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The Athens earthquake (7 September 1999): intensity distribution and controlling factors

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Abstract

The Athens earthquake, $M_s = 5.9$, that occurred on 7th September 1999 with epicenter located at the southern flank of Mount Parnitha (Greece, Attiki) according to instrumental data, is attributed to the reactivation of an ESE–WNW south- dipping fault without surficial expression. The earthquake caused a large number of casualties and extensive damage within an extended area. Damage displayed significant differentiation from place to place, as well as a peculiar geographic distribution. Based on geological, tectonic and morphological characteristics of the affected area and on the elaboration of damage recordings for intensity evaluation, it can be safely suggested that intensity distribution was the result of the combination of a number of parameters both on macro and microscale. On the macroscale, the parameters are the strike of the seismogenic fault, seismic wave directivity effects and to an old NNE–SSW tectonic structure, and they are also responsible for the maximum intensity arrangement in two perpendicular directions ESE–WNW and NNE–SSW. On the microscale, site foundation formations, old tectonic structures buried under recent formations and morphology are the parameters that differentiated intensities within the affected area. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Athens; Earthquake; Intensity; Distribution; Tectonics; Fault

1. Introduction

On September 7, 1999 at 14:56 local time (11:56 GMT), the City of Athens was rocked by an earthquake of local magnitude 5.4 (5.9 M_s). The epicenter of the event was located at the southwestern flank of Mount Parnitha in the northwestern sector of the sprawling Greek capital that is home to four million people. The shock was a surprise given the known seismicity of the region and the fault that caused it is not accurately determined. The most heavily damaged area lies within a distance of 12 km from the epicenter. A number of modern buildings collapsed, including industrial installations, causing 140 deaths. The strongly affected area is inhabited by about 1 million people, 10% of whom are estimated to be homeless.

The seismic history of Athens spans 25 centuries. In the 5th century BC, there are reports of earthquakes that have been associated with the graven of the North Euboia Gulf. After an information gap of almost 16 centuries, during which the city was reduced to an insignificant town, the records offer an account of rather severe earthquake damage to the city on September 3, 1705. The earthquake caused considerable damage to various structures in and around the Acropolis. Subsequent small earthquakes have caused panic and some damage to precarious stone monuments (Papazachos and Papazachou 1989;

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Makropoulos et al., 1989). On April 20 and 27, 1894, two large events of magnitude 6.4 and 6.7, respectively, caused minor damage to several buildings and ancient monuments. The earthquakes originated in the north Euboia Gulf, around 100 km from Athens. At that time the city numbered 140,000 inhabitants.

An earthquake in the eastern Gulf of Corinth damaged the modern city. On February 24, 1981 $M = 6.7$ earthquake located 77 km away caused severe damage to 500 buildings. No buildings collapsed and no casualties were reported in Athens.

The lack of historical reports of heavy earthquake damage in Athens, and the fact that many ancient monuments in the city are still standing, resulted in the placement of Athens in the zone of low seismicity in the seismic code of 1959. The recent seismic code, adapted in 1995, places Athens in a higher seismic zone (Zone II).

Despite all the aforementioned, Athens was seismically considered to be one of the safest areas in Greece. Therefore, the event surprised both the authorities and scientists, given the fact that other areas of Greece that belong to zones of higher seismicity (e.g. external Aegean arc) are more likely to be hit by strong earthquakes.

The purpose of this paper is to describe accurately the geological, tectonic and geotechnical conditions, to record damage and finally to evaluate the intensities of the meizoseismal area. After the correlation of the above data, it is noteworthy to determine the effects that contributed to the damage distribution.

2. Seismotectonic setting — the earthquake data

The Athens plane lies in a piece of crust under extension. Extension in Central Greece is very intense — on the order of 10–20 mm/year — and the neotectonic deformation can be seen on the topography (McKenzie, 1988). The large grabens of the Corinth and Euboia Gulfs have resulted from concentration of the extensional deformation (Fig. 1). The axis of the grabens and the bounding active faults has a general direction E–W to WNW–ESE. The same direction is apparent on the topographic relief of the region, including a pronounced feature NW of Athens.

The main shock registered 5.4 M_L (5.9 M_s). The preliminary location of the epicenter was placed at 38.12N, 23.64E, at a distance of about 20 km from the center of Athens. The estimated seismic moment was 7×10^{17} Nm and the moment magnitude $M_W = 5.9$. The focal depth was placed at 9–14 km, and the preliminary fault plane solutions show ESE–WNW nodal planes dipping to the SW (USGS, 1999). The main shock was followed by hundreds of aftershocks (Fig. 2). The strongest of them ($M_s = 4.7$) occurred on 7th September at 20:44 and 8th September at 12:54 GMT. The meizoseismal area included the industrial area of Chelidonou along Kifissos River and the suburbs of Adames, Ano Liosia, Menidi and Thrakomakedones.

According to the most recent data, the seismic fault strikes 117° and dips about 52° (Tselentis and Zahradnik, 1999). There are no reports of surface fault traces. The area NW of Athens is dominated by WNW–ESE lineaments, clearly visible on Landsat images (see Ganas et al., 2000) and in broad agreement with the fault plane solution. One of them passes close to the 5th century BC castle of Fyli. The eastern extent of this lineament passes near the villages of Ano Liosia and Menidi. Widespread rock falls and gravitational cracks have been observed and mapped all over the southern flank of Mount Parnitha and especially along the Fyli structure and the Aspropyrgos-Elefsis recent fault, the most pronounced feature on the relief of the area (Fig. 3). The measured faults are dip-slip normal structures, though some of them show a small left lateral component.

Strong-motion recordings of the main shock are available from 14 sites in the wider Athens area at epicentral distances of 10–20 km. According to these data, the range of significant frequencies is approximately 1.5–10.0 Hz, while the range of the horizontal peak ground accelerations is between 0.04 and 0.35 g (Anastasiadis et al., 1999). A record near the city center (Monastiraki), giving an isolated peak value of 0.53 g, was probably affected by the complicated foundation conditions and the response of a steel structure covering an archaeological excavation close to the accelerometer.

Recordings at shorter epicentral distances are not available for direct assessment of the strong-motion characteristics in the epicentral zone. Nevertheless, an indirect estimation, based on observed movements (sliding and overturning) at cemeteries close to the epicentral area (Chelidonou, Thrakomakedones),

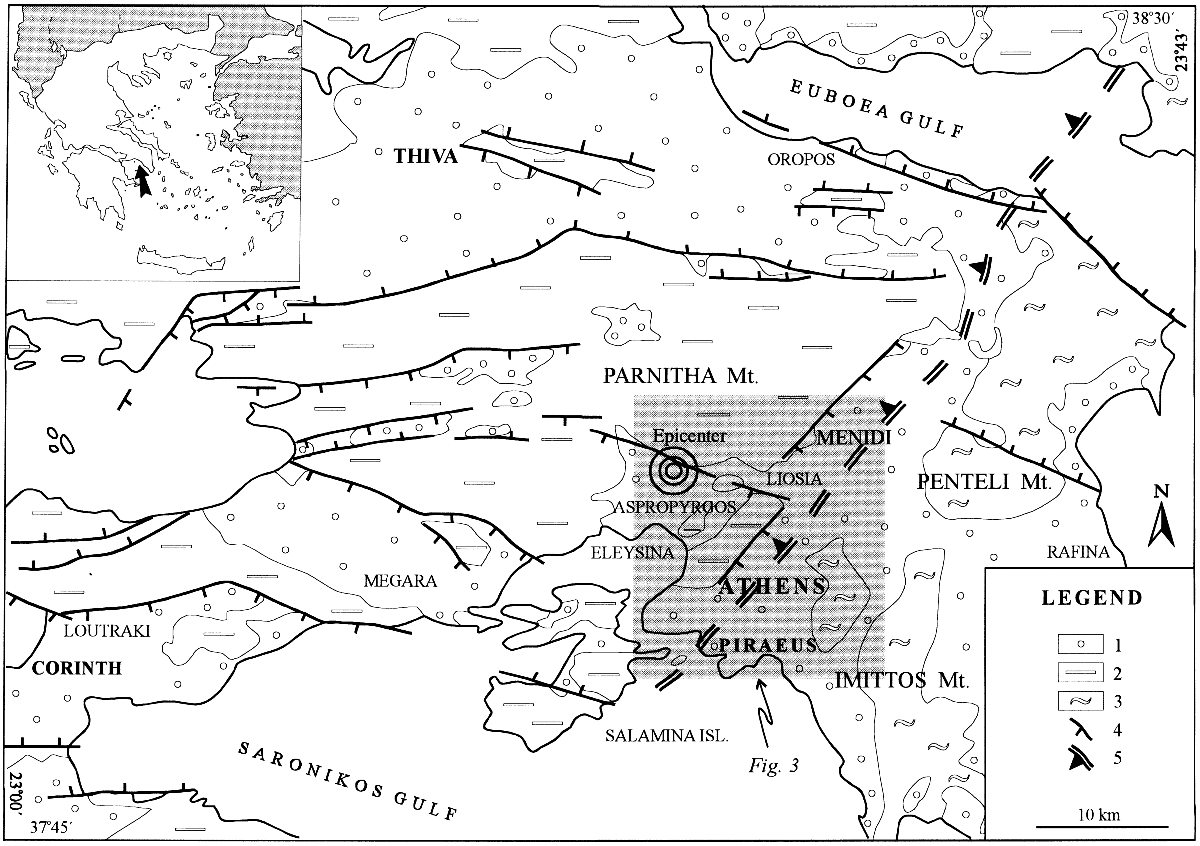

Fig. 1. Sketch map of the wider area of Attiki illustrating major tectonic-neotectonic structures and the epicenter location (1. Post alpine deposits of Upper Miocene–Holocene, 2. Alpine basement rocks mainly of Mesozoic carbonates, 3. Alpine basement rocks mainly of Mesozoic metamorphics, 4. Major active neotectonic faults, 5. Major tectonic contact separating the two groups of alpine basement rocks). Shaded rectangle shows the location of Fig. 3.

suggests that horizontal peak acceleration may have exceeded 0.50 g (Psycharis et al., 1999).

3. Geological-geotechnical conditions

The wider area is characterized by successive tectonic structures, namely neotectonic grabens and horsts, which have already been mentioned, while the area of Attiki is characterized by a major tectonic NNE–SSW striking zone, which separates the mountains of Parnitha and Aegaleo on the west from the mountains of Pendeli and Imittos on the east. Furthermore, Eastern Attiki (the area east of the zone) lies mostly on metamorphic rocks (marbles and schists) that compose a massive, westward-dipping body. On the other hand, Western Attiki is mainly built on sedimentary rocks, such as limestones and clastic formations (Fig. 1).

These formations belong to the alpine basement and outcrop in the mountains and the hills of the area. Recent post-alpine sediments cover areas of lower altitude. These sediments mostly comprise talus cones and scree and very often cover the slopes of the mountains.

Since most of the urban structure is founded on these formations and because of their highly variable character, it is important to describe them briefly (Lekkas 1991; Sambatakakis 1991; Papanikolaou et al., 1999; Marinos et al., 1999; Antoniou, 2000) as follows (Fig. 3):

- *Neogene marls.* Compact yellow sediments

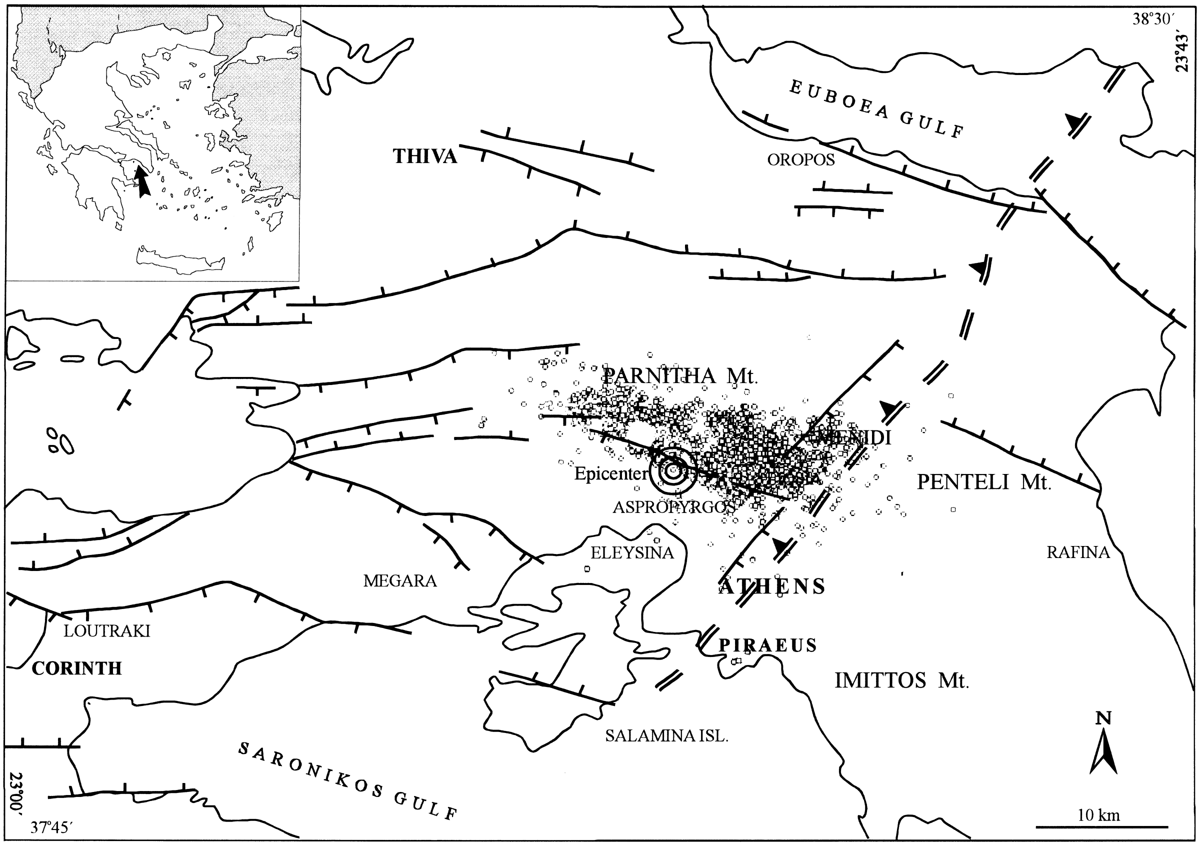

Fig. 2. Epicentral distribution map (data from the Geophysical Laboratory, University of Athens) of the Athens earthquake sequence and the major tectonic features of the wider area. Heavy hachured lines are faults, double thick line is the major tectonic contact.

including locally alternations of cohesive and semi-cohesive conglomerates and sands resting uncomformably on the alpine basement. They outcrop only in places where the younger formations have been eroded and classified as rocks or semi-rocks with theoretically good seismic performance.

- *Pliocene deposits.* Marls, sands, muds, clays and gravel, with alternations of semi-cohesive conglomerates covering uncomformably the neogene marls. They are cohesive to semi-cohesive, when not weathered.
- *Scree.* Lateral and vertical alternations of gravel, angular clasts, sands and muds with varying geotechnical behavior and degree of cohesion, according to their location and the degree of weathering. They mostly occupy the flanks of the mountains and hills.
- *Fluvial deposits and terraces.* Loose breccia and conglomerates with sand and mud alternations, developing along the banks of streams. They are characterized by poor geotechnical performance.
- *Alluvial deposits.* Alternations of non-cemented gravel, angular clasts, sand-gravel, sands, mud and red siliceous materials. Their performance is poor.

The aforementioned formations, mostly the oldest sediments, have sustained tectonic deformation and have been ruptured by a multitude of faults. Some fault planes are clearly expressed on the surface, while some are buried under recent sediments (Fig. 4).

Faults are better identifiable at the flanks of mountains and hills, where their role in the tectonic control of horst-graben arrangement is obvious. In these cases, it is the neogene marls and pliocene formations that are fault-bounded.

On the contrary, faults are not surfacially visible in areas of low altitude since they are covered by recent

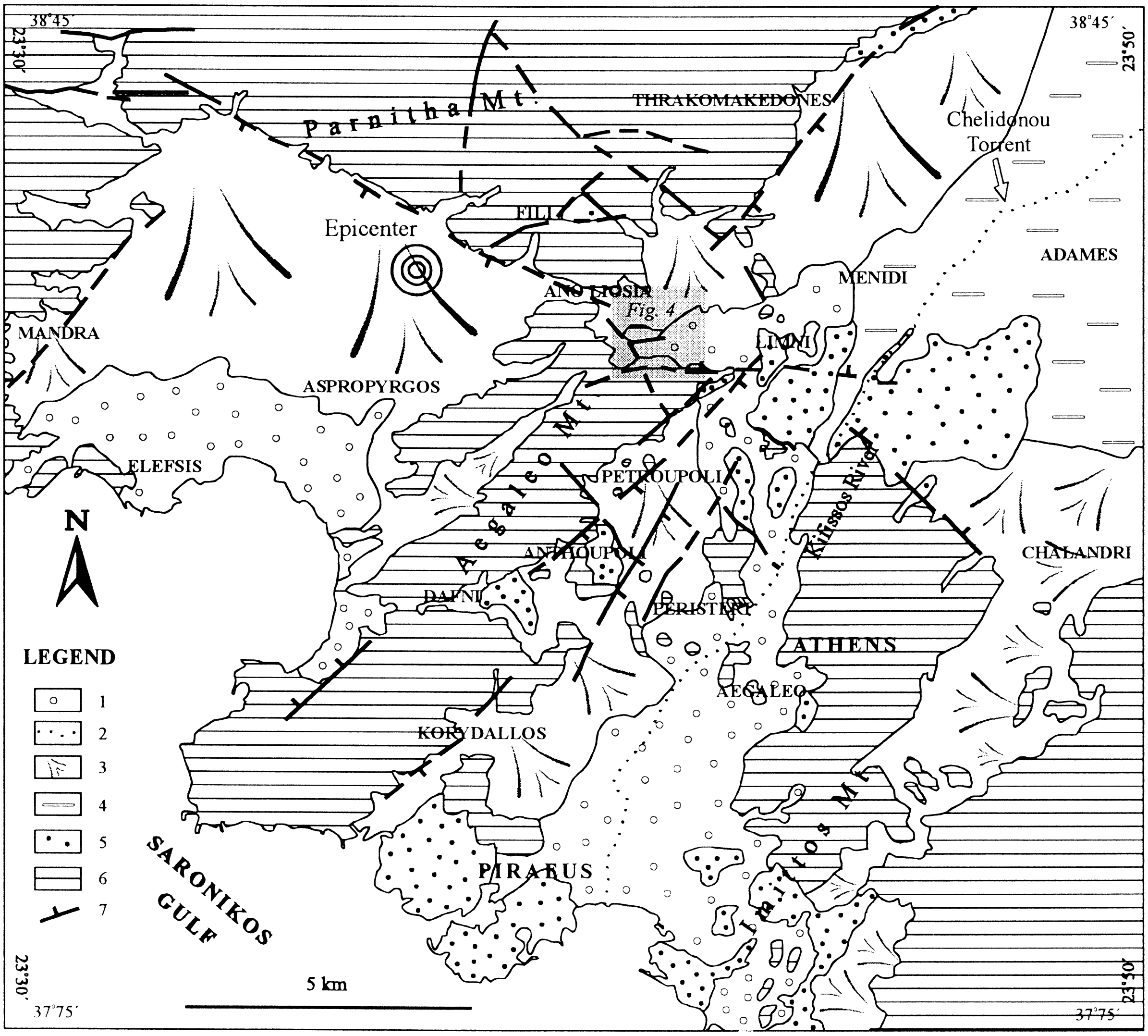

Fig. 3. Geological map of the affected area (1. Alluvials, 2. Fluvial deposits and terraces, 3. Scree, 4. Pliocene deposits, 5. Neogene formations, 6. Alpine formations, 7. Fault). Dotted line is Kifissos River. Shaded rectangle shows location of Fig. 4.

deposits, particularly by alluvium and scree. Their existence is ascertained by boreholes, geophysical and other methods at several places (Lekkas et al., 2000a) or is inferred-with a satisfactory degree of certainty- in other places (Lekkas, 1991).

4. Damage to buildings

Most of the damage occurred within 10 km of the epicenter. Structural damage decreased rapidly with the distance from the epicenter. In most areas of Athens damage was nonstructural, consisting mainly of cracks to infill brick walls. The distribution of damage was not regular and in some places may have been influenced by the local site conditions.

The buildings were marked by the state authorities as green (no visible damage affecting the structural capacity), yellow (minor damage to structural elements and significant damage to nonstructural elements and

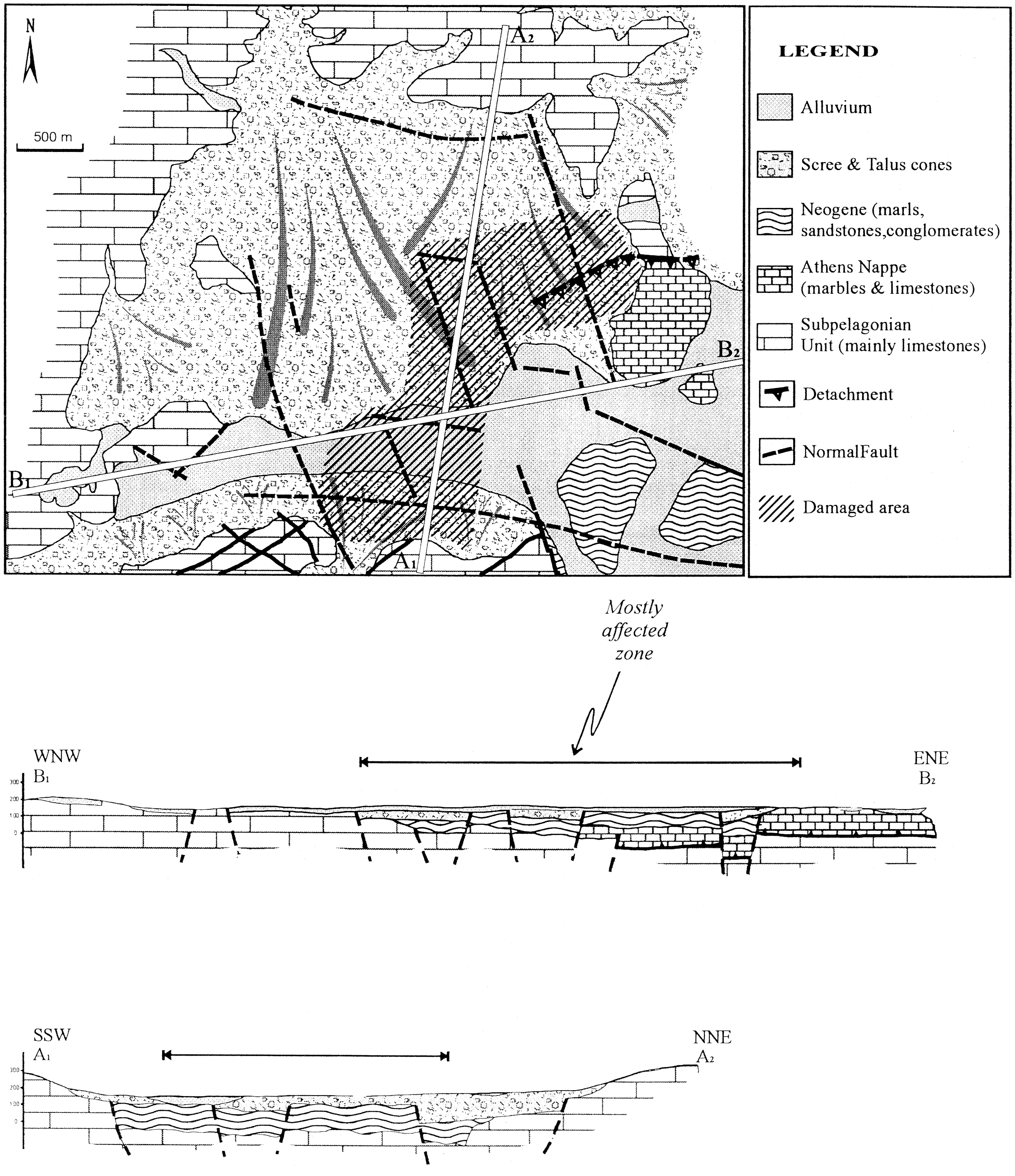

Fig. 4. Geological map of the Ano Liosia area and cross sections (see Fig. 3 for location) that shows the sequence of horsts and graben, buried under the scree cover. Note that the highly damaged area is situated just above these buried structures.

Fig. 5. Reinforced concrete column failure of a single-story building with damage degree 4 in Ano Liosia.

the red (heavy damage to structural elements; the building should not be used until it is repaired). The data indicate that out of almost 217,940 inspected buildings, 6519 (3%) were marked as red, 88,784 (40.7%) as yellow, and 122,637 (56.3%) as green.

Damage to structures is as follows, according to structure type:

4.1. Reinforced concrets frame structures

A number of RC buildings sustained severe structural damage and some of them collapsed, totally or partially. Most of the severely damaged structures were designed according to older seismic codes, with significantly lower seismic forces than those experienced during the earthquake. The overall behavior of RC structures was satisfactory.

The majority of the RC structures in the broader area of Athens suffered only minor structural damage because they had strength reserves such as infill walls, over strength and redundancy. The most common damage to RC frame buildings can be classified according to the cause as follows (Psycharis et al., 1999):

- *Damage to column-beam joints due to bad concrete quality and insufficient reinforcement.* In many cases, stirrup reinforcement was almost nonexistent. Such damage was common in less prosperous areas, as for example in Ano Liosia, where many of the structures were constructed without legal permission, and it is doubtful whether a structural design was applied.
- *Damage to columns due to the short column effect.* Damage due to the short column effect occurred in many industrial buildings, in which brick infill walls had been raised between the columns of the perimeter up to 1/2 to 2/3 of the story height. As a result, the columns along the perimeter became short columns compared to the interior ones. The damage was due to shear failure, which in many cases caused a total deterioration of the columns.

- *Damage to buildings with a soft ground floor (pilotis).* Buildings with a soft ground floor are a common practice in Greece. Significantly less rigidity in this floor, compared to the rest of the building, leads to large deformations of the soft story. The damage occurred mainly on the joints, which were totally destroyed in a number of cases. As a result, the structural system became a mechanism, and large permanent horizontal displacements were observed (Figs. 5 and 6).

4.2. Masonry structures

In the meizoseismal area, most abode houses and stone masonry structures with undressed stones, constructed in the first half of the century, suffered significant damage. This included partial collapse of external walls, collapse of corners, separation of the two walls converging at a corner, and extensive cracking (Fig. 7).

4.3. Classical monuments and historical buildings

All classical monuments survived the earthquake almost without damage, and only minor effects were reported in some cases. On the Acropolis, small rotations of some columns of the Parthenon and the Erechthion were observed, which were considered of minor importance. Historical masonry buildings of the last century did not suffer significant damage, either. Older monuments, which were already in bad condition before the earthquake, sustained significant damage. This was the case with the 11th century monastery at Dafni and the 5th century *bc* fortress at Fyli, in which large cracks appeared, and some sections are close to collapse.

5. Intensity estimation—Geographic distribution

Intensity estimation of the broader area was accomplished through the use of European Macroseismic

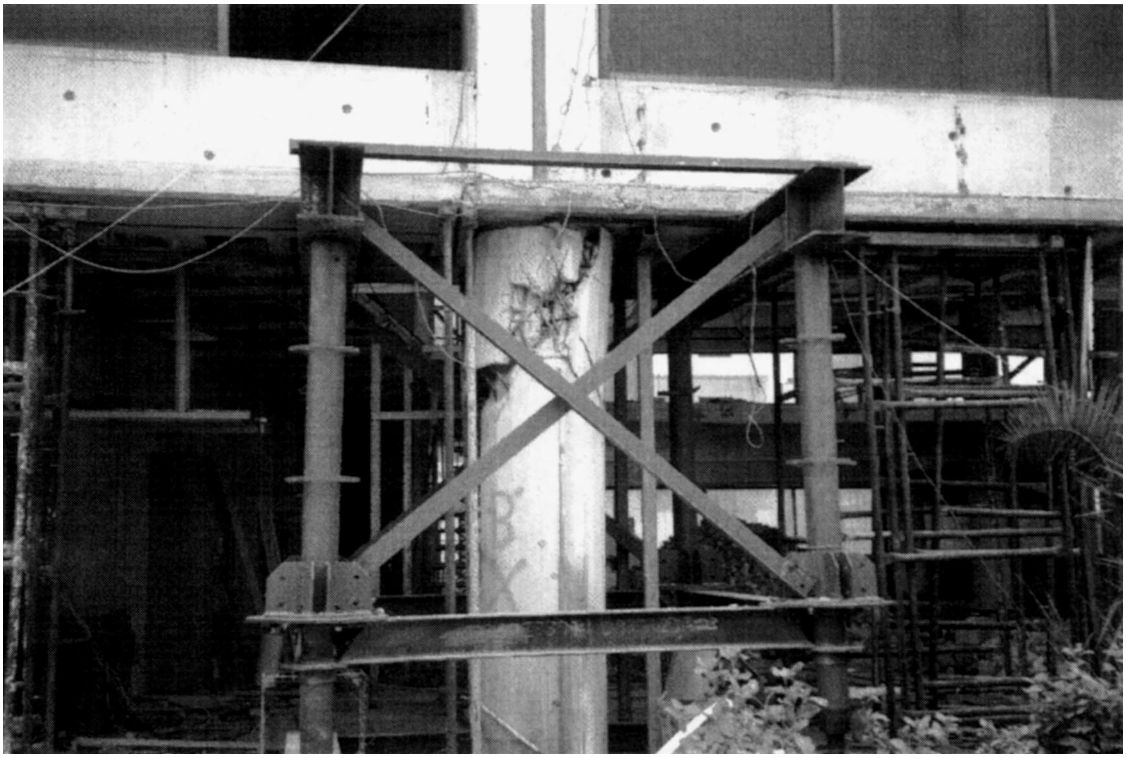

Fig. 6. Reinforced concrete column of a multi-story building that failed in the area of Menidi.

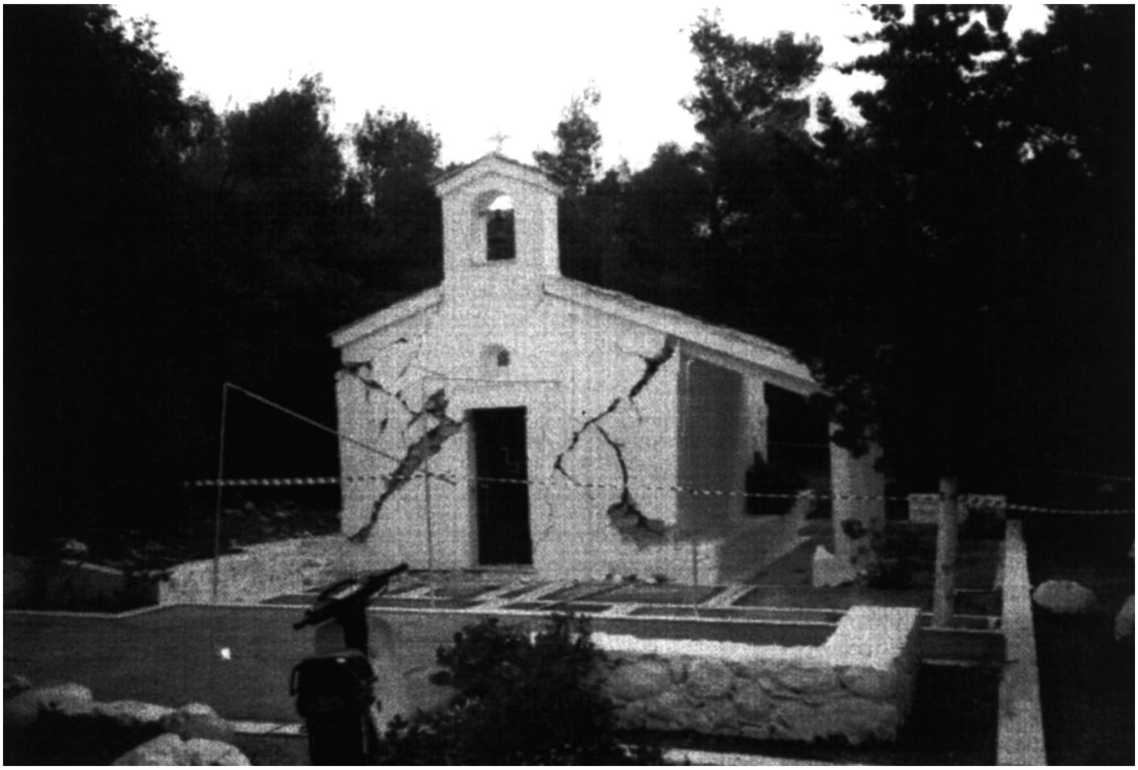

Fig. 7. Severe damage (Fourth degree) in a simple stone masonry church at Thrakomakedones area.

Scale (EMS)-1992 (Grünthal, 1993) and the enhanced version of EMS-1998 (Grünthal, 1998).

Intensity estimation is primarily based on the damage distribution of the affected area, as well as on recordings of other effects, according to the EMS-1998 instructions. Urban blocks were used as the basic units for the elaboration of damage recordings. The dimensions of each block ranges from 50 by 50 to 100 by 100 m and each block contains about 10–50 buildings.

The procedure involved the elaboration of data for each urban block according to the EMS-1998, contributed and the incorporation of the intensities of all blocks for the compilation of the intensity map according to the EMS-1998 (Figs. 8 and 9). This procedure has been successfully applied elsewhere, particularly at the 1993 Pyrgos earthquake in Western Greece (Lekkas, 1996), as well as at the 1995 Kobe earthquake (Japan) (Lekkas and Kranis, 1998) using the EMS-1992 scale.

The intensity distribution map ($I_{\text{EMS-1998}}$) shows that:

- The maximum intensities caused by the earthquake of 7th September 1999 were estimated at $\mathrm{I}_{\text{EMS-1998}} = \mathrm{X}$ Maximum intensities appear as small pockets in restricted areas that occupy only few urban blocks and were recorded in Liosia Lake area, Menidi, Chelidonou torrent and Adames (Figs. 8 and 9), are arranged in a E–W direction with respect to the epicentre. In these areas, many (30–40%) ordinary well built buildings collapsed (Figs. 5, 6, 10, 11 and 12). The official damage assessment performed by the authorities had marked most of the buildings in these areas as 'red'.
- Intensities of $\mathrm{I}_{\text{EMS-1998}} = \mathrm{IX}$ basically surround the maximum ones, occupy more extended areas (tens of urban blocks) and are specifically present in Ano Liosia, Menidi, Thrakomakedones, Chelidonou

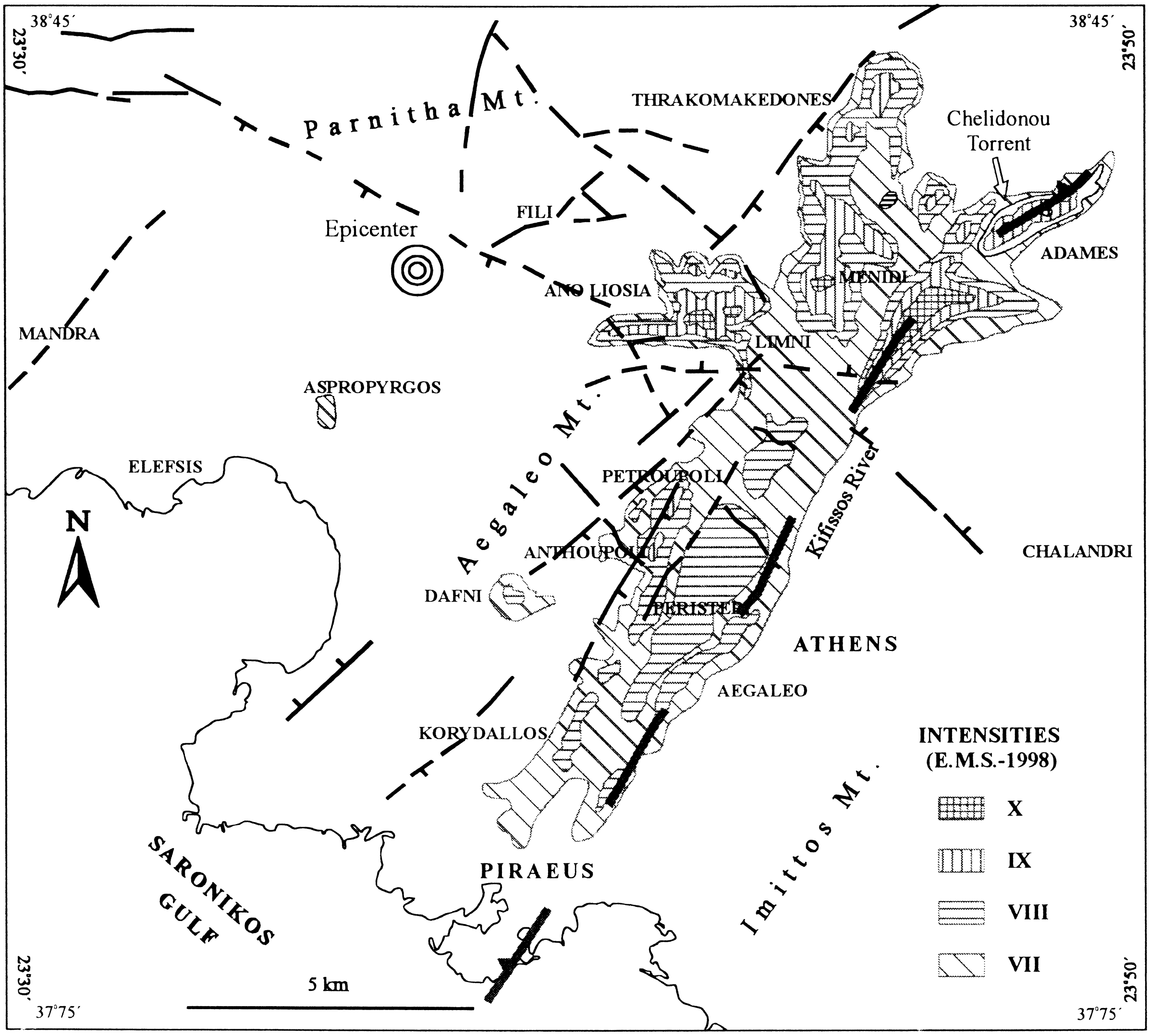

Fig. 8. Intensity ($I_{\text{EMS-1998}}$) distribution map of the broader area of Athens in the earthquake of 7th September 1999 (thich lines are major faults (tick on downthrown side), heavy line with teeth is the major tectonic contact (see also Figs. 1 and 2)).

torrent area and Adames. Many weak constructions collapsed. Even well-built ordinary buildings showed very heavy damage, serious failure of walls and partial structural failure. Heavy damage ($I_{\text{EMS-1998}} = \text{IX}$) was also recorded in southern areas such as Petroupoli and Anthoupoli, and was restricted in few urban blocks.

- $I_{\text{EMS-1998}} = \text{VIII}$ intensities extend around the aforementioned localities, occupy wider areas and characterize most of the urban areas of Ano Liosia, Menidi, Thrakomakedones, Chelidonou area and Adames. Furthermore, they form a NNE–SSW elongated zone at the south (the areas of Koridallos, Aegaleo, Peristeri and Petroupoli). To the east, a second elongated zone was recorded, parallel to the previous one and along the downstream portion of Kifissos River.
- $I_{\text{EMS-1998}} = \text{VII}$ intensities basically surround the previous areas, but also they occur as isolated islets in the areas of Aspropyrgos, Dafni, and so on, in

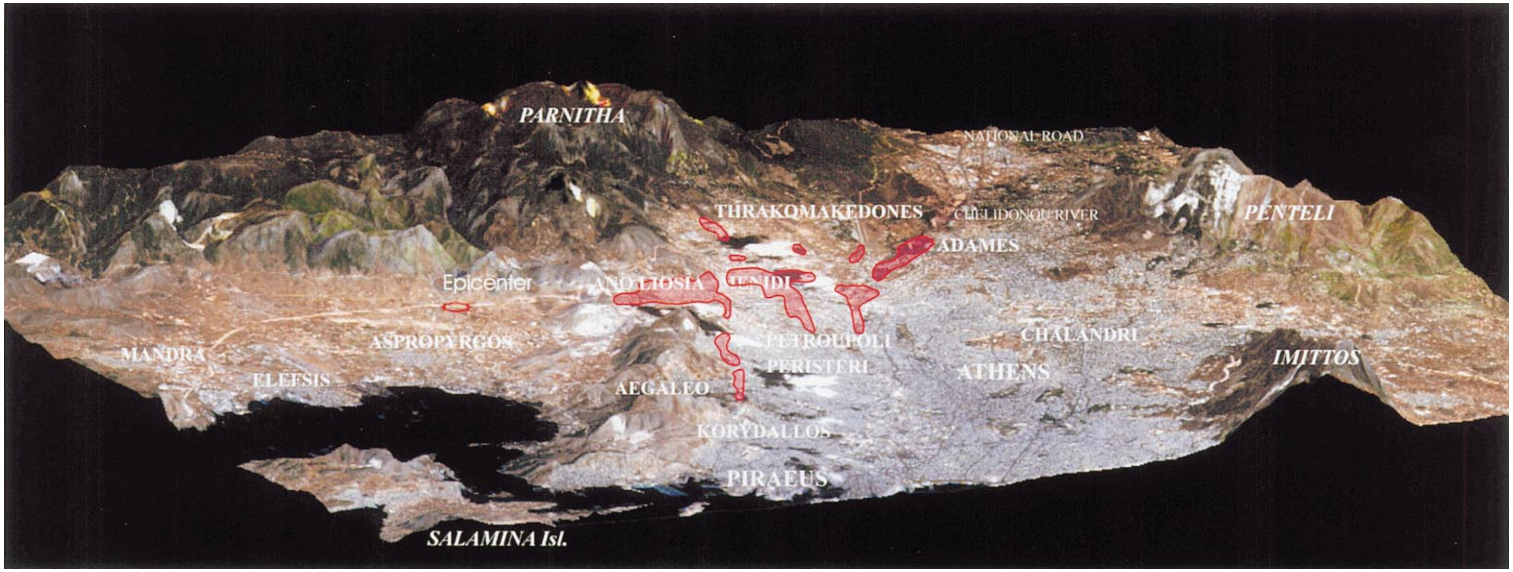

Fig. 9. 3D-model produced from satellite and digital data elaboration, and intensity ($I_{\text{EMS-1998}} > \text{IX}$) distribution of the 7th September 1999 earthquake.

Fig. 10. A brick masonry and reinforced concrete slab construction with almost nonexistent supporting columns that collapsed in Ano Liosia.

the broader area, as well as in areas relatively away from the maximum intensities. In this case such intensities ($I_{EMS\text{-}1998} = VII$) were recorded only in few urban blocks and were easily visible because of the light damage in the neighboring areas.

- Minor intensities ($I_{EMS\text{-}1998} < VII$) are not present on the map since it was not often easy enough to clarify their boundaries. This is attributed to (i) the enormous number of constructions in the capital of Athens, (ii) the difficulty to distinguish very light damage, especially in the interior of the constructions, and (iii) the small differentiation in damage to buildings elsewhere, which was usually indiscernible.

As a result, it is obvious that intensity distribution shows a complicated geographic variability and arrangement. This variability - arrangement is observed on (i) the microscale, where areas of low intensities alternate with others of high intensity, and (ii) the macroscale, with elongated zones along two perpendicular directions, WNW–ESE and NNE–SSW.

6. Discussion and conclusions

Based on the geographic distribution of intensities that were caused by the Athens earthquake ($M_s = 5.9$) on 7th September 1999, it became possible to make a number of correlations that include a number of factors that control damage distribution and to reach some noteworthy conclusions. This was necessary because there was not a dense network of installed seismological instruments (e.g. accelerometers) with only few exceptions in the meizoseismal area. Therefore, there was no alternative way of investigation.

The correlation of these parameters can be made on two levels. The first is that of the macroscale and is related to the spatial distribution of damage; this is mainly controlled by the alpine and post-alpine macrostructure and deformation, the characteristics

Fig. 11. Column failure of a reinforced concrete frame structure with damage degree 4 in Menidi.

of the seismic source and the seismogenic fault. The second one refers to the microscale intensity distribution and is mostly related to the soil seismic response in specific areas and sites.

On the macroscale, intensity contours develop in two preferred orientations. Specifically, the first is almost ESE–WNW and is observed in Ano Liosia, Menidi and Chelidonou tributary area, whereas the second NNE–SSW direction characterizes the areas of Petroupoli, Aegaleo, Peristeri, Kifissos river and Thrakomakedones (Figs. 8 and 9).

The ESE–WNW arranged intensities must be immediately correlated to the seismic fault direction, or at least to a great degree. The maximum intensities located on the eastern prolongation of the seismic fault must be due to fault-directivity effects (Papadimitriou et al., 2000). It is important to note that areas located on the western prolongation of the fault, as Aspropyrgos and Elefsina that lie only 2 km south of the epicenter, experienced significantly low intensities and very low damage.

High intensity NNE–SSW oriented zones coincide with or are parallel with a major tectonic zone that separates Western from Eastern Attiki and consequently bounds clearly distinct geological masses of the alpine basement. This zone seems to have performed passively from Piraeus up to the depression between the mountains of Parnitha and Pendeli. The eastward termination of the seismic fault and all neotectonic macrostructures lies on this tectonic zone. Consequently, high intensities that are restricted in the areas of Liosia, Menidi, Chelidonou (Western block) are abruptly blocked by the east and, therefore, do not enter in the suburbs of Eastern Attiki. Subsequently, the role of this tectonic zone was absolutely decisive in the seismic energy distribution for the rest of the capital since it functioned as an underground barrage.

On the microscale, the role of foundation formations seems to be important but not decisive. Undoubtedly, areas lying on alpine rocky formations suffered very low, minor damage. The same would be

Fig. 12. Collapse of a concrete-frame pharmaceutical factory wing (damage degree 5) at Adames.

expected for the formation of Neogene marls. Despite their good performance, in some cases intensities were significantly high, as for example in particular sites of the urban blocks in Anthoupoli, Menidi and Ano Liosia (Figs. 10 and 11). A similar but more severe situation was recorded in areas lying on Pliocene formations, where intensities were also high. This peculiarity may be attributed to buried tectonic structures, mainly of the alpine basement, that formed tectonic grabens before the deposition of younger sediments (Papanikolaou et al., 1999). Additionally, buried neotectonic structures and faults controlling post-alpine grabens played an important part, too. Also, these tectonic structures behaved passively and did not participate in the seismic energy distribution, as was verified in other seismic events in Greece (Lekkas 1996; Lekkas et al., 2000b).

Generally, high intensities were recorded in areas that loose formations crop out. In some cases of loose soils, such as alluvium with poor seismic performance, the intensities were relatively lower than the expected (e.g. Ano Liosia, Menidi) or even the ones observed in other areas founded on similar formations or even on ones with better seismic performance, as, for example, marls. This is attributed to the fact that layers of loose sediments absorbed the severe impact-type vibration that dominated in the epicentral area. Therefore, the energy that reached the foundations of the constructions was significantly reduced especially in areas that the vertical component dominated due to the short epicentral distance.

Finally, it is noteworthy that topography and, particularly the morphological discontinuities may have played an important part in some areas as at Chelidonou torrent and Adames (Fig. 12). The performance of foundation soils was not the poorest possible in these areas, so, high intensities that were almost linear-arranged may be directly correlated to the adjacentmorphological discontinuities. It should be noted that in neighboring areas with the same soil profile, lithostratigraphic structure and azimuthal location, closer to the epicenter, but away from morphologic discontinuities, intensities were significantly lower.

Nevertheless, it is important to notice that all the aforementioned parameters that contributed to the damage distribution both on macro and microscale did not act individually. The combination of more than one parameter was responsible for the manifestation of high intensities in particular areas. The response of each site seemed to be controlled by a primary parameter, accompanied by secondary ones, which definitely contributed to the exceedance of construction performance levels.

References

Anastasiadis, A., Demosthenous, M., Karakostas, Ch., Klimis, N., Lekidis, B., Margaris, E., Papaioannou, Ch., Papazachos, C., Theodulidis, N., 1999. The Athens (Greece) Earthquake of September 7, 1999. Preliminary report on strong motion data and structural response.http://www.itsak.gr/report.html.

Antoniou, V., 2000. Geoenvironmental conditions of Athens plain using Geographical Information Systems. PhD. Thesis, Laboratory of Mineralogy and Geology, Agricultural University of Athens, 272p.

Ganas, A., Papadopoulos, G., Pavlides, S.B., 2000. The 7th September Athens unexpected earthquake: 3D visualisation and field evidence of the seismic fault. Ann. Geol. Pays Hellen XXXVIII (B), 113–129.

Grünthal, G. (Ed.), 1993. European Macroseismic Scale 1992 (updated MSK-scale). Conseil de 1' Europe, 7, 79p.

Grünthal, G. (Ed.), 1998. European Macroseismic Scale 1998. Conseil de 1' Europe, 15, 99p.

Lekkas, E., 1991. Earthquake Protection Project of Ano Liosia (Geological, Neotectonic research). Project, Department of Geology, University of Athens, Athens, 34p.

Lekkas, E., 1996. Pyrgos earthquake damages (based on EMS-1992) in relation with geological and geotechnical conditions. Soil Dynamics and Earthquake Engineering, 15. Elsevier Science, pp. 61–68.

Lekkas, E., Kranis, H., 1998. EMS-1992 application on Kobe earthquake — Controlling factors of damage distribution. XXVI General Assembly of the European Seismological Commission (ESC), Tel Aviv, pp. 236–240.

Lekkas, E., Lozios, S., Danamos, G., 2000a. Geological — Neotectonic research of Municipality of Ano Liosia. Project, Department of Geology, University of Athens, Athens, 98p.

Lekkas, E., Fountoulis, I., Papanikolaou, D., 2000b. Intensity distribution and neotectonic macrostructure — Pyrgos Earthquake Data (march 26, 1993, Greece). Natural Hazards, 21. Kluwer Academic Publishers, pp. 19–33.

Makropoulos, K., Drakopoulos, J., Latousakis, J., 1989. A revised and extended Earthquake catalogue for Greece since 1900. Geophys. J. Int. 98, 391–394.

Marinos, P., Boukovalas, G., Tsiambaos, G., Protonotarios, G., Sabatakakis, N., and collaborators, 1999. Damage distribution in the western part of Athens after the 7 September 1999 earthquake. Newsletter of ECPFE, Council of Europe, Issue No 3, December 1999, Athens, pp. 37–39.

Mckenzie, J., 1988. Rates of active deformation in the Aegean Sea and surrounding regions. Basin Res. 1, 121–128.

Papadimitriou, P., Kaviris, G., Voulgaris, N., Kassarras, I., Delibasis, N., Makropoulos, K., 2000. The September 7, 1999 Athens earthquake sequence recorded by the Cornet network: preliminary results of source parameters determination of the main shock. Ann. Geol. Pays Hellen XXXVIII (B), 29–39.

Papanikolaou, D., Lekkas, E., Sideris, Ch., Fountoulis, I., Danamos, G., Kranis, Ch., Lozios, S., at the contribution of Antoniou, I., Vassilakis, E., Vasilopoulou, S., Nomikou, P., Papanikolaou, I., Skourtsos, E., Soukis, K., 1999. Geology and tectonics of Western Attica in relation to the 7 September 1999 earthquake. Newsletter of ECPFE, Council of Europe, Issue No 3, December 1999, Athens, 30–34.

Papazachos, V., Papazachou, Ch., 1989. Greece Earthquakes. Ziti publishers, Athens, p. 356.

Psycharis, I., Papastamatiou, I., Taflambas, I., Carydis, P., Bouckovalas, G., Gazetas, G., Kalogeras, I., Stavrakakis, G., Pavlides, S., Lekkas, E., Kranis, C., Ioannidis, C., Cholevas, C., Pyrros, D., 1999. The Athens, Greece Earthquake of September 7, 1999. EERI Newsletter, Special Earthquake Report, November 1995, Vol. 33, No 11, pp. 1–12, California.

Sambatakakis, G., 1991. Engineering-Geological study of Athens plain. PhD. Thesis, Department of Geology, University of Patras, 210p.

Tselentis, A., Zahradnik, J., 1999. The Athens earthquake of September 7, 1999. Bull. Seismological Society of America (submitted for publication).

U.S.G.S. National Earthquake Information Center, World Data Center A for Seismology, 1999. http://wwwneic.cr.usgs.gov/neis/FM/Q9909071156.html.