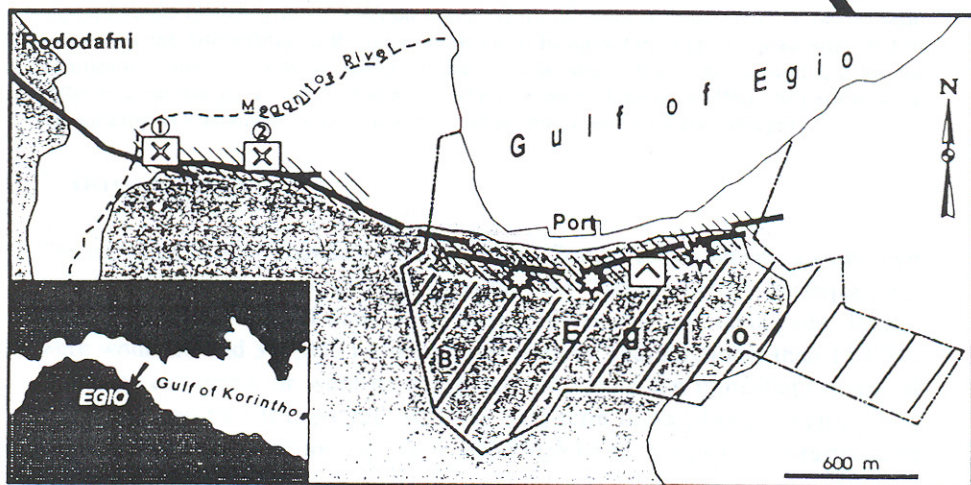


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Linear damage distribution and seismic fractures at the Egio earthquake (15 June 1995, Greece)

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Abstract

On June 15, 1995, a $M_s=6.1$ R earthquake hit the region around Egio (Northern Peloponnese, Greece), killing 26 people, damaging severely 2,000 buildings while 10,000 more suffered minor damage. The shock gave rise to liquefaction, submarine landslides, coastline changes, while seismic fractures of considerable magnitude were observed. The latter occurred along an E-W trending zone, from the city of Egio and for 2 km to the West. They cut river terraces, recent and artificial landfill, and Late Pleistocene consolidated conglomerates. The highest intensities were observed along the fractures, with virtually all constructions that lay along them being significantly damaged. Not only older houses, roads and minor constructions were damaged, but also modern apartment blocks and residences. In particular, where liquefaction also occurred, the destruction included vital buildings, such as factories and other modern constructions. On the other hand, all over the rest of the meizoseismal area the collapsed buildings were mostly the ones not built of reinforced concrete. All the above-mentioned point to the fact that the intensity was particularly accentuated along the earthquake fractures, while an important fact was played by the liquefaction phenomena.

1 Introduction

A strong surficial ($h=26$ km, N.O.A., [1]) earthquake hit the region of Egio, (Northern Peloponnessos, Greece) on 15 June 1995, at 0316 local time. Its magnitude was $M_s=6.1$ (N.O.A., [1]) and its epicentre lay at 38.36 N, 22.15 E (Fig. 1). Twenty-six people were buried and died under the debris of two partially collapsed multi-story buildings, an apartment block in the city of Egio and a hotel at Valimitika, a few km east of the city. In total, 2,000 buildings collapsed or were damaged beyond repair, 2,801 were rendered uninhabitable and about 10,000 more suffered minor damage. The shock was also felt at the opposite coast of Korinthos Gulf, at Sterea Hellas, but the damage there was

significantly smaller. The total cost of the earthquake amounted to \$ 600 million (Carydis *et al.*, [2]).

A large part of the damage was due to the occurrence of surficial geological effects as ground fissures, liquefaction and coastline change in the region around Egio (Lekkas *et al.*, [3]).

The earthquake of 15 June 1995 was the latest to a series of destructive events that have hit Egio and its environs. The oldest recorded shock was in 373 BC, when ancient *Eliki* vanished (Mougiaris *et al.*, [4]). Also, in 1748 and 1817 the town of Egio was destroyed by the tsunami caused by the earthquake (Stavropoulos, [5]). In December 1861, the town was again hit by a lower intensity shock (Schmidt, [6]). Seventeen events of magnitude more than 5 R have been recorded instrumentally since the beginning of this century (Fig. 1); the largest one occurred on 31 March 1965 (M=6.6R).

The aim of this paper is the interpretation of the damage distribution through the identification of the seismogeological parameters present in the region. This, because from the very beginning of the recording of damage, it became obvious that it not depend only on the construction type, but is located at certain zones, where not only old but modern houses were hit. The factors that were examined were (apart from the construction type) the following:

- occurrence of seismic ground fractures.
- engineering geological parameters of foundation soils.
- morphology, relief stability.
- secondary destructive effects (liquefaction, subsidence, etc.).

2 Neotectonic regime - regional geological setting

2.1 Generalities

The meizoseismal area belongs in the Gulf of Korinthos neotectonic macrostructure, developing normal to the contemporary Hellenic Arc in an E-W direction. Rifting started in Late Miocene (Kellat *et al.*, [7]) while during Plio-Quaternary a rapid northward migration of the north Peloponnessos shoreline has taken place (Papanikolaou *et al.*, [8]).

The Gulf of Korinthos is an asymmetric graben, with its northern boundary being relatively inactive, in contrast to the southern one. From dynamic point of view, there is a predominant regional NNE-SSW extension (McKenzie, [9]; Doutsos *et al.*, [10]). The southern margin is characterized by the occurrence of large ESE-WNW trending faults with northward dips of 45°-80°. A characteristic example is the Eliki fault, which strikes $290^{\circ} \pm 10^{\circ}$ and dips 40-70°N. Its vertical throw has been estimated at 450 m. and has had an average uplift movement rate of 0.25 mm yr⁻¹ (Doutsos and Poulimenos, [11]).

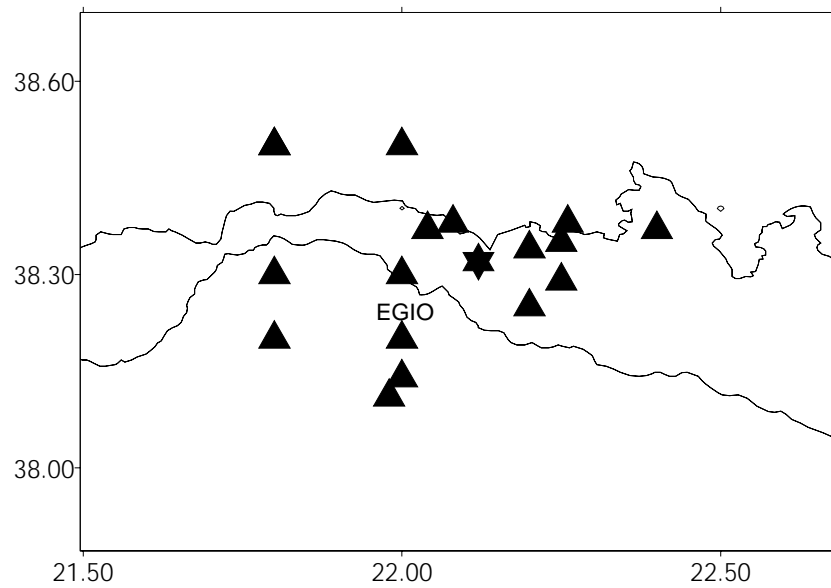


Figure 1. Regional earthquake activity ($M > 5.0$) in the current century (triangles). The star denotes the 15 June 1995 epicentre.



Figure 2. The Egio fault scarp. View to the south

2.2 Lithostratigraphy

In order to interpret the damage distribution the geologic formations that crop out at the area of Egio have been grouped according to their engineering geological properties. Thus, two lithostratigraphic types can be distinguished:

1. **Holocene formation:** It comprises deltaic of fluvial deposits, river terrace deposits and coastal sediments; they consist of loose conglomerates, sands, sandstones, sandy marls, clays, loose pebbles and gravel. They outcrop at the plain to the north and northwest of Egio and along river Meganeitos. The formation has poor engineering geological properties (Table 1).
2. **Egio formation:** It comprises deltaic and alluvial-fan deposits of Late Pleistocene-Holocene age and develops in terrace form that is under constant tectonic control (see following sections). The deposits consist of consolidated conglomerates, sandstones and sands with cross-bedding, internal unconformities and rapid lateral differentiation. The main outcrop lies at the area occupied by the town of Egio. Their engineering geological properties are shown in Table 1.

Table 1. Engineering geological properties of the outcropping formations at Egio (after Rozos, [12]).

	Holocene formation	Egio formation
density	2-2.4 gr cm ⁻³	2.1-2.8 gr cm ⁻³
cohesion	0-1 kgr cm ⁻²	2-30 kgr cm ⁻²
internal friction angle	25-50°	35-65°
compressibility	0.1-0.4	-

3 Earthquake fractures

The 15 June 1995 earthquake caused fracturing at the northern and western flanks of the town, and up to Rododafni. Around Egio the fractures strike E-W, while to the west their strike changes to WNW-ESE.

The fractures occurs at the base of a 100 m.-high, E-W trending escarpment, whose height decreases heading eastwards. To the north of the scarp there is a flat area with a mean altitude of 30 m., while to the south we meet hilly terrain with altitudes of more than 120 m. The scarp must have been created by a (?)normal fault (Egio fault, Fig. 2), the hanging wall of which consists of loose alluvial and fluvial deposits and its footwall comprises Late Pleistocene-Holocene consolidated conglomerates.

The seismic fractures occur along the foot of the scarp and display a small vertical offset of 1-2 cm (north side downthrown). They are visible at the western end of the fault, from the western outskirts of Egio up to Rododafni.

To the east of Egio such fractures are hard to be located, mostly because of the densely built area and their occurrence can only be deduced through the distribution of damage. It is characteristic that these fractures cut and offset alluvial deposits, river terraces, recent fluvial deposits, Late-Pleistocene conglomerates (at Rododafni), artificial landfill as well as small-scale constructions (property walls, gutters, pavements, etc.).

4 Damage intensity and distribution

Both after the initial estimations, soon after the earthquake and the subsequent detailed recording of damage, the following observations can be stated:

- As for the spatial distribution of damage, it can be said that it was mainly located inside the town of Egio, at the wider area of the northern coast of Peloponnessos (Eleonas, Rodia, Valimitika, Rododafni, Avythos, Selianitika) and to a lesser extent along the southern coast of Sterea Hellas (Erateini).
- There was both extensive damage (building collapse or severe structural failure) and lighter damage.
- Several building types were damaged, both old and modern constructions.
- Focusing now on the urban complex of Egio, where the sufficient number of buildings allows for comparative observations, it can be said the intense damage was confined in a narrow E-W to WNW-ESE trending zone that forms the prolongation of the fractured zone outside the town.

In the following sections the distribution of damage will be discussed in detail, together with the prevailing geological factors. The town of Egio was divided into two zones (A and B) depending on the intensity of damage (Fig. 3). These two zones strike roughly E-W; zone A is characterised by intense damage, while in zone B the damage is less and mostly non-structural. More specifically:

4.1 Zone A

It covers the northern part of the town that develops parallel to the coast and lies at the footwall of the Egio fault, adjacent the fault trace. The most severe damage was located there, with R/C, and stone-built houses having suffered structural damage. A considerable number of houses was rendered demolishable.

It should be noted that all over zone A most of R/C constructions suffered extensive damage. In Fig. 3 four cases of destroyed houses built to meet the 1984 Earthquake-Resistance Regulation are shown. Besides, the apartment block that collapsed lay in this zone..

The morphology of the zone is characterised by the prominent escarpment of the tectonically-controlled terrace on which Egio has been built. There was an increasing trend in the intensity of damage at locations of steep topographic

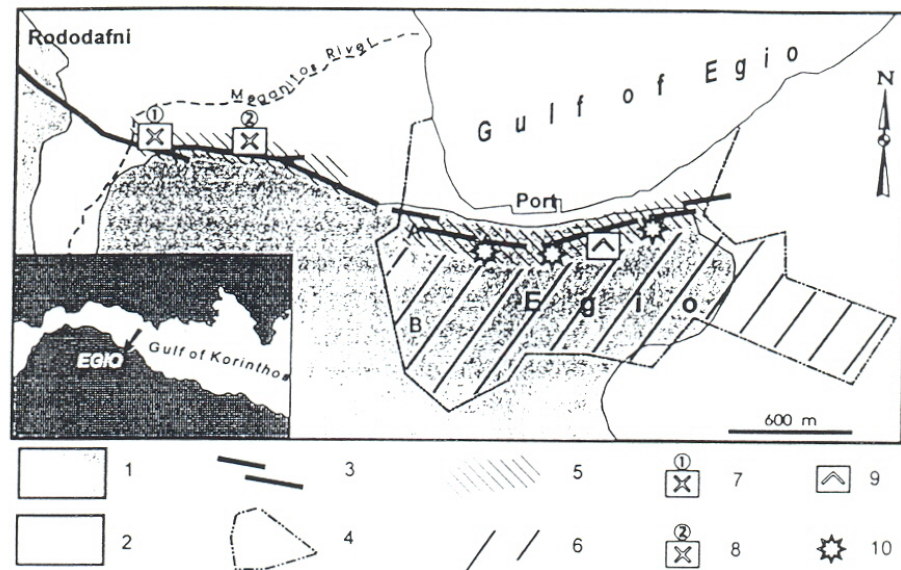


Figure 3. Damage distribution sketch. 1: Egio formation, 2. Holocene formation, 3. Seismic fractures, 4. Town limits, 5. Zone A, 6. Zone B, 7. Hellenic Weapon Industry, 8. Kouniniotis factory, 9. Collapsed apartment block, 10. Demolishable apartment blocks

gradient. As for the foundation formations, no significant differentiation occurs throughout the zone; they comprise the consolidated conglomerates that have quite satisfactory engineering geological properties (Table 1).

4.1.1 The collapsed apartment block

The collapsed building was next to the possible trace of the seismic fracture (Figs 3, 4), on the footwall of Egio fault. It was built adjacent to the fringe of the escarpment, where the topographic gradient exceeds 70%. The foundation soil has relatively good quality, while no subsidiary effects (local subsidence, liquefaction, etc.) were observed.

Similar are the conditions for the other 3 modern buildings that were damaged beyond repair in zone A.

4.1.2 Damage in the vicinity of Hellenic Weapon Industry

The area is at the west of Egio, on the southern margin of the plain that coincides with the tectonically controlled escarpment (Egio fault). Built on the



Figure 4. Aerial view of the collapsed apartment block. The port of Egio can be seen in the background. The Egio fault scarp runs from the top left to the middle right of the photo, directly beneath the row of buildings



Figure 5. Severe structural damage at the building of Hellenic Weapon Industry.

foot of the escarpment (hanging wall of Egio fault) are several buildings with increased anti-seismic properties, as the HWI and Kouniniotis factories. Despite the fact that these buildings were built to meet high earthquake-design standards, they suffered severe structural and non-structural damage (certain parts collapsed, deformed beams and columns, destroyed masonry) (Fig 5).

The foundation soil has poor geotechnical parameters (Table 1), since it comprises loose conglomerates and sands of Meganeitos river terrace. The thickness of these deposits is 50 m. and overlies the consolidated conglomerates of Egio.

The trace of the seismic fracture has an overall WNW-ESE trend and coincides with the foot of the escarpment of Egio fault. It is traceable from Egio to Rododafni and can be seen cutting not only the soil but also the constructions (walls, columns, floors, etc.) founded on it. Traces of the fracture were found all over the destroyed or collapsed part of the HWI building. Besides, two liquefied sites were located, along the seismic fracture and inside the southern part of the premises. However, the deformation of the ground floors at other places suggests that liquefaction was more widespread and affected the majority of constructions.

4.2 Zone B

It comprises the central and southern part of the town. The intensity of damage was lower here and was almost exclusively limited to older stone-built and masonry houses, most of which were already falling apart because of inadequate preservation. On the contrary, at modern R/C buildings, only non-structural elements were destroyed.

The foundation soil is the same as in zone A (consolidated conglomerates) with quite good geotechnical parameters, except for the eastern part where loose sediments occur (Fig. 3); the topographic relief is almost flat.

4.3 Damage at the port of Egio

The port is located at the northern part of the town, at the flat coastal zone lying to the north of the Egio fault scarp. The foundation soil comprises coastal deposits, alluvial and artificial landfill. Subsidence occurred at numerous locations. All damage here is believed to be due to strong seismic shaking.

5 Discussion - Conclusions

Based on all the above, the following can be said about the geodynamic parameters that affected the damage distribution of the 15 June 1995 earthquake.

1. The construction type (modern R/C houses, and older masonry and stone-built ones) played an important part in the damage distribution, but was not

the most crucial factor, as all types of buildings suffered severe damage. It should be noted here that buildings as the HWI that had been built to meet high earthquake design requirements suffered irreparable damage, while other “regular” constructions located in the area suffered only non-structural damage. The deciding factor in this case has been the surficial geological effects, that is seismic fractures and liquefaction.

2. The damage distribution develops in a linear fashion, along a E-W to WNW-ESE trend, delineating a 4-km long zone that coincides with the trace of the seismic fracture, which in turn coincides with the Egio fault escarpment.
3. At the eastern part of the zone, which is mostly inside the town, severe and irreparable damage was observed at modern buildings (as the collapsed apartment block). Damage here is believed to be mainly related to the occurrence of seismic fractures. The morphological conditions were negative, but played a secondary part, while the foundation conditions are quite good.
4. At the western part the zone, extending from the west of Egio to the industrial area there was considerable damage to high-standard buildings, and is attributed to a combination of negative factors, that is the occurrence of the seismic fracture and liquefaction of foundation soils, which have poor geotechnical parameters and were suitable for liquefaction.
5. At the rest of the town, the damage was limited and is directly related to the construction type, since mostly old, dilapidated houses were hit, in contrast to the modern, R/C ones that suffered only non-structural damage. In other words, the destruction at this part was a by-product of seismic shaking.
6. As for the port area, the main bulk of damage was due to localized subsidence, mainly at the artificial landfill for the quays.
7. Similar is the situation all over the remainder of the meizoseismal area, mainly along the northern coast of Peloponnessos and, to a lesser extent in Sterea Hellas, where the small-scale damage was mainly due to seismic shaking. An exception is coastal zone from Valimitika to cape Trypia, where light constructions (pavements, property walls, etc.) were destroyed, mostly because of liquefaction and ground fissures.

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