time histories recorded at Vasilikades (VSK1) station and their corresponding pseudovelocity and acceleration response spectra for the mainshock of 3/2/2014, 03:08GMT (M6.0) and damping D=0.05.

According to information compiled by Papazachos and Papazachou (1997, 2003) since mid of 15th century AD the causative fault where both the event of 26/1/2014 and 3/2/2014 occurred, produced events whose maximum magnitude reached M7.2.

The most recent large event on the causative fault occurred in January 17, 1983 with magnitude M7.0. Despite its large magnitude this event caused a macroseismic intensity I_{MM}=VI (Bulletin of Geodynamic Inst., NOA) while a peak ground acceleration of 0.17g was recorded at an epicentral distance of 35km in Argostoli (Theodoulidis et al., 2004).

In Fig. 1.9, comparison of acceleration response spectra recorded at Argostoli of the 26/1/2014 (M6.1) earthquake with that of 17/1/1983 (M7.0), is presented. For periods less than 1.2sec, ground motion of the recent event is two to three times stronger than that of 1983, which is probably due to shorter hypocenter-to-station distance.

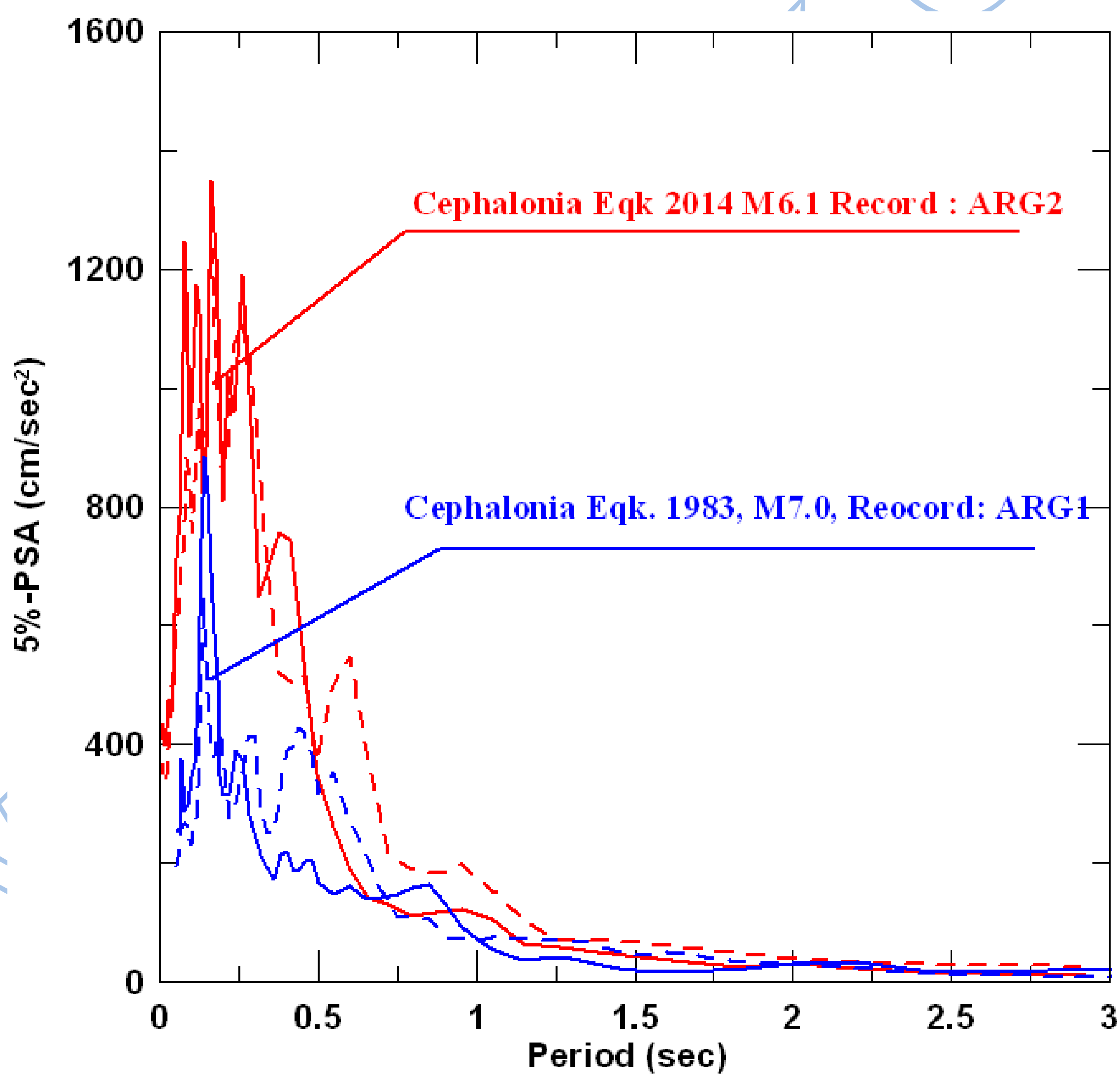

Figure 1.9. Comparison of horizontal components acceleration response spectra of the 17/1/1983 (M7.0) and 26/1/1983 (M6.1), Cephalonia earthquakes.

In Figure 1.10, comparison between acceleration response spectra of the event of 3/2/2014, 03:08GMT (M6.0) observed at Lixouri(LXR1) and Argostoli(ARG2) sites, is given. For the entire period range, spectral values at LXR1 are higher than those observed at ARG2. Interestingly, spectral values of LXR1, around T≈1.5sec, are up to 25 times greater than the corresponding of ARG2 site. Such a huge difference may be attributed either to near-field effects or/and possible site effects. Further study on this issue may shed light on the interpretation of these observations.

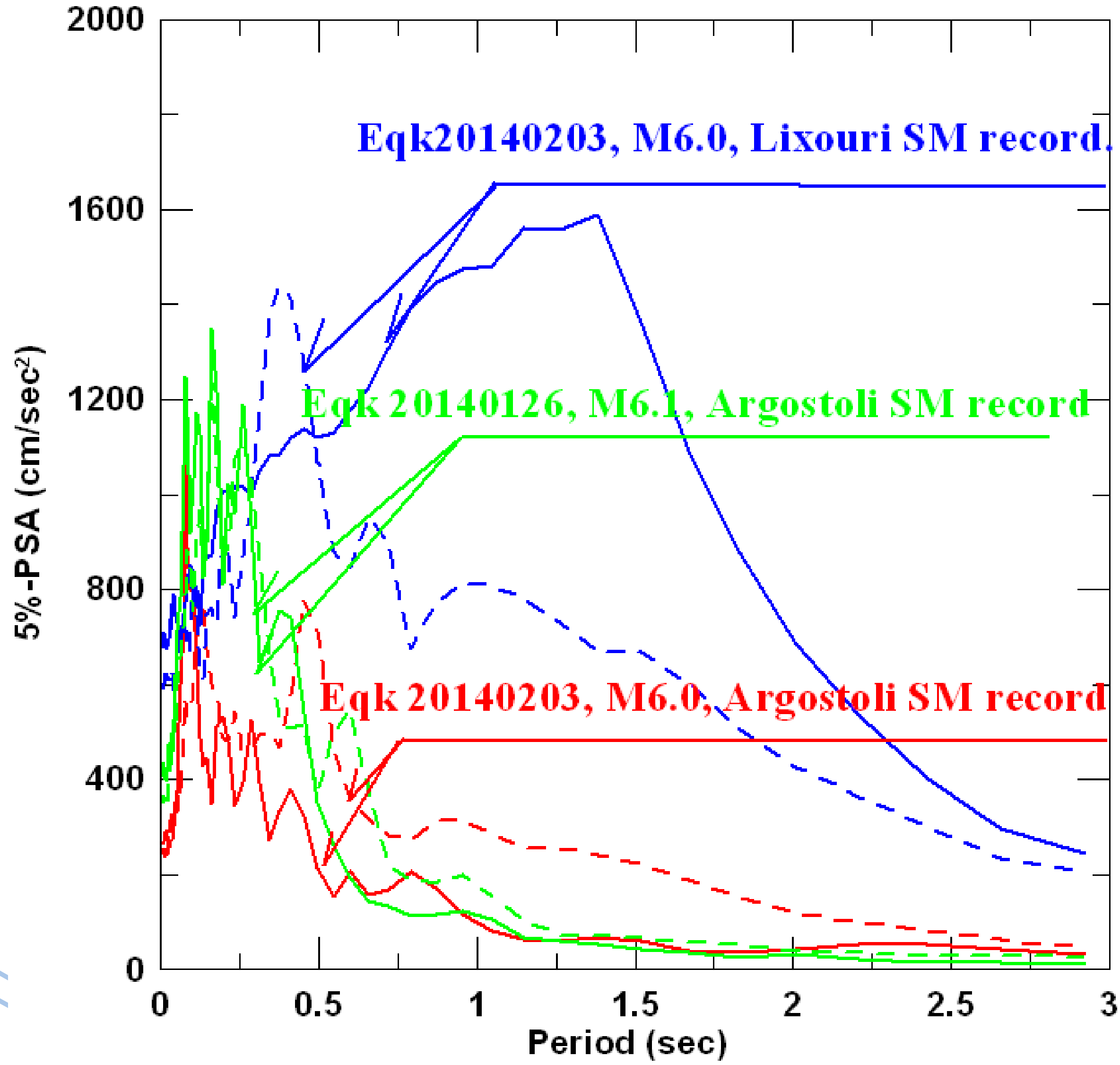

Figure 1.10. Acceleration response spectra (horizontal comps.) of the 3/2/2014 (M6.0) observed at the station of Argostoli (ARG2, red color) and Lixouri (LXR1, blue color). For comparison reasons, response spectra observed during the 26/1/2014 event at Argostoli (ARG2, green color), are also shown.

2. GEOTECHNICAL ISSUES AND SEISMIC RESPONSE OF LIFELINES

2.1. RECORDED AND DESIGN ELASTIC RESPONSE SPECTRA AT ARG2 AND VSK1 STATIONS

Geological, geotechnical and geophysical characteristics of soil at ARG2 (Argostoli), and VSK1 (Vasilikades) accelerographic stations of the Greek National Accelerographic Network were described in the first report of ITSAK (EPPO- ITSAK, Report, 2014) following the strong earthquake of 26/1/2014. In this section, earthquake motion recorded from the above stations is presented referring to the second strong earthquake of 03/02/2014.

Response spectra corresponding to NS, EW and vertical component of the M6.1 Cephalonia earthquake (26th Jan. 2014, 13:55 GMT) and the M6.0 Cephalonia earthquake motions (3rd Feb. 2014, 03:08 GMT) recorded at ARG2 and VSK1 accelerographic stations are compared in Figure 2.1 with the design elastic spectrum referring to soil type B (for ARG2) and A (for VSK1) according to EAK2003 and EC8, respectively.

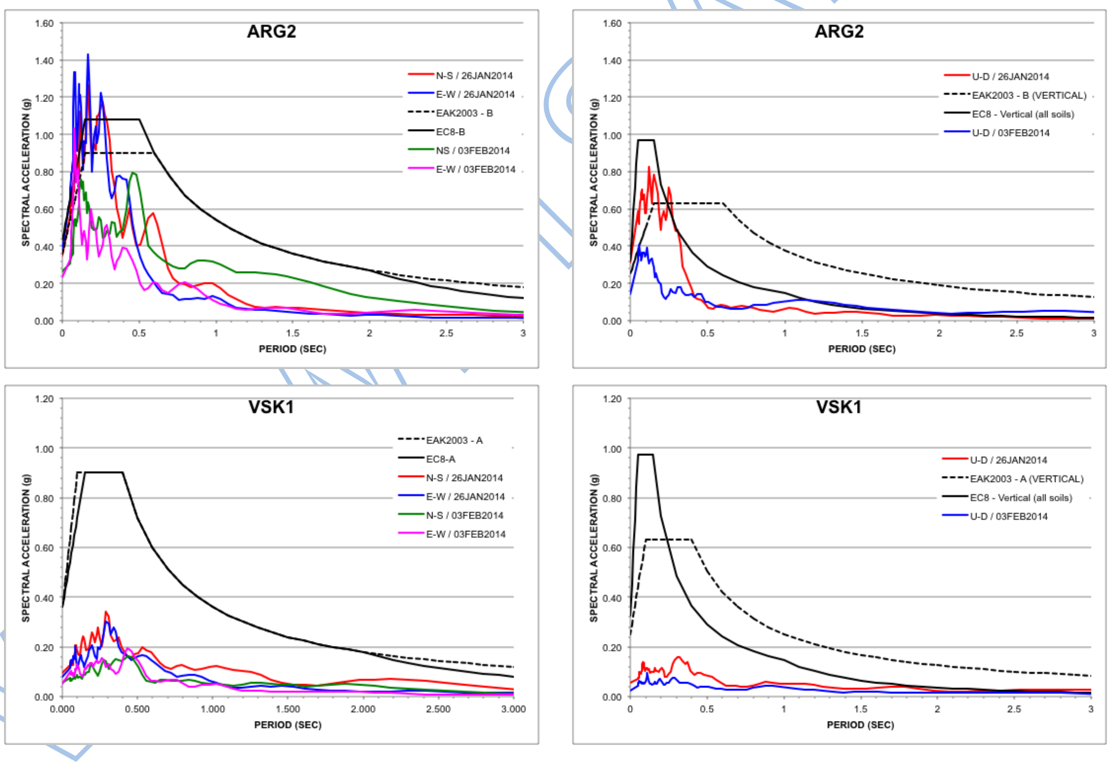

Figure 2.1. Response spectra obtained from the recordings of the earthquakes occurred on 26/1/2014 and 03/02/2014 with respect to elastic design spectra of greek seismic code (EAK2003) and Eurocode 8 (EC8). Top: ARG2 strong motion site at Argostoli, Cephalonia. Bottom: VSK1 strong motion site at Vasilikades, Cephalonia. Left: Horizontal components. Right: Vertical components.

It is observed (figure 2.1, top) that the recorded spectral accelerations of the first earthquake event recorded at ARG2 are higher than the code-defined values of EAK2003 within the period range of 0.1 and 0.3sec. On the other hand, EC8 defines higher spectral values closer to the recorded motion due to the soil amplification coefficient that is adopted by EC8 contrary to EAK2003. For the particular soil type (B) the above coefficient is equal to 1.20, multiplying the peak ground acceleration (0.36g for zone III) in rock conditions. Recordings of the second earthquake (03/02/2014) are consistently prescribed by the code-defined values of EAK2003 for the whole period range. It can thus be concluded that earthquake loading induced by the second strong earthquake of 03/02/2014 was significantly lower with respect to the first earthquake of 26/1/2014.

Similar results referring to VSK1 accelerographic station are shown in Figure 2.1 (bottom). In this case, the response spectrum of NS, EW and vertical components of ground motion during the earthquakes on January 26, 2014 (13:55 GMT) and on February 3, 2014 (03:08 GMT) is significantly lower than the elastic design spectrum defined by EAK2003 or Eurocode 8 for soil type A (Figure 2.1, bottom).

2.2. RECORDED AND DESIGN ELASTIC RESPONSE SPECTRA AT LXR1 AND CHV1 STATIONS

On January 27th 2014, just after the 1st strong earthquake, EPPO-ITSAK installed 2 additional accelerographic stations at the Paliki peninsula (details are given in the 1st section of this report). One of them is installed at Lixouri Town Hall (LXR1) while the other one at the old elementary school in the Chavriata village (CHV1).

Both stations recorded the M6.0 earthquake (3rd Feb. 2014, 03:08 GMT). Response spectra corresponding to NS, EW and vertical component of the second strong earthquake recorded from LXR1 (top) and CHV1 (bottom) accelerographic stations are compared in Figure 2.2 with the design elastic spectrum corresponding to all soil types according to EAK2003 and EC8, respectively. In terms of peak ground accelerations, the recorded values are of the order of 0.6g to 0.8g, independently of component of motion and recorded site, and are the highest values ever recorded in Greece.

From geological point of view, LXR1 and CHV1 sites could be characterized as soil type B, we choose, however, to present elastic design spectra for all soil types, to give emphasis to the severity and specificity of the recordings of the earthquake on Feb 3rd, 2014 at these sites.

More precisely, at LXR1 site (Figure 2.2, top), the EW component is composed mainly of long period waves that could be prescribed by none of the elastic design spectra and has a remarkably different shape with respect to NS one (Figure 2.2, top-left). Additionally, the short-period vertical component (Figure 2.2, top-right) presents higher maximum spectral acceleration values than the horizontal ones, almost double than the code-defined values of vertical elastic design spectra for EC8.

At CHV1 site (Figure 2.2, bottom), the situation is quite the opposite. Spectral accelerations of horizontal components of ground motion are almost double compared to the vertical ones with a remarkable spectral acceleration of 3g at 0.25sec period (Figure 2.2, bottom-left). Certainly, the observed spectral values are far beyond any code specification for periods ranging between 0.2 to 0.8sec. On the other hand, vertical spectral acceleration values are comparable to those of EC8 spectrum for periods less than 0.2sec, while between 0.2sec to 0.6sec, spectral values are higher than those prescribed by EC8 and EAK2003 code spectra (Figure 2.2, bottom-right).

Due to the characteristics of recorded ground motion at LXR1 and CHV1 that briefly presented in Figure 2.2, a detailed analysis of the recorded motion is necessary including possible near-field and directivity effects as well as local soil conditions in conjunction with the observed structural damage.

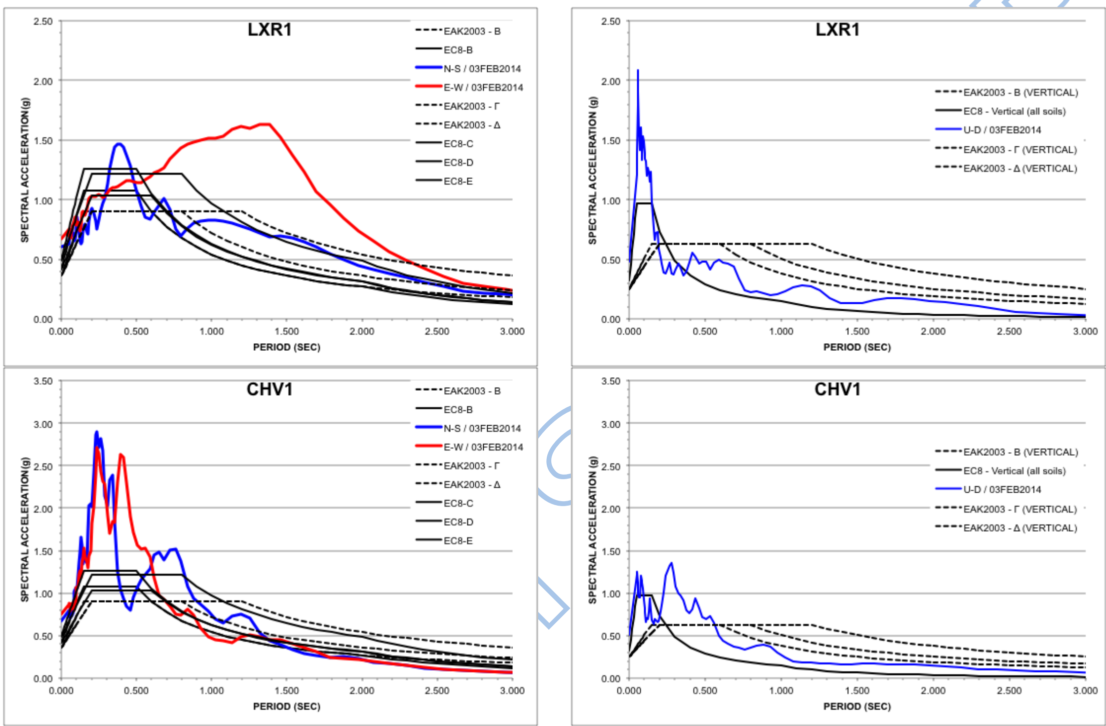

Figure 2.2. Response spectra obtained from the recordings of the earthquakes occurred on 26/1/2014 and 03/02/2014 with respect to elastic design spectra of greek seismic code (EAK2003) and Eurocode 8 (EC8). Top: LXR1 strong motion site at Lixouri, Cephalonia. Bottom: CHV1 strong motion site at Chavriata, Cephalonia. Left: Horizontal components. Right: Vertical components.

2.3 GEOTECHNICAL FAILURES

Following the second major M6.0 earthquake of 03/02/2014, researchers from EPPO-ITSAK visited the affected area of Cephalonia Island to investigate earthquake-induced geotechnical failures covering the periods 8-12 February and 18-20 February, 2014. A substantial number of geotechnical failures referring to:

- Landslides on soil or rock formations.
- Stone masonry retaining walls
- Debosset Bridge

- Road embankments and road network failures
- Ports and liquefaction

The above mentioned were recorded from ground reconnaissance mainly in the western part of the island (peninsula of Paliki) presenting a similar geographical distribution (Figure 2.3) with respect to the first earthquake of 26/01/2014 (EPPO-ITSAK, Report, 2014). The latter indicates that the geotechnical failures recorded after the first earthquake (of 26/1/2014) were further evolved due to the second earthquake (of 3/2/2014). In support to the above, characteristic case studies are compared in the following in order to show the performance of specific geotechnical structures after occurrence of both events. A special reference is also made to the extended liquefaction phenomena that occurred mainly at the port area of Lixouri after the second earthquake that hadn't been recorded previously.

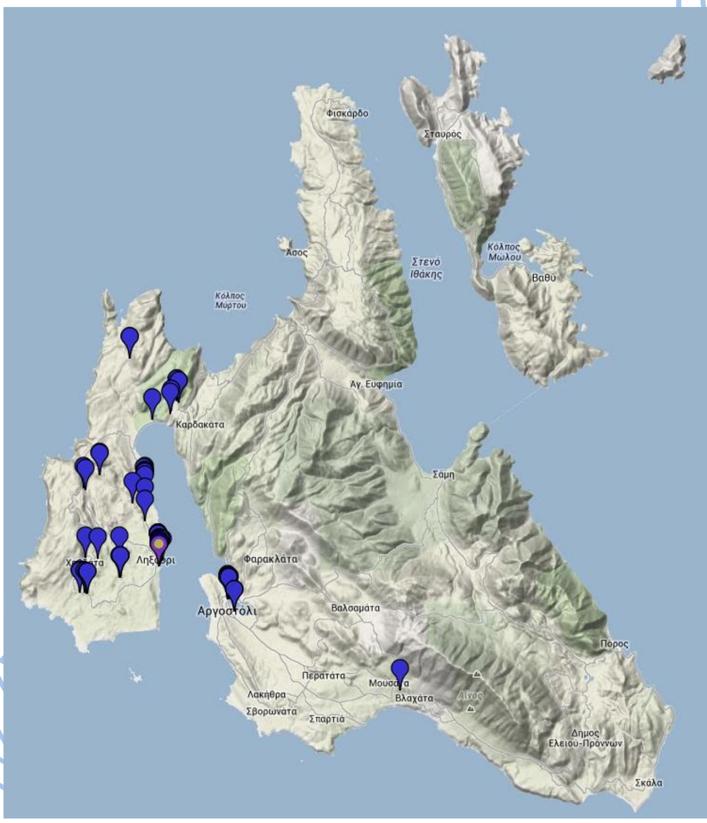

Figure 2.3. Geographical distribution of geotechnical failures recorded by EPPO-ITSAK reconnaissance teams during in-situ visits on 10-12 and 18-20 February 2014.

2.3.1 LANDSLIDES AND ROCK SLIDING EFFECTS

Many minor and major shallow rock failures were recorded at steep cliffs along the west coast of Paliki. The more pronounced of those seems to be several disaggregated slides with debris flow observed at the Petani shoreline (38.260941° N, 20.377410° E), inducing damage to the road (Figure 2.4). An extended rock slope type of failure (almost 250m long) was also recorded at a sandy marl escarpment in the shoreline of Xi area (from 38.159537° N,

Figure 2.4. Disaggregated slides with debris flow observed after the second earthquake of 03/02/2014 at Petani shoreline (38.260941° N, 20.377410° E).

Figure 2.5. Shoreline of Xi area (from 38.159537° N, 20.410148° E to 38.160405° N, 20.413083° E) south of Paliki peninsula where an extended slide (almost 250m long) of a sandy marl escarpment was observed.

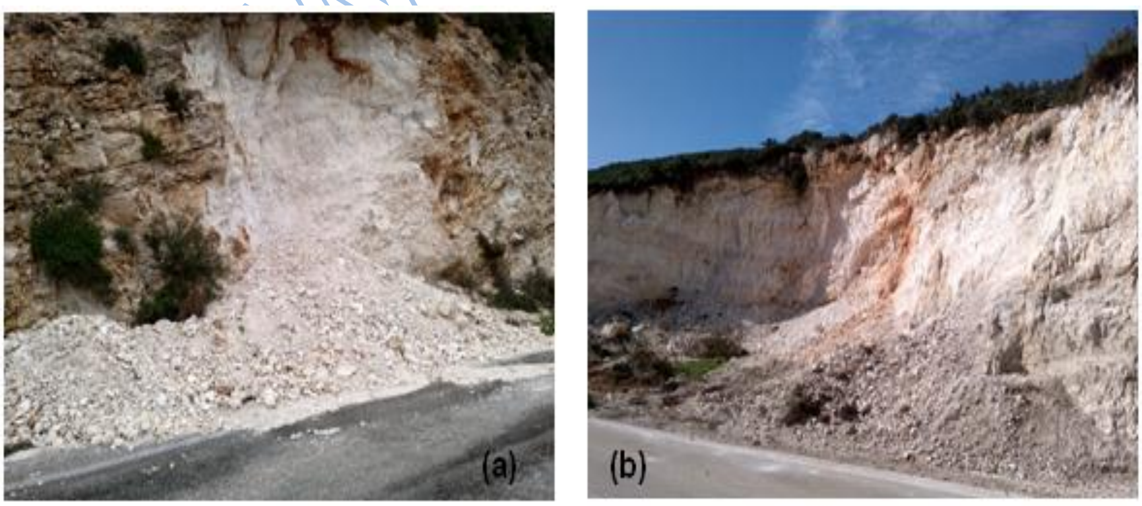

Figure 2.6. Rock slides in cracked limestone formations recorded at the northern part of Argostoli bay (38.287065° N, 20.448024° E) following (a) the first strong earthquake of 26/01/2014 and (b) the second strong earthquake of 03/02/2014

20.410148° E to 38.160405° N, 20.413083° E) south of Paliki peninsula (Figure 2.5). Rock slides in cracked limestone formations were also recorded at the northern part of Argostoli bay (38.287065° N, 20.448024° E). Evidently, the second earthquake contributed further to the evolution of the above rock slide as shown in Figure 2.6. Substantial rock slope failures were recorded in Myrtos Bay. On the east slope, two limestone blocks rolled down causing total damage to the road (38.337833°N, 20.532317°E). The above roll path is depicted in Figure 2.7.

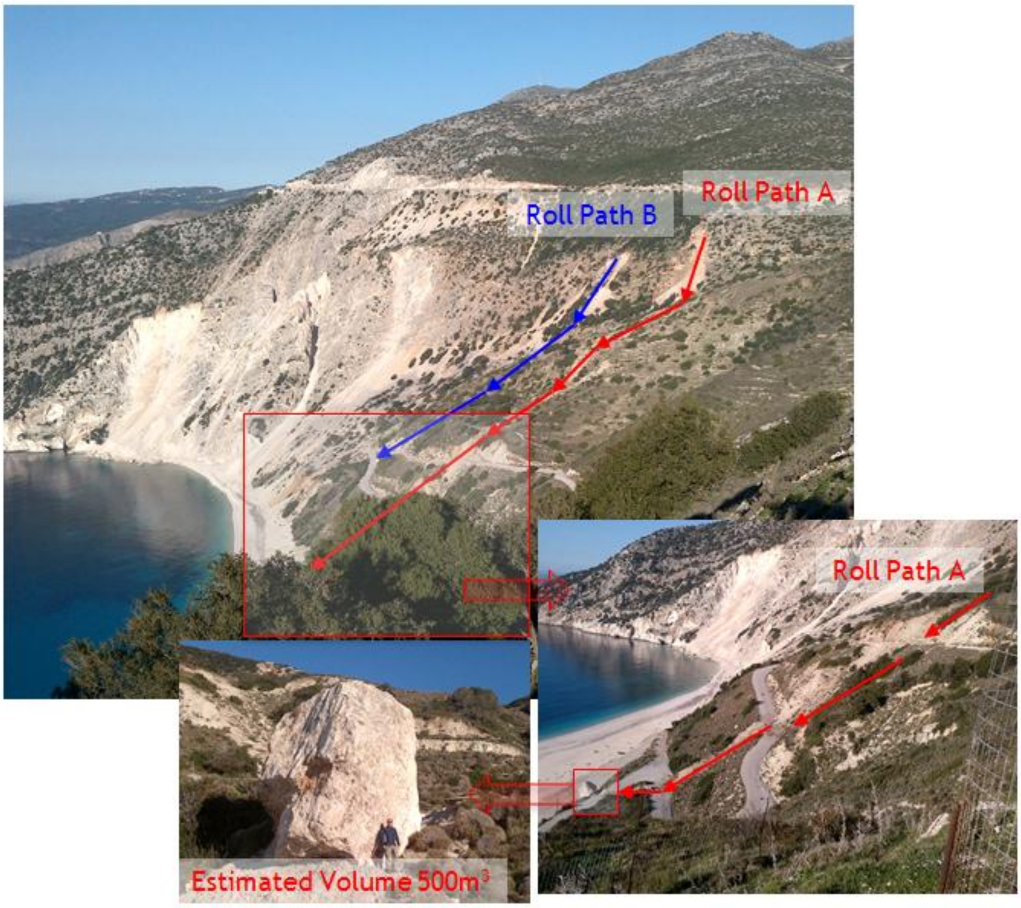

Figure 2.7. Roll path of two limestone blocks recorded at Myrtos Bay after the first earthquake inducing total damage to the descending road (38.337833° N, 20.532317° E).

2.3.2 Stone Masonry Retaining Walls

Most of the recorded failures refer to stone masonry retaining walls supporting either road embankments or foundation soil of structures. A typical damage pattern was characterized by out-of-plane collapse of the stone masonry walls, away from the backfill. Besides significant earthquake-induced earth pressures and accelerations imposed on the old stone masonry walls, possible structural deficiencies and poor condition of joint mortars should also be taken into account within interpretation of the observed damage. Representative cases of the above type of failures are briefly described in the following:

- Atheras village: Stone masonry retaining wall supporting a road embankment

A major failure of a long stone masonry retaining wall was observed along the road network (38.293224° N, 20.45217° E) leading to Atheras village north of Paliki peninsula. Out-of-plane collapse was recorded in two successive points after the first strong earthquake of 26/01/2014 having an estimated failure length of 10m and 20m respectively (Figure 2.8a). The above failures were further deployed after the second strong earthquake of 03/02/2014 imposing an additional failure surface at a third location (Figure 2.8b).

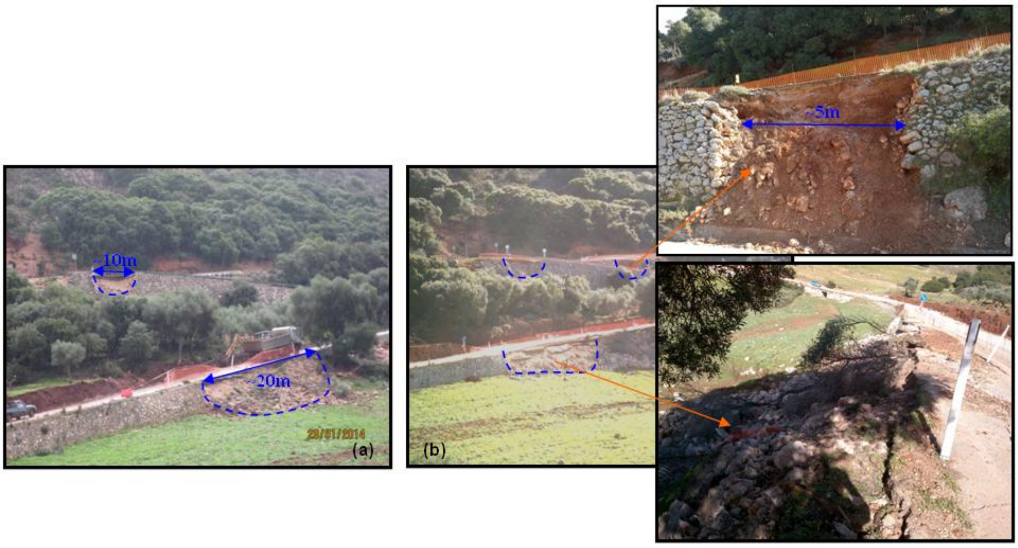

Figure 2.8. (a) Extensive failure of a stone masonry retaining wall followed by road embankment settlement close to Atheras Village (38.293224° N, 20.45217° E) after the first earthquake of 26/01/2014. (b) Additional failure surface at a third location of the wall induced by the second strong earthquake of 03/02/2014.

- Chavriata village: Stone masonry retaining wall supporting the foundation soil of a church

Particularly extensive cracks were observed at a 5m high stone masonry retaining wall supporting the foundation soil of a church in Chavriata village (38.182677° N, 20.387261° E), following the first strong earthquake on 01/26/2014 (Figure 2.9a). The evident disruption and loss of connection between the stones should have minimized the lateral strength of the wall mobilizing a total collapse and subsequent debris fall of the supporting ground after the second earthquake of 03/02/2014 (Figure 2.9b). On the contrary, the underlying stone masonry retaining wall supporting the road embankment (shown by an arrow in Figure 2.9) was slightly displaced (by approximately 5cm) from his original position without any visible failures.

- Kouvalata village: Stone masonry retaining wall supporting the foundation soil of a single-storey building

A similar type of failure was recorded after the first earthquake of 26/01/2014 at a stone masonry retaining wall of a physical slope upon which a single-storey building is founded (Figure 2.10). The above failure was recorded close to Kouvalata village (38.234484° N, 20.419554°E) and followed by a local landslide of the backfill. The observed failure was further deployed after the second earthquake of 03/02/2014 whereas heavy rainfall should also have contributed to the evolution of the landslide phenomena.

Figure 2.9. Major failure of a three-level stone masonry retaining wall supporting the foundation soil of a church in Chavriata village (38.182677° N, 20.387261° E): (a) Extensive cracks observed following the first earthquake of 26/01/2014 (b) total collapse of the wall following the second strong earthquake of 03/02/2014.

Figure 2.10. Single-storey building close to Kouvalata village (38.234484° N, 20.419554° E): (a) Failure of the stone masonry retaining wall followed by local landslide of the supporting foundation soil after the first earthquake of 26/01/2014, (b) Further deployment of the failure surface after the second earthquake of 03/02/2014.

2.3.3 DE BOSSET BRIDGE

In 2005, a multidisciplinary research project (Pitilakis and associates 2006, Rovithis and Pitilakis 2011) for the seismic assessment and restoration of the De Bosset bridge (Figure 2.11a) was undertaken by the Laboratory of Soil Mechanics, Foundations & Geotechnical Earthquake Engineering of the Aristotle University of Thessaloniki under the auspices of the Greek Ministry of Culture (Directorate for the Restoration of Byzantine and Post-byzantine Monuments). Based on the above study, a set of intervention measures including groups of micro-piles to improve the soft clayey foundation soil and lateral tendons to increase the transverse strength of the bridge were recently deployed at the bridge site prior to 26/1/2014 earthquake. Architectural restoration of the bridge lateral facades was also partially completed at that time (Figure 2.11b).

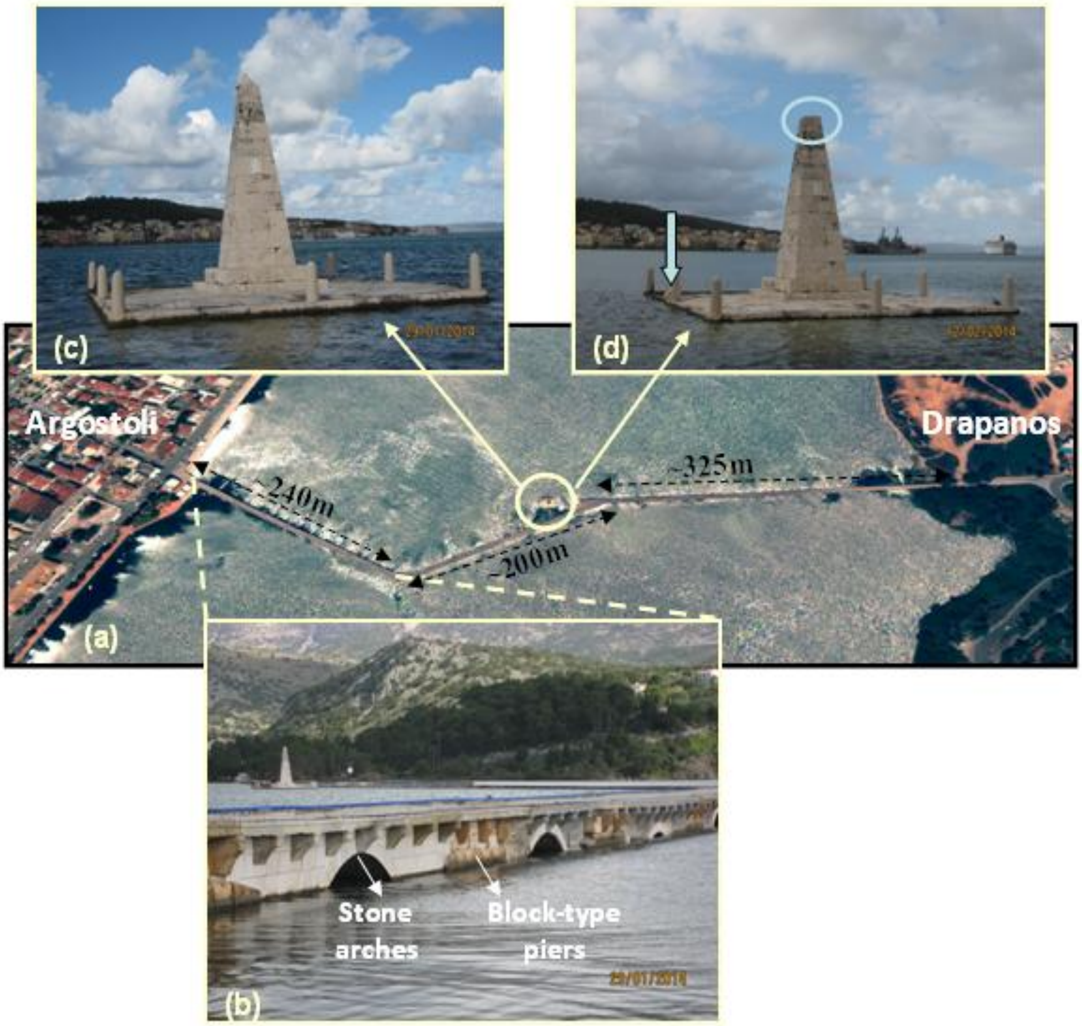

Figure 2.11. (a) De Bosset bridge (38°10'26.25"N, 20°29'45.59"E), (b) Rehabilitated bridge with no damage recorded after the two major earthquakes of 26/01/2014 and 03/02/2014, (c) Multi-drum column monument remained intact after the first earthquake and (d) Toppling of the upper drum of the column monument induced by the second earthquake.

The rehabilitated "De Bosset" bridge inspected after the two major earthquakes of 26/01/2014 and 03/02/2014 and revealed no damage or visible defects on the bridge indicating a very satisfactory seismic performance, despite the high accelerations induced by these major earthquakes. Apparently, the rehabilitation measures should have contributed to the observed seismic behavior of the bridge. The only visible effect of the earthquake sequence was recorded at a 10m multi drum limestone column monument located very close to the middle part of the bridge (Figure 2.11c), where the upper drum toppled down after the second earthquake of 03/02/2014 (Figure 2.11d).

2.3.4 ROAD EMBANKMENTS AND ROAD NETWORK FAILURES

Geotechnical failures referring to extensive cracks along the road network following settlement or slide of the underlying embankment were repeatedly recorded after the second earthquake of 03/02/2014 in a similar manner and frequency as occurred after the first event. Again, the majority of the above failures were observed at the local road network of Paliki peninsula. Two representative case studies are presented herein:

- Road connecting Chavriata and Vouni villages

The circular type of embankment sliding observed after the first earthquake was further deployed inducing severe damage on the road after the second earthquake (Figure 2.12). Due to the particularly extensive damage the local authorities were forced to close down the road access.

- Road connecting Agios Dimitrios and Livadi villages

A similar but less extensive evolution of road cracking after the second earthquake due to the settlement of the underlying embankment was recorded at the road network between Agios Dimitrios and Livadi villages (Figure 2.13). In this case, the settlement of the embankment was measured at 20cm approximately.

Figure 2.12. Road connecting Chavriata and Vouni villages. Left: Circular type of sliding observed after the first earthquake. Right: Embankment failure after the second earthquake inducing total road damage.

Figure 2.13. Cracks and embankment settlement recorded at the road network between Agios Dimitrios and Livadi villages (38.238103°N, 20.428973°E) induced by the first (left) and the second (right) earthquake.

2.3.5 PORTS AND LIQUEFACTION

- **Lixouri port**

The second earthquake of 03/02/2014 induced severe failures at the port of Lixouri including important horizontal displacements and rotations of the quay walls, extensive cracks on the port jetties and major liquefaction *ejecta* followed by lateral spreading. The above type of failures was repeatedly observed along the 950m long main piers of Lixouri port (Figure 2.14). The severity of the induced failures is evident in Figure 2.15 showing the magnitude of relative displacement between two adjacent quay walls and settlement of the backfill recorded at the same point along the south part of the 250m main pier of Lixouri port due to lateral spreading. Interestingly, the north side of the same pier (shown in Figure 2.14 with a blue dashed line) remained practically intact after the second earthquake. A similar deformation pattern was observed at the old jetty of the above pier (Figure 2.16). The recorded displacement of the quay walls were recorded as high as 80cm.
One of the main findings during reconnaissance of Lixouri port was the particularly extensive liquefaction *ejecta* recorded in several locations (Figure 2.17) ejecting gravel particles of significant size in some cases. Typical liquefaction *ejecta* are shown in Figure 2.18. It should be mentioned that liquefaction was mainly recorded after the second earthquake event. Substantially less extensive failures of the above type were recorded after the first earthquake

of 26/01/2014. In support to the above, Figure 2.19 compares two snapshots taken from a different angle at the same point of Lixouri port after the two successive major earthquakes. The difference between the effects of both earthquakes in terms of liquefaction *ejecta* is evident. With reference to quay walls, deformations and settlements of the backfill a similar difference was recorded (Figure 2.20) between the two earthquakes indicating the severity of the second one.

Figure 2.14. General outline of the severity of damage induced by the second earthquake of 03/02/2014 at the main piers of Lixouri port.

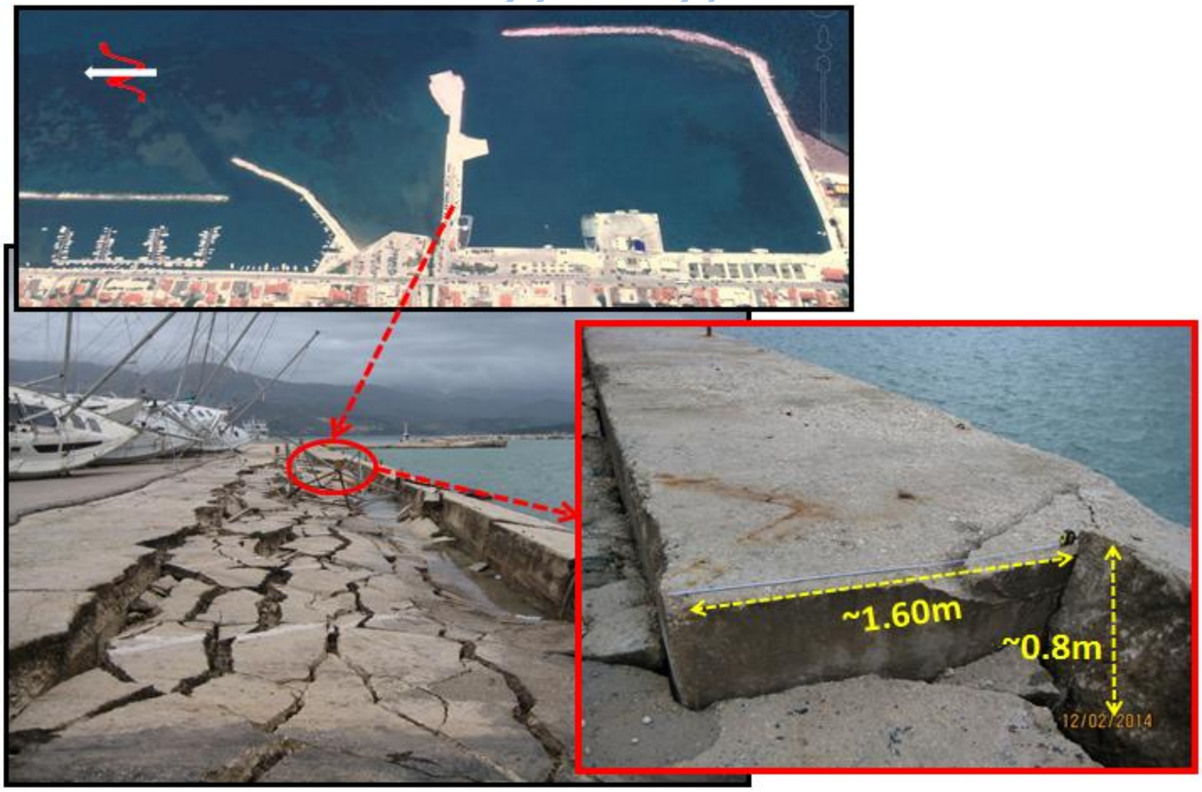

Figure 2.15. Extensive lateral spreading and quay walls deformation induced by the second earthquake on the 250m main pier of Lixouri port.

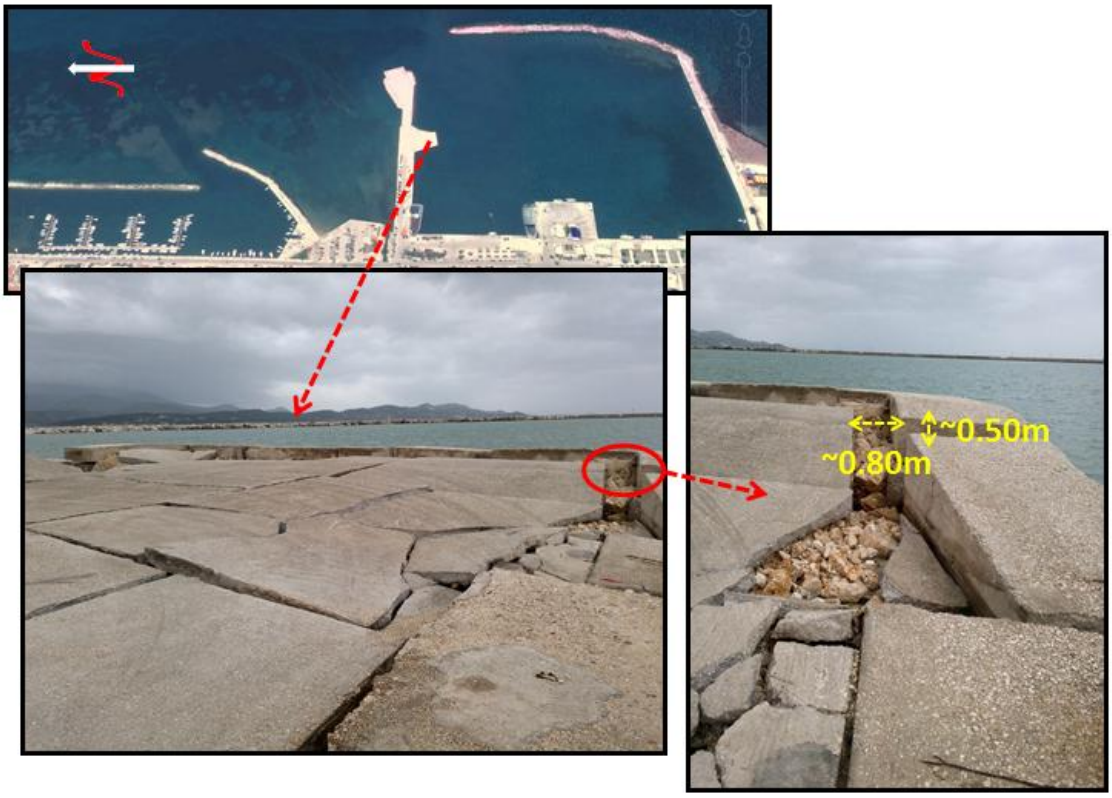

Figure 2.16. Extensive lateral spreading induced by the second earthquake on the 250m main pier of Lixouri port.

Figure 2.17. General outline of liquefaction traces recorded after the second earthquake along Lixouri port.

Figure 2.18. Typical liquefaction *ejecta* recorded along Lixouri port.

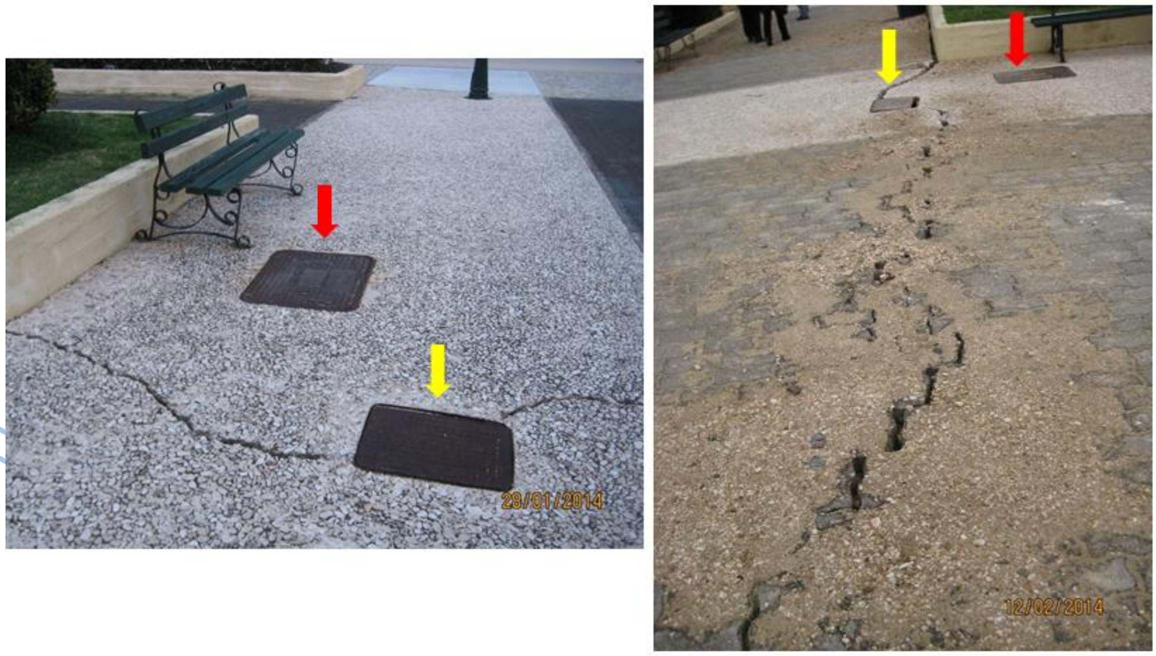

Figure 2.19. Indicative case of the extensive liquefaction *ejecta* induced by the second earthquake of 03/02/2014 (right) compared to the first earthquake of 26/01/2014. Photos taken at the same point form a different angle.

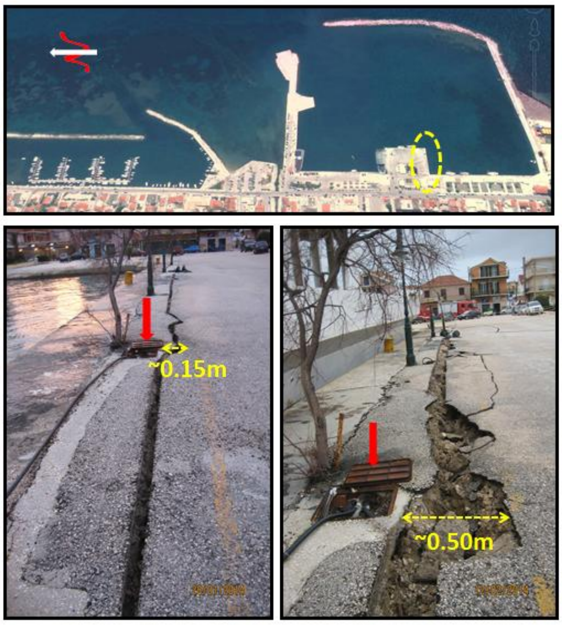

Figure 2.20. Performance of a typical quay wall at Lixouri port after the first (left) and second (right) earthquake. The evolution of lateral displacement is evident denoting the severe damage induced by the second earthquake of 03/02/2104.

- **Argostoli port**

Compared to Lixouri port, substantial but less extensive liquefaction phenomena were also recorded in the port of Argostoli. The corresponding distribution of liquefaction traces along Argostoli port as recorded after the second earthquake is given in Figure 2.21. A representative case showing the effect of the second earthquake on the quay walls of

Figure 2.21. General outline of liquefaction traces recorded after the second earthquake along Argostoli port.

Argostoli port was recorded at a location close to De Bosset bridge. The adjacent quay wall suffered permanent horizontal displacement of 10cm towards the shoreline whereas backfill settlement was measured at 15cm approximately due to the first earthquake of 01/26/2014 (Figure 2.22a). The observed lateral movement of the quay wall and settlement of the backfill were further increased (almost doubled in some points) after the second earthquake (Figure 2.22b).

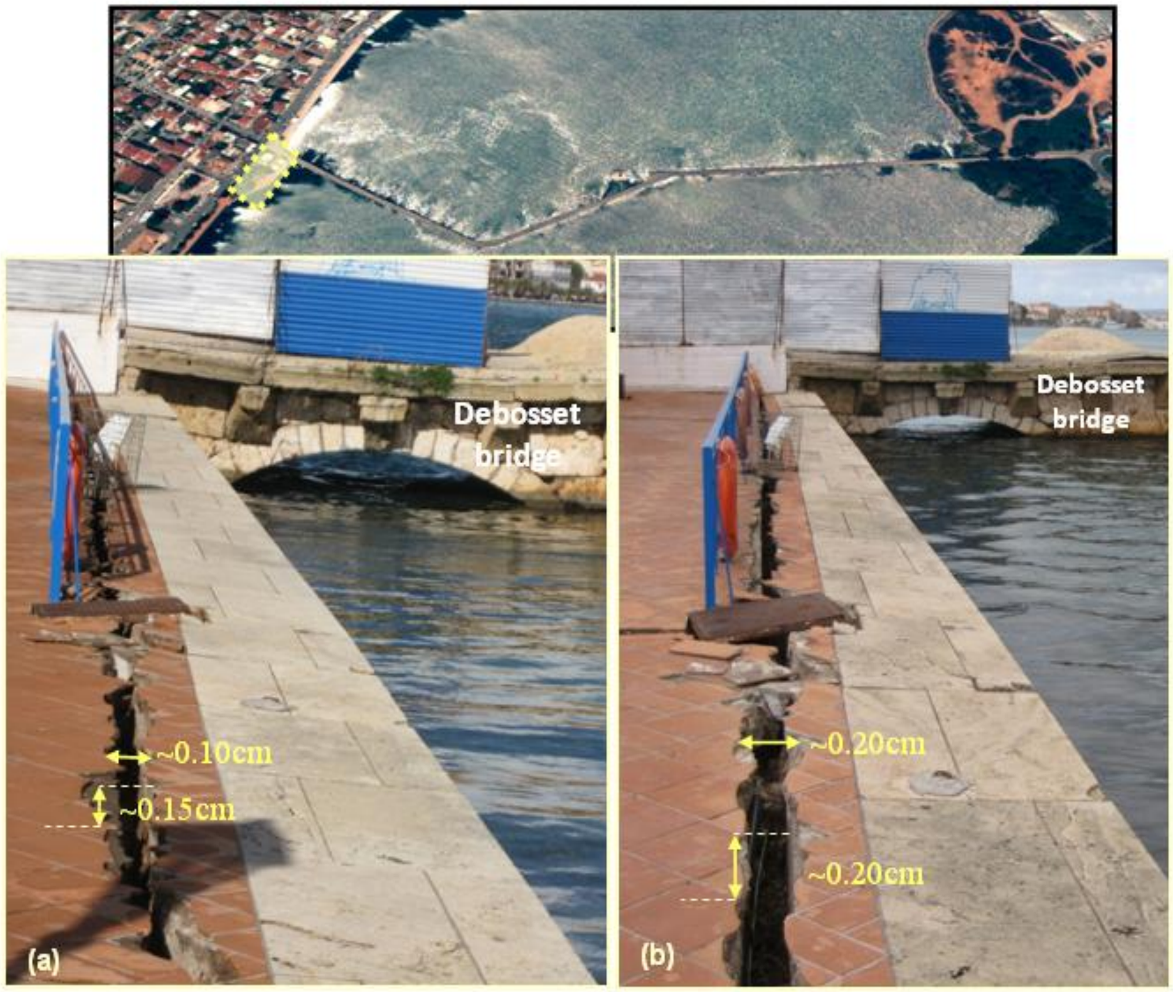

Figure 2.22. Observed failures of the quay wall adjacent to the Debosset bridge: permanent lateral displacement of the quay wall and settlement of the backfill induced by (a) the first earthquake of 01/26/2014 and (b) the second earthquake of 03/02/2014.

3. RESPONSE OF STRUCTURES

3.1. TYPE OF STRUCTURES

The types of structures that are located at the stricken areas were mainly constructed after the 1953 Cephalonia earthquake. They are divided in four major categories in relation to the type of the load bearing system. In the wider meisoseismal area where structures were strongly affected by the 26/01/2014 earthquake the structural systems are grouped as follows:

- *One to two storey masonry buildings:* These buildings are further subdivided according to location criteria. There are masonry buildings that were constructed by clay or stone or concrete bricks and by higher quality mortar, which are mainly located at Argostoli and Lixouri. There are also one storey masonry buildings that are located at small villages. These buildings have walls that are composed by roughly treated stones and low-strength clay mortar. These buildings are of secondary use serving as barns or stables and are not numerous, since most of them were destroyed during the catastrophic earthquake that took place in the island in 1953.
- *Reinforced concrete buildings:* These buildings are located at the whole island and were constructed mainly after the 1953 earthquake, till nowadays. They are of one to four storeys, they have well reinforced concrete frames, as well as shear walls qualified as such under Eurocode standards. There are also many reinforced concrete buildings that were constructed after 1953 and are characterized as monuments. The most important towns on the island are Argostoli and Lixouri and the main building stock there, belongs to the present category.
- *Monumental and other cultural heritage masonry buildings:* These buildings serve mainly as churches or schools at country villages and have one or two storeys. They were constructed by adopting traditional antiseismic techniques and in most cases their construction was financed by benefactors.
- *Other buildings:* During the in situ inspections some wooden buildings were found, as well as some stone and reinforced concrete bridges.

3.2. TYPE OF DAMAGE ON STRUCTURES AT THE STRICKEN AREA

The earthquake of 26 January 2014 at Cephalonia caused limited damage to the structures of the island. Among others, extensive inspections were performed and damage on buildings and other structures was recorded. The day after the earthquake there was not significant available information about the range of the damage throughout the meisoseismal area, so it was decided to inspect buildings in the two main towns of Cephalonia, namely, Argostoli and Lixouri, asking citizens to show the damaged buildings. Two days after the earthquake important information was available about the situation at many villages, so it was decided to inspect those areas. It was deduced that the damaged structures were mainly located at the

Paliki peninsula, which is the part of Cephalonia where Lixouri is located. Inspections were performed at the villages of Agios Dimitrios, Livadi, Vilatoria, Agia Thekli, Kalata, Monopolata, Kaminarata, Mandourata, Favata, Havdata, Havriata, Vouni and Manzavinata. Bellow, description of damage that were observed on the load bearing systems of buildings according to the aforementioned categories is given and photos for the most important types of damage are presented.

(a) One to two storey masonry buildings: These buildings were not constructed according to any seismic code and are located mostly at the small villages along the whole area of Paliki peninsula. Diagonal cracks and/or partial collapses where observed for buildings of this category. These buildings are of low importance, of secondary use or occasionally habitable and inadequately maintained. In some cases, cracks that were formed due to previous earthquakes and inadequately repaired with different type of mortar, were further opened. Also some buildings were totally abandoned and had partially collapsed. The number of these buildings was significantly limited and it is not possible to define a specific area where many damaged buildings of this type are concentrated. During 3-2-2014 event these buildings suffered additional damage and partial collapses. Damage patterns usually appeared at the buildings of this category, because of their high vulnerability and accumulated stress during the earthquake of 26-1-2014.

(b) Reinforced concrete (R/C) buildings: The majority of the existing building stock in Cephalonia pertains to this group. The most common type of damage was the detachment of the infill walls from the surrounding concrete beam-column frames. This type of damage was observed in numerous cases and was a reason for concern of the population since it was the main type of observed damage to structures. After detailed inspections no cracks were observed at the reinforced concrete elements of almost all checked building. In most cases no diagonal cracks were observed at the infill walls indicating thus that the infill walls were well constructed. It was observed observed that typically, along the height of the infill wall, two concrete wall ties were constructed. Due to the good construction practices applied to the infill walls, the reinforced concrete frames were supported and the developed inter-storey drift was significantly limited. In this way it is possible to deduce that the absence of diagonal cracks at the infill walls is related to the absence of cracks at the reinforced concrete elements. Of course, some exceptions were observed. In some (R/C) buildings significant damage to structural elements or/and in infill walls were observed. These structures, with significant damage at the structural elements and infill walls are mainly located along the road at the north of Lixouri (towards Agios Dimitrios and Livadi). The most serious damage was observed in the village of Livadi, where the second floor of a three storey building totally collapsed, falling on the ground floor. However, in most cases it was found that concrete buildings were reinforced with adequate number of steel bars and stirrups and no failures due to the inelastic elongation of steel bars were observed. Observed failures were mainly due to concrete crashing and diagonal tension. Also, there is a subcategory of public and museum R/C buildings that were constructed after the 1953 devastating earthquake. These buildings have local failures at their structural element that

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can be attributed to the reduced strength due to the reduced durability and the intensity of the earthquake. Through corrosion of the reinforcement due to carbonation of concrete, the strength of the R/C structural elements is significantly reduced and the most common type of damage is the loss of concrete cover. These buildings were built half a century ago and were not properly maintained to preserve their strength capacity, which was reduced by the pass of time. In general, the reinforced concrete buildings behaved well during both earthquakes, especially those that constructed after 1985 earthquake code. The few buildings that were damaged during the first earthquake had more extensive damage during second earthquake. This is attributed to the reduction of the total stiffness of the building due to the cracks at the infill walls and due to the local loss of concrete cover, at the ends of the columns, in some cases during the first earthquake. It is clear that during the second earthquake the damage at the load carrying structural elements, of the R/C buildings were more extensive than during the first one. In this cases higher level of inelastic deformations and significant concrete crashing were observed. In the few cases of reinforced concrete buildings with damage to the structural elements, damage at the infill walls was also observed. In these cases during first earthquake the damage to concrete elements was significantly lower and also the infill walls appeared only detachment cracks from the surrounding frames. Thus, it becomes clear that the infill walls played a key role to reduction of the imposed displacements and base shear forces due to the destructive power of both strong earthquakes. The types of damage that were observed at the reinforced concrete elements are given bellow:

- Flexural tension cracks
- Flexural compression failure of concrete
- Diagonal tension cracks
- Diagonal compression cracks
- Sliding shear cracks
- Local or total buckling of steel bars, usually due to breaking to pieces of concrete

The types of damage that were observed at the infill walls are given bellow:

- Diagonal tension cracks
- Horizontal sliding shear cracks
- Out of plane failure and collapses

(c) Monumental and other cultural heritage masonry buildings: The temples and other cultural heritage buildings were one or two storey masonry structures. Some of these buildings had no damage or light damage. Many of them had cracks at the exterior walls (no detailed inspection was performed). More specifically, the temples churches at the south of the Paliki peninsula had suffered significant damage. In some cases strengthening techniques were applied to these buildings in the past and local failures at the top of the temples were observed. The bell towers were not constructed in touch with the temples in order to avoid impact phenomena of the bell tower to the main structure. In masonry buildings that were constructed at the villages through funding by benefactors damage at the exterior walls were observed. The main damage at this type of structures where observed at

the top of the temple walls. Mostly, cracks were observed over the openings at the walls (spandrels) of these structures as well as at the piers between the windows. At the points of connection of the main temple with other structures cracks and openings of the construction joints were also observed. During the second earthquake the aforementioned types of cracks were significantly widened. In general, new damage due to the second earthquake was not observed as it was observed for the widening of damage occurred during the first earthquake. In the temples of the stricken area the wooden roofs were constructed inclined in two directions and triangle masonry infills were placed at the ends of the roof. These triangle infills at the ends of the wooden roofs were lightly damaged during the first strong earthquake while during the second one extended damage two collapses of the triangle infills were observed.

(d) Other constructions: During the in situ inspections some wooden buildings as well as some stone and reinforced concrete bridges were found. No damage to stone or reinforced concrete bridges were observed during the inspections. Also, a wooden building that was examined had no damage.

(e) Additional remarks: During the inspections, detachment and displacement of many tiles from the roof of many buildings was observed mainly at Argostoli and Lixouri and less at the other villages. This is explained by the fact that wooden roofs were constructed without any wooden board panel under the tiles. In contrast, the tiles were resting on wooden rafters placed at 20cm to 30cm distance. In addition to the repair cost, this detachment and displacement of tiles had as a consequence the entrance and flow of the rainwater on furniture, electric devices and inside electric wires, causing short circuits. In many temples ceiling decorations under the wooden roof were constructed. By the detachment and displacement of the roof tiles, these decorations were exposed to rainwater and should be repainted or repaired or possibly reconstructed. During the first seismic event many household belongings, furniture, commercial goods and museum contents fell at the floor and some of them were broken. For the museum contents the damage happened through the detachment at the interfaces where the exhibits previously were bonded. During the second earthquake similar phenomena were observed. In this case, the habitants were more experienced and plastic coatings were used to close openings at the tile roofs, whether these were formed during the first or second earthquake.

3.3 INSTRUMENTATION OF A TYPICAL BUILDING

After the main event of 26/1/2014, the Earthquake Engineering research team of EPPO-ITSAK instrumented a building in the town of Lixouri with a mobile accelerometer array in order to record its response to various aftershocks. The selected building is the new administrative building of the Lixouri hospital (Figure 3.1). The building was erected in 2009, with granting from the Stavros Niarxos Foundation (www.snf.org), according to the 2003 Greek New Seismic Code, which is compatible to a great extend to Eurocode 8 (EC8). Given the intensity of the 26/1/2014 main event (PGA=0.39g at the station ARG2 in Argostoli and

PGA=0.53g at the station LXRA at Lixouri), the building exhibited a remarkable behavior, with essentially no damage to either its load bearing structural system or the infill walls.

The aim of the instrumentation was to record the building's seismic behavior, in order to investigate its response to the 26/1/2014 mainshock, whose characteristics (PGA, response spectrum) were very similar to the design earthquake prescribed in modern codes. The specific building (a two-storey one with basement) was chosen since it meets the following characteristics that were desirable in the present instrumentation effort: (a) it has a more or less "regular" structural and architectural system, both in plane and in height (i.e. no soft story, static eccentricities or other factors that would lead to particularities in its seismic response). Also its plan dimensions and height (two storeys) are typical of many buildings in the island of Cephalonia. It is thus representative of building types that are both especially recommended in modern seismic codes and are also frequently met in the stricken area. (b) it is a stand-alone building, with no adjacent ones that might affect its response, e.g. through pounding (c) being a public building, access to it and the ability to instrument it and assess its seismic capacity is in general easier than the case of a private-owned building (not ignoring potential legal issues that may arise) (d) it does not in general host a lot of people that might accidentally disrupt the recording system's operation (in the particular case, the ground floor was temporarily used as an emergency medical center, since the nearby main hospital building was evacuated until its seismic safety was certified by qualified engineers. For this reason, it was decided not to instrument the ground floor of the building (e) another not critical, however desirable, asset was the availability of as-built drawings that will facilitate the development of reliable finite element models of the building. The models will be further calibrated using the recorded response of the building, as it is explained in more detail later.


Figure 3.1. The administration building of the Lixouri Hospital (left) and photos from its instrumentation with the special accelerometer array (right).

The special structural array used in the instrumentation consists of a central recording unit (type *K2*© by Kinematics Inc.), that can support up to 12 sensors (uniaxial, ± 2g full scale, *Episensor*© accelerometers). The recording unit has a 19-bit resolution, a sampling rate capacity of up to 200sps and a dynamic range of 108 dB @ 200 sps. The system offers the capability of setting independent triggering threshold (ranging from 0.01% to 100 % full scale) for each sensor, while the user can predetermine the sensors, or combinations of them, that will trigger the system. Recordings are stored in the system's flash memory, and can be retrieved either in situ, or through a modem.

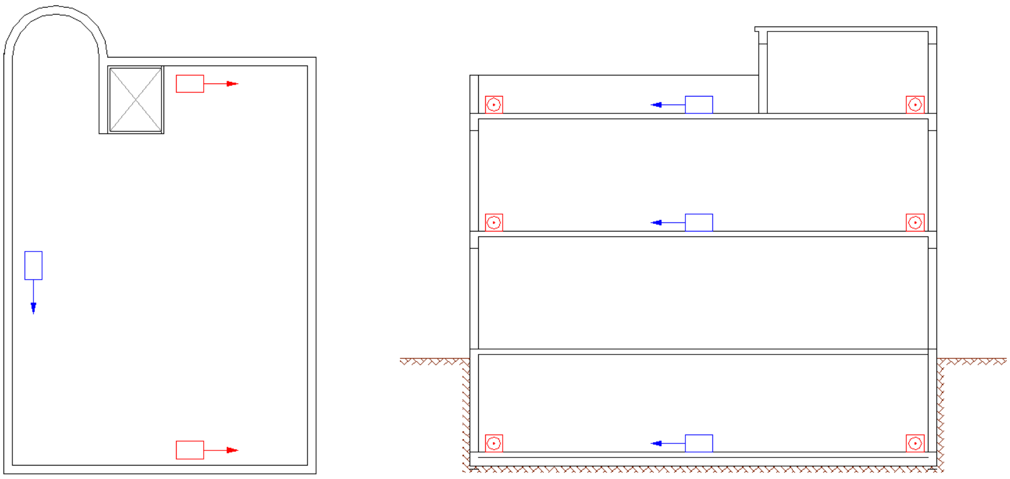

Figure 3.2. Administration building at the Hospital of Lixouri - instrumentation layout.

In the present instrumentation effort nine uniaxial sensors were used, in sets of three at three different levels of the building: its basement, the first floor and the terrace (as previously described, the ground floor level was not instrumented). At each level, two uniaxial sensors were placed in parallel along the floor's extreme edges (Fig. 3.2 in red color), and the third (Fig. 3.2 in blue color) was placed in an orthogonal direction along one of the other two edges. In this way it is possible to record both the translational response of the floor diaphragms along two orthogonal directions, as well as their torsional response.

The recorded response of the building to various aftershocks will be used to assess its actual dynamic characteristics (eigenvalues, eigenmodes, damping ratios). These will then be used to properly calibrate finite element models of the structure that will be developed in order to reliably represent its actual dynamic behavior and to further investigate its overall response to seismic excitations in general and the 26/1/2014 mainshock in particular. The whole effort is expected to help enrich the EPPO-ITSAK's research contribution on the seismic response of civil engineering structures (e.g. Karakostas et al. 2003, 2005, 2006, Lekidis et al. 1999, 2005, 2013, Sous et al. 2004). Since the recent investigation effort is at its beginnings, detailed results are expected to be available in the near future.

3.4. CONCLUSIONS THAT RESULTED FROM OBSERVATIONS ON THE RESPONSE OF THE STRUCTURES

In general, the recorded intensity of the earthquake (acceleration, energy, spectra) does not correspond to the observed damage at the buildings on the island. Certainly, there are damage mainly at the stone masonry buildings and at the buildings that were designed by older codes. No cases were observed in which hysteretic damping was developed through the flexural cracking of concrete structural elements and through a high level of inelastic deformation of steel bars. This is also justified by the fact, that cracks at the R/C structural elements were not observed, with only few exceptions. Moreover, it is noted that existing buildings possess a substantial amount of strength reserves (depending mainly on their redundancy and on the over-strength of individual structural members), as well as possible additional energy dissipation mechanisms, which contribute to a significant increase of their behavior factor.

Experience gained from this as well as previous strong seismic events suggests that the seismic protection of Greek urban areas relies also on several alternative factors (such as infill walls, regular configuration of the structural system, proper material and workmanship quality, etc.) Due to the magnitude of the recorded accelerations, soil-structure interaction phenomena probably developed with positive effects for the structural response. The aforementioned remarks show that there are additional mechanisms that are activated for the dissipation of the imposed seismic energy when a strong earthquake happens. In this way the response of the structures that are subjected to strong earthquakes is improved. Additionally, through the accumulated experience from past earthquakes as well as from the present earthquake, it is concluded that the seismic protection, not only in Cephalonia but also in other seismic regions, is additionally improved by other parameters such as the correct arrangement of the load carrying structural elements, the use of shear walls, the well constructed infill walls and the use of high quality construction details and materials. Also, the high construction quality that was applied at the majority of buildings in Cephalonia, together with the long lasting experience of local construction personnel to anti-seismic construction contributes to the positive response of the built environment.

For Cephalonia, the base shear seismic design coefficient, according to the 1959 Greek Seismic Code was $\varepsilon = 0.08$, 0.12 and 0.16, for firm, medium and soft soils, respectively. This coefficient was constant, independently of the building's period and applied uniformly to all buildings. Since the 1959 Code was based on the allowable-stress design method, the coefficient is modified to correspond to ultimate strength design, leading to values of $\varepsilon' = 0.14$, 0.21 and 0.27 (Anagnostopoulos et al.1986). In the 1985 revised code there were provisions which imposed dense stirrups in joints and instead of one storey model analysis of the building (1959 code) impose frame analysis for a multi-storey building. In 1992 for first time a response spectrum analysis as well as the dynamic analysis of a structure were introduced. For seismic zone III, at which Cephalonia falls in, seismic codes from 1992 and onwards, established a ground acceleration coefficient of $\alpha=0.36g$ and typical design spectra, with a spectral magnification factor, $\beta o=2.5$. It is obvious that low-rise buildings designed according to the 1995 code and onwards, with relatively small mass and fundamental period ($T<0.15sec \div 0.20sec$) where a significant number of the Cephalonia buildings belong, they were not heavily stressed, due to the particular shape of the response spectrum of both earthquakes. The ductility demands imposed by these particular events on buildings (after 1995 code) in this specific range were not too high, explaining thus the limited degree of observed damage.

Additionally to the structural damage, the earthquake generated secondary damage to commercial wares and household contents. Also, due to damage at the tile-roofs it is possible for rainwater to enter the house, causing damage to furniture, electric devices and electric networks. In these cases it is important to repair tile-roofs immediately and if this is not possible, to cover temporarily the openings at the roof. In masonry wall buildings special and immediate measures should be applied after an earthquake, since rainwater may deteriorate the mortar between the bricks as well as cause damage to paintings, museum contents e.t.c.

The buildings that had light or heavy damage during first earthquake were extensively damaged during second shock of 3/2/2014. For reinforced concrete buildings, in few cases, heavy damage were observed, denoting initially failure to the concrete due to crushing and afterwards local buckling of steel reinforcement. The quantity of stirrups played a key roll to the failure of R/C elements. After the second earthquake, it was clear that the demands on stirrups quantity by modern codes is justified since the structural integrity of the concrete and the reinforcement in structural elements depends on the capacity of stirrups to keep concrete pieces in position and to prevent buckling of reinforcement, especially when concrete cover is lost. Also it was confirmed that well constructed infill walls, with concrete ties along height, may efficiently support the reinforced concrete frames by improving the stiffness and strength of the buildings against seismic actions. For masonry monumental temples the widening of cracks during the second earthquake was also observed. These cracks were mainly formed during the first earthquake. The damage were observed at the top spandrels and piers between windows.

Finally it is mentioned that the buildings constructed according to the 1959 Greek Seismic Code or before, should be carefully checked, evaluated and when necessary strengthened according to modern techniques.

ANNEX A

RESPONSE OF THE BUILT ENVIRONMENT DURING 26-1-2014 EARTHQUAKE

Photos 3.1, 3.2. Two neighbor masonry buildings at the villages. The building with strong R/C ties at top had no damage.

Photos 3.3, 3.4. Partial collapses of masonry buildings of secondary use.

Photos 3.5, 3.6. Multistory buildings with detachment of infill walls from the R/C frames. No damage to the structural elements were observed.

Photos 3.7, 3.8. Cracks between structural element and infill walls of the elderly people nursary (up) and the hospital (bottom) at Argostoli. These buildings were temporarily abandoned.

Photos 3.9, 3.10. Damage at the Labour houses at Lixouri.

Photos 3.11, 3.12. Damage at a two storey building in Agios Dimitrios.

Photos 3.13, 3.14. Three storey building severely damaged in Livadi. Total collapse of

second floor coming to reston the ground floor.

Photos 3.15, 3.16. Two storey building with damage, at the Northern road from Lixouri.

Photos 3.17, 3.18. Flexural cracks at the ends of R/C columns at the Northern road from Lixouri.

Photos 3.19, 3.20. Two temples at the southern area close to Lixouri.

Photos 3.21, 3.22. Temple at the southern area close to Lixouri.

Photos 3.23, 3.24. Cultural heritage masonry building and temple, with damage, at the center of Paliki peninsula.

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Photo 3.25. Damage at glass panes.

Photo 3.26. Damage on tile - roofs.

Photo 3.27. Damage of commercial wares.


Photo 3.28. Damage of commercial wares

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ANNEX B

RESPONSE OF THE BUILT ENVIRONMENT DURING THE 26-1-2014 & 3-2-2014 EARTHQUAKES

Photos 3.29, 3.30. Building in Argostoli as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.31, 3.32. Building in Argostoli as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.33, 3.34. Hospital in Argostoli as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.35, 3.36. Labor houses in Lixouri as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.37, 3.38. Labor houses in Lixouri as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.39, 3.40. School building in Lixouri as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.41, 3.42. Building in Lixouri as damaged during 3-2-2014 earthquake.

Photos 3.43, 3.44. Building in Agios Dimitrios as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.45, 3.46. Building in Agios Dimitrios as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.47, 3.48. Building on the way to Livadi as damaged during 3-2-2014 earthquake.

Photos 3.49, 3.50. Building on the way to Livadi as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

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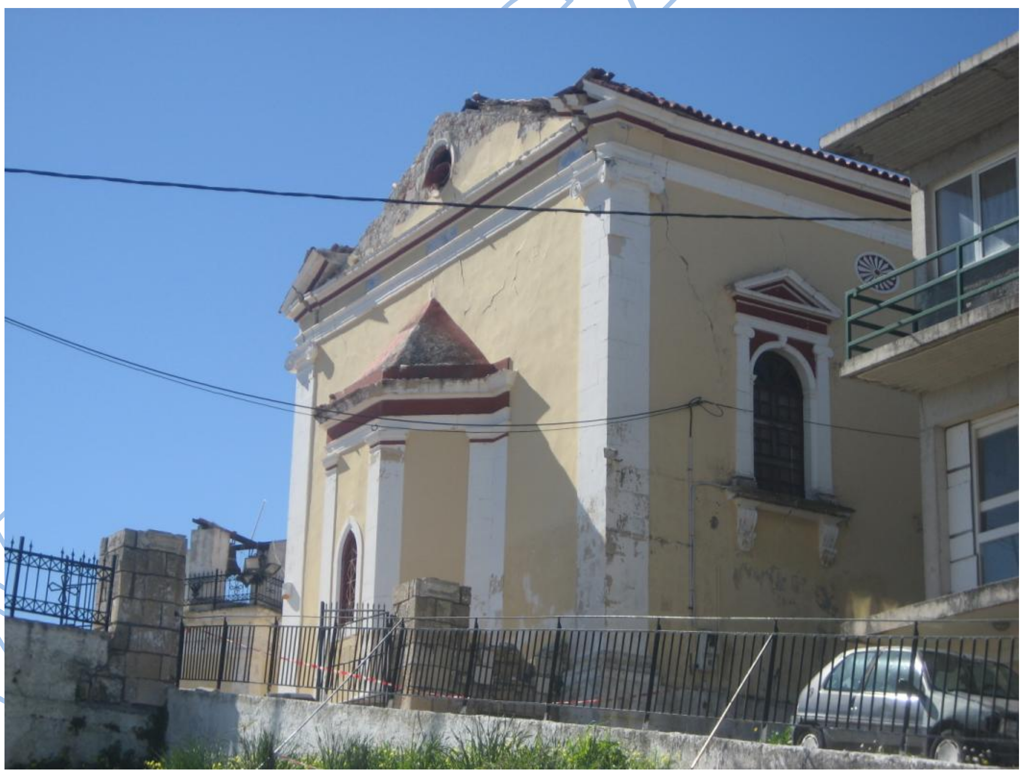
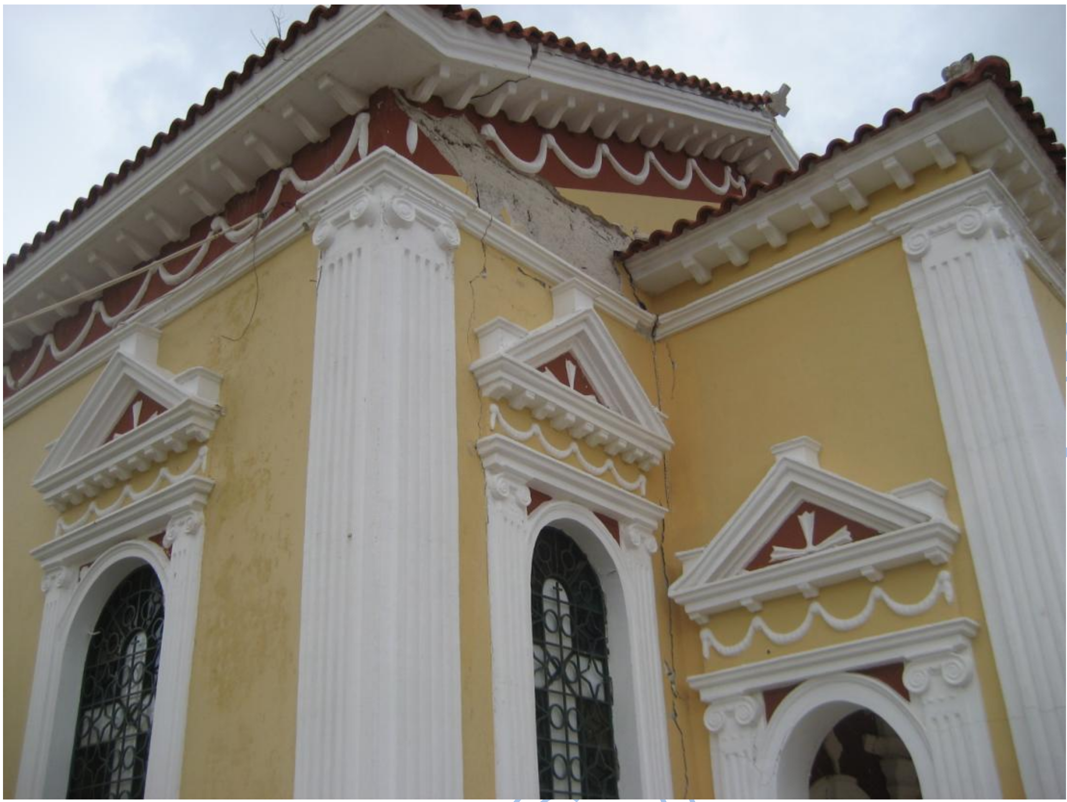
Photos 3.51, 3.52. Temple at the northern villages of Paliki peninsula as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.



Photos 3.53, 3.54. Temple at a village of central Paliki peninsula as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.55, 3.56. Reinforced concrete building at the southern villages of Paliki peninsula as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.



Photos 3.57, 3.58. Temple at the southern villages of Paliki peninsula as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

Photos 3.59, 3.60. Temple at the southern villages of Paliki peninsula as damaged during 26-1-2014 (up) and during 3-2-2014 (low) earthquakes.

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