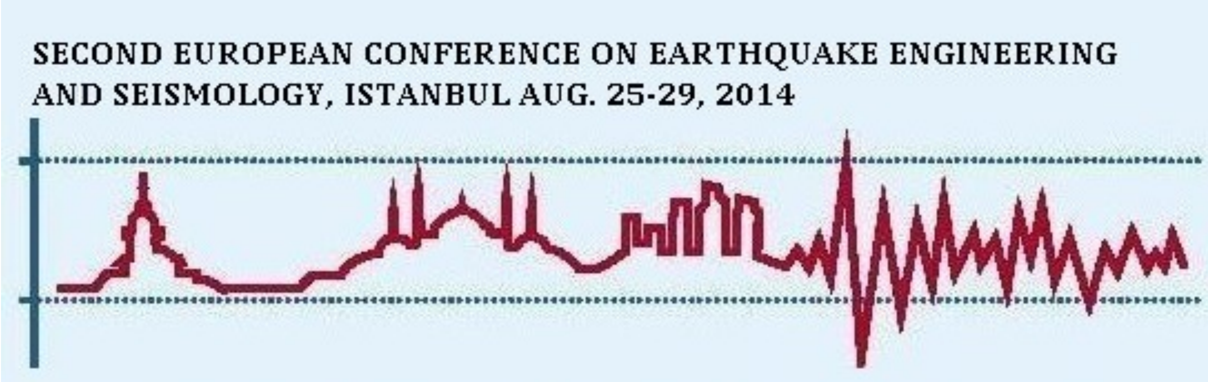

THE CEPHALONIA(GREECE) EARTHQUAKES OF JANUARY 26 & FEBRUARY 3, 2014: EFFECTS ON SOIL AND BUILT ENVIRONMENT

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In January 26, 2014, (13:55 GMT), a strong earthquake with moment magnitude M6.1 hit the region of Cephalonia (Greece) causing damage mainly to the western part of the island. In February 3 (03:08 GMT), a second event (M6.0) occurred with an epicenter about 10km north of the first one, on the Paliki peninsula, causing additional damage to built environment. According to the Hellenic Unified Seismological Network (HUSN), both earthquakes were shallow crustal with a depth around 10km and epicenters 38.16N, 20.34E and 38.25N, 20.39E for the first and second one, respectively (Fig. 1). From the epicenters and focal mechanisms of the earthquakes it is deduced that they are related to the Cephalonia Transform Fault (CTF) (Scordilis et al. 1985).

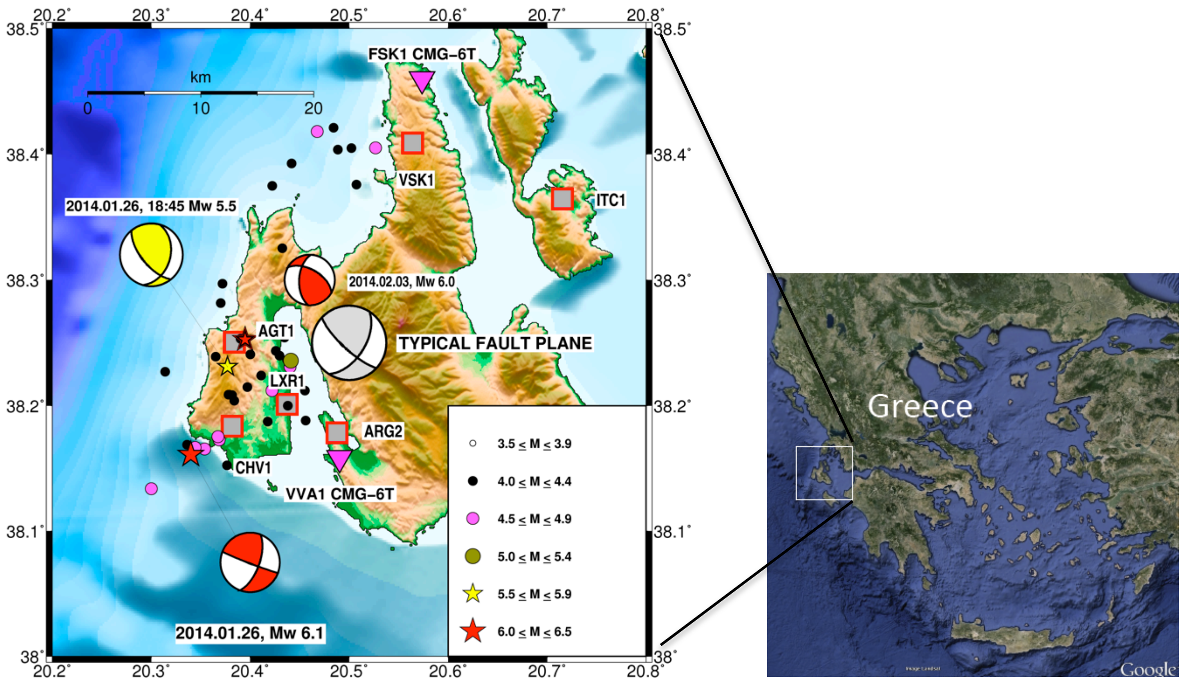

Figure 1. Epicenters of the 26/1/2014(M6.1, larger red star) and 3/2/2014 earthquake (M6.0, smaller red star) and aftershock distribution (M≥4.0) of the seismic sequence in Cephalonia one month after the first event (source: HUSN). Aftershock of the 26/1/2014 (M5.5, yellow star) is also shown. The focal mechanisms of these events (GCMT solutions) in respective color balloons and typical focal mechanism of Cephalonia (Papazachos and Papazachou, 2003) in grey color balloon are also given. Accelerographs of EPPO-ITSAK in grey squares and seismographs in pink triangles are shown.

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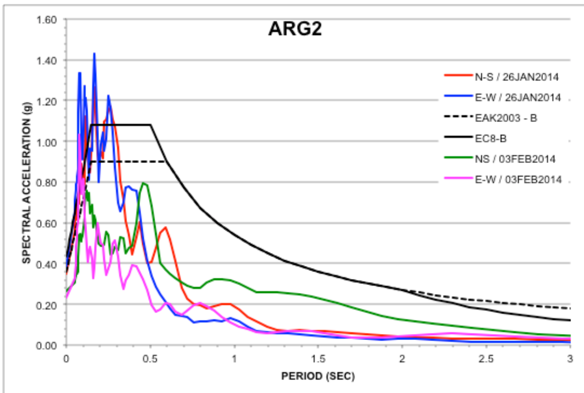
Ground motion of the mainshock was recorded by the permanent accelerographic network on the islands of Cephalonia and Ithaki as well as throughout Greece. In near real time, in about 10 minutes after the origin time, preliminary shakemaps were produced and uploaded on the web. These maps include distribution of instrumental intensity, peak ground acceleration, velocity and spectral acceleration values for natural periods T=0.3, 1.0, 3.0 sec. During the earthquake of 3/2/2014, 03:08GMT (M6.0) very high peak and spectral values were observed, especially at the temporary accelerograph stations installed in Paliki peninsula (CHV1, LXR1). At the Chavriata site (CHV1), the peak ground acceleration, PGA=0.77g, was the greatest value recorded to date in Greece. This is mainly due to the fact that these recordings were acquired in near-field conditions.

In Fig. 2, response spectra corresponding to horizontal components of the first and second earthquake recorded at ARG2 and of the second shock at CHV1 accelerographic stations are compared with the design elastic spectra corresponding to the greek seismic code-EAK2003 and EC8. In Argostoli (ARG2) spectral values of the first event are higher for short periods (T<0.4sec), while the NS component of the second event exhibits higher spectral values for intermediate and long periods (T>0.7sec). Response spectra observed at ARG2 station are quite well covered by the elastic design spectra, for soil category B, foreseen by both EAK2000 and EC8. On the other hand, for the CHV1 site the observed spectral values seem to be far beyond any code prediction regarding short to intermediate periods (0.1sec<T<0.8sec), for any soil category. Strong ground motion modeling could explain any possible origin of this frequency content, whether it is source or/and site effect factor.



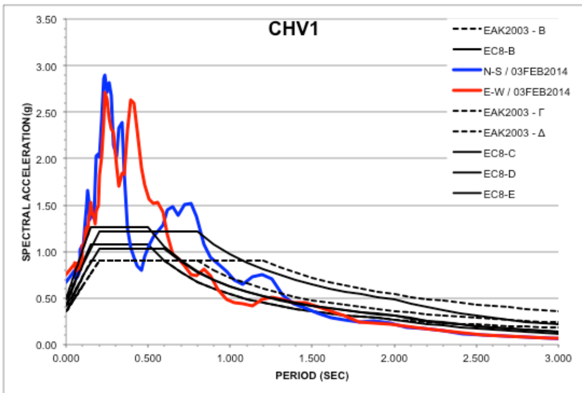


Figure 2. Horizontal component response spectra (D=0.05) obtained from the recordings of the 26/1 and 3/2/2014 earthquakes at Argostoli (ARG2) and of the 3/2/2014 earthquake at Chavriata (CHV1) with respect to the elastic design spectra of greek seismic code (EAK2003) and Eurocode 8 (EC8).

From geotechnical point of view, the main earthquake-induced geotechnical failures may be summarized as follows:

- The road network was significantly affected by the earthquake triggered landslides at slopes composed mainly of limestone formations.
- A large number of stone retaining walls failures were observed that may be attributed to significant lateral earth pressures during seismic shaking imposed on old stone-walls.
- Significant displacements and rocking motion were recorded on the quay walls of Lixouri port and (to a lesser extent) Argostoli port combined with extensive cracks on the jetties parallel to the shoreline that should be associated with liquefaction and lateral spreading phenomena.
- The second shock increased the aforementioned geotechnical failures while in some cases new earthquake induced phenomena on soil were observed.

From structural point of view conclusions may be summarized as follows:

- In general, the recorded intensity of the two earthquakes was not clearly reflected on the observed damage of buildings. Certainly, there was damage mainly at stone-masonry buildings and buildings designed by older codes. Thus, buildings constructed according to the 1959 Greek Seismic Code or before, should be carefully checked, evaluated and when necessary strengthened according to modern techniques.

- Very few 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. Buildings possessed a substantial amount of strength reserves, depending mainly on their redundancy and on over-strength of individual structural members, as well as possible additional energy dissipation mechanisms, which contributed to a significant increase of their behavior factor. However, more refined analyses (e.g. inelastic time-history analyses using recorded excitation at the LXR1-Lixouri) must be performed in order to better understand the actual seismic response of buildings in the meisoseismal area.
- Experience gained from this as well as previous strong seismic events suggests that the seismic protection of urban areas in Greece relies also on several alternative factors (such as infill walls, regular configuration of the structural system, proper material and workmanship quality, etc.). 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, contributed to positive response of the built environment.
- Low-rise buildings designed according to the 1995 code and onwards, with relatively small mass and fundamental period (T<0.15sec÷0.30sec) where a significant number of the Cephalonia buildings pertains, were not heavily stressed, due to the particular shape of the response spectrum of both earthquakes. Generally, ductility demands imposed by these particular events on buildings of this category in this specific range, were not too high, explaining thus the limited degree of observed damage.
- It was confirmed once more that well constructed infill walls, with concrete ties along height, may efficiently support the reinforced concrete frames by improving the stiffness and strength of buildings against seismic actions.
- Apart from structural damage, the earthquakes generated secondary damage to commercial wares and household contents. Due to damage of tile-roofs it was possible for rainwater to enter houses, causing damage to furniture, electric devices and circuits. In such cases it is important to repair tile-roofs immediately or cover temporarily the roof openings. In masonry wall buildings special and immediate measures had to be applied, since rainwater may deteriorate the mortar between the bricks.
- The buildings that had light or heavy damage during earthquake of 26/1/2014 were extensively damaged during the shock of 3/2/2014. For R/C buildings, in few cases, heavy damage were observed, denoting initially failure of 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. For masonry monumental temples, cracks formed during the first shock widened during the second one.

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REFERENCES

EAK2003 (2003). Greek Seismic Code, EPPO, Athens, 152 p. (*in greek*).

EC-8, EUROCODE No 8, (1998). “Structures in seismic regions”, Commission of the European Communities, ELOT2004.

Papazachos B. And C. Papazachou (2003). The Earthquakes in Greece, Ziti Publ. Co., 286 p. *(in greek).*

Scordilis, E. M., G. F. Karakaisis, B. G. Karakostas, D. G. Panagiotopoulos, P. E. Comninakis, and B. C. Papazachos (1985). Evidence for transform faulting in the Ionian Sea: the Cephalonia Island earthquake sequence, Pure Appl. Geophys., 123, 388–397.