Proceedings Seventh International Congress International Association of Engineering Geology

5–9 SEPTEMBER 1994 / LISBOA / PORTUGAL

Editors

R.OLIVEIRA, L.F.RODRIGUES, A.G.COELHO & A.P.CUNHA

LNEC, Lisboa, Portugal

OFFPRINT

A.A.BALKEMA / ROTTERDAM / BROOKFIELD / 1994

7th International IAEG Congress / 7ème Congrès International de AIGI, © 1994 Balkema, Rotterdam, ISBN 90 5410 503 8

Liquefaction – Risk zonation and urban development at Western Peloponnesus (Greece)

Liquéfaction – Zonage du risque et développement urban au Peloponèse Occidental (Grèce)

E.L. Lekkas
Department of Geology, University of Athens, Greece

ABSTRACT: This paper deals with the liquefaction events that are likely to occur during earthquake activity at Western Peloponnessus and the liquefaction-risk zonation for the areas that are prone to such possibillity. At first, the geological outline of the greater area of Western Greece and the geological conditions of Western Peloponnessus are described in detail. Following, the liquefaction events that occured during the earthquakes of Oct. 16, 1988 and Mar. 26, 1993 are described together with the geological and geotechnical conditions prevailing at these locations. Finally, the areas along the coastlines that present the same geological and geotechnical conditions are zonated. These are the regions liable to liquefaction. The zonation of those areas is of particularly high importance for the reduction of eathquake risk, given that the region is characterized by intense urbanization.

RÉSUMÉ: Cet article décrit les phénomènes de liquéfaction susceptibles de se produire pendant les tremblements de terre en Péloponnèse Occidental et le zonage du risque de liquéfaction pour les régions exposées aux séismes. Au premier, quelques données géotectoniques sont présentées et les conditions géologiques du Péloponnèse Occidental sont esquissées en détail. De suite, les phénomènes de liquéfaction qui ont été observés en deux points pendant les tremblements de terre de 16/10/88 et 26/3/93 ainsi que les conditions géologiques et géotectoniques sont décrites. Enfin, on identifie les régions au long du littoral caractérisées par les mêmes conditions géologiques et géotectoniques où est probable la manifestation des phénomènes de liquéfaction. La détermination de ces régions est très important pour la réduction du risque séismique puisque la région est caractérisé par une intense urbanisation.

1 INTRODUCTION

It is widely known that the Hellenic territory is subject to high seismic activity, a result of the geodynamic processes that have been taking place in the environment of both the Alpine orogeny and its succeeding post-alpine period. As regards Western Greece (Ionian islands, Western Peloponnessus, Western Sterea) is characterized by the most intense seismicity in Greece due to its neighbouring to the convergent margin where the African plate is subducted under the Eurasian one. This high seismicity is expressed through numerous earthquakes of various magnitudes which have repeatedly caused losses of both human lives and properties. There are historic reports on liquefaction phenomena in the distant past; besides, during the recent tremors (October 16, 1988, M_L = 5.5R and March 26, 1993, M_L = 5.4R) a considerable number of scientifically exploitable liquefaction events was spotted. (Fig. 1). The investigation carried out on these liquefaction led to the determination of the geological and geotechnical conditions that caused those phenomena. Following, and based on the data from the investigations, a liquefaction-risk zonation was carried out. This zonation has a considerable contribution, alongside with the appropriate urban planning, to the reduction of seismic risk in the region where intense urban development through mainly prefabricated structures, is observed.

2 GEOTECTONIC SETTING - GEOLOGICAL MACROSTRUCTURE

The Hellenic territory is built of a number of Alpine geotectonic units which have undergone intense deformation, a result of both the Alpine

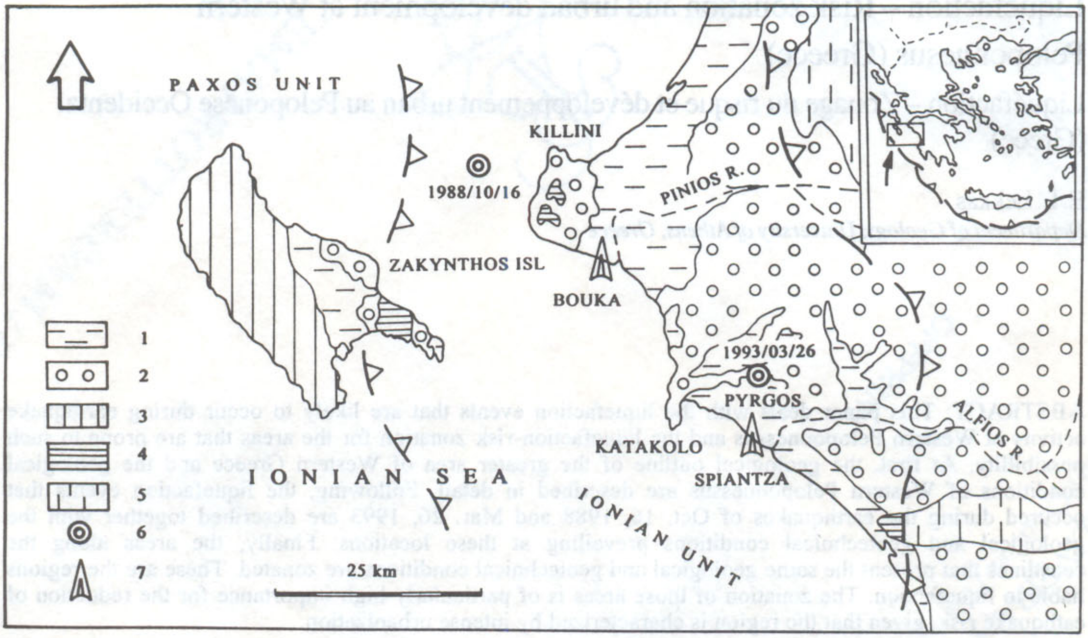

Fig. 1. Geotectonic sketch of the greater area of the manifestation of liquefaction events at W. Peloponnessus. (1. Holocene formations, 2. M. Miocene - Pleistocene formations, 3. Paxos Unit formations, 4. Ionian Unit formations, 5. Gavrovo Unit formations, 6. Earthquake epicentres, 7. Liquefaction sites).

orogeny and the post-alpine activity. The region where the described liquefaction phenomena occured belongs to the greater area of the Ionian unit (Fig. 1), which, together with the Paxos Unit almost correspond to the foremost ones, adjacent to the convergent margin of the Africa, and Eurasian plates.

As for the Ionian Unit, the results of the post-alpine deformation that started in Late Miocene were added to the structures created by the alpine one. This has led to the creation of numerous grabens, filled with post-alpine sediments of considerable thickness. More specifically, since Miocene, the co-sedimentary tectonism which led to the complexity of both the development of the formations through time and their lithostratigraphical structure has been the prevailing factor. Of particular importance, too, have been the diapirical phenomena of the evaporites that belong to the Ionian Unit (Mariolakos et al., 1991).

Fault tectonics is prominent all along the coastal zone from Mt. Lapithas to Killini peninsula (Lekkas et al., 1992) (Fig. 2). Throughout Holocene, this form of intense tectonism has both uplifted and downthrown blocks, thus affecting even the outcrops of L. Pleistocene formations. The downtrown blocks correspond to locations where the recent sediments such as alluvial, marshy deposits, fluvial deposits and dunes, occur. At some of these blocks, and depending on the conditions present, liquefaction phenomena are likely to occur. On the contrary, at the uplifted blocks, where the remainer of the post-alpine and the Ionian Unit formations crop out, there is no equivalent possibility.

3 GEOLOGICAL SETTING OF THE AREA

A considerable number of formations outcrop along the coastal zone of Western Peloponnessus. (Fig. 2). The alpine basement crops out at Killini peninsula and Mt. Lapithas and comprises formations of the Ionian Unit (limestones - evaporites). The remainder of the area is covered with post - apline sediments, which are (Kamberis, 1987; Lekkas et al., 1992; Fountoulis & Lekkas, 1991):

a. Peristeri formation: conglomerates of limestone origin. Total thickness: over 300 meters. Age: M. Pliocene. They outcrop north of Pyrgos.

b. Vounargos formation. Alternating sandstones, marls and clays. The results from the drillings showed that its thickness is over 1000 meters. Age: L. Pliocene - Pleistocene. It crops out at

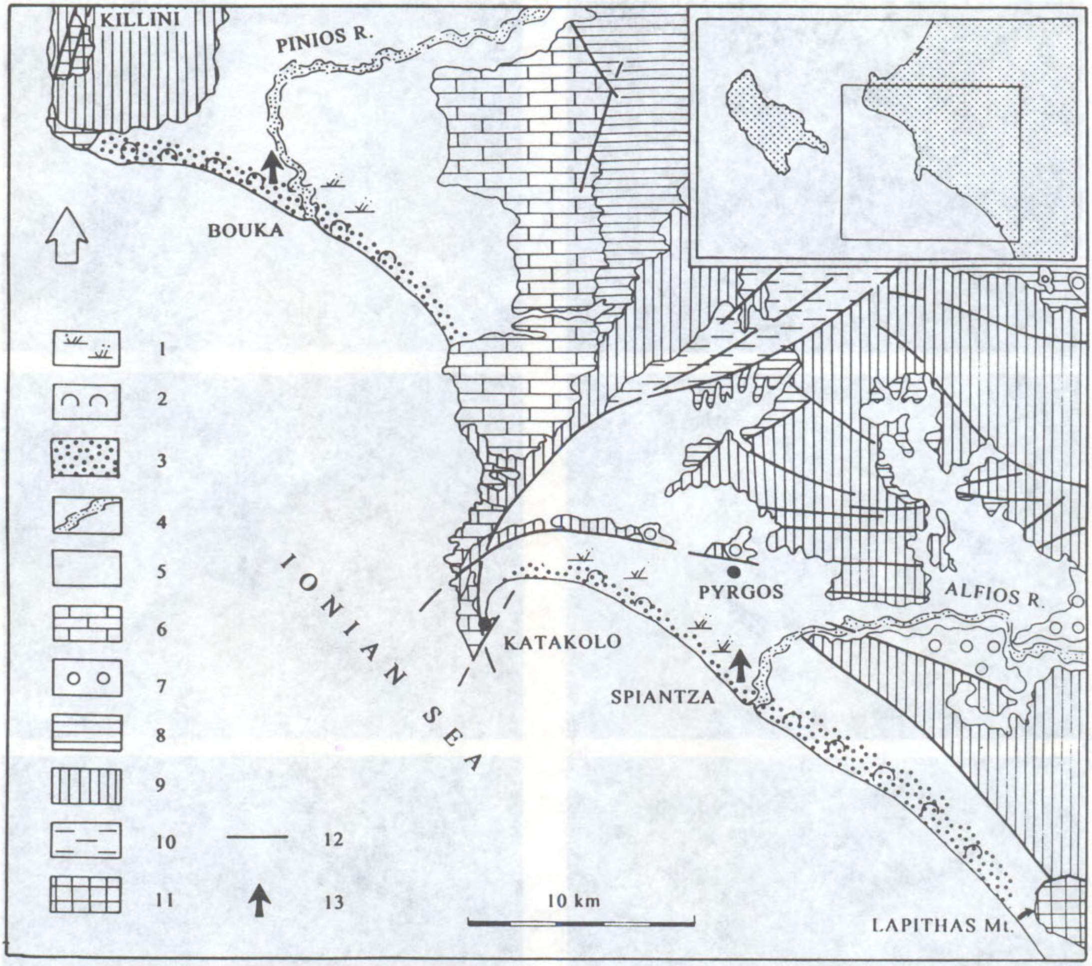

Fig. 2. Simplified geological map of the greater area of the manifestation of liquefactions at W. Peloponnessus. (1. Marshy deposits, 2. Dunes, 3. Coastal deposits, 4. Fluvial deposits, 5. Alluvial deposits, 6. Calc-sandstones formation, 7. Erymanthos formation, 8. Keramidia formation, 9. Vounargos formation, 10. Peristeri formation, 11. Alpine formations, 12. Fault, 13. Liquefaction sites).

Killini peninsula and north of Mt. Lapithas and overlies the Alpine basement. It also crops out at Katakolo region.

c. Keramidia formation. Clays with lignite intercalations. Age: Pleistocene, thickness ca. 200 metres. It does not outcrop along the coastal zone, but minor occurences of it lie northwest of Katakolo.

d. Erymanthos formation. Mainly conglomerate of terrestrial origin. Its maximum thickness is about 100 metres and outcrops at the greater area of Pyrgos. Age: Pleistocene.

e. Katakolo Calc-Sandstones formation. Porous calcitic sandstones, which locally bear coarse material. Its thickness is about 10 - 20 metres and crops out at the region of Katakolo and at the southern part of Killini peninsula. Age: L. Pleistocene.

f. Alluvial Deposits formation. Unconsolidated deposits covering the plain lowland. They are mainly clays, silt, sands and pebbles in alternating strata, with a total thickness of about 10 - 15 metres.

g. Fluvial deposits formation. Unconsolidated pebbels, sands and silts alongside Alfios and Pinios rivers.

h. Coastal Deposits formation. Mainly sands of varying granularity and gravels that occur at a 200-metre wide band along the coastline. Its thickness is about 5 - 10 metres.

Fig. 3. Soil fractures and holes at the overlying formation (a, b, c, d) through which the liquified material (e, f), of the underlying one were poured out.

i. Dunes formation. They develop along the coast and comprise unconsolidated sands of varying granularity. Actually, these are the coastal deposits that move towards the interior and cover the existing deposits. At a number of spots, the dunes have propagated up to two kilometres from the coast and are covered by soil and recent deposits.

j. Marshy deposits. Silts, sands with abundant floral remnants. Maximum thickness: 5 metres.

As mentioned before, this region has undergone intense deformation, so the outcrops are mostly controlled by the tectonics. A striking example is the outcrops of Vounargos formation and the Katakolo calc-sandstones correspond to a horst that has been under constant uplift, where the liquefaction risk is minimized, because of the nature of the formations and the abscence of shallow aquifer. On the other hand, at the regions of Alfios and Pinios rivers that have been undergoing subsidence the liquefaction risk is high, due to the characters of the formations and the shallow aquifer that exists there.

4 DESCRIPTION OF THE LIQUEFACTION PHENOMENA AT WESTERN PELOPONNESSUS.

Liquefaction events took place along the coastal zone at Western Peloponnessus from Mt. Lapithas to Killini peninsula during two recent tremors. After the investigation of those, a clear picture of the geological and geotechnical conditions has been obtained.

4.1 *Bouka Area*

During the earthquake of Oct.16, 1988, M_L=5.5R, whose epicenter lay to the west of Killini peninsula, numerous liquefactions were observed, along (i) the coastal zone and (ii) Pinios river (Mariolakos et al., 1990; Lekkas et al.,1991). In a number of cases, the liquefactions were accompanied by soil fractures, sandblow and water-blow phenomena (Fig. 3). The latter were accomplished either through fractures up to 50 metres long, or holes of 0.2 - 0.8 m in diameter. All these phenomena happend at a distance of about 400 metres from the coast and expand over an area of several acres.

In order to investigate the liquefaction phenomena a number of boreholes was drilled and samples were obtained and analysed (Fig. 4). The boreholes and analyses produced the following results:

a. From the ground surface and up to a depth of 60 cm the overlying formations acquire a grey colour and consist of sand, silt and clay. This was very difficult to drill with the hand-held drill. The grain size analysis showed that it contains sand (40%-55%), silt (20%-50%) and clay (10%-25%). Numerous floral remnants were also present.

b. This surficial formation (i.e. from 0.6m to 6-7 metres) is followed by another one consisting of grey-reddish sand with intercalations of blue silts (10-15 cm thick) at various depths; gravel is also present. This formation could be relatively easily drilled with the hand-held drill. The grain size analysis showed that it contains gravel (0%-2%), coarse sand (0%-8%), medium sand (10%-30%), fine sand (45%-90%) and silt (0%-25%). It corresponds to coastal deposits, dunes and marshy deposits, a conclusion reached after considering the identical grain size composition of the latter and the drilled one. This is the liquified formation which was subsequently poured through the holes and fractures created in the overlying stratum. The water table lay at a depth of 0.6-0.8 m.

4.2 *Spiantza Area*

During the earthquake of March 26, 1993, M_L=5.4R, whose epicenter lay at the town of Pyrgos, liquefactions were observed at the location of Spiantza (S. of Pyrgos), at about 100-500 m from Alfios river. The liquefactions became noticeable because of the abundant flow of liquid and solid material on the ground surface. This took place through soil fractures of up to 30 metres long, or holes of ca. 0.5 in diameter (Fig. 3). The liquefaction at that location caused considerable damage to the prefabricated residences whose foundations lay directly on the ground surface.

A number of boreholes was drilled for the investigation of the liquefactions and samples were obtained and analysed (Fig. 4). The boreholes and the analyses produced the following results:

a. From the ground surface up to a depth of 1 m. the overlying formation comprizing grey-brown sand, silt and clay, was observed. This horizon was difficult to drill with the hand-held drill. The grain size analysis showed that it contains sand (50%-60%), silt (20%-40%) and clay (10%-20%). Abundant floral remnants were also present.

b. Below the surficial formation (i.e. from 2 m. to 8 m.) there is another one comprizing brown sand with numerous intercalations of grey silt (5-10 cm thick). The grain size analysis showed that it contains gravel (0%-5%), coarse sand (0%-15%), medium sand (10%-45%), fine sand (20%-85%) and silt (5%-35%). This formation also accomodated an aquifer.

The observations, boreholes and laboratory tests showed that the geological and geotechnical conditions at the locations where liquefaction events occured were more or less identical. More specifically, the liquefactions affected the aeolian-origin formations throughout which an aquifer develops (Fig. 5). This fomation is overlain by deposits with a high percentage of clay and occurence of floral remnants. The latter corresponds to the surficial soil mantle that has been created through recent processes (instant covering by marshy and fluvial deposits, flood material, maninduced procedures, vegetation, etc.)

5 LIQUEFACTION-RISK ZONATION.

At its first stage, the liquefaction-risk zonation along the coast of Western Peloponnessus should be based upon the localization and mapping of formations similar to those where the liquefactions phenomena were observed.

The liquifiable formations are the ones having

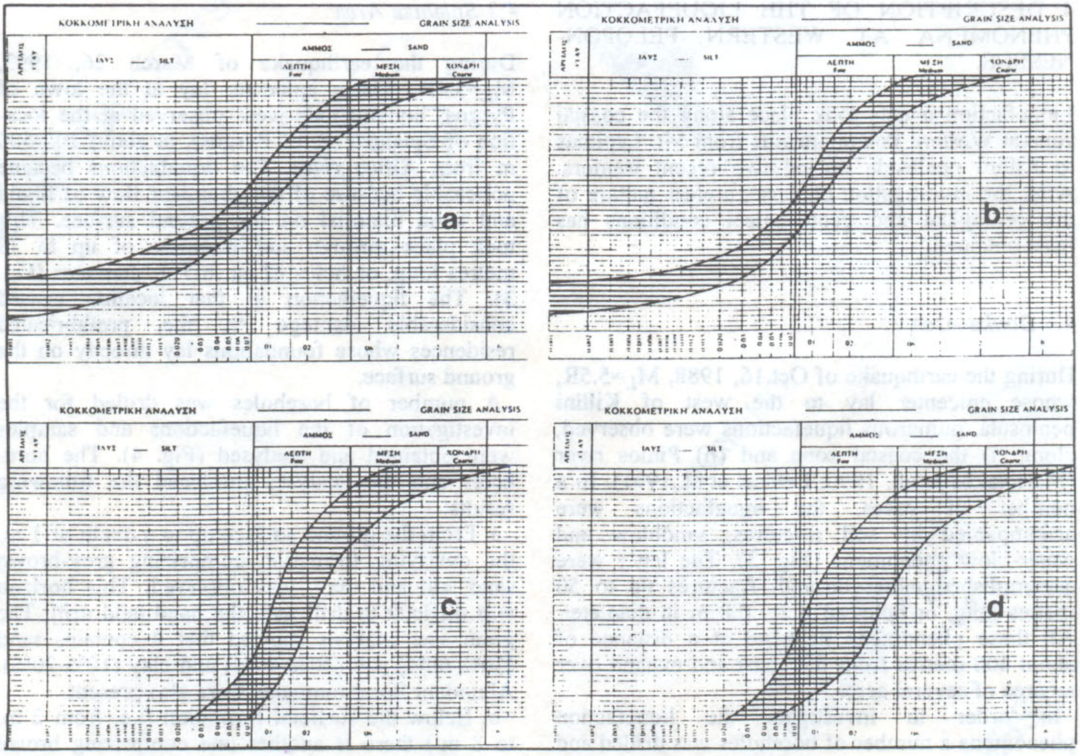

Fig. 4. Grain size analysis diagrammes of the surficial formations that were not liquified (a, b) and the ones that undergone liquefaction (c, d) at the locations of Bouca (a, c) and Spiantza (b, d).

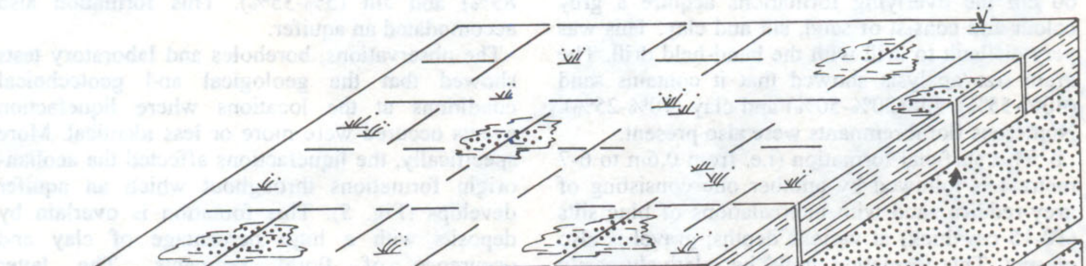

Fig. 5. Block diagram depicting the overlying formation (a) which was fractured and the underlying, liquified one (b).

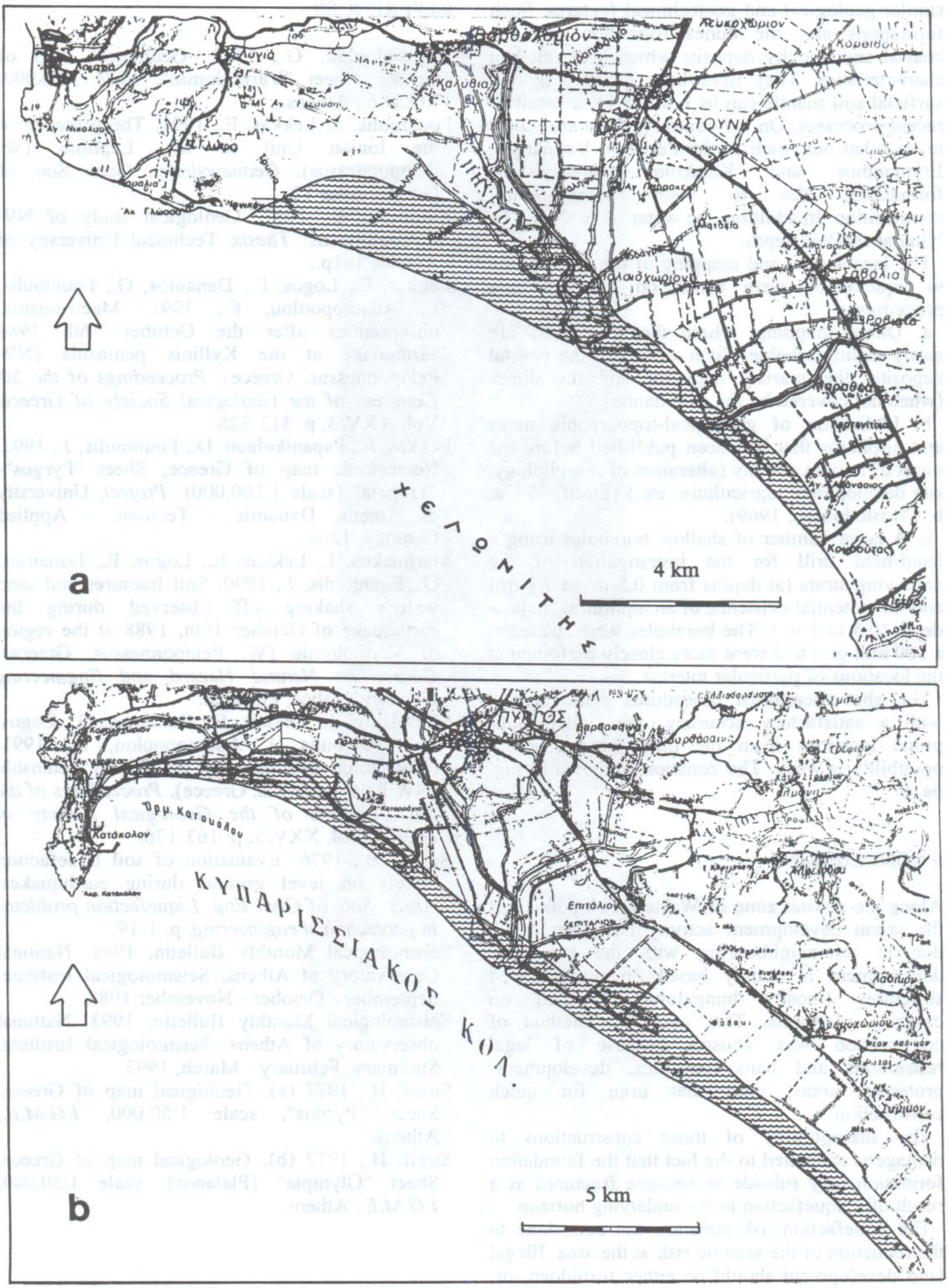

Fig. 6. Liquefaction - prone locations (dashed) at the greater area of Bouka (a) and of Spiantza (b).

similar geological and geotechnical features. Such formations are: the dunes formation and the coastal and marchy deposits which bear relevant characteristics. They have been covered by the surficial soil mantle (up to 1 m thick), a result of recent processes. On the contrary, there are others to be ruled out, such as the Peristeri, Vounargos, Erymanthos and Katakolo calc-sandstone formations, due to their "inappropriate" composition. In addition, the water table should be lying at shallow depth.

The localization and mapping of the areas prone to liquefaction were based on the following procedures:

a. Direct mapping, where the formations are easily distinguishable. Such cases are the coastal deposits, the marshy deposits, and the dunes (when not covered by the soil mantle).

b. Utilization of geological-topographic maps and airphotos that had been published before the onset of human activity (alteration of morphology, site development, agriculture, etc.) (Streif, 1977a, b; Christodoulou, 1969).

c. A large number of shallow boreholes using a hand-held drill for the investigation of the undelying strata (at depths from 0.5 m. to 7.7 m.) and the potential existence of an aquifer at shallow depth (0.5 to 1 m.). The boreholes were spaced at a 500 m.n grid and were more closely perfomed at the locations of particular interest.

The abovementioned procedures distinguished, with a satisfactory accuracy, the liquefaction-prone locations from the ones where such a possibility is weak. The zonation is shown in Fig. 6a, b.

6 CONCLUSIONS

Along the coastal zone of Western Peloponnessus the urban development activity has been rapid, due to its neighbouring with the sea. The development is mainly based on prefabricated structures (mostly bungalows) founded on concrete platforms. This particular method of construction was chosen beacuse of legal restrictions and bans (royalties, development-protected areas, etc.) that urge for quick construction.

The susceptibility of those constructions to damage is attributed to the fact that the foundation formation may subside or become fractured as a result of a liquefaction in the undelying horizon.

The liquefaction-risk zonation can contribute to the reduction of the seismic risk at the area. Illegal land development should be either forbidden, or, where allowed, preceded by special foundation studies.

REFERENCES

Christodoulou, G., 1969. Geological map of Greece, Sheet "Vartholomio", scale 1:50.000, *I.G.M.E.*, Athens.

Fountoulis, J., Lekkas, E., 1991. The presence of the Ionian Unit in Mt. Lapithas (W. Peloponnessus). *Geonewsletter,* Geol. Soc. of Greece, Issue 12.

Kamberis, E., 1987. Geological study of NW Peloponnessus. *Thesis,* Technical University of Athens, 161p..

Lekkas, E., Logos, E., Danamos, G., Fountoulis, I., Adamopoulou, E., 1991. Macroseismic observations after the October 16th 1988 earthquake at the Kyllinis peninsula (NW Peloponnessus, Greece). *Proceedings of the 5th Congress of the Geological Society of Greece,* Vol. XXV/3, p. 313-328.

Lekkas, E., Papanikolaou, D., Fountoulis, J., 1992. Neotectonic map of Greece, Sheet "Pyrgos"-"Tropaia" (scale 1:100.000). *Project,* University of Athens, Dynamic - Tectonic - Applied Geology, 120p..

Mariolakos, I., Lekkas, E., Logos, E., Danamos, G., Fountoulis, J., 1990. Soil fractures and sand water's shaking off observed during the earthquake of October 16th, 1988 at the region of Vartholomio (W. Peloponnessus, Greece). *Course on Natural Hazard and Engineering Geology,* Lisboa, Portugal.

Mariolakos, I., Lekkas, E., Danamos, G., Logos, E., Fountoulis, I, Adamopoulou, E., 1991. Neotectonic evolution of the Killini peninsula (NW Peloponnessus, Greece). *Proceedings of the 5th Congress of the Geological Society of Greece,* Vol. XXV/3, p. 163-176.

Seed, I.B., 1976. Evaluation of soil liquefaction effects on level ground during earthquakes. *Amer. Soc. of Civil Eng. Liquefaction problems in geotechnical engineering,* p. 1-19.

Seismological Monthly Bulletin, 1989. National Observatory of Athens, Seismological Institute, September - October - November 1988.

Seismological Monthly Bulletin, 1993. National observatory of Athens, Seismological Institute, Summary, February - March, 1993.

Streif, H., 1977 (a). Geological map of Greece, Sheet "Pyrgos", scale 1:50.000, *I.G.M.E.*, Athens.

Streif, H., 1977 (b). Geological map of Greece, Sheet "Olympia" (Platanos), scale 1:50.000, *I.G.M.E.*, Athens.