Geo-engineering assessment of liquefaction hazard of the town of Larissa, Central Greece

Un essaie pour estimer le risqué de liquéfaction a la ville de Larissa, Grèce Centrale

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ABSTRACT

The goal of this paper is the assessment of the liquefaction hazard using data from borings with SPT. The town of Larissa is situated upon sediments, deposited by the river of Pinios which traverses the city, that are considered as potentially liquefiable regarding their depositional process. In addition, the region of Thessaly, where Larissa is located, is characterized as an earthquake prone area where the design acceleration on seismic bedrock is assigned as 0.24g according to the Greek seismic code. Moreover, liquefaction-induced ground deformations, triggered by the event of 1941, were reported at the town of Larissa according to historical seismicity. Therefore, a detailed geotechnical investigation is necessary in order to evaluate the liquefaction potential of the soil elements. Initially, geotechnical profiles of borings with SPT were collected and the factors of safety against liquefaction of the soil layers were estimated. Afterwards, the liquefaction potential index, LPI, of each boring and the possibility of liquefaction-induced surface disruption per site were computed in order to compile a liquefaction hazard map. The results of this study indicate the existence of liquefiable soil layers below the surface. However, the probability of liquefaction-induced surface disruption is very small at the urban area of Larissa for an earthquake magnitude and a PGA value of 7 and 0.24g, respectively. Only in two sites, at the northern part of the city, the percent of probability approach the value of 50% that can be defined as the boundary between the occurrence and non-occurrence of liquefaction-induced ground disruption.

Keywords: Liquefaction, probability, Larissa, susceptibility, Thessaly, Greece

1 INTRODUCTION

The town of Larissa located at central Greece, at the region of Thessaly. This area is characterized as medium to high seismicity due to the fact that strong earthquakes occurred at the 20th century. Particularly, severe ground deformations such as surface faulting, rockfalls, liquefaction, ground cracks etc., triggered by the events of 1941 (M 6.3), 1954 (M 6.7), 1955 (M 6.6), 1957 (M 6.2) and 1980 (M 6.4), were widespread to the whole area. According to the Greek Seismic Code (EAK, 2000) Larissa located to the second seismic hazard zone where the design acceleration on seismic bedrock is assigned as 0.24g while the maximum earthquake magnitude for the same recurrence interval is M = 7 (Papazachos & Papazachou, 1997).

The last decade, the town of Larissa was rapidly developed and the urban area was extended on new areas that were inhabitant in the past. Some of this areas included sites close to the river of Pinios, where the surface geology consisted by quaternary sediments. The initial scope of this paper was the evaluation of the liquefaction susceptibility of the sediments at the town of Larissa regarding the surface geology. In order to achieve this, the geological units of the urban area of Larissa were correlated to the recommendations of CDMG (1999).

Furthermore, the liquefaction susceptibility of the subsoil layers was investigated based on the modified susceptibility criteria of Seed et al. (2003) while the liquefaction potential was computed according to the recommendation of Youd et al. (2001). For the assessment of the liquefaction susceptibility and the potential of the subsoil of the urban area of Larissa, data provided by borings with SPT were used. The earthquake parameters that were employed for the evaluation of liquefaction potential and the hazard at the town of Larissa were earthquake magnitude equal to 7 and PGA equal to 0.24g.

The liquefaction hazard map of Larissa was compiled using the value of the probability of liquefaction-induced ground disruption that was computed according to the methodology proposed by Papathanassiou (2008). This study resulted that no liquefaction surface evidence is expected to occur at the urban area of Larissa with the exception of two sites where a possibility of 50% was assessed.

2 GEOLOGY AND TECTONICS OF THE AREA

The Larissa Basin is bordered by NW-SE trending faults, namely the Rodia and Gyrtoni faults to the North and the Tyrnavos and Larissa faults to the South, and is one of the main graben of the Internal Hellenides that were created by the NE-SW crustal trenching during Late Miocene-Pliocene (Caputo et al. 2004). Recently, a N-S extensional phase started during the Middle to Late Pleistocene, generating a new system of normal faults mainly trending E-W to ESE-WNW (fig. 1), where these new structures ignore and cut-across pre-existing faults (Caputo & Pavlides, 1993). The recent seismicity of Northern Thessaly shows that this extensional regimen is active (Caputo et al. 2004).

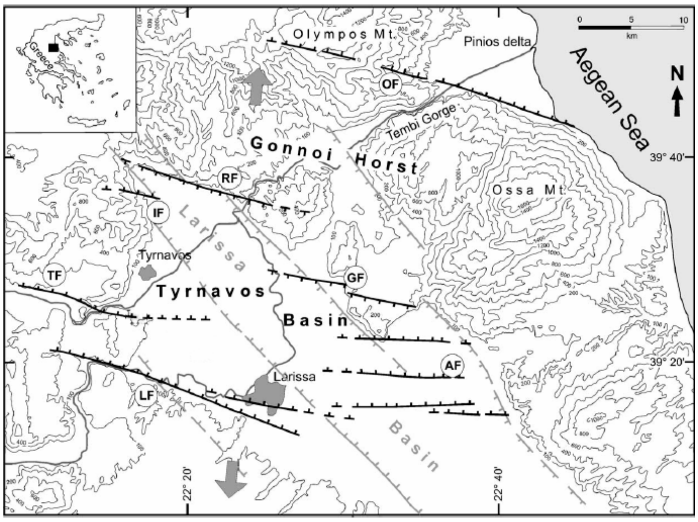

Figure 1. Major tectonic structures at the area of Thessaly (from Caputo et al. 2004)

Caputo & Pavlides (1993) concluded that the Larissa basin is an alluvial plain that is formed by quaternary deposits that are in stratigraphic continuity with the Pliocene sediments. Pliocene deposits crop out on the northern border of Larissa basin near Rodia and they seem to overlie the Palaeozoic Mesozoic substratum, while Red Beds outcrops are locally present along the borders of the basin (Caputo & Pavlides, 1993). The maximum thickness of the deposits has been estimated to 500 meters and is comprised by lacustrine and torrential formations at the lower and upper layers, respectively. The town of Larissa is built on recent alluvial deposits of the plain, on man-made deposits consisted of embankments and artificial fills and on formation of Neogene age.

3 HISTORICAL SEISMICITY

The area of Thessaly is separated into two parts, the northern and the southern one, regarding the occurrence of earthquakes. The southern sector of Thessaly was ruptured by strong earthquakes the 20th century after an apparent quiescence since 1773, while the northern part have not ruptured since 1781 (Caputo et al., 2005). According to Papadopoulos (1992) this gap is possibly not due to an incomplete earthquake record, but rather to changing seismicity patterns in the area.

The strongest earthquake that occurred close to the town of Larissa during the 20th century is the event of 1941, which triggered secondary effects such as ground cracks, liquefaction and settlements in many places. In particular, as it is reported in Maravelakis (1943): «…along the river Pinios and its tributaries the ground slumped and cracks appeared along banks running for many kilometres liquefaction of the ground was reported from many places in the town as well as the development of high artesian pressures that resulted in the damage of deep wells… At the village of Eleftherion, water ejected from a well. Sand volcanoes were observed at the banks of river Mirou, while at the village of Nesson, water ejection was observed in many places…».

4 EVALUATION OF LIQUEFACTION SUSCEPTIBILITY

The liquefaction potential of a site depends on two factors: the nature of shaking and the liquefaction susceptibility of the sediments (TC4, 1999). Thus, the first step for the assessment of potential is the evaluation of surface geology susceptibility to liquefaction based on published criteria such as the guidelines proposed by CDMG (1999) and the criteria suggested by Youd (1998). In particular, a liquefiable area is delineated when reports of past liquefaction occurrences exist and the geological and geomorphological characteristics are meeting the susceptibility criteria. Afterwards, the liquefaction potential and hazard of the area can be computed using geotechnical and seismological data.

In this study, the guidelines published by the California Department of Conservation, Division of Mines and Geology (CDMG, 1999) were applied in order to evaluate the liquefaction susceptibility of the sediments upon which the town of Larissa is situated. According to CDMG (1999) an area is characterized as Liquefaction zone when meeting one or more of the following criteria:

- evidence of historical liquefaction occurrences
- data from in-situ tests and analyses indicate that the soils are likely to liquefy

in case of lacking of the above data, a site is considered as susceptible to liquefaction when:

- area containing soils of late Holocene age, the groundwater is less 13 meters deep and the peak ground acceleration (PGA) having a 10% probability of being exceeded in 50 years is greater than 0.1g
- soils of Holocene age where the depth of groundwater table is less than 10 meters and the PGA (10% in 50 years) is greater than 0.2g

The area of Thessaly, where Larissa is situated, is characterized as a medium seismicity area regarding the seismic potential of Greece. The designed peak ground acceleration (PGA) of the Greek Seismic Code is equal to 0.24g, having a 10% probability of being exceeded in 50 years (EAK, 2000) while the maximum earthquake magnitude for the same recurrence interval is M = 7 (Papazachos & Papazachou, 1997). Moreover, the material upon which the town of Larissa was built has been mapped as recent alluvial deposits while man-made deposits consisted of embankments and artificial fills appear in some places. Furthermore, the average of the groundwater level is 6m depth according to data from boreholes that were performed to the urban area of Larissa. Hence, the urban area of Larissa is meeting all the above criteria of CDMG (1999) and consequently, is delineated as a susceptible to liquefaction zone.

5 EVALUATION OF LIQUEFACTION POTENTIAL

In order to evaluate the liquefaction potential at the urban area of Larissa, data from geotechnical boreholes with SPT that were drilled for construction purposes by the private company of Georesearch GP, were used. A total of 53 boreholes were taken into account where the maximum and the minimum depth of drilling were 15 and 10 meters, respectively.

Initially, the susceptibility to liquefaction of soil layers was evaluated based on the modified criteria proposed by Seed et al. (2003). According to these criteria a soil layer is defined as liquefiable when the value of liquid limit is LL<37 and the plasticity index is PI<12. In figure 2 is shown the classification of the soil layers into liquefiable and non-liquefiable ones, of the town of Larissa based on their Atterberg limits.

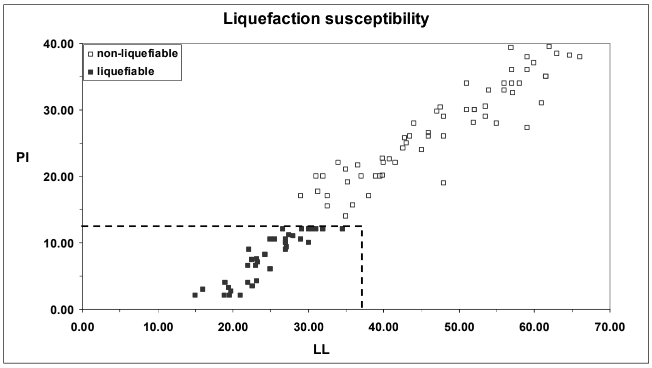

Figure 2. Liquefaction susceptibility of the subsoil layers based on the Seed et al. (2003) criteria.

Afterwards, the factor of safety against liquefaction per layer, fs, was calculated as the ratio of CRR (cyclic resistance ratio) to the CSR (cyclic stress ratio), based on the deterministic procedure, most known as the “simplified procedure” (Seed & Idriss, 1971; Seed et al., 1985; Youd et al., 2001).

The CRR, according to Youd et al. (2001) is computed using the following equation:

$$CRR = \frac{1}{34 - N_{1(60)}} + \frac{N_{1(60)}}{135} + \frac{50}{\left[10 \times N_{1(60)} + 45\right]^2} - \frac{1}{200}$$

(1)

The normalized SPT-N value is influenced by the measured standard penetration resistance N, the overburden pressure factor Cn, the correction for hammer energy ratio (ER) Ce, the correction for borehole diameter, Cb the correction factor for rod length Cr and the correction for samplers with or without liners. The Cn was calculated according to the equation proposed by Liao & Whitman (1986), while the borehole correction factors were estimated using the parameters suggested by Youd et al. (2001). Afterwards, a “fine content” correction was applied to the calculated $N_{1(60)}$ value in order to obtain an equivalent clean sand value $N_{1(60)cs}$ given by the equations proposed by Youd et al. (2001).

The CSR defines the seismic demand and is expressed as:

$$CSR = 0.65 \times \left(\frac{a_{\max}}{g}\right) \times \left(\frac{\sigma_{\omega o}}{{}'\sigma'_{vo}}\right) \times r_d \qquad (2)$$

Where σ_{vo}: total vertical stress at depth z, σ'_{vo}: effective vertical stress at the same depth, a_{max}: peak horizontal ground acceleration, g: acceleration due to gravity and r_d: stress reduction factor; estimated using the Liao & Whitman (1986) equation.

Finally, the CSR values have been divided by the magnitude scaling factor, MSF, which is calculated using the equation proposed by Youd et al. (2001). In this study, the magnitude and the a_{max} that were employed for all the calculations, were equal to 7

(Papazachos & Papazachou, 1997) and 0.24g (EAK, 2000), respectively.

Afterwards, the Liquefaction potential index of the boreholes was computed using the equation proposed by Iwasaki et al. (1982):

$$LPI = \int_{0}^{z} F(z)W(z)dz \tag{3}$$

Where z is the depth below the ground surface in meters and is calculated as w(z)=10-0.5z; F(z) is a function of the factor of safety against liquefaction, fs, where F(z) =1-fs when fs<1 and if fs>1 than F(z)=0. Equation (3) gives the values of LPI ranging from 0 to 100.

6 ASSESSMENT OF LIQUEFACTION HAZARD

Varnes et al. (1984) defined the natural hazard as the probability of occurrence of a potentially damaging phenomenon within a given area and in a given period of time. The goal of this study was the assessment of liquefaction hazard and the compilation of a map where the distribution of probability of liquefaction-induced surface disruption is shown.

In order to assess the liquefaction hazard at the town of Larissa, the computed values of Liquefaction Potential Index (LPI) per site were employed to the equation proposed by Papathanassiou (2008):

$$\Pr ob(liquefaction) = \left(\frac{1}{1 + e^{-(-3.092 + 0.218 \times LPI)}} \right) \tag{4}$$

This equation was defined by applying the statistical approach of logistic regression to a dataset that was consisted by records from post earthquake in-situ tests in Turkey, Taiwan and Greece. In this model, the LPI value is the independent variable while the occurrence or not of liquefaction phenomena is the dependent one. At sites where the Prob(liquefaction) is bigger or equal to 0.5, liquefaction phenomena are expected to be triggered while non-occurrence of liquefaction is predicted where Prob<0.5.

As it is shown in figure 3, the probability of liquefaction-induced ground failures to occur is very low at the town of Larissa. Only in two areas, close to the river Pinios, the computed value of probability approaches the boundary of 50%. At these sites, the occurrence of liquefaction surface evidence is likely in case of an earthquake with magnitude equal to 7 and a PGA equal to 0.24g.

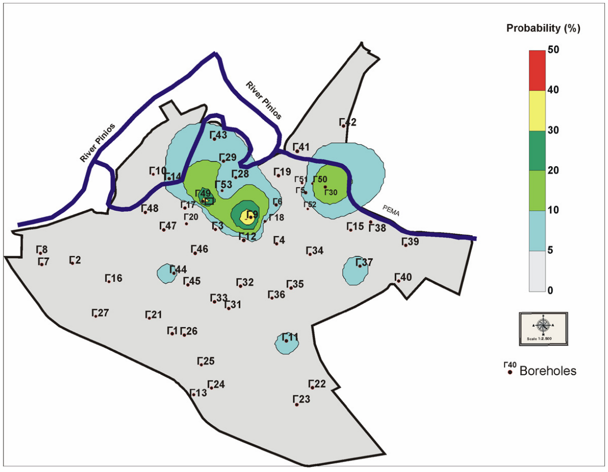

Figure 3. Map showing the probability of liquefaction-surface manifestation in the town of Larissa

7 CONCLUSIONS

The town of Larissa is located at the region of Thessaly, Central Greece, an area characterized as medium seismicity zone. The design acceleration provided by the Greek Seismic Code is 0.24g on seismic bedrock, with a 10% probability (Pt) of being exceeded over a period (t) of 50 years.

The aim of this paper was the evaluation of liquefaction susceptibility of the sediments and the assessment of the liquefaction hazard at the urban area of Larissa. In order to achieve this, the surface geology at the town of Larissa was correlated to the guidelines proposed by CDMG (1999), concluding that this area must be considered as likely to liquefaction zone.

Afterwards, the liquefaction potential was evaluated based on collected data from geotechnical profiles of borings with SPT while the Liquefaction Potential Index per borehole was computed using the provided by the Greek Seismic Code, PGA equal to 0.24g, and an earthquake magnitude equal to 7. The outcome of this study indicates that only at two areas liquefaction surface evidences are likely to occur for these earthquake parameters.

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