# Assessment of SPT-Based Liquefaction Potential of Erbaa (Tokat), Turkey

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ABSTRACT

Turkey is one of the earthquake prone countries in the world. The seismicity of the northern part of Turkey is mainly controlled by active North Anatolian Fault Zone. Several earthquakes and earthquake triggered hazards occurred by the tectonic activity of this fault zone. In recent past, 1999 Adapazari earthquake ($M_w$=7.4) has caused several fatalities in the western part of this fault zone. One of the most important observations after the earthquake was the liquefaction-related damages of the buildings. In this study, the liquefaction potential of Erbaa (Tokat) settlement area in Turkey, located partly on an alluvial plain of Kelkit river within the North Anatolian Fault Zone has been evaluated. Several boreholes were drilled and laboratory tests were performed on soil samples. Liquefaction analysis was performed by using SPT-based methods suggested by Youd et al. (2001), Cetin et al. (2004), and Idriss and Boulanger (2006). For the analysis, an earthquake magnitude of $M_w$=7.4 and the different peak ground acceleration (PGA) values were considered. The distribution of the liquefaction potential areas was presented on the maps. Based on the analysis, the loose granular materials of alluvium are likely to liquefy in case of occurrence of large magnitude earthquake with high PGA value.

## INTRODUCTION

Turkey is one of the earthquake prone countries in the world. The seismicity of the northern part of Turkey is mainly controlled by the active North Anatolian Fault Zone (NAFZ). Several earthquakes and earthquake triggered hazards occurred by the tectonic activity of this fault zone. In recent past, 1999 Adapazari earthquake with a magnitude of 7.4 and 1999 Duzce earthquake with a magnitude of 7.2 caused several fatalities recently in the western part of this fault zone.

There are various types of damages that may occur based on the earthquake magnitude and energy. One of the most important observations after an earthquake is the liquefaction-related damages of the structures. Evidences of liquefaction phenomenon may exist for historical earthquakes as well. The study of case histories shows that conditions, effects and criteria of the liquefaction cases should be analyzed to evaluate liquefaction hazards and delineate the susceptible areas.

The concept of the liquefaction was first introduced by Casagrande in the late 1930s (Day, 2002). Liquefaction can be defined as the development of high pore water pressures due to the ground shaking and the upward flow of water may turn the sand into liquefied condition. This phenomenon can also be explained as the temporary loss of strength of saturated loose granular soils. It can cause many catastrophic failures during and after the earthquakes. These failures may occur in the form of settlement and tilting of the buildings, as well as lateral spreading of the soils.

The study area, Erbaa located in the North Anatolian Fault Zone (NAFZ), is one of the biggest towns of Tokat with a population of 47000 in Turkey. Erbaa is partly located on Kelkit river plain also called as Erbaa basin (Figure 1). The city center of old Erbaa was located on the left embankment of the Kelkit River. After the disastrous 1942 earthquake (M=7.1), the settlement area was seriously damaged and moved southwards of its old place in 1944.

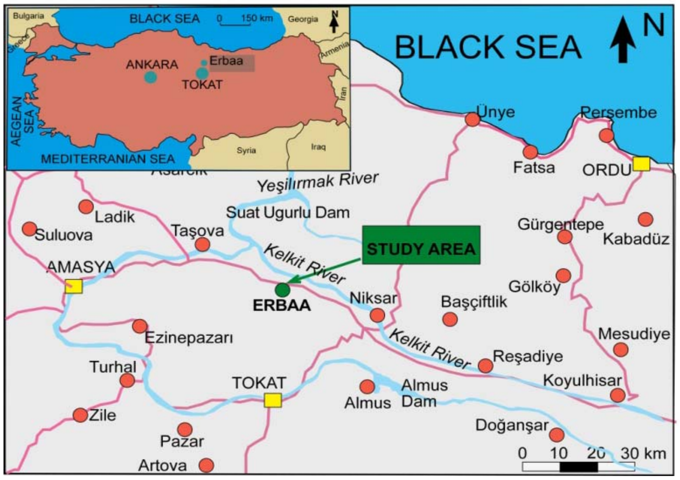


*Fig. 1. Location map of the study area.*

In this study, it is aimed to explore the liquefaction potential of Erbaa. In order to investigate the liquefaction potential of the area, geotechnical investigations including geological mapping, drilling with in-situ tests and sampling were conducted. The data obtained from this study were evaluated together with existing data. Liquefaction analysis was performed on the basis of field and laboratory test results.

In the past, a total of 56 boreholes were drilled for different purposes in the study area. The depths of these boreholes vary from 10m to 20m. In most of them, ground water was observed. As a preliminary step, new boreholes with 30m depth were opened and the essential laboratory tests were conducted in this study. Ground water exists in some of the boreholes, and its depth ranges between 0.75m to 9 m in the alluvial units. The distribution of the boreholes can be seen in Figure 2. New boreholes assigned with "N" letter to distinguish from the previous ones in the figure.

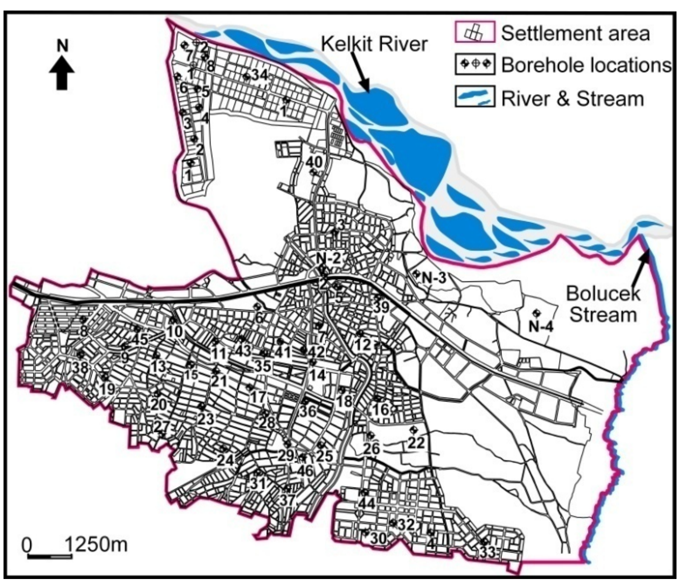


*Fig. 2. The distribution of boreholes in the study area.*

There are various methods to evaluate the liquefaction potential of saturated soils. These methods are based on SPT, CPT or Vs measurements, separately or all of them (Kayen et al., 1992; Andrus and Stokoe, 2000). In this study, SPT-based three methods suggested by Youd et al. (2001), Cetin et al. (2004), and Idriss and Boulanger (2006) were used to figure out the liquefiable zones in the study area.

## GEOLOGY AND TECTONICS OF THE STUDY AREA

The study area and its close vicinity in the Erbaa basin can be defined as pull-apart basin which was formed by the tectonic activity of the North Anatolian Fault Zone (NAFZ). The NAFZ is a 1500 km long seismically active right lateral strike slip fault that develops relative motion between the Anatolian Plate and Black Sea Plate (Şengör et al., 1985). Between 1939 and 1967, the NAFZ ruptured by a westward propagating six large earthquakes with a magnitude greater than 7, and caused approximately 900 km surface break (Allen, 1969; Ketin, 1969; Ambraseys, 1970).

The study area is located on the eastern part of the NAFZ. Surface ruptures of 1939, 1942 (M=7.1) and 1943 (M=7.6) earthquakes occurred in Tasova- Erbaa and Niksar basins (Barka et al., 2000). The Tasova-Erbaa pull-apart basin is approximately 65 km long and 15-18 km wide (Figure 3).

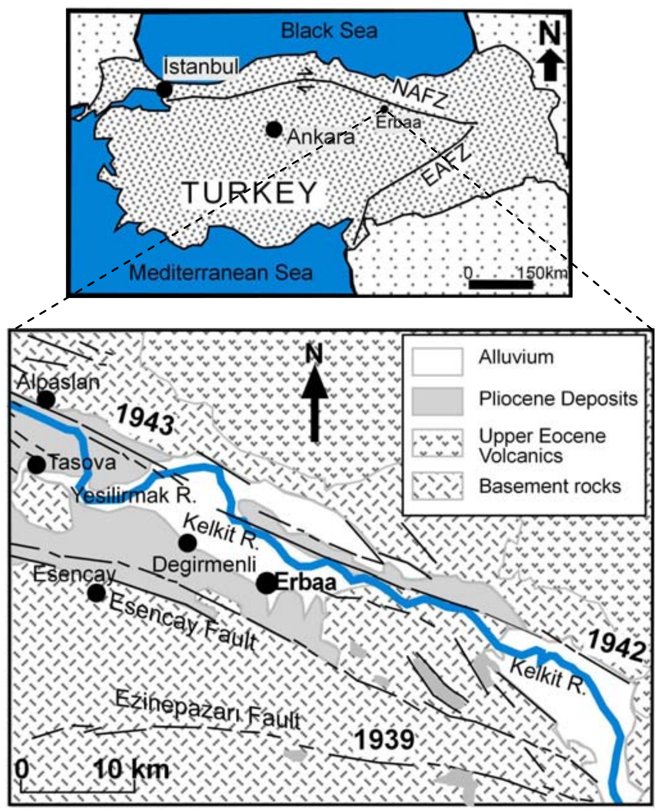


*Fig. 3. Geology and the faults in the close vicinity of Erbaa*

It is bounded near its northern margin by fault segments that ruptured in the 1942 and 1943 earthquakes (Figure 3). The southern margin is bounded by the Esencay fault, which has a distinct morphological expression; however, no instrumental and/or historical earthquakes have been mentioned in the study of Barka et al. (2000).

In the study area, metamorphic rocks and the limestone layers as basement rocks can be observed with an age from Permian to Eocene. These rocks can be followed by Upper Eocene volcanics that contain basalt, andesite, agglomerate, tuff and the alternation of sandstone-siltstone layers. These units are overlaid by Pliocene deposits consisting of semi-consolidated clay, silt, sand, and gravel with an unconformity and recent Quaternary alluvial unit (Aktimur et al., 1992) (Figure 3). The alluvium including gravel, sand, and silty clay can be observed in the basement of Kelkit river valleys and in the northern part of the Erbaa basin. The alluvial unit consists of heterogeneous materials, derived from various older geological units in the vicinity. Their lateral and vertical extents cannot be easily traced because they are in the form of wedges and lenses. The Quaternary alluvial unit and Pliocene deposits most extensively cover the study area. While the northern part of the settlement area is located on the alluvial unit, the Pliocene deposits dominate the southern part of Erbaa (Yilmaz, 1998).

## METHODOLOGY

Previous geotechnical investigations of the study area include 56 drillings and the laboratory results (Canik and Kayabali, 2000; Akademi, 2002; Metropol, 2005). The depths of these boreholes change between 10 and 20m. SPT blow counts of the boreholes which were taken at every 1,5m depth are considered and the laboratory test results are used for the liquefaction analyses. In addition to that, new boreholes with 30m depth were opened as a preliminary stage of this study. During the 30m depth of drilling, undisturbed sampling and SPT tests were applied at every 0,50m intervals to identify the potential liquefiable layers. Thus, continuous samples were taken.

In this study, the liquefaction analysis was conducted down to 20 m depth of the soil layers. The SPT-based methods which were updated by Youd et al. (2001), Cetin et al. (2004) and Idriss and Boulanger (2006) were employed. Based on the earthquake magnitudes recorded in the past along the NAFZ, magnitude of the earthquake was considered as 7.4 and different peak ground acceleration (PGA) values (0,35g; 0,40g; 0,45g) were applied to model the possible earthquake scenarios. The distribution of the liquefiable areas with a factor of safety less than 1 was presented on the maps.

## EVALUATION OF THE LIQUEFACTION POTENTIAL OF THE STUDY AREA

In the literature; several methodologies were suggested by many scientists to evaluate liquefaction potential of the areas (Seed and Idriss, 1971; 1983; Seed et al., 1985; 2001; Poulos et al., 1985; NCEER, 1997; Youd and Noble, 1997; Youd et al., 2001; Kramer, 1997; Cetin, 2000; Cetin et al., 2004; Idriss and Boulanger, 2006). These methods consider SPT, CPT and $V_s$ measurements at a site. Mostly, SPT-based methods are used in the literature since the SPT applications are more practical and cheaper than the other applications. However, CPT-based (Robertson and Wride, 1998; Toprak, et al., 1999; Juang, et al., 2003; Olsen, 1984; 1997; Moss, 2003; Moss et al., 2004) and $V_s$-based (Andrus and Stokoe, 1997; 2000) measurements can be correlated with other methods and used for the liquefaction potential analyses, as well.

The goal of this study is to point out the liquefaction potential of Erbaa. The SPT measurements and the laboratory data were evaluated and three SPT-based procedures which are updated by Youd et al. (2001), Cetin et al. (2004), and Idriss and Boulanger (2006) were considered in this research. These procedures are based on the ratio of cyclic resistance ratio (CRR) and the cyclic stress ratio (CSR). CRR represents the liquefaction resistance of soils covering some essential corrections for the obtained SPT blow-counts. The equivalent overburden stress of 100 kPa using the correction factor ($C_N$) is one of the important corrections for the analyses. Several equations for $C_N$ were suggested by different researchers (Peck et al., 1974; Seed, 1976; Seed and Idriss, 1983; Tokimatsu and Yoshimi, 1983; Liao and Whitman, 1986; Bowles, 1988; Boulanger and Idriss, 2004). Liao and Whitman (1986) equation (1) was used for the Youd et al. (2001) and Cetin et al. (2004) methods. The iteration of the overburden pressure equation (2) was considered for the Idriss and Boulanger (2006) method.

$$C_N = (1 / \sigma'_v)^{0.5} \qquad (1)$$

$$C_N = (Pa / \sigma'_v)^{\alpha} \leq 1.7 \qquad (2a)$$

$$\alpha = 0.784 - 0.0768 \sqrt{(N_1)_{60}} \qquad (2b)$$

The other corrections were applied for hole-diameter, rod-length and the type of sampler to calculate corrected SPT N-value of each layer. The depth of the ground water table and the unit weights of the soils were considered for the calculations. The normalized SPT blow-count ($N_{1,\ 60}$) including fines content correction was taken for the CRR calculations.

For CRR and/or CSR calculations, different approaches were suggested by these three researches. In the Youd et al. (2001) method, CRR gives cyclic resistance ratio for magnitude 7.5 earthquakes and it is recommended to use magnitude scaling factor (MSF) for normalizing the exact magnitude value. Additionally, correction factors developed by Seed and Idriss (1983) were extended to include larger overburden pressure ($K_\sigma$) and static shear stress conditions ($K_\alpha$) in the application of Youd et al. (2001) method. In the study of Cetin et al. (2004), new correlations related to magnitude correlated duration ($DWF_M$), correction of fines content, stress reduction factor ($r_d$) and overburden stress were proposed based on the field data. In the research of Idriss and Boulanger (2006), the previous procedures were re-evaluated by using the SPT-CPT case histories, and semi-empirical procedures were recommended. On the basis of the simplified procedure, the stress reduction factor ($r_d$), magnitude scaling factor (MSF) overburden correction factor for cyclic stress ratio ($K\sigma$), and the overburden normalization factor for penetration resistances ($C_N$) were given in their studies (Boulanger, 2003; Boulanger and Idriss, 2004; Idriss and Boulanger, 2003).

The cyclic stress ratio (CSR) represents the earthquake load conditions which mean the seismic factors for the site. This ratio includes the earthquake magnitude and peak ground acceleration to estimate the liquefaction resistance. As it is known, records from the earthquakes include the relationship between the duration and the magnitude of an earthquake. For instance, duration may increase with a distance from the earthquake source and change with site conditions. Moreover, peak ground acceleration (PGA) can be obtained from different approaches such as equations of attenuation relationships, site response analyses and the amplification ratios of estimating peak ground acceleration.

In order to determine the seismic factors of the area, similar earthquakes that occurred in the North Anatolian Fault Zone (NAFZ) were considered for the analyses since no earthquake records are available for the site and its close vicinity. That is why, the magnitude was chosen as 7.4 according to the very recent 1999 Adapazari earthquake and different peak ground acceleration (PGA) values (0,35g; 0,40g; 0,45g) were employed for the study area. The zonation maps of the settlement area obtained for three different methodologies and PGA values are presented in Figures 4-12.

Based on the distribution of the liquefaction potential for the same PGA value, the methodology of Youd et al. (2001) generally presents higher factor of safety results especially in the middle regions of the district which leads a larger non-liquefiable area. On the contrary, the other two methods show lower values and they point out the same zones as liquefiable.
In case different PGA values are considered, the method of Cetin et al. (2004) illustrates the northern part of the settlement area as completely liquefiable for 0,40g and 0,45g. However, according to Youd et al. (2001), there are some non-liquefiable zones in the northern part (e.g. BH 1). These liquefiable regions are very close to Kelkit River. The different factor of safety results in Youd et al. (2001) may be due to the methodology restrictions. In the methodology of Youd et al. (2001), CRR equation is valid for $(N_1)_{60cs}$ (normalized SPT blow count) less than 30. They recommended that if normalized SPT blow count is higher than 30, the granular soils are too dense to liquefy and can be defined directly as non-liquefiable. Therefore, the differences in liquefaction potential of Erbaa using Youd et al (2001) method may be attributed to the above mentioned limitation.

Evaluation of the overall data reveals that only the northern part of Erbaa has liquefaction potential. This zone mainly corresponds to alluvium of the Kelkit River. Therefore, the alluvial deposits should be paid due consideration for the purpose of future urban planning.

## CONCLUSIONS

The liquefaction potential of Erbaa is evaluated on the basis of the zonation maps. These zonation maps are prepared by using three different methodologies with dissimilar PGA values.

As a conclusion, the liquefaction potential in the Erbaa district is dominant in the northern part of the study area. The northern part is on loose alluvial units and is very close to the Kelkit River. Although there are some alluvial units in the southern part, stiffer Pliocene deposits are mainly observed there. The Pliocene deposits are less sensitive to liquefaction. Besides, the alluvial deposits are getting thicker towards the Kelkit River. As a result, the loose granular materials may easily liquefy in the case of the occurrence of large magnitude earthquakes with high PGA values.

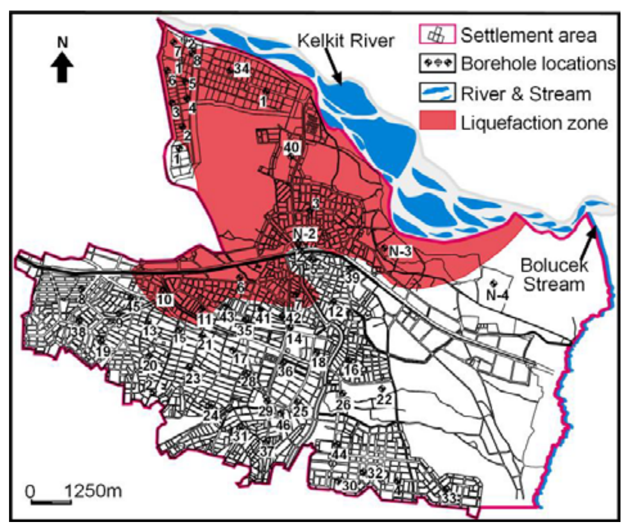


*Fig.4. Liquefaction potential of Erbaa based on Youd et al. (2001) for 0,35g.*

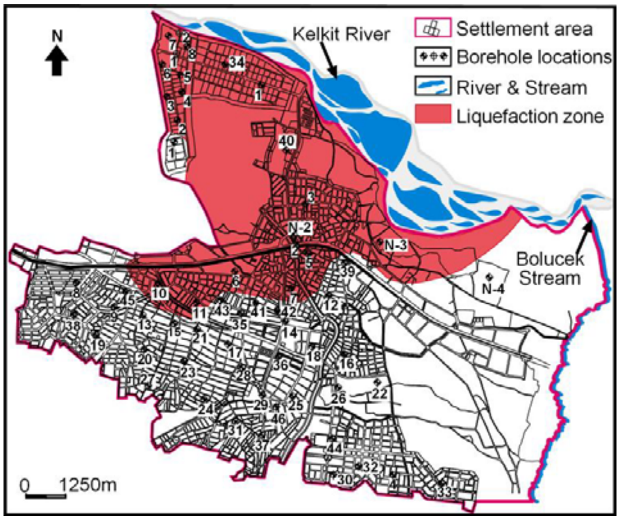


*Fig.5. Liquefaction potential of Erbaa based on Cetin et al. (2004) for 0,35g.*

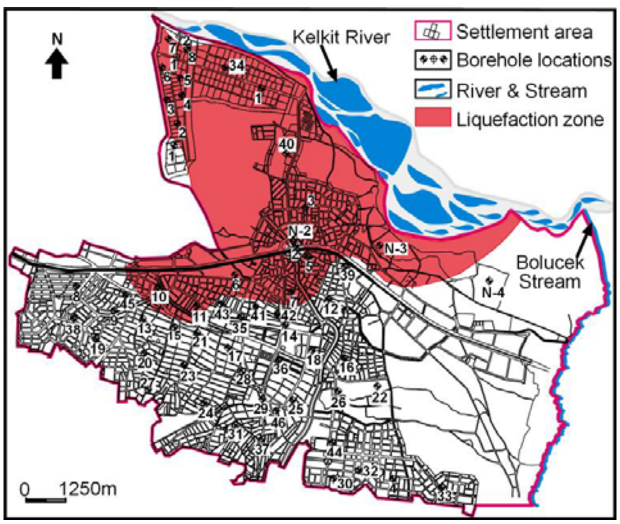


*Fig.6. Liquefaction potential of Erbaa based on Idriss and Boulanger (2006) for 0,35g.*

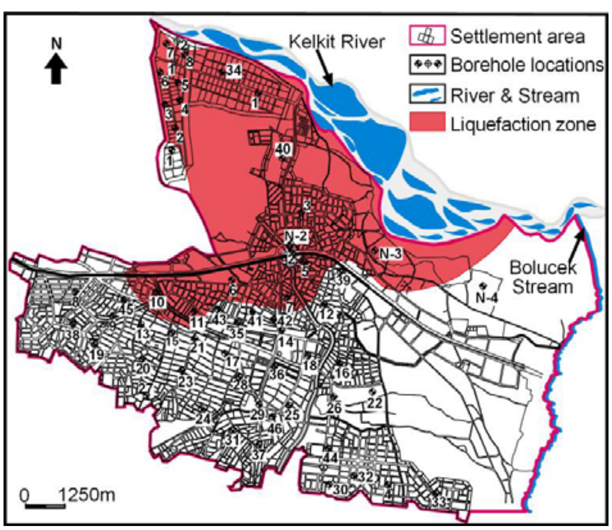


*Fig.7. Liquefaction potential of Erbaa based on Youd et al. (2001) for 0,40g.*

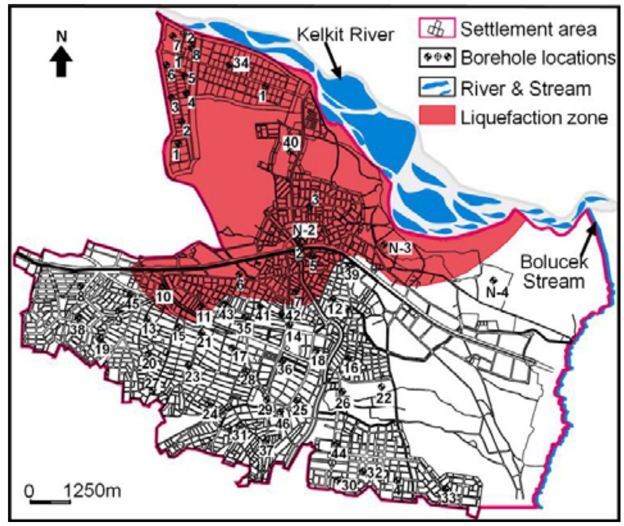


*Fig.8. Liquefaction potential of Erbaa based on Cetin et al. (2004) for 0,40g.*

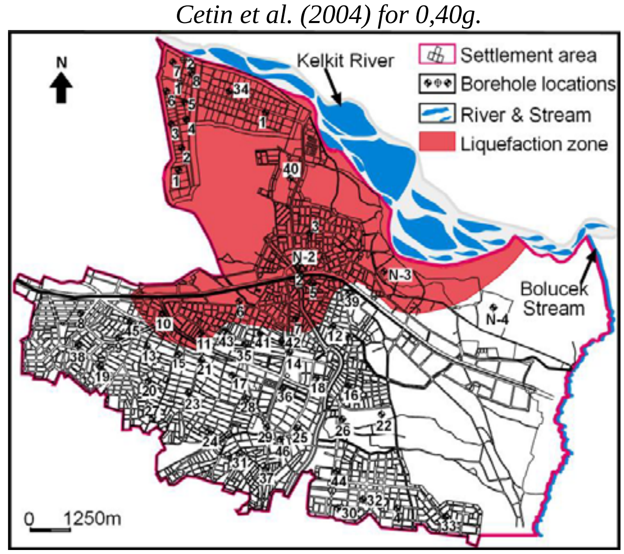


*Fig.9. Liquefaction potential of Erbaa based on Idriss and Boulanger (2006) for 0,40g.*

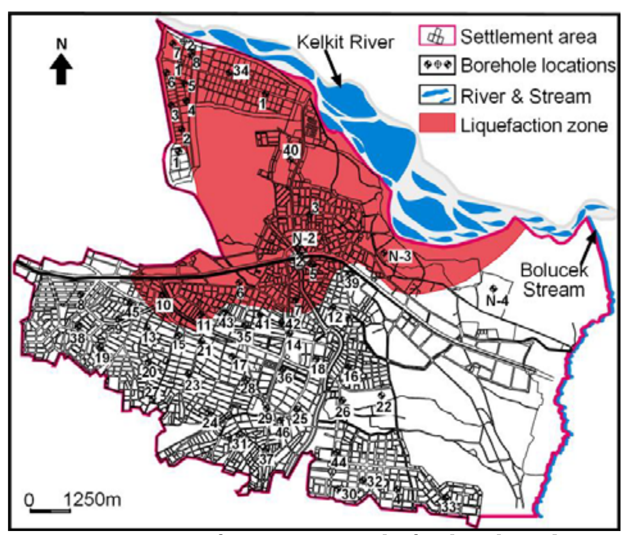


*Fig.10. Liquefaction potential of Erbaa based on Youd et al. (2001) for 0,45g.*

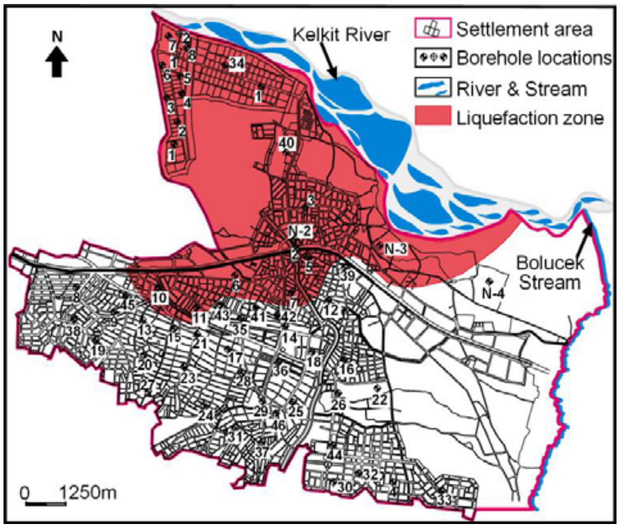


*Fig.11. Liquefaction potential of Erbaa based on Cetin et al. (2004) for 0,45g.*

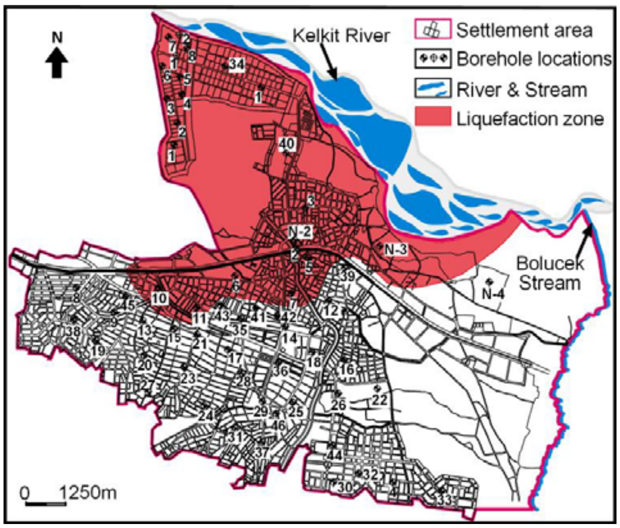


*Fig.12. Liquefaction potential of Erbaa based on Idriss and Boulanger (2006) for 0,45g.*

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