CHAPTER 8

Active faults and seismic hazard assessment at municipality level – the case of Tenea (Corinthia, Greece)

H.D. Kranis, E.L. Lekkas, S.G. Lozios and A.S. Bakopoulou
Faculty of Geology,University of Athens, Greece.

Abstract

We present the results of the multidisciplinary study on earthquake planning and protection for the municipality of Tenea, Corinthia. The paper focuses on the population centres and describes the geological effects in the case of activation of the fault structures that cross the area. The locations most prone to the occurrence of ground fracturing, liquefaction, rockfalls, landslides and local intensity amplification, caused by the basin edge effect, are presented. Moreover, we examine the cases where the road or railway connections may be disrupted because of fault reactivation and suggest the locations most susceptible to this.

1 Introduction

The topic of earthquake hazard assessment has been the focus of numerous studies applying deterministic and probabilistic methods (see Yeats et al. [1] for a comprehensive review).

In this paper we try to address the same issue using a quasi-deterministic technique, and to predict the problems that may arise from the occurrence of a medium or large earthquake within, or close to, the administrative boundaries of the municipality of Tenea, prefecture of Corinth, north-eastern Peloponnesus, Greece (Fig. 1). The administrative division (municipality) of Tenea has a total area of 162.4 km^2, lies between 37º30’43’’S, 37º30’53’’N, 22º30’44’’W and 22º30’55’’E and is the result of a recent public administration law merging the multitude of small townships into larger administrative divisions, for the sake of simpler and more effective administration. However, this new law entailed the reconsideration of local emergency planning, as local authorities have now to face an increased variety of contingencies in the event of a destructive earthquake.

Another aspect that we have taken into consideration is the fact that Tenea is crossed by major lifelines: the main Tripolis-Korinthos-Athens motorway, the trunk line of the Peloponnesian railway network and the main powerlines that transport electricity from the power plants of the central Peloponnessus to Athens, Korinthos, Loutraki and other population centres (Fig. 1).

The central and northwestern parts of the area are rather flat-lying, save for the odd hill, while the relief becomes rougher at the northern and north-eastern part, with steeper slopes, cliffs and prominent mountain tops (highest peak: Profitis Ilias, alt. 701 m) The southern part is mountainous, with steep terrain and altitudes as high as 1,078 m (Psili Rahi).

The capital is Hiliomodi (population 1,750), built at the eastern extremity of the administrative division. Other population centres (towns, villages) are Agios Vassileios, Klenia, Spathovouni, Koutalas and Mapsos (Figs 2 & 3).

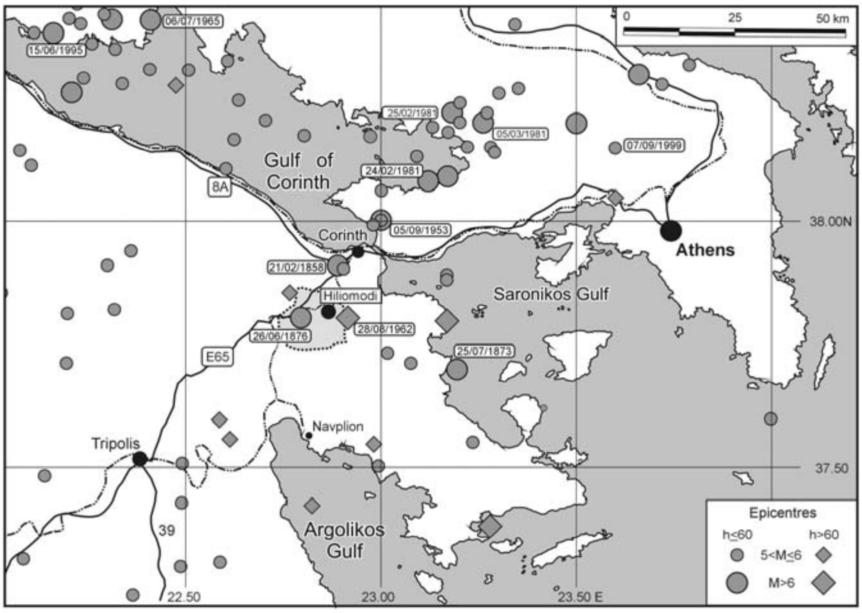

Figure 1: Map of the north-eastern Peloponnessus, with the epicentres of the medium and large earthquakes (Nat. Observatory of Athens, revised catalogue; Papazachos and Papazachou, [2]). The dates in boxes refer to the earthquakes discussed in the text. The shaded area corresponds to the municipality of Tenea. The major road (continuous line) and railroad (dash-and-dot line) networks are also shown.

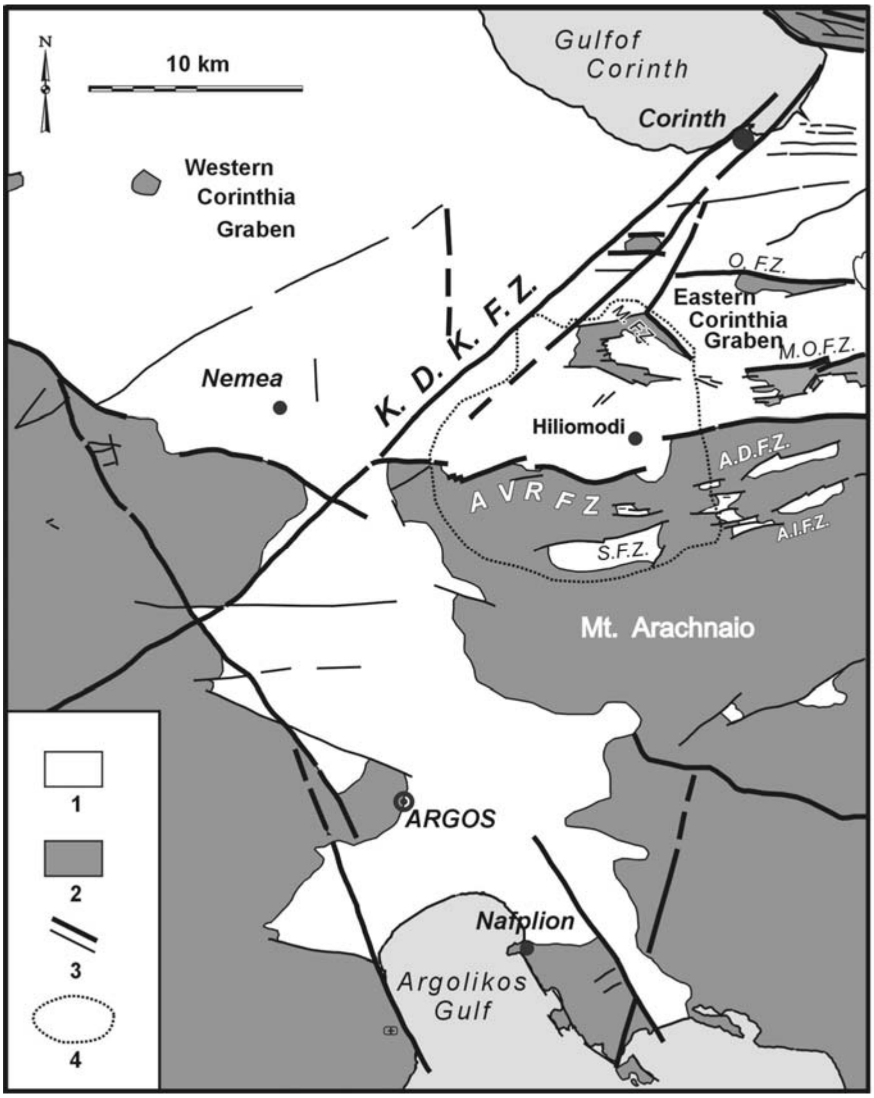

Figure 2: Tectonic sketch map of the broader study area, modified from Papanikolaou et al. [3]. 1: Neogene-quaternary sediments; 2: alpine rocks; 3: major (thick line) and secondary (thin line) faults; 4: administrative boundaries of Tenea. KDKFZ: Korinthos-Dervenakia-Kaparelli F.Z.; AVRFZ: Agios Vassileios-Ryton F.Z.; ADFZ: Agios Dimitrios F.Z.; SFZ: Stefanion F.Z.; AIFZ: Agios Ioannis F.Z.; MFZ: Mapsos F.Z.; OFZ: Oneia F.Z.; MOFZ: Mavri Ora F.Z.

The procedure we followed consisted of the well-established steps of field reconnaissance and mapping (geological and geotechnical), satellite image and aerial-photograph interpretation and examination and evaluation of local and regional seismicity patterns. All data were administered on a GIS platform (ArcGIS).

The examination of historically and instrumentally recorded seismicity, earthquake source modelling and the determination of response spectra are invaluable sources of information for the study of the behaviour of constructions. All these were seamlessly integrated with the field survey of active faults and the mapping of pre-existing landslides, liquefaction sites, and so forth.

In the following sections we shall first give an outline of the geological and the neotectonic conditions of the study area. Then we shall present the current local and regional seismicity pattern, as it is derived from instrumental recordings and historical references. We shall then examine the population centres, infrastructure and lifelines of Tenea, in respect to their seismic vulnerability. Finally, we shall discuss the results of this study and the implications for seismic hazard assessment.

2 Geology and tectonics

The geological formations that crop out in the area comprise both Neogene – Quaternary deposits (post-alpine formations) and Tertiary rocks (alpine formations). The latter outcrop mainly at the southern, mountainous part. In the northern part, the alpine substratum is usually exposed in neotectonic horsts and/or bedrock ridges (Fig. 2). The post-alpine ("synrift") deposits cover most of the northern part of the area and cover unconformably the alpine basement; their thickness is highly variable and ranges between a few tens of metres and (probably) more than 200 m. This variability is explained by the fact that the study area belongs within the Eastern Corinthia Graben (ECG, Fig. 2) (Papanikolaou et al. [3]), in which the synrift deposits have either covered a highly tectonized basement and/or have been faulted against alpine rocks. This situation is rather less obvious in the Western Graben, where the thickness of the synrift sediments is much higher and the alpine substratum is only sporadically exposed (Fig. 2).

Both the Eastern and Western Corinthia Grabens form the onshore prolongation of the present-day Gulf of Corinth, an active rift structure with very high deformation rates and seismicity (e.g. Davies et al. [4], Hatzfeld et al. [5], and references therein).

The study area hosts a range-bounding fault zone, the Agios Vassileios-Ryton F.Z. (Table 1; Figs 2 and 3) and numerous other second- and third-order faults. Besides a first-order transverse tectonic structure, the Korinthos-Dervenakia-Kaparelli F.Z. (KDKFZ) has been identified by Papanikolaou et al. [3] and it is held responsible for the geologic a tectonic differentiation between the Eastern and the Western Corinthia Graben. The fault characteristics are summarized in Table 1.

Table 1: Active fault and fault zone characteristics in the vicinity of Tenea and environs, modified from Papanikolaou et al. [3].

Fault name	Population centres	Order*	Length (km)	Strike	Kinematics†	Throw (m)	Potential (Ms) §
Korinthos-Dervenakia-Kaparelli F.Z.	Korinthos, Nemea, Spathovouni, Kleonai	1	48	N 045	Oblique-dip slip, left-lateral	> 150	6.4 R
Oneia Mts F.Z.	Solomos, Kenchraii, Xylokeriza	1	~ 9	E-W	Normal	> 150	5.5 R
Agios Vassileios-Ryto F.Z.	Agios Vassileios, Klenia, Hiliomodi	1	~ 24	NW-SE**	Normal	> 150	6.3 R
Mapsos F.Z.	Mapsos	1	3.5	NW-SE	Normal	>150	4.7 R
Mapsos horst faults	Mapsos	2	0.5-1	E-W	N/A	<100	N/A
Mavri Ora F.Z.	Athikia, Myrtea	1	~ 9	E-W**	Normal	> 150	5.5 R
Agios Dimitrios F.		2	~ 6	††	Normal	< 100	5.2 R
Stefanion F.	Stefanion, Agionorion	2	~ 7	N 080 E	Normal	< 100	5.3 R
Agios Ioannis F.	Agios Ioannis, Agionorion	2	~ 5	ENE-WSW	Normal	< 100	5.0 R

* 1: Main fault or marginal, 2: second order fault.

† Refers to the last reactivation. In a number of cases, the kinematic character of the zone has changed during its existence. Classification after Mariolakos and Papanikolaou [6].

§ After Papazachos [7].

Comprises E-W and ENE-WSW en echelon segments.

** Mean strike; it consists of en echelon segments.

†† Four WSW-ENE en echelon segments linked through NNW-SSE linking faults.

3 Seismological data

The narrow area itself has not hosted many large earthquake epicentres; however, several seismic events have affected the existing infrastructure. The nearest seismogenic areas are the Gulf of Corinth and its easternmost extremity, the Alkyonides Gulf (Fig.1). The most notable earthquakes are shown in Table 2.

Table 2. The most destructive earthquakes that have affected Tenea in the past 150 years. Data from Papazachos and Papazachou [2] and the revised catalogue of the National Observatory of Athens.

Date	Longitude (E)	Latitude (N)	Magnitude (Ms)(*)	Notes
21 Feb 1858	22.90	37.90	6.5	Io=X at Corinth, 21 casualties
25 Jul 1873	23.20	37.7	6.0	Io=VII at Epidauros
26 Jun 1876	22.80	37.8	6.1	Imax= at Nemea
22 Apr 1928	23.00	37.90	6.3	Io=IX at Corinth
6 Jul 1962	37.80	22.90	6.6	Io=VIII+ at Ancient Corinth. Medium depth eq. (h=95 km)
24 Feb 1981	22.90	38.10	6.8	Io=IX at Perachora

(*) Estimated magnitude for the 19th century events.

The 21 February 1858 earthquake ravaged the city of Corinth and caused extensive damage to the surrounding population centres, including Hiliomodi. The maximum recorded intensity was Io=X at Corinth and this must be the most serious seismic event in the recent history of the study area. Fifteen years later (25 July 1873) a M=6.0 shock took place; its epicentre must have been approximately 30 km to the east of the administrative division of Tenea, which is included in the I=VI isoseismal of the shock. Another strong earthquake occurred in 1876 (26 June); this time, the epicentre lay within the area of the municipality, approximately 7-8 km west of Hiliomodi, at Nemea. Again, as in the 1858 event, damage was widespread. The maximum recorded intensity was Io=VIII at Nemea, located a few km west of Hiliomodi.

Unfortunately, for all the aforementioned events only a small amount of reliable data are available and especially when it comes to our knowledge of surficial faulting, geological site effects and so on, we have almost no information, save for vague second-hand reports, documented in the works of Schmidt [8], Papazachos & Papazachou [2] and Ambraseys [9].

In the twentieth century, three significant events occurred, for all of which the available data are plentiful and more accurate. The 22 April 1928 earthquake razed Corinth, killed more than 20 people and wreaked havoc in numerous towns and villages, including most of the population centres within the administrative boundaries of Tenea. In 1953 (13 June), the epicentre of the earthquake lay along the south-eastern coast of the Gulf of Corinth and caused moderate damage. The most serious event of the last century was the Alkyonides earthquake (24 February 1981), which was followed by a series of destructive aftershocks, the most important of which was on 4 March 1981 (Ms= 6.4).

Bearing in mind all the above, we can have an estimate of the maximum intensities, the depth, focal mechanism and epicentral distance of the medium and large earthquakes which have affected the study area in the last 150 years. Smaller events (M<5.0) have not been considered in this study; we believe that only a M>5.0 (possibly M>5.5), shallow earthquake with an epicentral distance of no more than 30 km is capable of seriously disrupting the functions, lifelines and services and, most of all, pose a serious threat to human lives in the municipality of Tenea. The large shocks that occur on either of the margins of the Gulf of Corinth (e.g. the 1965 Erateini (Ms=6.5) and the 1995 Egion (M=6.5) earthquakes), with an epicentral distance of 80-90 km have left the area unharmed; the same goes for major events (M>7.0) that occur sporadically along the southwestern part of the Hellenic Arc.

4 Examination of population centres and infrastructure

4.1 Hiliomodi – Koutalas

The capital is located within the Eastern Corinthia Graben (ECG), close to the Agios Vassileios – Ryto Fault Zone (AVRFZ), which is an E-W range-bounding structure (Table 1; Figs 2 & 3). It should also be noted that the town lies within the ECG in which numerous active small faults have been mapped, bounding second- and third-order horsts and graben. The most prominent neotectonic feature is the Koutalas horst, bounded on the south by the namesake fault (Fig. 3), striking WNW-ESE and with a visible trace of 4 km. In the same area and NW of the town (Profitis Ilias), another NE-SW fault set has been mapped, consisting of overlapping faults of 1-2 km visible length. Hiliomodi is located within the hanging wall of these normal faults. The Koutalas fault presents all the signs of late Quaternary activity (fresh slickensides, loose debris, sharp morphologic discontinuity, etc.) and is considered active. The Profitis Ilias fault set seems to be less active, with the exception of one strand that interacts with the Koutalas Fault and is active. All these faults are prone to reactivation in the sense that they can accommodate differential movements of fault-bounded blocks in the event of a shallow, near-field earthquake originating in one of the seismogenic structures of the area.

Reactivation of the aforementioned faults can lead to a suite of geological site effects. Rockfalls and slides are highly probable, especially along the fault traces, due to high topographic gradient and intense pre-existing fracturing of the host rock. Liquefaction is also likely at the eastern and southern outskirts of the town, where the topography, lithology and the hydrogeological conditions (very shallow aquifer) are favourable. Note that the railway line is founded on these loose, liquefaction-prone formations.

Another serious threat for Hiliomodi is posed by possible reactivation of the range-bounding AVRFZ, an active, 25-km long structure with an accumulated vertical throw of more than 150 m and seismic potential M=6.3 R (Table 2). The available data of historical seismicity suggest that the AVRFZ may have ruptured in the 1876 event (Table 2), judging from the presumed epicentre and distribution of macroseismic intensities. The effects from the reactivation of this fault will be analogous to those already mentioned before, though in this case their magnitude and extent are expected to be much greater. The road connections between Hiliomodi and the towns to the south may be seriously disrupted (especially the road leading to Klenia, Agionori and Stefani). Liquefaction is highly likely to occur in the soft alluvial sediments within and around the town and this will seriously affect the railway line. Fortunately enough, the town hall and the elementary and secondary school complex are founded on more competent formations and are not expected to suffer damage caused by liquefaction. However, the possibility for ground fracturing is very high, as the town lies just west of the tip of an active fault strand that belongs to the AVRFZ (Fig. 3).

4.2 Klenia – Agios Vassileios

These two villages are located at the foot of the faulted mounted front of Psili Rahi – Dafnias, which occupies the southern sector of the study area and belongs to the neotectonic horst of Mt. Arachnaio (Figs. 2 and 3). Both villages lie on the trace of the AVRFZ and this, coupled with the fact that the geological and topographic conditions are unfavourable, makes them more vulnerable.

More specifically, the topographic gradient at both Agios Vassileios and Klenia is rather high (25-55%) and this factor, combined with the lithology of the area, adds to the risk of rockfalls and landslides. The villages are built on the surface of highly heterogeneous talus cones, which, although they are covered by a well-indurated carapace, artificial and natural cuts have exposed extended lenses of loose sand and gravel, interlayerings of silt and finer sediment, as well as cavities of various sizes. This type of geological formation is prone to differential settlement because the lithological heterogeneity occurs rapidly both in the vertical and the horizontal sense. Also, if the AVRFZ is reactivated extensive ground fracturing is expected to occur; the fracture sets will most probably develop parallel or sub-parallel to the fault zone, i.e. along the E-W and ENE-WSW directions, although connecting fractures, striking approximately NNW-SSE will also be present. Ground fracturing will cause small-scale (up to some m.) depressions and culminations of the free surface, while open gashes are also likely to develop. All these may cause serious problems to the foundations of the buildings, especially the older ones, and the local road network.

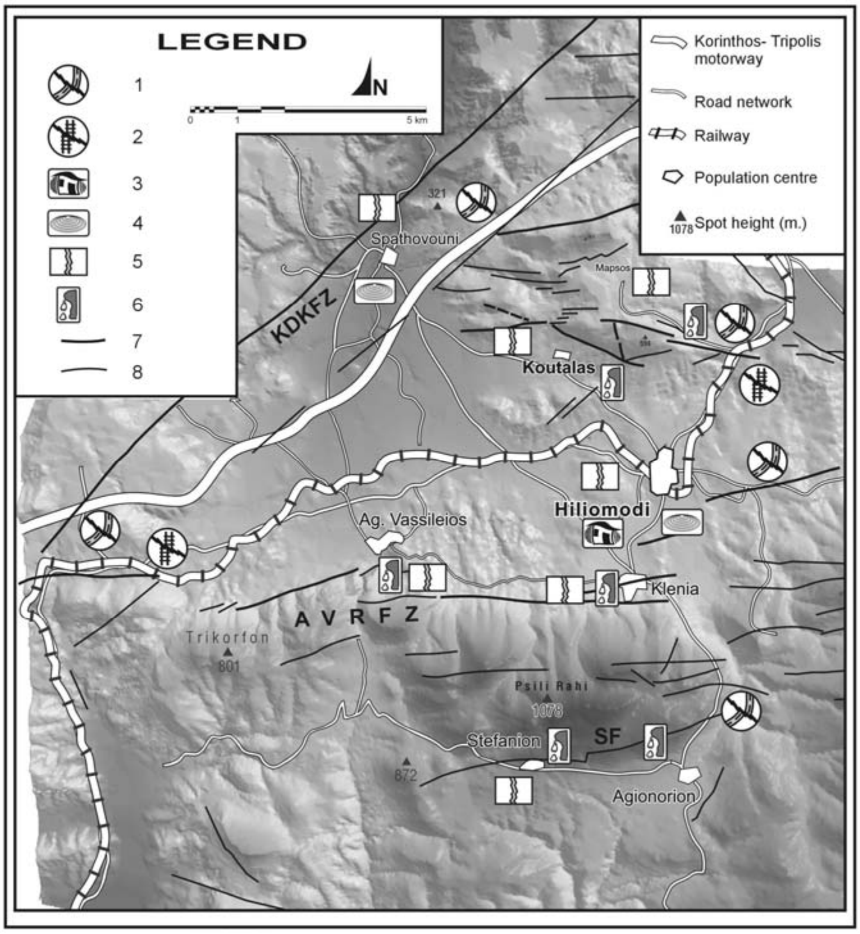

Figure 3: Shaded relief map, lit from the NE, of the municipality of Tenea, showing the active faults in the area (same annotation as in Figure 2) and the possible occurrences of geological effects induced by reactivation of the tectonic structures shown here. 1. disruption of traffic due to fault displacement; 2. disruption of rail transport due to fault displacement; 3. amplified ground shaking; 4. liquefaction; 5. soil fracturing; 6. rockfalls; 7. major fault; 8. secondary fault.

Figure 4: The Mapsos Fault. View to SW.

4.3 Stefanion – Agionorion

The southernmost villages of the area are located within the mountainous area, on the flanks of a plateau. The nearest fault is the Stefanion Fault (SF) (Fig. 3), with E-W to ENE-WSW strike and a visible length of 7 km. It consists of two en echelon segments, linked with a small N-S fault. Debris, with various degrees of cohesion, occur all along its trace, on a 50-150 m-wide zone. The fault does not display signs of recent activity (i.e. in the past 10,000 years), however, and judging by the form of the morphological discontinuity and the extent and degree of cohesion of the slope wash material we can assume that it has moved in the Quaternary. Any reactivation on this fault will have immediate effects on Stefanion, which lies practically on the trace of the fault; Agionorion is also expected to be affected by ground (subsidiary) fracturing. Rockfalls are also very likely, especially at Stefanion. Note also that the SF runs across the road connecting the two villages with the other population centres. The most crucial intersection point is NE of Agionorion, and displacement on the fault may seriously impede transportation.

4.4 Spathovouni – Corinth-Tripolis motorway

The village of Mapsos lies at the NW part of the municipality and is founded partly on the plioquaternary formations of the ECG and partly on alluvium. The main neotectonic structure in the vicinity is the first-order Korinthos-Dervenakia – Kaparelli Fault Zone (KDKFZ), a transcurrent fault, which is the critical boundary between the eastern and western basins of Corinthia (Fig. 2). It has a length of approximately 50 km, striking NE-SW. Its degree of activity is still unclear, as it displays a certain north-eastward migration in the Quaternary (Papanikolaou et al., [3], with its SW segment being dormant or possibly active and the NE active. The part KDKFZ that crosses the area of interest is actually the transfer region (not in the structural sense) between the dormant and active segments. Its topographic expression is subdued, partly due to its kinematic character (strike-slip) and partly because the geomorphic processes in the Late Quaternary may have outpaced its degree of activity. Nonetheless, it separates an area of very low relief to the north-west from a hilly area in the south-west that corresponds to the north-eastern sector of the municipality. All the hills are either bedrock ridges and/or small horsts bounded by the faults described in this paper (Fig. 3). This difference in the morphology between the two blocks of the KDKFZ reflects its tectonic significance: the ECG is a shallow basin, while the thickness of the synrift deposits in the greater Western Corinth Graben (WCG) is much higher. It is therefore expected that the basement morphology under the study area will be highly uneven and probably the synrift deposits have buried small horsts and graben; unfortunately, no systematic geophysical investigations have been conducted in order to clarify the basement morphology and this could be of high value in the estimation of strong motion parameters, as the uneven basement morphology is bound to produce multiple inter-basin reflections of seismic waves (Takemiya and Adam [10]).

The trace of the KDKFZ is parallel to the Corinth-Tripolis motorway in the study area and also crosses it at the west of the municipality boundaries (Fig.3). Besides, another suspected fault strand, parallel to the KDKFZ almost coincides with the motorway; the latter is little more than a photo-lineament and there are no available data for better estimations.

The motorway could be affected if the E-W faults at Mapsos (Fig. 3) are reactivated. These second- and third-order normal faults are active and at least three of these cross the motorway just east of Spathovouni. The most important of these is the Mapsos fault (Fig. 4), which may affect not only the road network, but also the village of Spathovouni, which lies very close to its visible western tip. This fault has a visible length of 3.5 km and its estimated cumulative throw may exceed 150 m.

Apart from problems arising directly from fault displacement, Spathovouni and its environs are susceptible to other geological site effects, namely liquefaction, soil fracturing and lateral spreading. Liquefaction is highly likely, due to the nature of the surficial geological formations.

4.5 Mapsos

The small village of Mapsos is located within a tectonic horst (actually a multi-block), dissected by a multitude of active and probably active faults. The area is sparsely populated and no critical infrastructure facilities are located there. However, the main problem at this north-eastern part of the municipality is the possibility of the disruption of road and railway connections caused by the reactivation of the Mapsos fault, which was described in the previous section, and another, WNW-ESE, fault system located approximately 2.5 km north of Hiliomodi. If these faults are reactivated, problems will arise from possible displacement of the ground surface and from rockfalls that are highly likely to occur on the steep NE and eastern slopes, blocking the existing transportation lines.

5 Discussion and conclusions

The municipality of Tenea is located within a zone of medium to medium-high seismicity. Historical and instrumental records show that is has been affected by at least six medium and large earthquakes in the past 150 years with epicentral distances ranging from a few to 45-50 km. The most destructive of these was the 1876 event (M=6.1), the epicentre of which was only 3-5 km west of Hiliomodi, and the available data allow us to associate it with reactivation of the KDKFZ. The 1962 event, although its epicentre lay only 2-4 km north of Hiliomodi, produced relatively little damage, as it was a medium-depth (h=95 km) earthquake.

The completion of the new Corinth-Tripolis motorway in the last decade, and the ongoing upgrading of the railway connection between Athens and the Peloponnesus, have made Tenea a key location for these lifelines in the event of an earthquake. The most serious threat, as far as near-field tremors are concerned, is posed by the KDKFZ which has been quiescent for the past 125 years. Both the motorway and the railrway cross the KDKFZ and this makes them susceptible to direct damage from fault displacement. Furthermore, a large stretch of these lifelines is constructed on the hanging-wall basin of the KDKFZ, which corresponds roughly with two-thirds of the area of the municipality. This area, which is a part of the ECG hosts bedrock ridges and tectonic horsts bounded by active or probably active faults, some of which cross the lifelines, such as the MF. Within this part of the ECG, and especially where loose geological formations occur (mainly alluvial silt and sand), liquefaction is highly likely, especially where the aquifer is shallow, as is the case east of Hiliomodi and south of Spathovouni (Fig. 3).

Rockfalls and landslides are a threat for the areas of relatively high relief (the villages of Agios Vassileios and Klenia) and may also disrupt traffic on the secondary artery which connects Hiliomodi with Korinthos.

Earthquakes with epicentral distances from 15-45 km have also been destructive for Tenea. In such a case, the major lifelines are not expected to be seriously hit; private and public buildings will, however, be threatened.

Bearing in mind all the aforementioned, we can say that the population centres and lifelines in the study area will have to withstand both the direct and the indirect (concomitant) effects of an earthquake. In most cases, experience has shown that the related (geological) site effects can prove more destructive than surficial fault displacement or ground shaking themselves. Especially with regard to the first parameter, human and property loss is usually confined within a narrow zone that may coincide with the fault trace or lie parallel to it (Lekkas and Kranis [11]; Lekkas et al. [12]). However, geological site effects can prove much more harmful if local conditions favour them. In the case of Tenea, the soil characteristics, the shallow water table and the unevenness of the alpine substratum of the ECG can trigger liquefaction, lateral spreading, soil fracturing and rockfalls at several locations (Fig. 3).

We believe that this type of approach for seismic hazards can help the administrators towards more effective risk management. The types of hazard, as well as the locations most prone to them, have been located; there remain, however, some aspects to be clarified, such as the detailed imaging of the alpine basement, which is essential for the clarification of the expected patterns of seismic wave propagation through the ECG.

References

[1] Yeats, R.S., Sieh, K. & Allen, C.R. *The Geology of Earthquakes*, Oxford University Press: New York and Oxford, 1997.

[2] Papazachos, B. & Papazachou, A. *The earthquakes of Greece*. Ziti Publications: Thessaloniki, 1989.

[3] Papanikolaou, D., Logos, E., Lozios, S. & Sideris, C. *Neotectonic Map of Greece, 1:100,000 scale, "Korinthos Sheet"* (map and accompanying volume). E.P.P.O & Europ. Centr. for Prev. and Pred. of Earthquakes, 1996.

[4] Davies, R., England, P., Parsons, B., Billiris, H., Paradissis, D. and Veis, G. Geodetic strain in Greece in the interval 1892-1992. *Journal of Geophysical Research*, **102**, B11, pp. 24571-24588, 1997.
[5] Hatzfeld, D., Karakostas, V., Ziazia, M., Kassaras, I., Papadimitriou, E., Makropoulos, K., Voulgaris, N. and Papaioannou, C. Microseismicity and faulting geometry in the Gulf of Corinth (Greece). *Geophysical J. Intern*., **141**, pp. 438-456, 2000.
[6] Mariolakos, I. & Papanikolaou, D. Type of deformation and relationships between deformation and seismicity in the Hellenic Arc. *Bulletin of the Geological Society of Greece*, **XIX**, pp. 59-76, 1986 [in Greek].
[7] Papazachos, B.C. The seismic zones in the Aegean and surrounding area. *Proceedings, European Seismol. Soc., XXI General Assembly*, Sofia, Bulgaria, pp. 82-87, 1989.
[8] Schmidt, J.F. *Studien über Erdbeben*, Leipzig, 1879.
[9] Ambraseys, N.N. Material for the investigation of the seismicity of central Greece. *Archaeoseismicity*, eds. S. Stiros & R.E. Jones, Fitch Lab. Occasional Paper 7, IGME-British School at Athens, 1996.
[10] Takemiya, H. & Adam, M. Why the heaviest damages occurred in Kobe during the Hyogo-ken Nanbu earthquake, Japan, 1995. *Advances in Earthquake Engineering – The Kobe earthquake: geodynamical aspects*, ed. C.A. Brebbia, Computational Mechanics Publications, Southampton and Boston, pp. 39-58, 1996.
[11] Lekkas, E & Kranis, H. Earthquake faulting and human life loss. *Proc.of the Int. Symp. on Eng. Geology and the Environment*, eds. P. Marinos, G. Koukis, G. Tsiambaos & G. Stournaras, A.A. Balkema Publ. Rotterdam, Athens, pp. 835-840, 1997.
[12] Lekkas, E., Lozios S., Kranis, H. & Skourtsos, E. Linear damage distribution and seismic fractures at the Egio earthquake (15 June 1995, Greece). *Advances in Earthquake Engineering: Earthquake Resistant Engineering Structures 2*, eds. G.D. Manolis, D.E. Beskos & C.A. Brebbia, Computational Mechanics Publications: Southampton and Boston, pp. 37-46, 1997.