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Testing the European Macroseismic Scale in Greece: cases of damaging and destructive earthquakes

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Abstract

The 1998 version of the European Macroseismic Scale was first tested during the Athens 1999 Mw6.0 earthquake and has been applied to a number of significant earthquakes in Greece ever since. The scale has been used in the field, as well as thru questionnaires. Photographic material supporting damage assessment and vulnerability class identification is available for each event. In the present study five earthquakes are presented: three destructive (Athens 1999, Lefkada 2003 and Andravida 2008) and two damaging (Gonnoi 2003 and Cephalonia 2007). Taking into account that EMS is not the official macroseismic scale in Greece, the number of data collected and the extent of the area investigated are strongly related to the availability of research teams. In the case of Andravida earthquake, a considerable number of researchers were able to cover the damage area at a satisfying degree and to proceed even further for collection of felt reports from localities with no damage.

Introduction

Macroseismic field surveys that have been carried out for several earthquakes by the Macroseismology team of the University of Athens in the last decade were mainly based on the European Macroseismic Scale 1998. The experience gained is also applied to previous earthquakes, thus allowing a different, more detailed and integrated perspective of assessing macroseismic intensity. In the examples presented in this study (**figure 1**), different cases are presented and discussed.

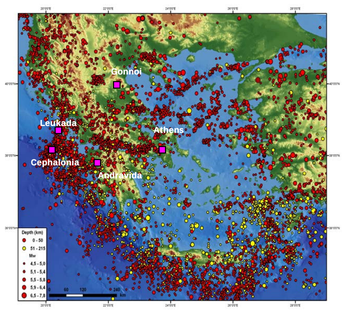


Figure 1

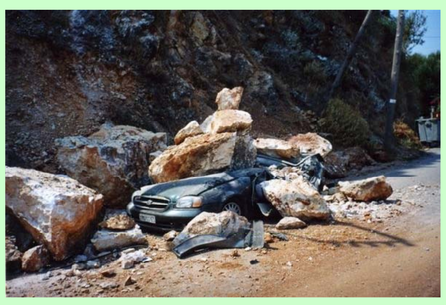
Destructive events

1) 1999 Athens (Parnitha) Mw6

The Athens 1999 September 7 Mw6 earthquake was the first major event to be investigated in the field for the application of the European macroseismic scale. Due to the vicinity of its epicentre (at the foothills of Mt Parnitha) to the Athens metropolitan area, its shallow depth, as well as the directivity of the source towards the city, a large variety of building were affected. Problems arise as to the definition of the limits of places/localities, for assigning their intensity. As stated in the handbook of EMS98 (Grünthal et al. 1998) "... it is reasonable to assign a single intensity value to, say, Piraeus, but not to the whole of modern Athens." However, maximum intensity I=9 for Athens has often appeared in the bibliography, which leads to erroneous assumptions for the "historical centre" of the city, where observed intensity was not more than I=6, especially for seismic hazard analysis studies, where Athens represents Intensity datapoints (Kouskouna and Malakatas 2000).

2) 2003 Leukada Mw6.3

The seismogenic source of the Leukada 2003 August 14 Mw6.3 event produced a number of destructive earthquakes in the last three centuries. The earthquake occurred at the peak of the tourist season and therefore organizing field teams was a rather difficult task. Higher damage grades, as well as rockfalls and small scale landslides and ground cracks were observed in the north and western parts of the island (photos from Agios Nikitas and Lazarata). Maximum intensity Imax=8-9EMS is assessed.



3) 2008 Andravida Mw6.3

The effects of the Andravida 2008 June 8 Mw6.3 earthquake have been extensively discussed, probably due to the lack of adequate historical data on the behavior of the buildings in the meizoseismal area. Apart from the city of Patras, which has experienced several earthquakes, and the area of Vartholomio to the west, the area most affected by the 2008 earthquake (yellow outline in **figure 2**) had no recent experience of earthquake damage.

Three days after the earthquake, four groups of 4-5 persons for macroseismic field surveys were formed. The groups were based in Kato Ahayia and Kato Alissos (red rectangular) and itineraries were scheduled after visiting the most damaged area. Photographic material and a large number of questionnaires were collected. The analysis is still in progress.

The photographs in the next column are representative of the relatively high vulnerability of the buildings in the most damaged area (Valmi, Fostaina). **Figure 3** shows a preliminary distribution of intensities over I=6EMS. Maximum intensity I_{max}=9EMS was assessed for Valmi.

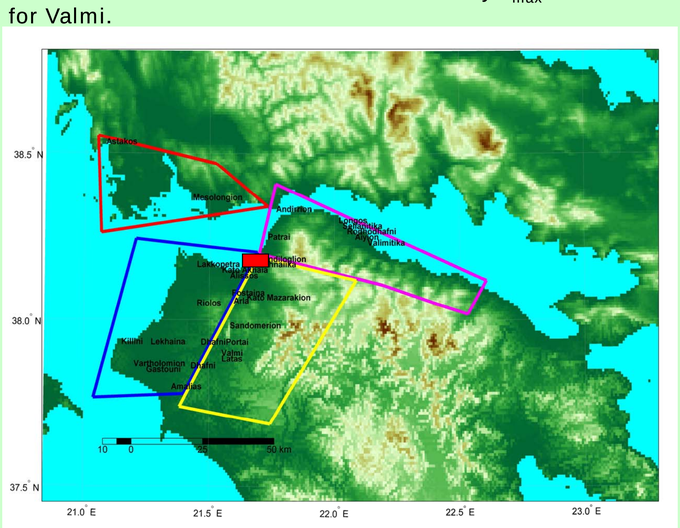


Figure 2

Figure 3

Damaging events

1) Gonnoi 2003 Mw5.5

On June 9, 2003 (10:07 L.T), northern Thessaly (central Greece) was shaken by a moderate size earthquake Mw=5.5. Dozens of buildings in the area of southern (or lower) Mt Olympus were damaged and the shock was felt throughout Thessaly, central and western Macedonia, Thessaloniki and the Sporades islands. No victims were reported. The maximum intensity was assessed at 6/7EMS-98.

The area is dominated by normal faults, which began forming during the Middle Pleistocene, as a consequence of the N-S extension, which affected the whole Aegean region (Caputo & Pavlides 1993). Geological and tectonic information of the broader study area, point out the occurrence of many small-to-moderate length faults and a major active fault (or series of faults) affecting this region of Thessaly, the so-called "Omolio Fault" (Caputo, 1990). This tectonic structure is a WNW-ESE trending northward-dipping dip-slip normal fault showing evidence of Late Quaternary activity.

Macroseismic information was collected by means of field investigation of the affected areas, comprising of in situ observations, photographic material and questionnaires. As in most such cases, the main problem was to survey the highest number of localities in the shortest possible time, so as to avoid further damage due to aftershocks. Luckily, the investigated area was rather limited, while the aftershocks were minor and did not produce cumulative damage. Therefore, the assessed intensities were purely due to the main shock.

The European Macroseismic Scale EMS-98 was applied and tested in the area. All the damaged localities were surveyed. Maximum intensity was assessed between the values 6 and 7. In the case of this earthquake the non-linearity in the scale arrangement at the junction of degrees VI and VII (Grünthal et al. 1998) was confirmed. *In some cases the intensity was closer to intensity VII, but not reaching VII (Parapotamos and Gonnoi). In other cases, it was closer to intensity VI, but not exceeding VI (Elatia). The upper values correspond to localities lying on very soft soil conditions and the lower to localities build on hard rock. However, in both cases, observed damage can be summarized as "few buildings of vulnerability class A or B suffered damage of grade 3 or 4". This points to intensity VI or VII, but it is somewhere in between.*

Intensity estimates may be affected by some uncertainties: in many localities a considerable number of houses were abandoned, mainly old, and therefore any possible damage could not be reported.

The "boxer" method (Gasperini et al. 1997; 1999) was applied, for the determination of the macroseismic epicentre (**figure 4**) and the size and orientation of the seismogenic zone. The equivalent moment magnitude was 6.06±0.36 (no. of radii used: 3).

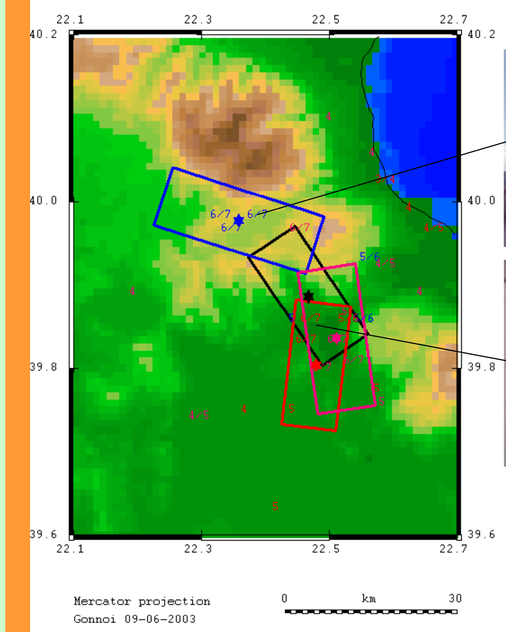


***Figure 4**: EMS98 intensity distribution, macroseismic epicentre and seismogenic sources determined for each soil category (blue: Hard Soils, brown: Soft Soils, red: Very Soft Soils, black: all soils). Photos inside: Damage to typical structures in the area.*

2) Cephalonia 2007 Mw5.8

On March 25 2007 (13:57:56.5 UTC) an earthquake occurred offshore Cephalonia, NW of Paliki peninsula, producing limited damage and minor rockfalls. On April 2-8 a macroseismic field survey was carried out on the island, followed by a detailed geological mapping of the affected area on August 6-10. Macroseismic questionnaires, photographic material and geological samples were collected and analysed from 32 localities and 3 rockfall sites on the island (**figure 5**).

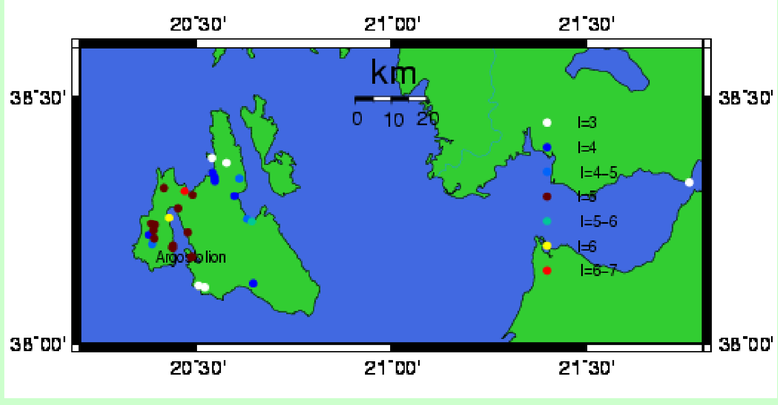


Figure 5

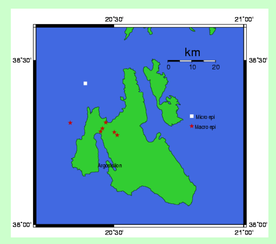


Figure 6

It is noted that the epicentre of the earthquake originates from a source (**figure 6**) that has produced major events in the past, such as the 1983 March 23 Mw6.2 event, with maximum observed intensity Imax=7(MM) in two localities, near the locality with the maximum intensity of the 2007 studied event.

Damage caused by the 2007 event was minor, mainly to older buildings, and it may be attributed to the high, antiseismic building standards of Cephalonia (the highest in Greece). However, maximum intensity Imax=6/7EMS at one single locality (Zola) and second highest I=6EMS at Livadi are the result of convolution of various factors, such as the local geology, topography, effects on objects and on nature, effects on people and, finally, damage to buildings. Zola is located on Eocene white limestones and the rockfalls nearby were observed at the grey Upper Cretatious limestones. In the photograph below, the red line outlines the former with respect to the latter, with Zola being on the right side of the picture. On the other hand, Livadi is situated on alluvial coastal deposits.

Conclusions

In the present study, detailed macroseismic surveys which incorporate vulnerability assessment, according to the European Macroseismic Scale 1998 are discussed. Higher degrees of damage were mostly observed to higher vulnerability, which is a consequence of the buildings' age (Andravida, Gonnoi), or additions to the existing ones without planning permission (Athens). In the cases where the strict building codes have been adhered to, observed damage was negligible (Cephalonia). Other factors affecting damage were the topograpgic effects (Athens), geological conditions (Cephalonia), directivity of the fault (Athens), vicinity to the epicentre (Athens) and rich seismic history (Leukada).

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