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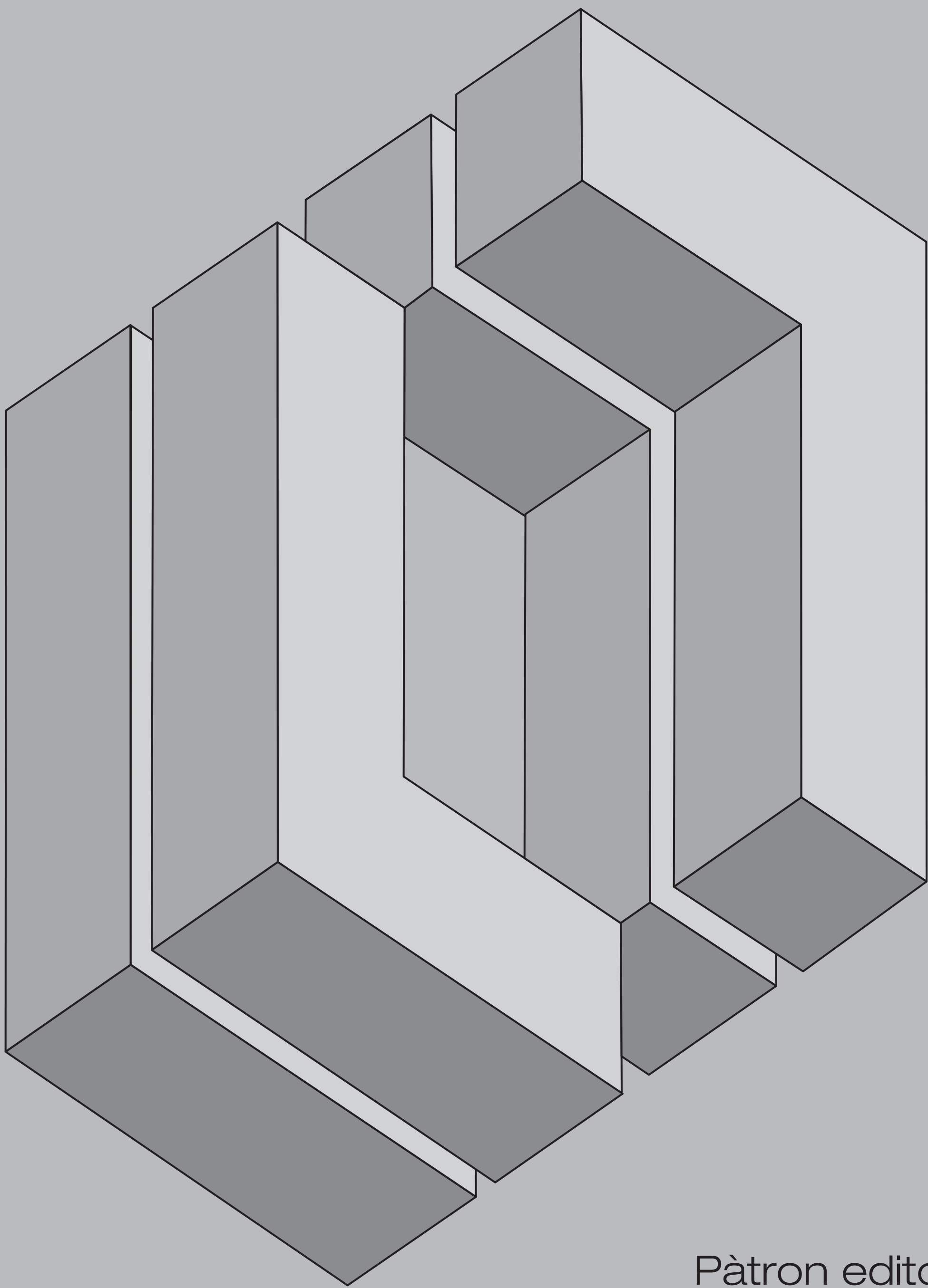

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The October 23 (M_W = 7.2) and November 9 (M_W = 5.7), 2011 Van, Turkey earthquakes. A geoscientific and engineering report

Panayotis Carydis*, Efthymis Lekkas**, Christos Papaioannou***, Andreas Tsokos****, John Delakouridis*****

SUMMARY – *On 23 October 2011 (13.41 LT) a disastrous earthquake with a magnitude of M_W = 7.2 occurred in Van Province of eastern Turkey. That is the region where the Arabian Plate drifting towards north-northeast collides with the Eurasian Plate, while the other smaller plates in the region are moving apart as if pushed by the stronger Arabian. As a result, the seismic history of the region is quite rich usually resulting in severe losses. The death toll due to the main shock reached 604 people and injured 4,152, with at least 188 pulled out of the rubble of collapsed buildings. The most heavily damaged Ercis city was at a distance of 35-40 km to the north of the causative fault. The city of Van suffered much less damage, being to the south of the fault at a distance of 25-30 km. The damage was concentrated mainly in the old city centers of both cities. On the 9th of November 2011 (21.23 LT) a strike slip earthquake of M_W = 5.7 occurred very close to the city center of Van, associated with a different fault. Due to this shock, an additional number of 40 people were killed and 260 injured, while the Bayram Hotel, in Van city, where the authors stayed from 25 to 29 October 2011, collapsed. The hotel building was visually inspected by the first author following a widely accepted methodology and it was considered to be earthquake safe. The available cross-checked information concerning the mechanism of the hotel's collapse is, at first glance, contradicted by the strong motion records presented in the paper. Unfortunately, during the main shock in both Van and Ercis cities, there were no strong motion recordings. In order to infer some basic characteristics of the ground motion due to the main shock, strong motion records from an aftershock, occurring in the same focal volume with that of the main shock, were used. Observations of the response of structures immediately after the main shock were carried out by the authors during their reconnaissance trip and led towards the same goal. The heaviest damage was observed to engineered reinforced concrete buildings. There are some cases of modern and even recently built, multistoried buildings with rather good reinforcement detailing that suffered extended damage or even collapse. On the contrary, nearby non-engineered, low-rise simple or traditional masonry houses, weathered the earthquake in the epicentral region almost without any damage. Most of the reinforced concrete structures are quite flexible, without shear walls, and used a flat-slab constructional system of rather small thickness compared to their spans. In spite of those characteristics justifying high flexibility, no noticeable horizontal motion or pounding was observed between adjacent buildings. For this reason it was thought helpful to present a critical evaluation of the published Turkish seismic building codes since 1940. A crucial subject directly related to the incurred damage and discussed by the authors is the widespread practice of building construction in the region that it is not according to the Turkish earthquake code requirements. It is shown that due to the main shock the numerous and heavy losses in Ercis city were due to the dominance of a severe vertical seismic component, while those in Van city due to resonance phenomena caused by the relatively weak horizontal ground motion. The losses due to the event of 9th November in Van city are attributed to the catalytic function of the vertical seismic component. The resulting collapse is usually quite abrupt and does not allow occupants time to egress safely.*

Keywords: Earthquake reconnaissance, Van earthquake, strong motion records, illegal building construction, vertical seismic component, structural seismic damage, Turkish seismic building codes.

1. **Introduction – seismotectonic setting**

A shallow focus earthquake of a magnitude M_W = 7.2 on 23 October 2011, 13.41 local time, rocked the Van Province of eastern Turkey. The causative fault is located to the south of Ercis city at a distance of 35-40 km and to the north of Van city at a distance of 25-30 km. The damage was concentrated in the old city centers of both cities, but the city of Ercis was the most heavily damaged. The death toll reached 604 people and 4,152 were injured. Of the 604 deaths, 466 occurred in Ercis city (77.2%), 61 in Van city, where 0.6% and 0.012% of each city's population was respectively killed and 77 in villages of the affected region according to AFAD. In Ercis city about 200 buildings collapsed, most of which were multistoried, while in Van no more than 10, forming specific agglomerates. Modern buildings are included among those most heavily damaged, said buildings have a reinforced concrete load bearing system possessing an adequate reinforcement detailing.

The main shock was followed by many aftershocks. An other earthquake of M_W = 5.7 occurred close to Van

* Professor of Earthquake Engineering, Professor emeritus of the National Technical University of Athens, Member of the European Academy of Sciences and Arts, Kifissia, Greece, e-mail: pkary@tee.gr.
** Professor of Dynamic Tectonic Applied Geology, Department of Dynamic, Tectonic and Applied Geology, National and Kapodistrian University of Athens, Panepistimiopolis Ilissia, Athens, Greece, e-mail: elekkas@geol.uoa.gr.
*** Seismologist, Research Director, Institute of Engineering Seismology and Earthquake Engineering, Thessaloniki, Greece, e-mail: chpapai@itsak.gr.
**** Geologist-Environmentalist, M. Sc., Department of Water Resources & Environmental Engineering N.T.U.A., e-mail: atsokos@central.ntua.gr.
***** Geologist-Environmentalist, M. Sc., Faculty of Geology and Geoenvironment, Department of Dynamic, Tectonic and Applied Geology, N.K.U.O.A., e-mail: jdelak@geol.uoa.gr.

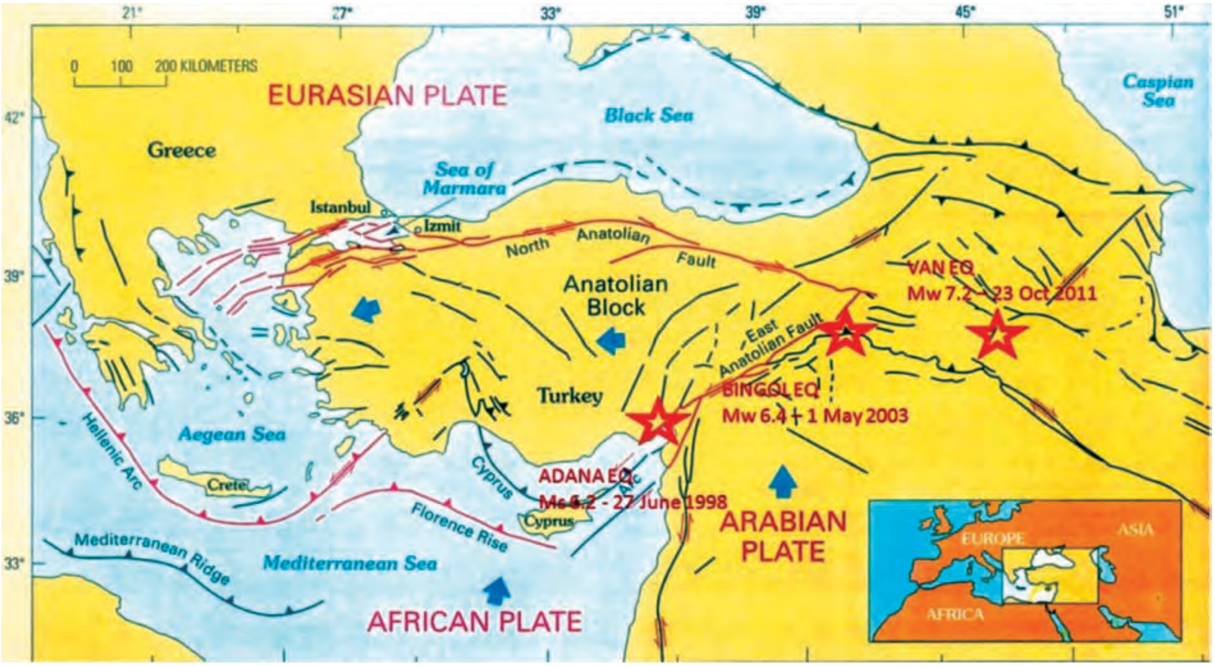

Fig. 1. *Geotectonic Map of the area and the epicenters of the main catastrophic earthquakes of the last 15 years at the front of the Arabian Plate.*

city center, on 9th of November 2011, 21.23 local time. This event caused 40 fatalities and 260 injuries. 25 buildings totally collapsed, 22 of which were evacuated after the main shock. Within 24 hours after the main shock the reconnaissance team members flew to Van. On the morning of 25th of October they were in the region from where they left on the 29th of the same month. During their visit the team members stayed in Bayram hotel that later collapsed during the event of the 9th of November 2011.

Turkey lies in a tectonically active region with frequent destructive earthquakes. It is surrounded by three major plates, the African, Eurasian, and Arabian plates and located on two minor plates, the Aegean and Anatolian. According to /27/, the drift of the Arabian Plate towards the north-northeast against Eurasia results in a collision in the region of Lake Van. The other smaller plates of the region - the Turkish, Iranian, Black Sea and South Caspian plates - move symmetrically away from the Lake Van region to the east and to the west, as if pushed aside by the advancing Arabian plate, Fig. 1.

Lake Van is the largest lake in Turkey with an approximate area of 3,600 km^2. It is located in the very intensely deformed Eastern Anatolian region, due to the continent to continent collision of the Arabian and Eurasian plates /34/. According to recent GPS studies, /11/, /26/, the Arabian Plate is moving in a north-northwest direction relative to Eurasia at a rate of about 25 mm/yr. About 10 mm/yr of this rate is taken up by shortening in the Caucasus, resulting in a continental collision along the Bitlis - Zagros fold and thrust belt. This motion is thought to cause intense seismic activity.

The East Anatolian Fault (EAF) is a left-lateral strike slip transform fault marking the boundary of the Arabian and Anatolian Plates, /4/. It extends 600 km from Karliova basin, where it meets NAF, to the city of Maras in the southwest, where it joins the Dead Sea Fault Zone (DSFZ).

The junction region is characterized by a number of small active faults parallel to either NAF or to EAF to the south and northeast of Erzincan, with a mosaic structure of small parallel faults which distribute the tectonic movements along these two main faults in the region. These results of /35/ are based on the fault breaks associated with the 1966 Varto Earthquake on NAF, the 1971 Bingol Earthquake on EAF, as well as their aftershocks and the locations of other smaller events in the region.

The Main Recent Fault (MRF) is a 1,500 km long fault bordering the Arabian Plate in the northeast. The fault enters Turkey at the meeting point of Iran, Iraq and Turkish borders and continues in the Yuksekova valley to the vicinity of the Zab River. No further northeast extension of the fault is observed beyond the Zab River. The Tabriz Fault (TF) starts near Bostanabad in the southeast, continues to the northwest passing north of the town of Tabriz and near Marand the fault is divided to two different directions, to Derik Fault and to the Northwest fault system. The Caldiran Fault is separated from the Northwest Fault System near the Turkish frontier and is directed toward ENE and extends about 60 km in this direction. In addition to the major faults described above, conjugate strike-slip faults of dextral and sinistral character paralleling to North and East Anatolian fault zones are the general dominant structural elements of the region. Some of these structures include Bulanik Fault, Agri Fault, Ercis Fault, Igdir Fault, Suphan Fault, Baskale Fault, Dogubayazit Fault Zone, Cobandede Fault Zone, Dumlu Fault Zone, Kavakbasi Fault, Kagizman Fault Zone, Karayazi Fault and the Northeast Anatolian Fault Zone /16/.

According to /22/, /2/, /3/, the most important historical earthquakes that have taken place in the East Anatolian tectonic province are:

a) The destructive event of Oct 3, 1276 in the region north of Lake Van. The earthquake destroyed Arges, Argish, Arkestia, Arces (Ercis) and Xlat (Ahlat). Walls and buildings collapsed and many people were killed.

b) The major event of March 31 1648 (M_W about 6.6) that is known to have damaged the city of Van. This earthquake has been associated with an east-west trending fault in the south of Van. The east-west trending Gurpinar thrust at this location can be associated with this event.

c) The March 8, 1715 earthquake that is associated with an estimated epicentral location between the eastern termination of Derik fault and Van.

d) The May 30, 1881 Tergut earthquake which took place in the western part of Lake Van.

e) The February 6, 1891 Adilcevas earthquake which took place in the northern part of Lake Van.

f) A more recent damaging earthquake in the same region is the Malazgirt earthquake of April 28, 1903. The distribution of damaged villages suggests a NNE-SSW trending in the rupture.

g) In 1941, a magnitude of about 5.9 earthquake affected Ercis and Van, causing 190 to 430 casualties.

h) The large scale destruction by earthquake in the Van region in 1945. A swarm type series of earthquakes with a maximum magnitude of about 5.2 started on June 28 and continued until December.

i) The last strong earthquake in the broader area occurred on November 24, 1976 (M_S 7.1), which caused the death of more than 4,000 people and all houses destroyed at Caldiran, Muradiye, Ercis, Diyadin and Ozalp (www.isc.ac.uk).

A number of large destructive earthquakes and active faults have been used to characterize the deformation of the East Anatolian Plateau (EAP), /24/. Most of this deformation is taken up by pure shear, along conjugate strike-slip faults trending NE and NW. There are two events that have strike slip character and give evidence for the shearing process. They are located on the Balik Golu Fault (BGF) and Tutak Fault (TF) respectively that have a dextral strike slip motion clearly seen from morphological evidence, /25/.

Fig. 2. *The seismic rupture, crossing the main road of Van-Ercis, is very close to epicenter, which is associated with the October 23rd, 2011 earthquake, see Fig. 5.*

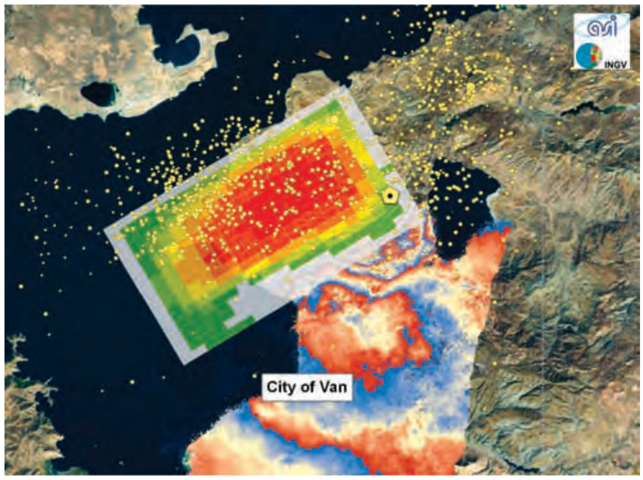

Fig. 3. *Surface projection of the North-dipping source modeled from the COSMO lnSAR ground displacements. Also shown: seismicity and wrapped interferogram, after /10/.*

2. **The seismic activity of October – November 2011**

Based on the seismotectonic setting, it is obvious that the dominant seismic faults of the wider Van area are the result of combined compression and shear in two major directions, NE-SW and NW-SE. The major faults are reverse faults with a significant horizontal component and directions NE-SW and NW-SE respectively. This directly affects the morphology of the area, mainly the morphological depressions, with the Van – Erçek Lake depression of NE-SW direction being the most characteristic. The direction of the depression coincides with a strike slip fault of similar direction. Along this fault, major changes of the geology and the structure of both blocks are observed, such as successive lakes and ground elevations, as a result of the pop-up and pop-down structures Fig. 2.

The seismic activity of October 23rd 2011 (Mw = 7.2), based on seismological and interferometry data, /10/, resulted from a fault of NEE-SWW direction, located 25-30 km north of Van and 35-40 km south of Ercis city. The outcrop of the fault, based on field observations, had a visible length of approximately 300 m and it crossed the main road of Van-Ercis. After consideration of all the data it can be concluded that this fault is a reverse fault of N80E direction and 70° dip, with the north block being the hanging wall, Fig. 3.

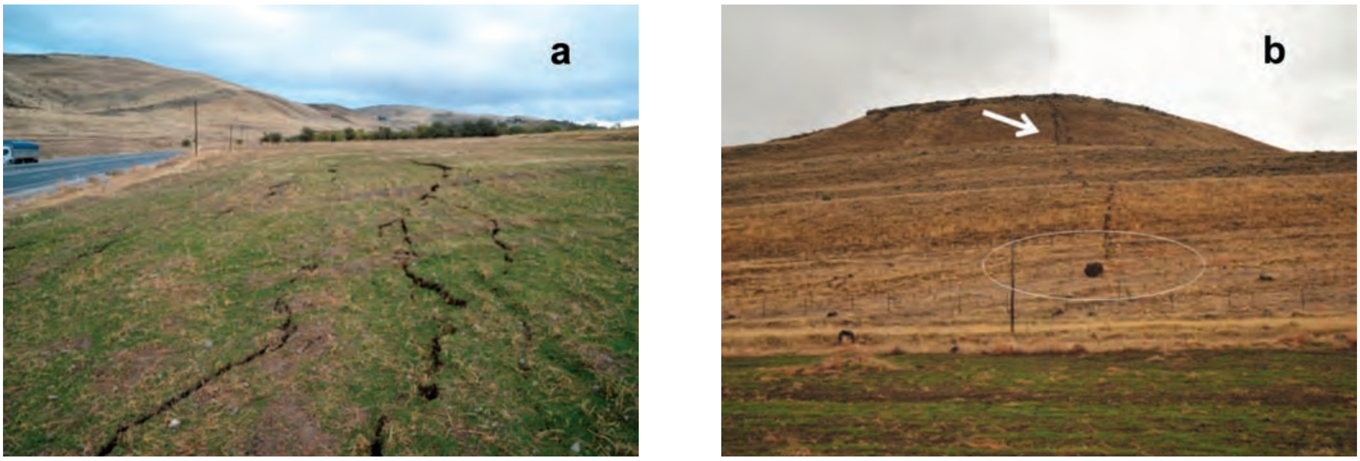

Fig. 4. *(a) Landslides and (b) rockfalls at the north of the epicentral area (hanging wall).*

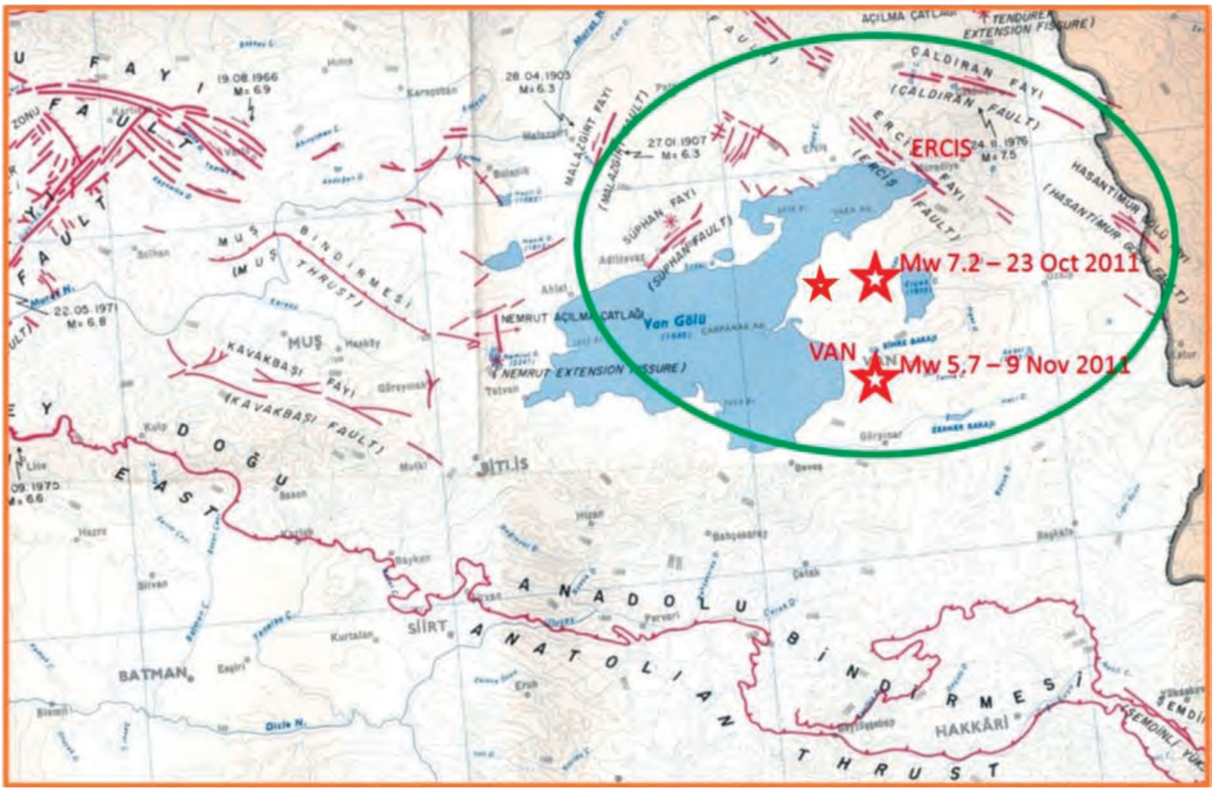

Fig. 5. *The wider area of Van-Ercis and the epicenters of the two recent catastrophic earthquakes. With a smaller asterisk an aftershock of $M_L = 4.6$, 21 November 2011 is also shown. Respectively ground motion records are commented in section 3.*

This conclusion is in accordance with the macroscopic results and mainly with the fact that the greatest damage is observed at the north uplifting block in the area of Ercis and not at the south block in the area of Van. Maximum intensities were observed at the north block and were at least 2 degrees (EMS-1998) greater than in the south block. It is characteristic that in the city of Van, during the earthquake of October 23rd 2011 a rather small number of multistoried buildings with load-bearing structure of reinforced concrete collapsed, whereas in the city of Ercis, where similar geotechnical conditions exist, hundreds of similar multistoried buildings collapsed. Moreover, the extensive damage in the city of Ercis may be interpreted as a combination of adverse soil dynamic conditions and the reflection of the seismic waves at the rock basement. Finally, several landslides and rockfalls were observed at the north block, whereas at the south block they are absent, Fig. 4.

The second major seismic event of November 9th 2011 ($M_W = 5.7$), took place after the activation of the strike slip fault between the city of Van and Erçek Lake. This fault has a general NE-SW direction, along which characteristic pop-up and pop-down structures occur and crosses under the city of Van. The activation of the fault resulted in damage that was observed only in the city of Van and not further north, in contrast to the earthquake of October 23rd 2011, Fig. 5.

In the report of the Turkish Prime Ministry Disaster and Emergency Management Presidency (AFAD) for the main earthquake the relocation of the aftershocks, using the HYPODD code defines an aftershock area with strike which coincides with the results of /1/. Surface rupture fragments 4 km-long striking almost EW are mapped in /1/. In /23/ an attempt was made to constrain the slip history using teleseismic broadband P and SH waveforms and it was suggested that the plane with strike 241 deg is the most likely one. In /10/ was attempted to model seismic source parameters adopting the geometries of the two nodal planes provided by NEIC. They found that the result based on the fault dipping NW shows higher residuals than the south dipping source, however it is better correlated with the spatial distribution of the epicenters of aftershocks. In /36/ was adopted as fault the one coinciding with the distribution of aftershocks for a multiple point source solution of the main event.

3. Strong motion records and estimation of some basic ground motion characteristics inferred from the observed response of structures

The main shock was recorded by numerous accelerographs operated by the Turkish Accelerometric Network, /33/. Unfortunately, according to our knowledge there is no record due to the main shock either in Van or in Ercis. However there is a record in Van due to the event of November 9th, 2011. The station is equipped with a broadband Guralp CMG-5TD instrument. A band pass filter 0.15-35 Hz was applied to the raw data. The corrected acceleration, velocity and displacement time histories are shown in Fig. 6. The acceleration response spectra and Fourier amplitude spectra are presented in Figs 7 and 8 respectively.

It is interesting to mention here that the peak acceleration of NS component reaches the value of 147.7 cmsec^{-2}, that of EW component 246.6 cmsec^{-2} and that of the vertical component 150.5 cmsec^{-2}. The duration

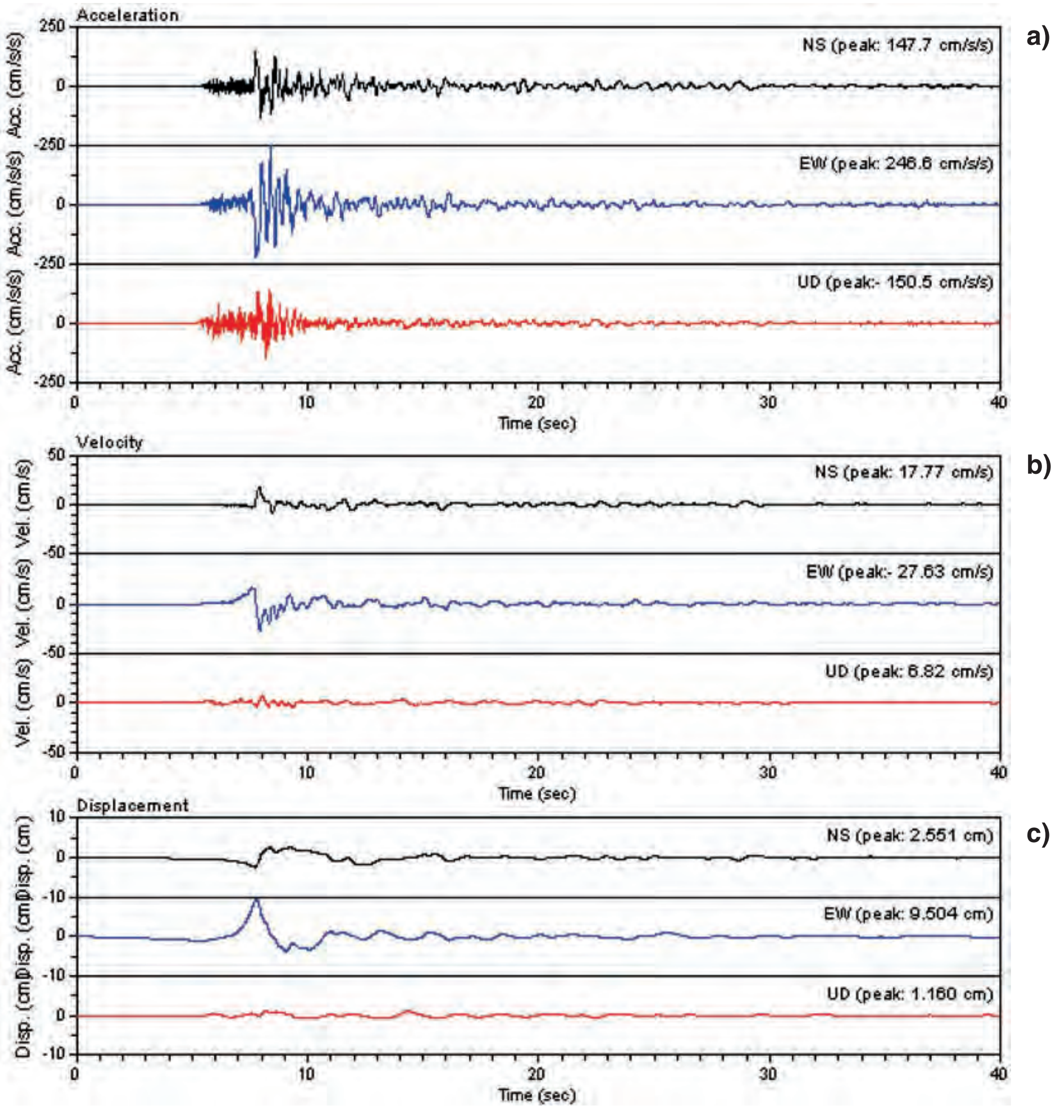

Fig. 6. *Corrected acceleration (a), velocity (b) and displacement (c), time histories for the M_W = 5.7, 9 November 2011, 21.23, LT event recorded in Van.*

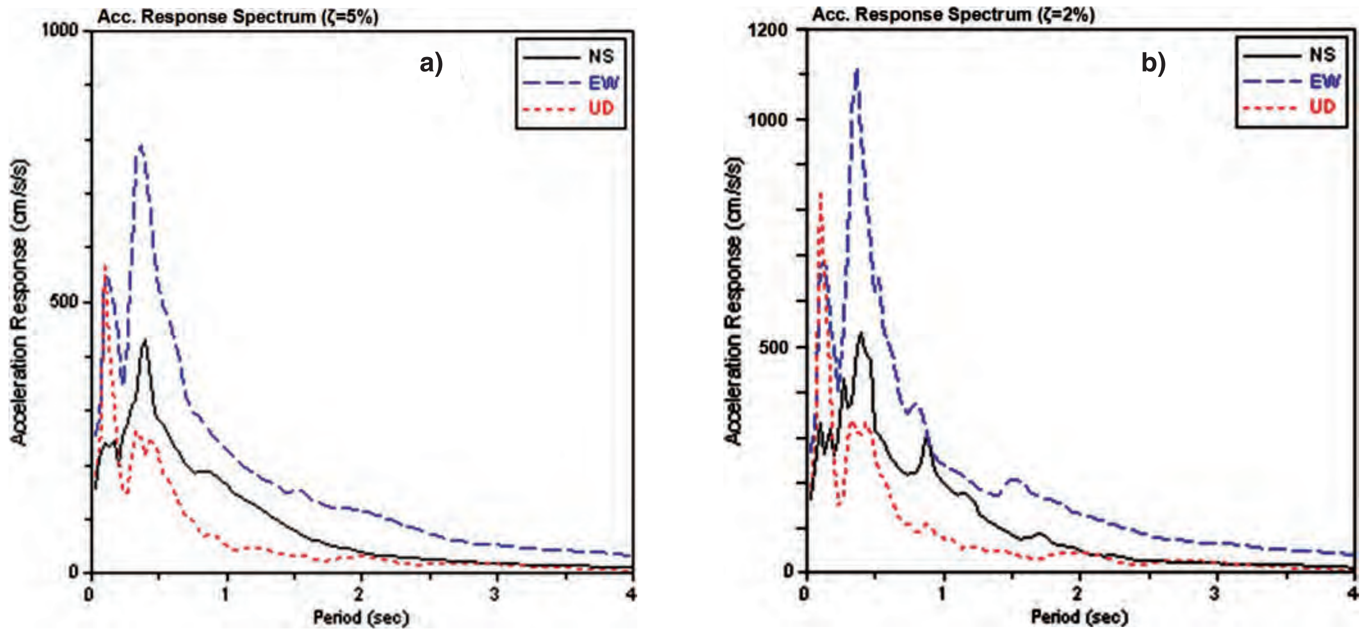

Fig. 7. *Acceleration response spectra for the M_W = 5.7, 9 November 2011 event recorded in Van, for ζ: (a) 5% and (b) 2%.*

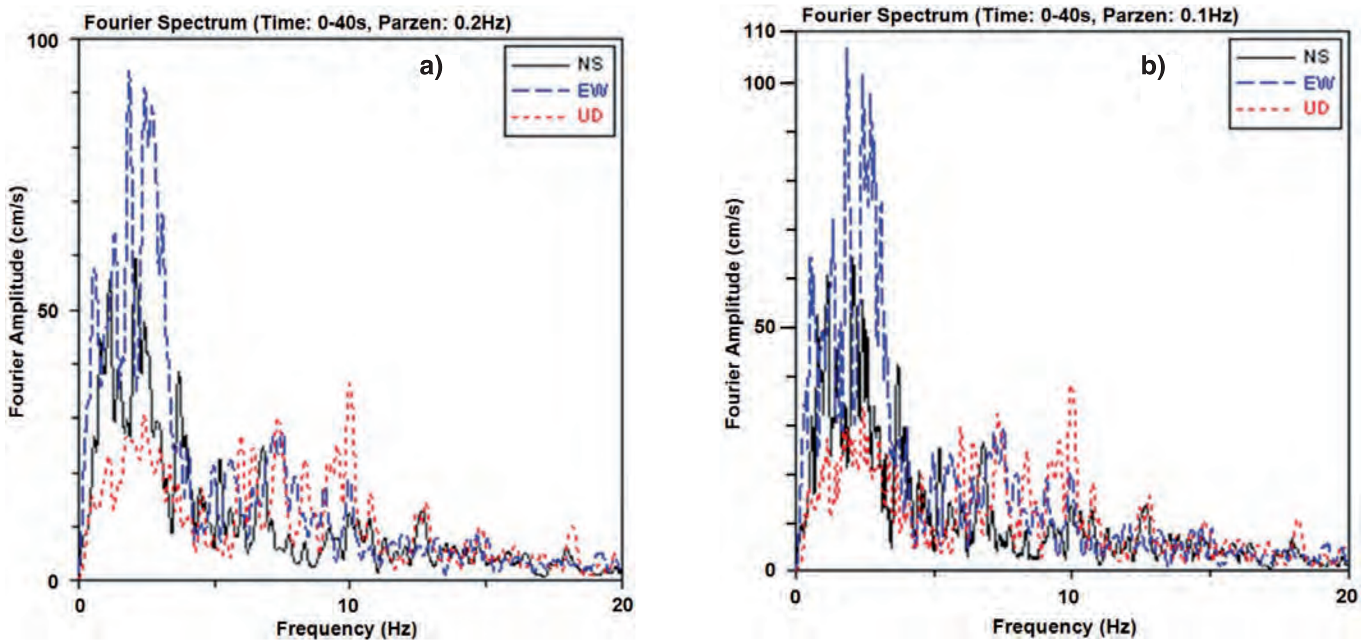

Fig. 8. *Fourier velocity spectra for the M_W = 5.7, 9 November 2011 event, corresponding to running windows smoothing process with width n: (a) 0.2 Hz and (b) 0.1 Hz.*

of the strong phase is of the order of 2.5 sec. The ratio of the peak acceleration values along NS is: V/A = 1.02 and along EW is: V/A = 0.61. Both values differ from the commonly accepted V/A = 0.7, recommended by many codes. Nevertheless, one would expect much higher acceleration values of the ground motion and especially along the vertical component since the accelerograph is installed in the epicentral region of this specific earthquake.

The shapes of the acceleration response spectra are simple, giving peak values at almost the same periods, of about 0.40 sec, for both horizontal components. Along the vertical component the peak corresponds to a period of about 0.10 sec. This may be justified from Fourier amplitude spectra, shown in Fig. 8, where the peak values for the two horizontal components are at around 2.5 Hz and for the vertical one at 10 Hz. It is worth mentioning that for the vertical component, the richer in information Fourier spectrum is almost flat for frequencies from low values up to 10-12 Hz. It is thus confirmed the impact character of the vertical seismic component, which possesses the potential of affecting a wide range of structures and, practically, independently from their natural periods.

On the other hand, the effect of damping ratio, ζ, on the response spectra values, may be shown by comparing the respective peak values in Figs 7a,b. For NS component $\eta = SA_{0.02}/SA_{0.05} = 525/440 = 1.19$; For EW, $\eta = SA_{0.02}/SA_{0.05} = 1100/800 = 1.38$; For UD, $\eta = SA_{0.02}/SA_{0.05} = 840/570 = 1.47$, while the EC-8 code formula for $\zeta = 0.02$ gives damping correction factor $\eta = \sqrt{10/(5+2)} = 1.20$. The higher value of η for the vertical is in agreement with the general opinion that the damping is more efficient for the vertical response of structures rather than for the horizontal one, since the vertical response is rich in higher frequencies.

By comparing Figs. 8a and 8b, almost similar conclusions can be drawn. More specifically, with the decrease of the width of the running window smoothing process from 0.2 Hz (Fig. 8a) to 0.1 Hz (Fig. 8b) the Fourier spectrum of the vertical component is approaching or exceeding that of the two horizontal ones.

The lack of acceleration records in the two cities due to main shock results in difficulties for robust conclusions on the explanation of the extensive degree of heavier damage observed in Ercis, compared to Van, although the epicentral distance of Ercis city is much greater than that of Van City.

In order to examine possible reasons for these phenomena, the available accelerometric records in Ercis and Van due to the same event have been selected (daphne.deprem.gov.tr) and studied. It must be noted that the first record by a CMG-5TD accelerograph, installed in Ercis, was on November 20. No information on site conditions are available. Seven pairs of records were found until January 31, 2012. A general characteristic of the records in Ercis is the significant amplitude of the P-waves (expressing motion along the vertical component) even for moderate magnitude (~5.0) events which in few cases is

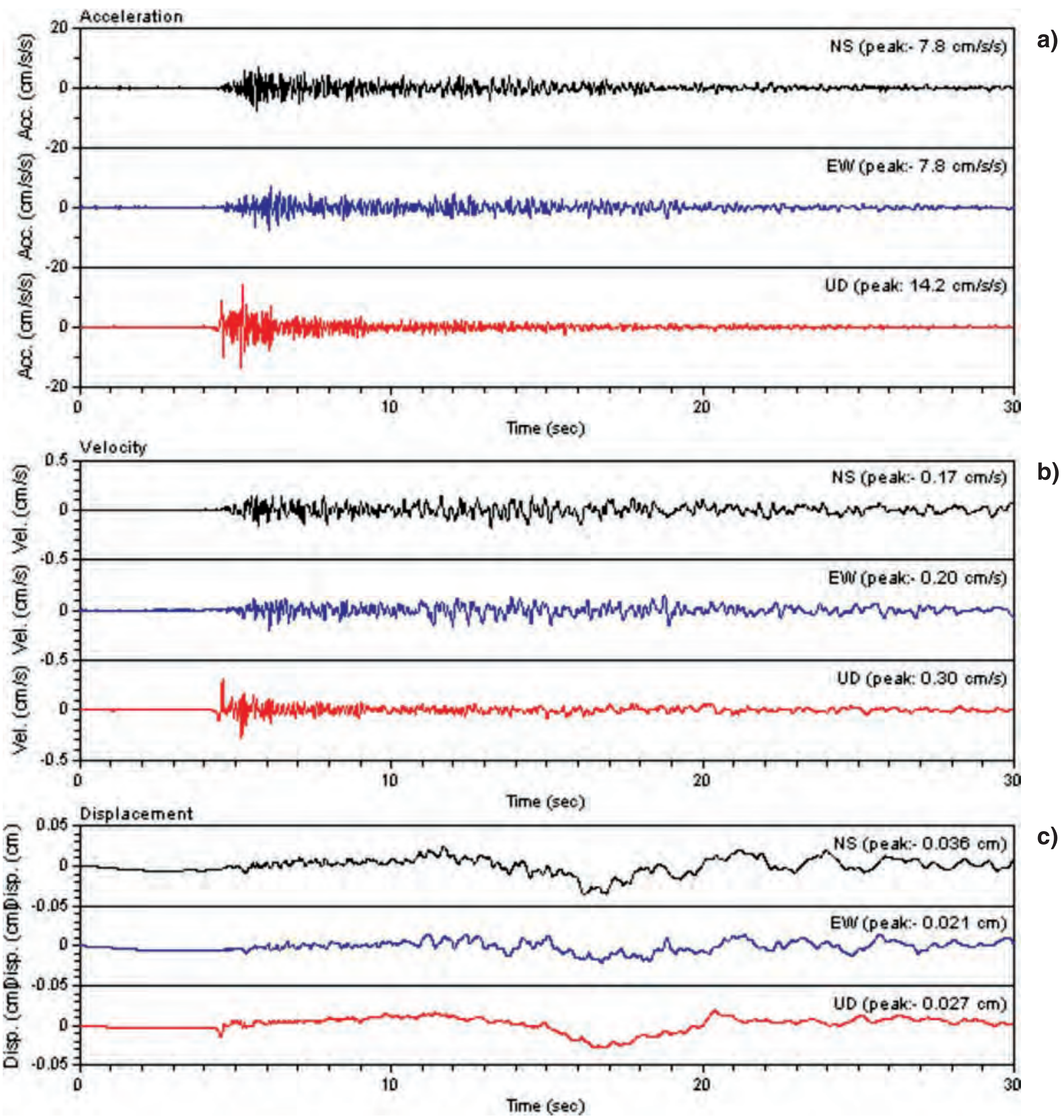

Fig. 9. *Corrected acceleration (a), velocity (b) and displacement (c), time histories for the M_L = 4.6, 21 November 2011 aftershock, recorded in Ercis. Soil conditions are still unknown. The epicenter is shown in Fig. 5. The epicentral distance is about 39 km.*

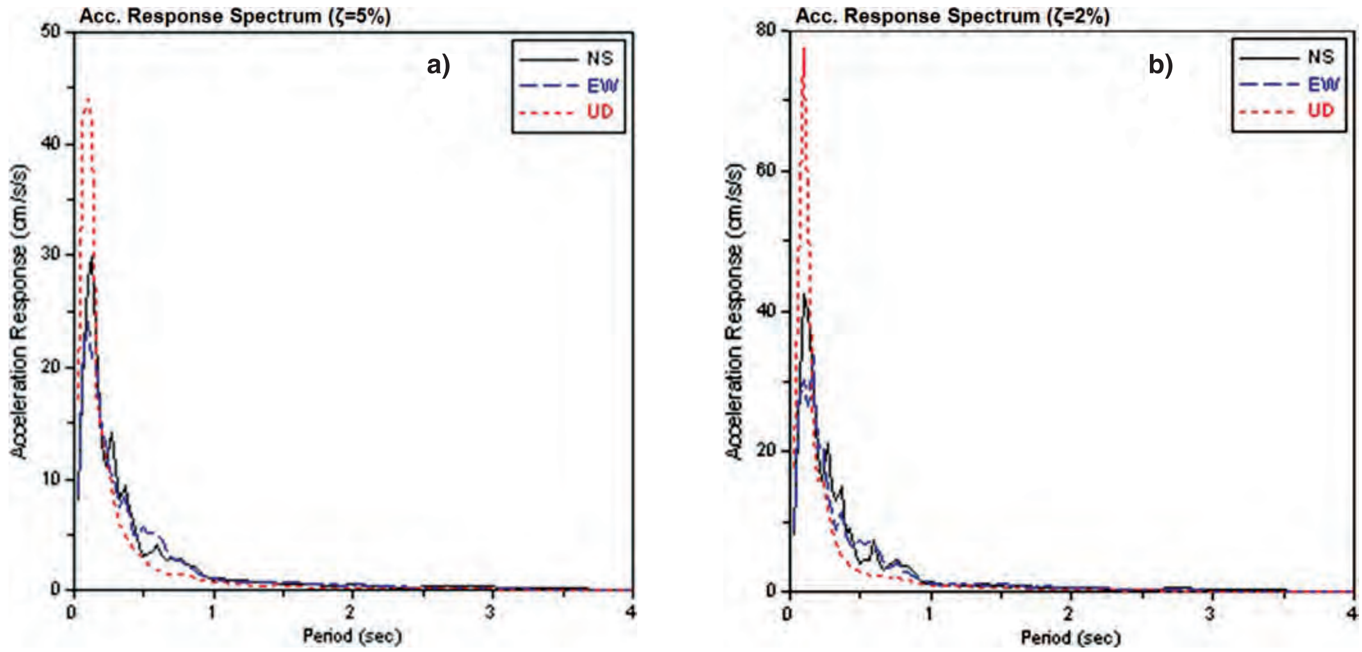

Fig. 10. *Acceleration response spectra for the M_L = 4.6, 21 November 2011 aftershock recorded in Ercis for ζ: (a) 5% and (b) 2%.*

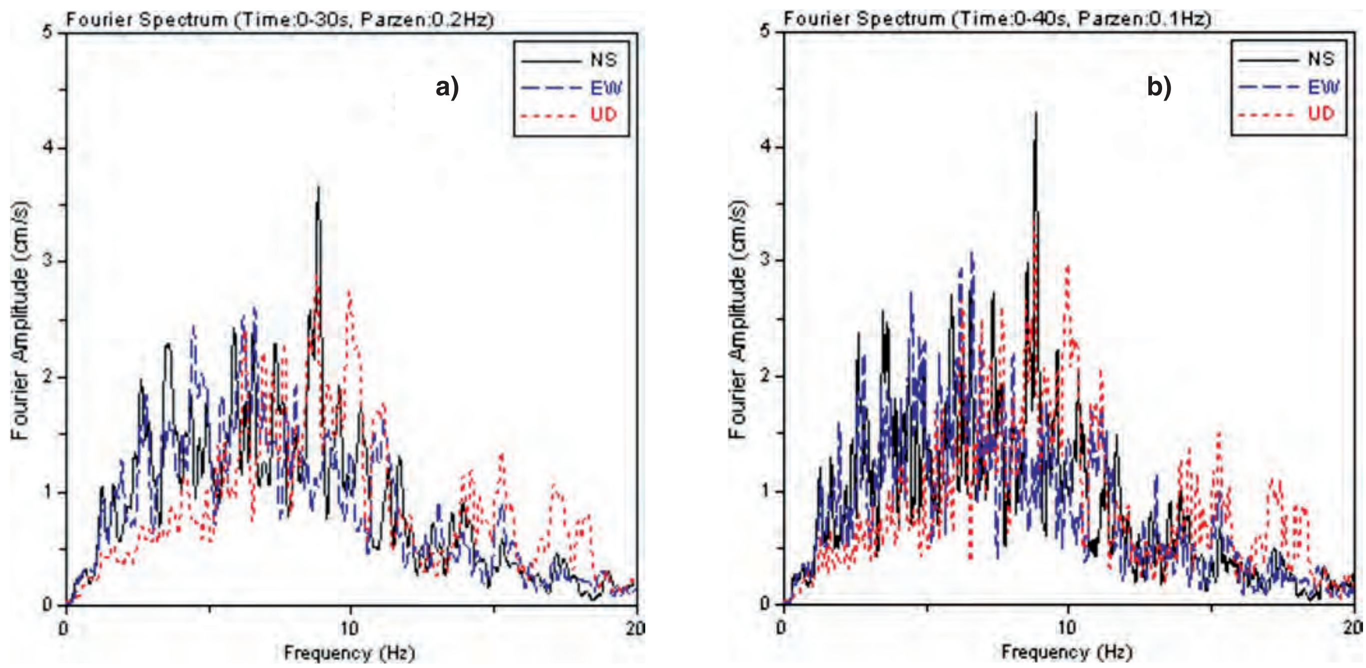

Fig. 11. *Fourier velocity spectra for the M_L = 4.6, 21 November 2011 aftershock, recorded in Ercis and corresponding to running windows smoothing process with width n: (a) 0.2 Hz and (b) 0.1 Hz.*

higher than that of the horizontal ones. An example is given in the corrected records in Fig. 9, at Ercis, located at epicentral distance of about 39 km, the peak acceleration value of the vertical component is 14.2 $cmsec^{-2}$ while that of both horizontal components are equal to about the half of it, namely 7.8 $cmsec^{-2}$. The peak values for the records at Van (epicentral distance of about 25 km) are 3.0, 3.2 and 2.5 $cmsec^{-2}$ for the UD, NS and EW components respectively. The respective corrected waveforms in Van city are shown in Fig. 12. In Figs 10 and 13 the acceleration response spectra and in Figs 11 and 14 the Fourier amplitude spectra for Ercis and Van cities are respectively presented.

Nevertheless, considering the waveform pattern in Ercis one may conclude that a possible interpretation of the heavy damage, due to the main shock, may be related to high amplitudes along the vertical component of the ground motion. A possible explanation could be the location of Ercis if we consider as the earthquake fault the one with strike 241 degrees which dips under Ercis. The town is located on the hanging wall, where shaking damage is generally greater and at fault-

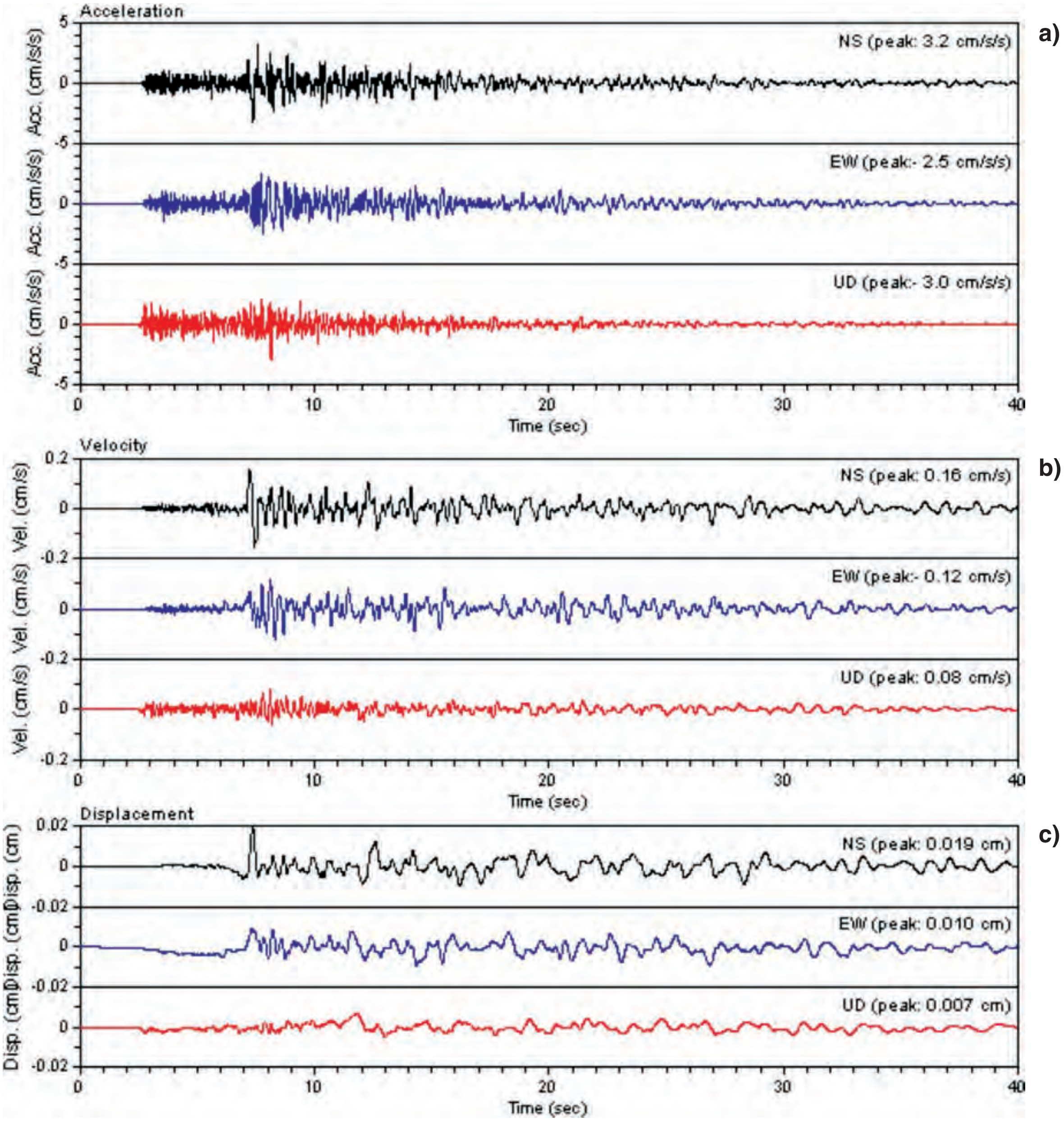

Fig.12. *Corrected acceleration (a), velocity (b) and displacement (c), time histories for the M_L = 4.6, 21 November 2011 aftershock, recorded in Van. The epicenter is shown in Fig. 5. The epicentral distance is about 25 km.*

distance of about 25 km, while Van is located on the foot wall. However the proximity to the fault (distance about 25 km) is a factor for interpretation. And this becomes more interesting since in /35/ it is concluded that the rupture was propagated to the southwest which contributes to the proximity of Van to the fault.

The estimation of some basic ground motion characteristics inferred from the observed response of buildings is based on the most frequently observed key building response that best reflects the ground motion characteristics. The observation is based on experienced engineering judgment by filtering the response from the specific building characteristics and any deficiency including the level of its earthquake resistant capacity. In other words, each building is considered as a kind of a 3-D seismoscope and its frozen response is observed and recorded by the researcher. The best structures, are the dynamically simplest. The goal of this evaluation is basically the clarification of the dominating, if any, direction of the ground motion which is responsible for the structural response. This is namely, horizontal or vertical, or a combination of these two ground motions including their distinctly different kinematic characteristics. Usually, in near field regions, it is observed that some peak acceleration pulses between the horizontal and the vertical seismic components may coincide in time, a parameter that should be taken under consideration. A decisive parameter that must be also taken under consideration is the time after the beginning of the motion in which the destruction of the structure takes place, and its mode as well. When the vertical seismic component is dominating in destructive earthquakes the following characteristic modes are evident:

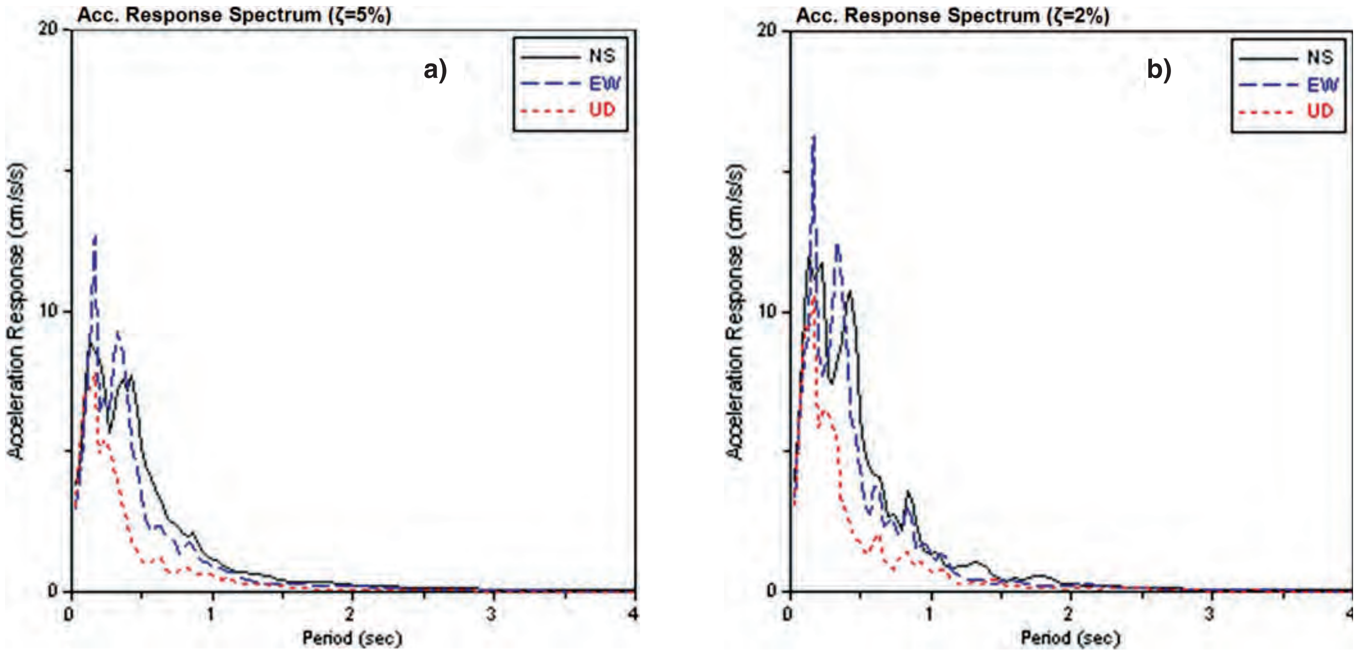

Fig. 13. *Acceleration response spectra for the M_L = 4.6, 21 November 2011 aftershock, recorded in Van, for ζ: (a) 5% and (b) 2%.*

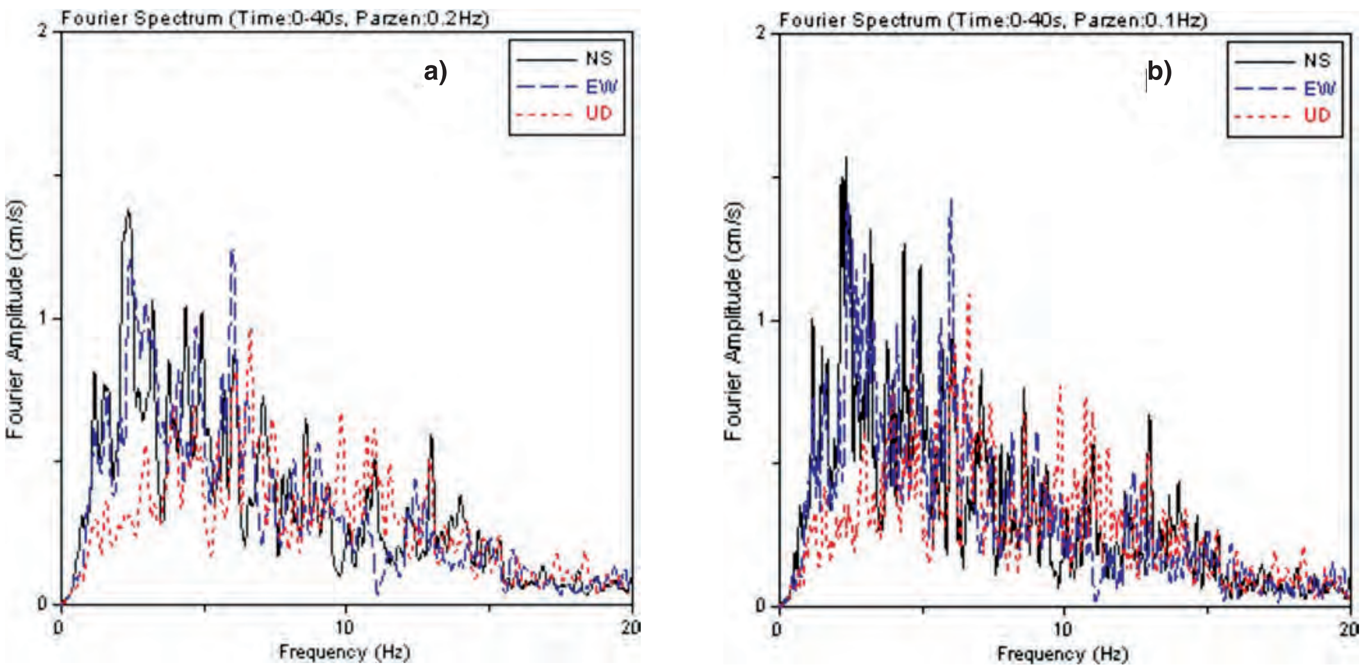

Fig. 14. *Fourier velocity spectra for the M_L = 4.6, 21 November 2011 aftershock, recorded in Van and corresponding to running windows smoothing process with width n: (a) 0.2 Hz and (b) 0.1 Hz.*

• The structures are caving into their foundation plan. Whole floors, and especially the lower ones, are compressed or squeezed, and generally, impact type phenomena are produced along the height of the structure.

• The destruction is abrupt and takes place within the first few seconds of the motion. Inhabitants have no time to react, or possibly, to escape safely.

• An explosive type of damage along the vertical load bearing elements, and especially of columns, of a relatively smaller cross section, is developed. The general image of the damage is as if explosives have been placed underneath the building foundation.

• Phenomena produced by the reduction of vertical axial forces and/or gravity loads. For example; the reduction or loss of friction, torsional phenomena of rigid bodies, increase of eccentricities in cross-sections of vertical load bearing elements may be observed.

In performing this type of rational evaluation of damage, one must be especially careful in order to avoid potential but plausible, at first glance, misinterpretations. For example, the reason for a crushing type damage of the vertical load bearing elements only around the perimeter of a building might be confused among the effects of overturning moments due to the horizontal seismic component and the direct effects of the vertical seismic component, as already mentioned. Furthermore the toppling of a structure can not be attributed to the function of a strong vertical seismic component without any other justification. Causes for toppling of a structure can be attributed to: a) the horizontal component; b) a simultaneous combination of horizontal and vertical components, and c) a weakening due to the vertical component and to an afterwards integration of the destruction due to the horizontal component. Of course, the final conclusions of the investigation must come to an agreement with the seismotectonic findings and strong motion records exposed in previous sections of the present paper.

The pictures presented (Figs. 16 up to 30), are representative and support the following conclusions at each site of interest.

The dominating destructive seismic component due to the main shock of $M_W = 7.2$ possesses all characteristics of a seismic motion along the vertical direction in the city of Ercis. The motion was extremely violent, probably exceeding in some locations the crucial threshold of 1.0 g. Its kinematic characteristics produce impact type and other phenomena as mentioned above, /13/, /14/ and /15/. These phenomena are yielding in epicentral regions of shallow focus earthquakes of even moderate magnitude earthquakes. Although, from the seismological point of view Ercis city cannot be considered as located in the microseismic epicenter (based on instrumental data) of this earthquake, the characteristics of the incurred building damage suggests that Ercis city is the macroseismic epicenter of this event. As it is mentioned in the seismotectonic sections and the discussion of the strong motion records of the present paper this might be due to the hanging wall effect, reflections of the seismic waves on the dipping-fault plane combined under Ercis city. In addition, some important directivity phenomena might have been involved and especially upwards, i.e. when the rupture starts from deeper layers and gradually propagates towards the surface. This phenomenon actually occurred during the main shock, and it can be proved by combining the origin time and respective depth, provided by /36/.

Nevertheless, it must be stated that in some locations the final damage could be attributed to the dominance of the horizontal seismic component too. This is depicted, for example, in the damage of a minaret, while many others remained intact.

As far as the city of Ercis is concerned, the original – direct P waves due to the distance and the rather shallow focal depth, might have been damped rather quickly. But, so that someone justifies the observed nature of the motion, which has undoubtedly the character of a strong vertical component, may take under consideration, according to /28/, the catalytic effect of the high underground water table level that exists in Ercis city. A high level of underground water table augments the damaging potential of the vertical seismic component. This might be due to the very small damping that water presents during the propagation of the rather high frequency P waves and, of course, due to its rather high incompressibility. And as it is well known S waves are not propagated in water, the seismic energy is propagated only by P wave function.

The destruction observed due to the main shock, in the city of Van, might be attributed to structural resonance phenomena produced by the horizontal component, which in any case was rather weak in the underlying bedrock. This argument is based on structural response and damage observations: a) the positioning and formation of the debris; b) the damage and crack pattern in collapsed and, especially, in non collapsed buildings; c) the evidence of the authors on the ground motions due to aftershocks from almost the same hypocenter that they experienced during their stay, and especially during relaxing time at night (see also section 4.5) and d) the records in Van from an aftershock shown in Figs. 12, 13 and 14. The best estimation for the value of the maximum ground horizontal acceleration around the city of Van during the main shock, except for some places of adverse soil conditions, was in the order of 0.15 g. The effects of the vertical seismic motion component were not noticeable.

On the contrary, the $M_W = 5.7$ event closer to the city of Van (10-12 km), produced a very intense vertical shaking of maximum acceleration, which, based on engineering judgment and the mode of collapse of Bayram Hotel, according to /13/, /14/ and /15/, might be estimated to be at the value of gravity for the site under consideration. Nevertheless, it must be stated that the authors recognize that the recorded and presented in Fig. 6a vertical PGA is equal to 0.15 g. The distance between the recording station and Bayram Hotel is about 700 m and the recorded values are not representative of ground motions of various locations around the city, /13/, /14/, /15/. The characteristics and the destructive effects of this event in the city of Van are quite similar to those observed after the main shock of $M_W = 7.2$ in Ercis city. The difference lies only on the size of the affected area, /14/, /15/, and, therefore, the number of collapsed buildings and fatalities.

4. Basic structural characteristics of existing buildings, related damage and an attempt for interpretation

In order to expose the basic structural characteristics of the existing building stock, one has first to examine the following two issues: (a) the up to now published seismic building codes based on which the structures should have been legally constructed, and (b) to what extent those regulations are actually realized.

4.1. *The up to now published seismic building codes and their relation to the incurred damage*

Seismic building codes, in general, stand on two different pedestals that originate from two rather different disciplines, which, nevertheless, overlap as far as the above the bedrock ground conditions are concerned. The one is seismic zonation based on geosciences and the other is the seismic response of buildings including that of the foundation ground based on engineering mechanics.

Currently, Turkey possesses one of the most advanced seismic building codes after several revisions since 1940, when the first code was published, /12/, /17/.

Since the first issue of the Turkish seismic code was published, one may count about five revisions of the seismic zoning maps and more than twice as many concerning the structural engineering part. A great part of the latter revisions followed the respective revisions of the seismic zones. Usually, those changes followed great destructive earthquakes. Such great destructive earthquakes have devastated many Turkish regions several times in the past. In general, it has been observed that after destructive earthquakes the incurred revisions almost always included an increase of the level of the seismic input actions in the earthquake stricken areas, as if this was the only reason for the destruction.

According to /12/and /17/ the preexisting Italian seismic code greatly influenced the first Turkish seismic code of 1940. The horizontal seismic load H applied to each floor of a building was equal to

$$H = 0.10 \times W \tag{1}$$

where:

– W = the total dead load of the respective floor, plus the ones of the above standing floors of the building.

This 10% uniform, all over the country, seismic coefficient was independent of the location, ground conditions or building characteristics. This situation lasted up to 1945 when the first seismic zoning map of Turkey (containing 3 zones) was published, that was later on incorporated into the 1947 revision of the 1940 code. At the highest seismic zone of that map the respective seismic coefficient has been maintained (0.10), while the one at the lower zone was halved (0.05). The allowable material stresses under the seismic load combination were increased by 25%.

The seismic 1945 zonation, also contained regions with zero seismic coefficient, which means that no earthquake provisions should be taken. This is because that zonation was based on available data of past earthquakes and recorded intensities.

The 1949, /17/ revision of the code, including a new map of three seismic zones, was introduced and for the first time introduced ground conditions into the seismic design process. The seismic coefficients at the highest seismic hazard zone were much lowered to 0.02 for thicker than 1.0 m rock ground formations, 0.03 for medium, and 0.04 for soft grounds. The seismic coefficients for the second – lowest seismic hazard zone were 0.01, 0.02 and 0.03 for the respective ground conditions, while the allowable material stresses for the earthquake load combination were increased by 50%. On the other hand the load W in Eq. (1) included besides the dead load, part of the live load equal to 1/3 of it for dwellings, 1/2 for office and the full live load for public buildings.

Nevertheless, the 1953 revision of the code, /29/, in the earthquake load combination added half of the wind loading. The values of the seismic coefficients and zonation of the 1953 code remained the same as those of the 1949 code. Of particular interest in the 1953 seismic code are the construction practice guidelines for masonry buildings of various types, adobe and wooden buildings. Some general guidelines for repair, strengthening and reconstruction of earthquake damaged buildings were also included. Furthermore, in the same issue of the code some, criteria for the earthquake design of dams, highways, railroads and harbor facilities were mentioned.

In the 1961 revision, /12/, /17/, a new map of three seismic zones was introduced. The highest, the lower and that with no earthquake design provision. The seismic coefficient was gradually increased along the height of the building from 0.06 for the first 16 m height, by increments of 0.01 for each segment of 6 m height over the first 16 m. This rate of increase continued up to 40 m height, in the last segment of which the seismic coefficient was 0.10. These coefficients were further multiplied by two factors: the first corresponding to the building type-ground condition combination coefficient, (n_1), equal to 0.8, 0.9 and 1.0 for reinforced concrete structures on hard, medium and soft ground conditions respectively. For steel structures, n_1 was equal to 0.6, 0.8 and 1.0 on the respective as above mentioned ground conditions. The second factor corresponding to the seismic zones, (n_2), was equal to 1.0 for the highest and 0.6 for the next two lower seismic zones.

In the 1963 revision of the 1961 code, /21/, following a zoning method based on expected Modified Mercalli intensities, four seismic hazard zones were defined. Nevertheless a close relation to the three 1961 zones was maintained, as far as the arithmetic values are concerned. The first (highest) zone of 1963 was equal to the first (highest) of 1961. The second and third of the 1963 code were equal to the second (lower) of the 1961 code, while the fourth was for regions without earthquake provisions. The other characteristics of the two codes, 1961 and 1963, are identical. In the 1963 seismic zoning map one may well distinguish the North Anatolian fault zone and its south-eastern bifurcations, as well as some regions in the western parts of Turkey. Those regions were quite early recognized as possessing the highest seismicity, but in other parts of the country the character of localized islands of the various seismic regions are evident.

Van province and Ercis city were included in the highest seismic zone. In order to illustrate what might be the value of the seismic coefficients, the following simple example is presented: Let's assume a five-storied hotel building in the city of Van with a reinforced concrete framing system on unknown ground conditions. This hotel building, built according to 1961 or 1963 seismic codes, should have been designed with a uniform along its height (since its total height is less or equal to 16 m) seismic coefficient for hard and soft ground conditions equal to:

$$C = 0.06 \times (0.8 \div 1.0) \times 1.0 = 0.048 \div 0.06 \quad (2)$$

If the same building was constructed at the next two lower seismic hazard zones, the seismic coefficient would be for hard and soft ground conditions:

$$C = 0.06 \times (0.8 \div 1.0) \times 0.6 = 0.029 \div 0.036 \quad (3)$$

Since the structure is a public building (hotel), the horizontal load, according to the code, will be $H = C \times (G + 1.0 \times P)$, where G is the permanent load and P is the live load. The state of allowable stresses was at that time still valid, with an increase of 50% for the earthquake load combination.

The logic of the new 1968 code was mainly based on dynamic characteristics of structures. The allowable stresses were still in use. The base shear coefficient was determined according to:

$$C = C_o \times S \times I \times \beta \quad (4)$$

where:

– C_o = the seismic hazard zone coefficient equal to 0.06, 0.04 and 0.02 for the highest, the medium and the lowest zone respectively,

– S = the ground conditions coefficient, 0.8 for hard, 1.0 for medium and 1.2 for soft ground conditions,

– I = the importance factor, 1.5 for critical and public buildings, and 1.0 for all the other buildings,

– β = the dynamic factor $0.3 \leq \beta \leq 1.0$, according to the relation $\beta = 0.5/T$, where T is the translational fundamental period of the structure calculated using the formula $T = 0.09 \times H/\sqrt{D}$, where H is the height and D is the respective length of the building.

In the addendum of the 1968 code, the use of adequate shear walls was recommended according to the building height and seismic zone, /12/, /17/.

According to that code, the previously mentioned hotel building in the city of Van should have been designed, for hard and soft ground conditions with the following base shear coefficient:

$$C = 0.06 \times (0.8 \div 1.2) \times 1.5 \times 1.0 = 0.072 \div 0.108 \quad (5)$$

and for the lowest seismic hazard zone for hard and soft ground conditions:

$$C = 0.02 \times (0.8 \div 1.2) \times 1.5 \times 1.0 = 0.024 \div 0.036 \quad (6)$$

The 1975 code, /18/, introduced important renovations based both on the updated 1972 seismic hazard zoning map of five zones (the fifth being for no seismic provisions) and leveraged on a new way of calculating the seismic forces by introducing the parameter and concept of ductile moment resisting space frames.

According to /18/ the base shear coefficient was equal to:

$$C = C_o \times K \times S \times I \quad (7)$$

where:

– C_o = is the seismic zone coefficient which is taking the values of 0.10, 0.08, 0.06 and 0.03 respectively for each of the four zones, starting from the highest,

– K = the structural coefficient receiving the value of 1.0 for all building framing systems, except those with a box system (K = 1.33), those with a ductile moment resisting frame (K = 0.6 for very strong partition walls, K = 0.8 for medium and K = 1.0 for light partition walls), those with a non-ductile moment resisting frame (K = 1.20, K = 1.50, K = 1.50 respectively for the same as above mentioned categories of partitions) and those with a steel space framing system with diagonal bracings (K = 1.33, K = 1.50 and K = 1.60 respectively for the above mentioned categories of partitions).

– S = the spectral coefficient which is equal to 1.0 for natural building period $T \leq 0.5$ sec for ground conditions with a shear wave velocity V_s, of ≥ 700 $m.sec^{-1}$, or predominant period of the ground $T_o = 0.3$ sec; for $T \leq 0.8$ sec for ground conditions of $400 \leq V_s < 700$ $m.sec^{-1}$, or $T_o = 0.6$ sec; for $T \leq 1.1$ sec for ground conditions of $200 \leq V_s < 400$ $m.sec^{-1}$, or $T_o = 0.9$ sec; and for $T \leq 1.4$ sec for ground conditions of $V_s < 200$ $m.sec^{-1}$, or $T_o = 1.2$ sec. For building periods, T, greater than the above mentioned values, $S = 1/|0.8 \times T - T_o|$.

– I = the importance factor, which is equal to 1.0 for buildings of low occupancy, as dwellings, hotels, office buildings, restaurants, industrial structures e.t.c. and equal to 1.50 for all other cases.

Therefore, if the same hotel in the city of Van was designed according to the 1975 seismic code, the following base shear coefficient should have been used (the exact values of the factor K are questionable and therefore they are taken equal to 1.0 or 1.5). The natural period of the building is assumed to be $T \leq 0.5$ sec. For hard and soft ground conditions:

$$C = 0.10 \times (1.0 \div 1.5) \times 1.0 \times 1.0 = 0.10 \div 0.15 \quad (8)$$

and for the lowest hazard zone for hard and soft ground conditions:

$$C = 0.03 \times (1.0 \div 1.5) \times 1.0 \times 1.0 = 0.03 \div 0.045 \quad (9)$$

The two codes issued later, on 1998 and 2007 are almost identical between themselves. The new seismic zoning, besides the past observed intensities, is now based on a probabilistic approach. In the respective seismic hazard map, Van province is placed in the second highest zone with effective ground acceleration equal to 0.30 g, over 0.40 g yielding for the highest seismic zone. Both codes, /30/, /31/, are based on the ultimate strength method, and on the ductile response of structures. This is specified in the codes, either as “Nominal Ductility Level” or as “High Ductility Level”, according to which the respective reduction coefficients are specified, (3 to 5 and 5 to 8 respectively).

Nevertheless, if the same hotel was to be designed according to the 1998 or 2007 code, the base shear coefficient would be of the same order with that given in Eqs 8 or 9. And this, after a normalization based on en-

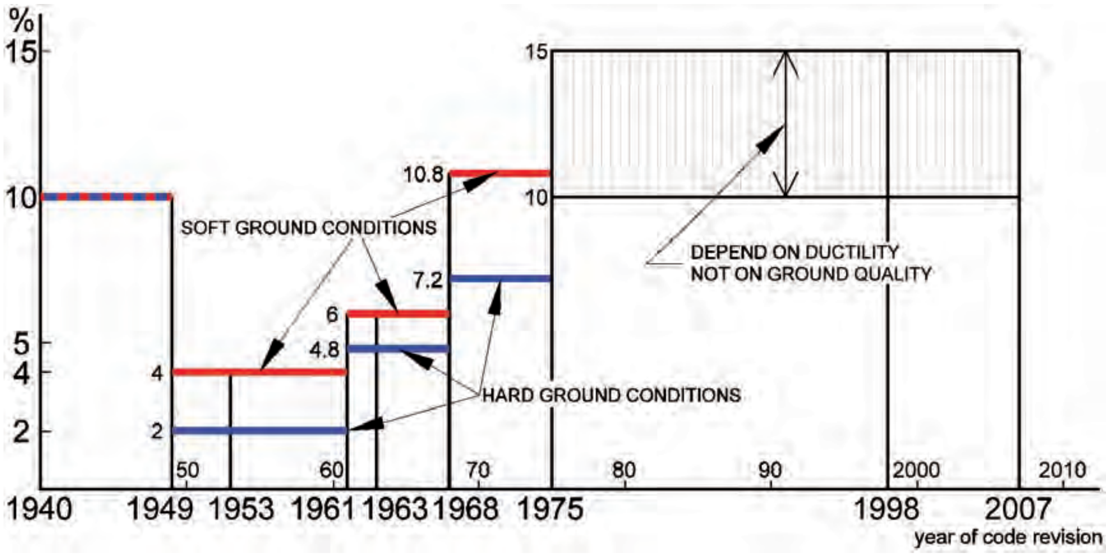

Fig. 15. *Evolution of base shear design coefficients for a 5-storey hotel building in the city of Van (in the highest seismic zone).*

gineering judgment by correlating the ultimate strength method to the allowable stresses method. The difference would be mostly on the quality of the structure and the detailing of the reinforcement as it is specified in the code. This reinforcement is placed on those positions of the load bearing members and in an adequate geometric form in order to primarily protect the building structure from seismic waves that are acting horizontally.

The 0.10 seismic coefficient of the 1940 code that did not include live loads and by a 25% increase of the allowable stresses, may come almost to the same base for comparison with the next code generations, that on one hand include portions of live load, but on the other hand increase the allowable stresses by 50%.

In Fig. 15 the base shear design coefficients for the hypothetical hotel building in the city of Van are plotted against time, with all calculations refering to the allowable stresses method.

Based on the diagram of Fig. 15, it is obvious that during the period 1949-1975 quite low seismic coefficients were used. It must be emphasized, also, that those low values of seismic coefficients correspond to the highest seismic zones in which the city of Van belonged before the last two revisions of the seismic code. The abrupt and excessive reduction of the seismic coefficients from 0.10 that were used during the decade 1940-1949, to something around 0.03, as a mean value during the next decade 1950-1960, should also be noted. It must be mentioned here that seismic coefficient values below 0.05 with a parallel increase of the allowable stresses by 50% do not consist any noteworthy earthquake structural resistance, especially in regions of the highest seismic hazard zone in the country. Namely, those buildings can hardly safely withstand an effective peak ground acceleration of more than 0.05 g and under the best structural qualifications 0.15 g. These thresholds are further reduced in the case of buildings with a soft ground storey as this is the case of buildings at the city shopping centers, with ground floors functioning as shops possessing larger show rooms, openings and shop windows. As far as the vertical seismic component is concerned, no provision is described in the respective codes. It must be emphasized that buildings with a soft ground storey are extremely vulnerable to a strong vertical seismic component.

In addition, it must be mentioned that the majority of buildings in the city centers of Van and Ercis have been erected within a period of about 25 years starting in 1950. In these regions and during that specific time period, multistoried buildings with a reinforced concrete framing system were most popular, conquering thus, a universal use. It is a belief that the lower values of the diagram of Fig. 15 were usually applied for the design of buildings in this period. This is because some parameters that are influencing the values of the seismic coefficients and to that extent the earthquake design loads, according to /21/ and /29/, are selected by the designer engineer and the controlling department, would only later check them.

The crucial question is: if the parameters assumed for the design proved insufficient, what should the controlling department do after the construction of the foundation or even of the whole building? In order for someone to try and give a probable response to these points, he must first take under consideration the surrounding atmosphere of the examined period (1950-1975) as far as the production of earthquake safe structures is concerned. Actually, the general belief was that the new building material, reinforced concrete and the relevant construction methods possessed an extraordinary strength and earthquake resistant capacity. In parallel to that, the abrupt excessive reduction of the seismic coefficients, officially promulgated by the code, gave the sign as if there was no notable earthquake risk even in the highest seismic hazard zones. Therefore, it is logical to expect from the design engineers to (rather superficially) select the parameters that lead to lower values of seismic coefficients. For example, it is given that the value of the seismic coefficient is a function, basically, of the ground characteristics, at the foundation level, which is some meters below the visible surface of the ground. These characteristics are unknown during the design of the structure, unless a soil investigation is carried out.

In general, a preliminary soil investigation was not carried out at the time, since it was not compulsory and the ground characteristics assumed for the design, were just guesstimated, by the designer. It is self-evident that, under the existing conditions, the designer had no reason to select ad hoc adverse ground conditions.

As a result of all these, the earthquake resistance of the structures was dramatically abased for building structures designed and constructed during the period 1950-1975 in the Van-Ercis region, according to the respective building codes used in the time. Therefore, a logical result of the above mentioned, is that one of the catalytic reasons for the observed severe destruction of buildings and loss of human lives in Van and Ercis is the result of the drastic reduction of the seismic coefficients, specified in the respective codes during the period 1950-1975. In full agreement with this point of view comes the fact that most of the damage occurred in the old city centers of Van and Ercis and in agglomerations of buildings constructed during that period. Of course, sparse, damage and collapse was observed in newer buildings too, but this will be discussed later on.

4.2. *Illegal building construction*

In the present section only parameters affecting the earthquake safety of buildings will be discussed, since the illegal building construction does not always imply an increase of the seismic vulnerability of the respective structures. After the above mentioned, it is logical to argue that even a small percentage of excess load over what the structure is legally capable to bear, may lead to a dramatic reduction of the existing safety margins (already greatly reduced) against even a low intensity earthquake. And this is mainly yielding for structures that are erected during the period 1950-1975 as already mentioned.

The authors during their visit to the earthquake-stricken areas noticed the following structural interventions to large percentage of existing buildings that might relate to illegal construction:

– extending the useful volume of the structure along its height with the addition of one or more floors either all over the plan or, at a part of it;

– extending the useful area of each apartment over the balconies by enclosing them with brick walls;

– demolishing bearing and/or non-bearing walls and other elements in order to create larger space, openings and shop windows mainly on the ground floors. This is observed in the city centers by repurposing older buildings, and

– by changing the use of existing buildings to a heavier one.

Taking into consideration, the already analyzed data about earthquake safety of buildings of that period, one may not be quite sure to what extent a legal building permit was precisely realized in practice.

It must be mentioned here that even a "legal" addition of floors along the height of a structure, or the enclosing of the balconies, or the demolition of vertical bearing or non-bearing elements, or the change to a heavier use, in general, contains an increased seismic risk for the building. For this reason a special design should be carried out based on a detailed investigation of the structural health condition of the existing building, on the mechanical characteristics of the construction materials including the foundation body and those of the ground. According to the authors experience after their visit at the respective sites, adequate structural strengthening should have been carried out in order for such additions and changes in such a building stock to be realized. After the said autopsy, became most evident that such strengthening did not take place to the collapsed or heavily damaged buildings. This argument is based on a detailed investigation of the structural condition and qualification of the load bearing members, their cross sections, the quality and workmanship of their reinforcement, the beam to column joints e.tc.

4.3. *Building characteristics and damage in urban areas*

Based on the construction period and type, the building stock in the urban areas of both cities, Ercis and Van, might be classified in four main categories as given below. Those categories responded differently after the two seismic events, of 23rd October 2011, $M_W = 7.2$ and 9th November 2011, $M_W = 5.7$. The differentiation in their response lies on the combination of their structural characteristics with the nature and the respective intensity of the ground motion (horizontal, vertical or both).

In the first category, only a rather limited number of buildings is included. Those are the oldest and in their majority are made out of load bearing masonry with a wooden roof. There are also, wooden buildings, or masonry mixed with wooden members and wooden extensions. These buildings are simple or two-storied, and in both cities performed quite well after the earthquakes, either the main shocks or the aftershocks.

In the second category, reinforced concrete buildings constructed during 1950-1975 or before, are included according to the respective codes. Most of these buildings were situated in the old city centers of Ercis and Van. Due to their age, position in the city centers and the corresponding occupancy, the respective building stock was liable to additions, alterations and any kind of interventions that, as already mentioned, reduced their already low earthquake resistance capacity. These buildings have a reinforced concrete load bearing system with fired hollow brick masonry partitions in the older ones. In newer buildings the partitions are with hollow concrete blocks. Shear walls were almost unknown that period, and the buildings were, in general, quite flexible. The columns are of rectangular cross section and the distances between themselves are rather large. In the newer buildings of this category, in order to create larger slab openings and reduce the nominal storey height, the flat-slab construction system was used. In some cases stronger beams around the perimeter of the buildings are used, while the respective columns were of orthogonal cross section with the larger dimension perpendicular to the building façade. In brief, the most fatal interventions to those buildings from an earthquake-safety point of view is the creation of open ground floors, namely without partitions, creating thus a soft ground floor, increasing the vulnerability of the building against horizontal and vertical ground motions. In most cases, probably due to heavy snow fall in the region, a roofing system out of steel truss with corrugated sheet-iron as a cover is used. The buildings are seven to eight storeys in height at the maximum. The height of the ground floor is rather higher in which a mezzanine of smaller plan dimensions is usually formed. There is no structural differentiation among office or commercial and residential buildings since the occupancy might be mixed in the same building. The adjacent buildings in the city centers are in full contact.

Almost the majority of multi-storied buildings at the old city center of Ercis either collapsed or suffered heavy damage, while much fewer buildings collapsed in the old city center of Van, after the main shock. This might be attributed to the high seismic vulnerability of these structures. This fact was combined with the intense vertical ground shaking in Ercis city, while in Van, resonance phenomena, in spite of the rather low peak horizontal ground accelerations may have developed. The total collapse of a number of buildings, in various parts of the city of Van during the 9th November earthquake might be attributed to the produced strong vertical component.

The third category includes buildings designed and constructed after 1975 with a reinforced concrete load bearing system. All those buildings, from a structural point of view, are quite similar with the use of the flat-slab system being predominant. The load bearing system is stronger and stiffer than that belonging to the previous category. Within this rather long period of time, one may recognize a first period from 1975 up to 1998 and a second one from 1999 up to 2011. The buildings in the latter period possess much better reinforcement detailing and workmanship, better concrete and steel quality, and the use of shear walls or wider column cross sections are more often found compared to those belonging to the period of 1975-1996. Residential multi-storied buildings have masonry partitions out of fired hollow brick walls or hollow concrete blocks 10-12 cm thick. Usually, the ground floor is formed and used in the same way with those buildings constructed during 1950-1975. Commercial buildings possess fewer partition walls. Instead, lightweight mobile partitions and glass panels are frequently used.

Unfortunately, buildings belonging to both sub-periods of the third category, also suffered, heavy damage. The difference depends on their plan size: If the plan is large enough, buildings belonging to the first time period may lose the ground floor or other floors above it while, they, usually, subside uniformly. Buildings belonging to the second time period suffered heavy cracks but, in general, with reduced structural damage on their vertical load bearing elements, usually on the ground floor. The squeezing nature of the damage is evident, and that type of damage is almost universal throughout the plan area of the building. If the dimensions of the plan are limited, buildings belonging to both time periods were usually overthrown.

Structures of special construction type belong in the fourth category, as for example are the mosques which are mainly composed out of domes and minarets. Both structures present high earthquake resistance against an intense vertical seismic component. And this might be attributed to their symmetrical geometry around the vertical axis. In general, those structures did not suffer any noticeable damage except for a few cases of minaret toppling. The direction of toppling was towards the macroseismic epicenter of the first event.

4.4. *Building characteristics and damage in rural areas*

Outside the cities of Ercis and Van one may find buildings belonging to two main categories: The first, consist of agglomerations of buildings of the same type and material, forming thus, various village nuclei. These villages give the impression that they are built under a certain development project on a well designed village plan. The buildings are one storied, made of masonry with concrete blocks and with a corrugated sheet-iron roofing system. These buildings are founded on a concrete base of a thickness of about 50 cm. Although many of those villages are located quite close to Ercis and Van cities, they weathered both events almost without any loss.

In the second category, isolated buildings up to five storeys may be found all over the region. These buildings feature a reinforced concrete load bearing system, are flexible, have a wooden roof or a steel truss roof and are always covered with a corrugated sheet-iron. All those buildings responded rather satisfactorily to both events.

4.5. *The collapse of Bayram hotel, after the M_W = 5.7 event of 9th November 2011*

The five-storey hotel Bayram, shown in Figs 30a and 30b collapsed after the M_W = 5.7 event. The collapse according to witness accounts, pictures and videos from security cameras functioning during the event, took place abruptly within the first few seconds of the earthquake motion and almost inside its ground floor plan. As a result, most of the occupants were trapped. This type of total collapse is a typical characteristic of the presence of a strong vertical seismic component, usually observed in epicentral regions of shallow focus earthquakes. Nevertheless, this type of collapse in spite of the above mentioned reasons, is not justified by the relevant strong motion records presented in Fig. 6. Unfortunately, for the time being, they are not known the soil conditions of the collapsed structure. The structure initially was five storeyed with a reinforced concrete load bearing system and brick walls for partitions, constructed around the early 70's. Some years ago, a sixth floor was added out of steel cross-sections as a load bearing system with a corrugated sheet-iron roof and the whole structure was renovated. The authors were staying in Bayram hotel during their visit.

The structure was optically inspected by the first author following a widely accepted methodology /5/, /6/, /7/, /8/, and the relevant ones, /9/, /19/ and /20/. It must be mentioned, to this day the same author has inspected and evaluated before or after destructive earthquakes more than 15,000 buildings in Greece and abroad. He found the hotel building earthquake safe – green tag, and therefore all the team members were convinced and decided to stay in that hotel building. Its column cross sections possessed adequate dimensions in a rather dense grid. The dimensions of the beams, most of them supported directly by columns, were quite satisfactory in their cross section dimensions, forming, thus, from a geometry point of view, acceptable beam to column joints. In a picture posted on the staircase wall of the hotel, a construction phase of its foundation was depicted. The image verified the aforementioned visual findings. The building did not present any structural damage after the first earthquake. The only damages observed were some vertical fissures between the non-bearing masonry partitions and some columns in a quite limited number. The fissures were of very small width at the lower building level, usually, less than 1 mm, gradually increasing along the building height. Additionally, no diagonal cracks in the non-bearing walls were observed.

The hotel building possesses the southwestern corner in the crossing of two main avenues in the city of Van. The observed cracks at the top floor of the southeast end of the building were larger than those observed at the same level of its northwest end. This suggests a torsional response of the building. This torsional response did not appear in the plan of the still standing roof over the collapsed building. This might be attributed to the fact that the torsional response was due to a horizontal ground motion during the October 23rd earthquake, while the subsequent collapse was due to the vertical motion that occurred abruptly, not permitting the development of any torsional response.

During various smaller aftershocks from the epicentral region of the main shock that were experienced by the authors, the response of the hotel building was quite normal. It could be characterized as possessing quite low damping, since the duration of the building's rather harmonic oscillation was longer than anticipated with very low amplitudes. It was really an experience of a resonance phenomenon produced by a damping out harmonic input motion. This may be justified by the ground motion time history, presented in Fig. 12, by the response spectra in Fig. 13 and especially by the Fourier spectra in Fig. 14, in which the predominant period of the horizontal ground motion was T = 1/2.5 = 0.4sec. This value almost coincides with the fundamental period of the five-storied building under consideration.

5. **Conclusions**

• The seismic activities of October – November 2011 occurred at the most seismically active area of eastern Turkey, an area of many devastating past earthquakes.

• The October 23rd, 2011, $M_W = 7.2$ earthquake was generated on a reverse fault of N80E direction and 70° dip. The mapping of the fault surface justifies the serious damage experienced in Ercis due to the fact that the city was on the hanging wall. As a result, 200 buildings in Ercis collapsed, while no more than 10 in the city of Van.

• The November 9th 2011 ($M_W = 5.7$) earthquake was due to the activation of a strike slip fault to the south and close to the city of Van. This fault has a general NE-SW direction, along which characteristic pop-up and pop-down structures occur and crosses under the city of Van. Due to this event 25 buildings collapsed.

• Due to both events the death toll reached 644 people and 4,412 injuries.

• The city of Ercis could be characterized as being the macroseismic epicenter of the first event while the city of Van as the macroseismic epicenter, coinciding with the microseismic one, of the second event.

• Based on engineering judgment with a critical evaluation of damage (crack – damage pattern, type of collapse) one may arrive to useful conclusions concerning basic characteristics of the causative seismic ground motion. As a result of this judgment it was concluded that in some locations of both epicentral regions, such as just previously characterized, the vertical seismic ground motion was extremely violent with an acceleration approximate to the value of gravity.

• Due to such a strong vertical component the destruction is quite abrupt so as no time was allowed for the occupants to protect themselves or escape to safety.

• Some aftershocks from the same causative volume with that of the main shock may have some similar characteristics with that of the main shock.

• During a period of 25 years starting from 1950, buildings of high seismic vulnerability have been constructed and especially in the two old city centers of the affected region. The prevalence of illegal constructions and modifications to existing buildings might have reduced the resistance of buildings.

• Some above average engineered structures also suffered quite extensive damage, while non engineered ones in the same area withstood the earthquake with very little or even without any damage.

• A shallow focus earthquake of magnitude 5.7 or 7.2 might be equally fatal in their macroseismic epicenter. The only difference lays on the size of the affected area.

• A strong vertical component with impact type characteristics must be introduced to new seismic design codes, in order to protect structures that happen to lay over the epicenter of a shallow focus earthquake.

• The content suffered less damage in older and softer buildings that presented some damage. On the contrary, similar content suffered more damage in stronger and stiffer modern buildings that were no damaged.

Fig. 16a, b. *This manner of damage of simple houses indicates the dominance of vertical seismic component.*

Fig. 17a, b. *Traditional masonry buildings survived the main shock with minor or no damage.*

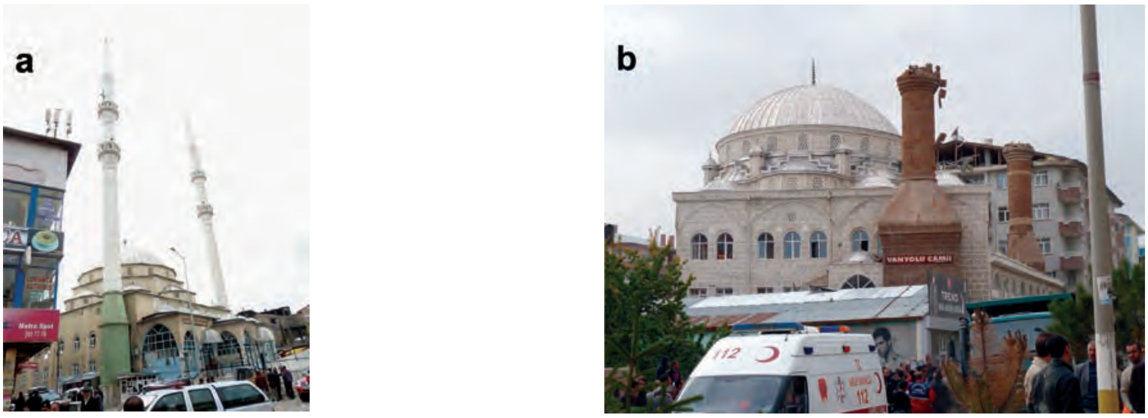

Fig. 18a, b. *Most of the mosques with their minarets weathered the main shock without any damage. In a limited number of cases parts of minarets toppled.*

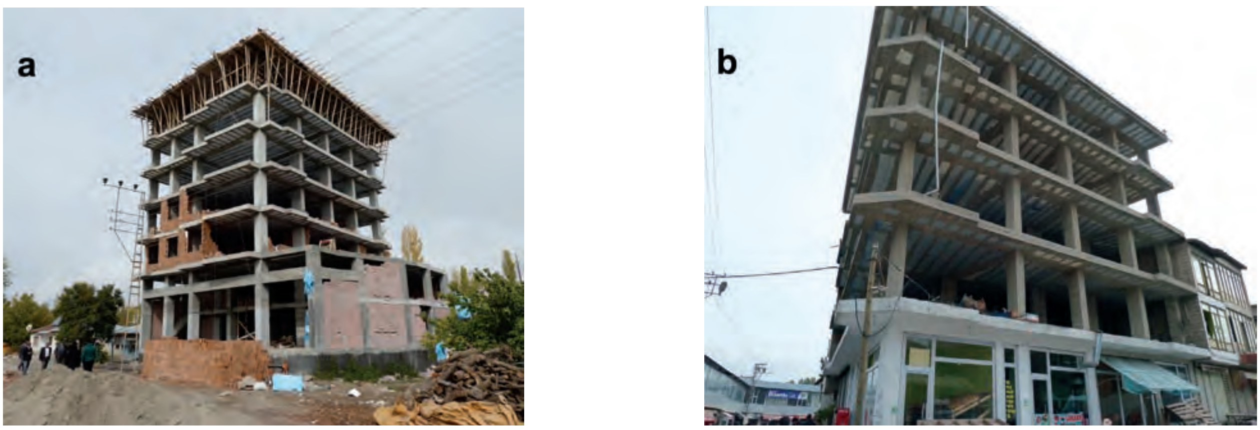

Fig. 19a, b. *Flexible buildings with rather large openings and without shear walls, as well as those with a one way flat-slab construction system are prevalent in new structures.*

Fig. 20a, b. *Usually, one or two storeys are added at the top and the balconies are externally closed with masonry partitions.*

Fig. 21a, b. *No evident horizontal motion, or breaking of glass panels, or pounding between adjacent buildings was observed.*

Fig. 22a, b. *Externally, some well designed and constructed strong modern buildings, did not present any damage. Internally, the secondary elements and the content suffered extensive damage.*

Fig. 23a, b. *The content and appendages in old / flexible / soft buildings weathered the events with rather limited losses.*

Fig. 24a-d. *An agglomerate of collapsed buildings in the city center of Ercis. Note, that some chimneys are standing upwards.*

Fig. 25a, b. *A technically interesting collapse. The reinforcement detailing is acceptable. Perhaps the concrete quality might have a problem or the concreting.*

Fig. 26a, b. *An other technically interesting collapse: a) In the fore-ground is the roof and the roofing corrugated iron-sheet; b) The top is the back column. The other columns are shaken off. Note that a flat-slab construction system does not allow any space for protection during collapse. The owner was describing that during the main shock he was staying on the ground. He felt two extremely violent upwards jolts, the one followed by the second making him to jump-up. At that time the building was jumping-up too. It was balancing, at the first cycle it stood on the front columns in parallel to the street. Next, the building stood on the back columns and then in the front ones with a stronger stroke when it toppled over.*

Fig. 27a-f. *Heavily damaged and collapsed buildings in Ercis city.*

Fig. 28a, b. *Note that the glass panels are intact while the walls are damaged especially at the lower levels. This is the case for almost the majority of the damaged-not collapsed multi-storeyed buildings, in Ercis city.*

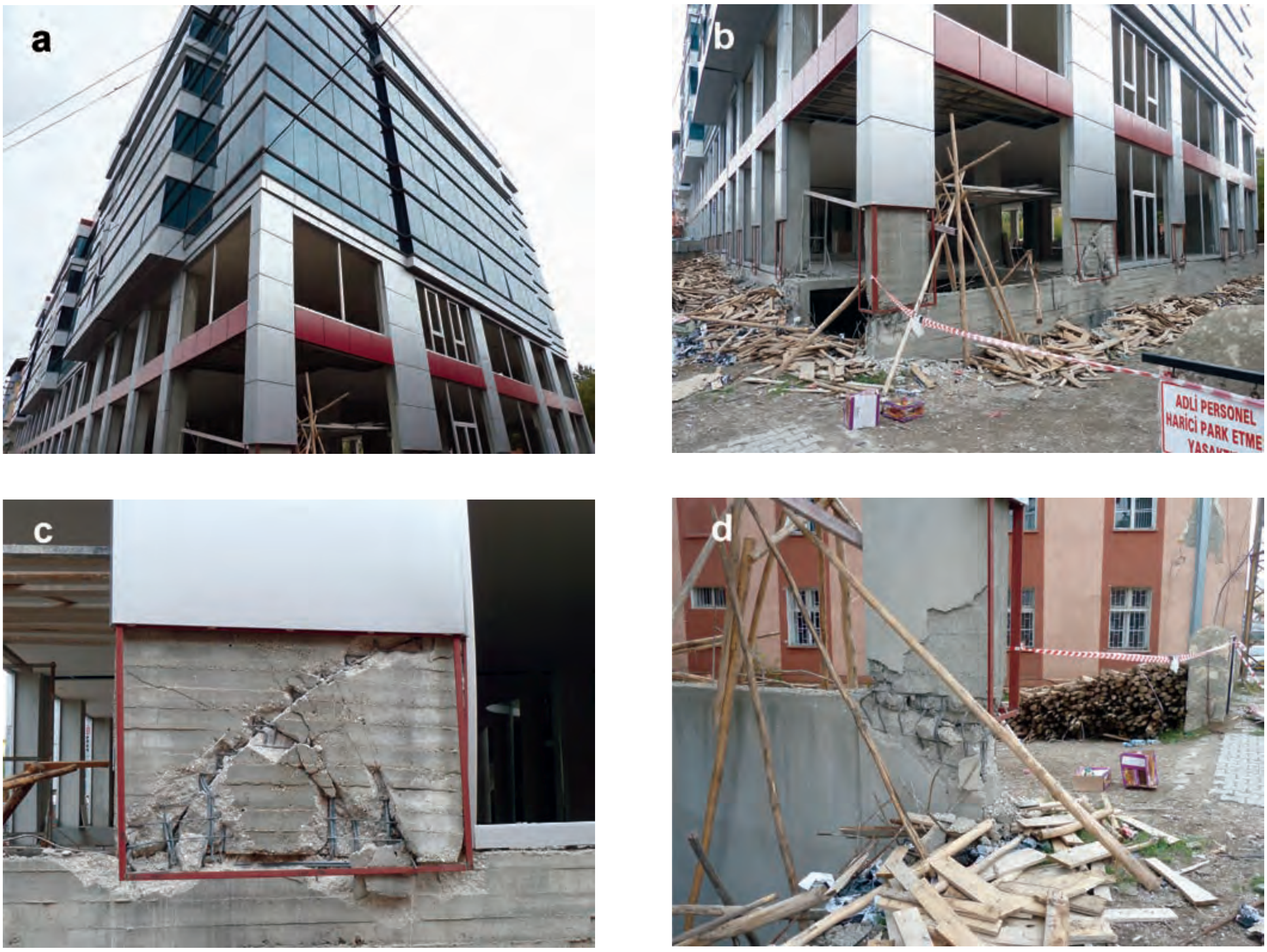

Fig. 29a-d. *A just erected building with acceptable reinforcement detailing. The majority of the columns in the ground floor suffered mainly compression damages. There are no noticeable horizontal displacements.*

Fig. 30. a) *The free standing Bayram Hotel before the earthquake and after the addition of a floor with a light weight roof. b) The collapsed roof is covering the plan, of the collapsed building in a parallel way to the pavements.*

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RIASSUNTO ESTESO

Il terremoto di Van in Turchia del 23 Ottobre 2011 e del 9 Novembre 2011 - Rapporto geoscientifico e ingegneristico

P. Carydis, E. Lekkas, C. Papaioannou, A. Tsokos, J. Delakouridis

Un devastante terremoto di magnitudine Mw = 7.2 ha colpito il 23 Ottobre 2011 la provincia di Van nella Turchia orientale. In quella regione la placca Arabica si muove in direzione Nord-Est a collidere con la placca Euroasiatica, mentre ulteriori placche di minori dimensioni si allontanano come se spinte dalla piu estesa placca Arabica. L'attività sismica di questa regione è notoriamente intensa con effetti spesso devastanti. Si ricorda l'evento del 1976 che causò la morte di circa 4000 persone. Il bilancio dell'evento del 23 Ottobre 2011 è di 604 vittime (466 in Ercis e 61 in Van) e 4152 feriti. La città piu gravemente danneggiata è la citta di Ercis, distante circa 35-40 km dalla faglia principale in direzione Nord. La città di Van ha sofferto danni più contenuti trovandosi a Sud della faglia, nonostante la piu ridotta distanza di circa 25-30 km. Particolarmente danneggiati sono risultati i centri storici di entrambe le città. Il giorno 9 Novembre 2011 un terremoto di intensità Mw = 5.7 si è verificato con epicentro molto vicino al centro della città di Van, generato da una faglia differente rispetto a quella associata al terremoto del precedente Ottobre. A causa di questa scossa il bilancio delle vittime è cresciuto di 40 fatalità e di 260 ulteriori feriti con il crollo di 25 edifici di cui buona parte fortunatamente evacuati in precedenza. L'hotel Bayram situato nella città di Van fu distrutto nonostante le sue condizioni strutturali risultassero soddisfacenti ad una ispezione da parte degli autori immediatamente successiva al sisma di Ottobre.

L'evento principale fu registrato da numerosi stazioni della rete accelerometrica nazionale. Sfortunatamente non furono acquisite registrazioni accelerometriche sia nella città di Van che a Ercis con l'eccezione di una registrazione del 9 Novembre a Van (Fig. 6). I livelli di accelerazione massima registrata sono di 147.7 cm/s^2 in direzione NS, di 246.6 cm/s^2 in direzione EW e di 150.5 cm/s^2 in direzione verticale. Va notato con il rapporto tra picco verticale ed orizzontale è di 1.02 e 0.61, in contrasto con quanto indicato da molti codici normativi (0.7).

Gli spettri di risposta in accelerazioni sono presentati in Fig. 7 e indicano un picco a circa 0.4 s per le due componenti orizzontali. La componente verticale mostra un picco per un periodo di circa 0.10 s.

L'indagine condotta dagli autori indica una concentrazione di danni in edifici in cemento armato multipiano di cui alcuni di recente realizzazione. Al contrario, costruzioni tradizionali quali edifici bassi in muratura hanno sofferto danni molto limitati anche nella regione epicentrale. La tipologia degli edifici in c.a della regione è di strutture piuttosto flessibili con assenza di pareti di taglio e orizzontamenti piuttosto sottili in proporzione alla luce delle campate. Nonostante queste caratteristiche di flessibilità non sono stati osservati casi di martellamento tra edifici adiacenti. Ad opinione degli autori molti casi di danneggiamento sono da attribuirsi al mancato rispetto della normativa sismica turca, dettagliatamente commentata nell'articolo nella sua evoluzione dal 1940.

I numerosi e piu severi casi di danneggiamento nella città di Ercis sono associabili ad una elevata componente verticale del moto mentre per la città di Van si ritiene che fenomeni di amplificazione della componente orizzontale, relativamente modesta, abbiano giocato un ruolo fondamentale. Gli autori ritengono che le onde P associate all'evento principale (23 Ottobre) possano essersi dissipate rapidamente a causa della notevole distanza della città di Ercis dalla zona epicentrale e l'origine superficiale dell'evento. Questa ipotesi non giustificherebbe le forti componenti verticale del moto ma va ricordato che la falda acquifera è molto alta nella città di Ercis con conseguente effetto smorzante sulle onde S, che non si propagano nell'acqua, e trasmissione praticamente non smorzata delle one P.

Il secondo evento di intensità Mw = 5.7 ha manifestato anch'esso, attraverso una analisi dei meccanismi di collasso degli edifici, una presenza di forte componente verticale. Il collasso del Bayram hotel, sopravvissuto senza danni alla prima scossa ma distrutto durante l'evento del 9 Novembre, è analizzato sulla base delle dirette osservazioni degli autori che ebbero modo di risiedere all'hotel immediatamente dopo l'evento di Ottobre. L'indagine suggerisce che la struttura abbia risposto al primo evento con una forte componente torsionale ma che sia collassato a causa dell'alta componente verticale della seconda scossa. L'inserimento nei codici normativi di una verifica a forte componente verticale di accelerazione è auspicata dagli autori per prevenire il collasso in caso di vicinanza della struttura alla zona epicentrale di un terremoto superficiale.