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DETERMINATION OF THE LİQUEFACTİON POTENTİAL OF SOİLS OF THE NORTHERN SEA COMMAND SİTE (İSTANBUL, TURKEY) BASED ON SPT DATA

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Abstract. Istanbul is the most populous and biggest city in Turkey. Its construction plans increase day by day. Large earthquakes of high magnitudes occurred along the North Anatolian Fault (NAF) in this city. İstanbul has seperated two parts as Europe and Asia, includes various types of rocks and soils. This study aimed at determining liquefaction analyses at the North Turkish Naval Forces site (Kasımpaşa, İstanbul) in İstanbul province. Military buildings were damaged by the Gölcük earthquake 7.4 magnitude in 1999. In-situ tests were done at opened boreholes and laboratory experiments were carried out by taking samples for this purpose. The liquefaction hazard of soils in Kasımpaşa district of Istanbul was investigated by Cyclic Stress Resistance approach. Matlab software was written by using the Seed-Idriss method for liquefaction analysis. The input parameters such as Standart Penetration Test-N (SPT-N) values taken from various depths, fine contents (FC), ground water levels (GWL) and liquid limits were used for all layers within 5.0 m from the surface. The magnitude and acceleration values of a scenario earthquake in the analysis for İstanbul were selected 7.5 (magnitude) and 0.4g, 0.5g (accelerations). Calculated the Cyclic Stress Ratio (CSR) and the Cyclic Resistance Ratio (CRR) were presented. The safety factor against liquefaction was also estimated. Geographic Information Systems (GIS) maps of groundwater level and liquefaction potential were established with the help of the necessary data parameters on survey area. The presences of liquefiable regions were determined by the results obtained. The results in this region are important for human security on the construction site.

Keywords: *liquefaction, North Anatolian fault, Istanbul, SPT, cyclic resistance ratio, cyclic stress ratio, Arc-GIS.*

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1. Introduction

To reduce the seismic hazards caused by earthquakes and to obtain the structural safety against earthquake forces, determination of the liquefaction behaviour of sandy soils is gaining importance in microzonation studies. The most influential factors of liquefaction are ground water close to surface and loose soils. Liquefaction potential of soils contributes to grain size distribution, fines content, geological time, sedimentation, permeability, earthquake magnitude and earthquake duration (Özaydın 2007). Although Turkey is an earthquake country because of its tectonic structure, there have been few surveys of liquefaction in Turkey. The importance of liquefaction phenomena has attracted relevant researchers' attention when extensive liquefaction events occurred during the 1999 Marmara Earthquake (Yılmaz and Yavuzer 2005; Fırat et al. 2009).

SPT-N values is the most common method for determining the liquefaction problems all over the world and especially in Turkey (Seed and Idriss 1971; Youd et al. 1997; Mollamahmutoğlu et al. 2003; Ozcep and Zarif 2009). Seed and Idriss (1971) suggested a simplified procedure based on SPT-N values for estimation of soils liquefaction resistance after two large earthquakes had happened in Alaska and in Nigeria in 1964. Iwasaki (1982) recommended lots of methods based on earthquakes to determine the potential of liquefaction for sandy soils. The most common deterministic approach based on SPT data proposed by Seed et al. (1984, 1985) was accepted by NCEER Working Group (NCEER 1997; Youd et al. 2001). Liao et al. (1988) 's approach used a larger number of data points later Seed *et al* 1984 used them. This relationship was developed using the maximum likelihood estimation method for probabilistic regression. Seed et al. (1984) used the same simplified rd for in-situ CSR especially at shallow depths. In the approach of Juang et al. (2002) used field performance data processed by previous investigators and probabilistically based triggering correlations developed using regression techniques including logistic regression, Bayesian updating and other methods. Shahri et al. (2012) conducted a survey called estimation of liquefaction potential at Korzan Earth Dam in İran. Kumar et al. (2012) presented approaches for estimating liquefaction potential of soils with conventional method and artificial neural network (ANN). Duman et al. (2014) published an article about the estimation of the soil liquefaction potential index using SPT data in the Erzincan, Turkey. Rezaei and Choobbasti (2014) applied the conventional method and ANN in Babol (Iran) for microtremor measurements of liquefaction potential. Sana and Nath (2016) established a liquefaction potential analysis of the Kasmir valley allivium in Himalaya with 64 SPT boreholes and earthquake of 7.6 magnitude in 2005 at Kashmir.

This paper will present to estimate potential of liquefaction related to SPT values and laboratory results for the military residential area in Marmara region (TURKEY). The potential of liquefaction was calculated by using Matlab software with the Seed- Idriss method. Maps of liquefaction result were prepared with Arc-GIS software.

2. Method and Theory

Pore water pressure increases due to earthquakes in saturated soils which are under cyclic loading. The soil will behave more like a liquid than a solid - hence, the name "liquefaction". The Cyclic Stress Resistance approach is the most common method for determining characteristic of liquefaction analysis. This method is based on numbers of shear stress and size of shear stress during earthquakes happened for potential of liquefaction. Two parameters are necessary for determining liquefaction resistance of soils (Seed and Idriss 1971). These are based on an earthquake cyclic stresses in the soil (CSR) and the measurement of liquefaction resistance (CRR).

The simplified procedure to evaluate stresses causing liquefaction (CSR), taken from Seed and Idriss (1977) is defined as

$$CSR = 0.65 * \left(\frac{a_{\max}}{g}\right) * \left(\frac{\sigma}{\sigma'}\right) * r_d \quad (1)$$

whereas a_{max} is the peak horizontal acceleration, g is the gravity, σ is the overburden stress, σ' is the effective overburden stress, r_d is the stress reduction coefficient. The following equation is used to determine mean values of r_d for practice (Liao and Whitman, 1986) $z < 9.15m$ $r_d = (1 - 0.00765z)$, for $z > 9.15$ $r_d = (1.174 - 0.0026z)$.

CRR based on the corrected SPT blow count $(N_1)_{60}$ were developed by Seed et al. (1985), who studied 125 liquefaction case histories in North and South America, Japan and China. Sandy soils sites that were subjected to known earthquake liquefaction case histories were categorized as liquefied or nonliquefied. $(N_1)_{60}$ is the SPT blow count normalized to an overburden pressure of approximately 100 kPa. By plotting CSR versus SPT $(N_1)_{60}$ pairs for liquefied and non-liquefied zones, it could be found that a curving threshold boundary between liquefied and nonliqufied zones defines CRR value. Curves were developed for granular soils with fines contents of 5% or less, 15% and 35% is the basic penetration criterion for the simplified procedure and is referred to as SPT clean-sand base curve. Liquefaction resistance (CRR) is defined as Eq.(2).

$$CRR = (1/34 - (N_1)_{60}) + (N_1)_{60}/135 + 50/(10*(N_1)_{60} + 45)) - 1/200 \quad (2)$$

The curve, which includes correlation between in-situ test and resistance of liquefaction, is for earthquakes with moment magnitude, Mw, of 7.5 and sands with fines content, FC < 5 %. To apply the curve to soils with FC > 5%, I. M. Idriss, with the assistance of R. B. Seed developed the correction of $(N_1)_{60}$ to an equivalent clean sand value shown in Eq.(3).

$$(N_1)_{60cs} = \alpha + \beta (N_1)_{60} \quad (3)$$

where $(N_1)_{60cs}$ is the equivalent clean sand value of $(N_1)_{60}$ and coefficients of α and β can defined as Eq.(4).

$$\begin{aligned} &\alpha = 0.0 && \textit{for } FC \le 5\% \\ &\alpha = \exp[1.76 - 190/FC^2] && \textit{for } 5\% \prec FC \prec 35\% \\ &\alpha = 5.0 && \textit{for } FC \ge 35\% \\ &\beta = 1.0 && \textit{for } FC \le 5\% \\ &\beta = \left[0.99 + FC^{1.5}/1000\right] && \textit{for } 5\% \prec FC \prec 35\% \\ &\beta = 1.2 && \textit{for } FC \ge 35\% \end{aligned} \quad (4)$$

The last step in the liquefaction analysis is to calculate the safety factor (SF). The safety factor for level ground liquefaction resistance can be defined as

$$SF = CRR/CSR \quad (5)$$

The safety factor is smaller than 1 if there is a risk of liquefaction in the region. Conversely, if the safety factor is bigger than 1, the region is free from liquefaction risk.

3. Application

3.1. Tectonics and General Geology of Istanbul

Istanbul is located in the NAF system and big earthquakes occured in the past. The North Anatolian (NA) is a transform fault about 1200 km. Its direction is from Karlıova to the Saros Gulf along the Black Sea mountains (figure 1). NAF is not a single and continuous transform fault under the sea. Its complex fault system was identified from seismic reflection sections. According to these sections, it has a potential big earthquake (Smith et al.0 1995; Okay et al., 2000; Parke et al., 2000). The NAF zone was broken by big earthquakes. This broken fault zone began with the Erzincan earthquake in 1939, which is 7.9 and has continued nine more destructive earthquakes with magnitudes greater than 7 since. The eastern Anatolian side of Istanbul is affected by small active faults. İstanbul's city centre is a few kilometers away from The NAF zone.

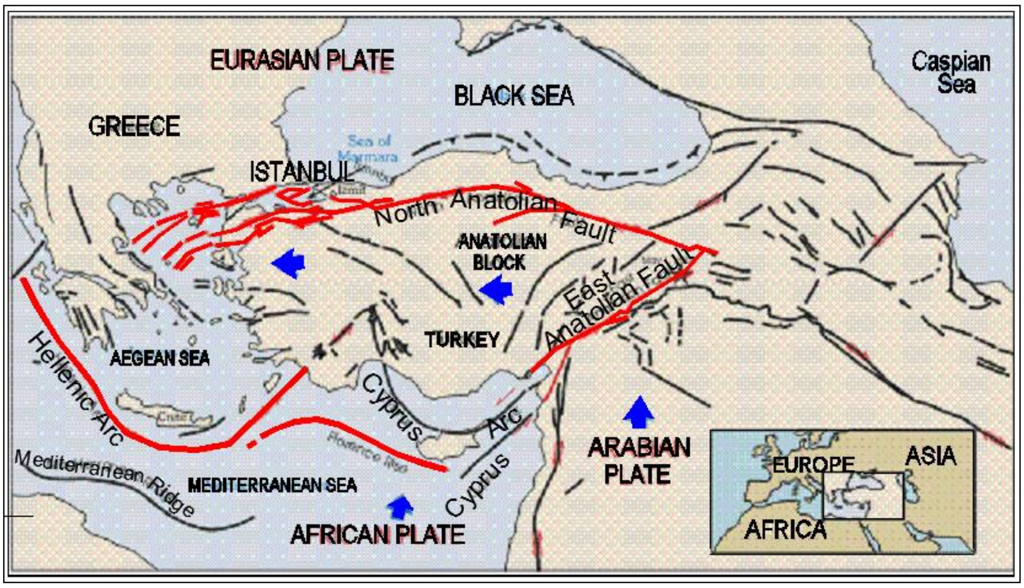


Fig. 1. Tectonic mechanism of NAF (modified from Barka (1992) and Rockwell et al., (2000))

In the Istanbul area Palaeozoic, Mesozoic and Cenozoic formations can be found (figure 2). Geology of survey site has been called as Carboniferous Trakya Formation. Trakya formation's thickness are from 600 metres to 1700 metres (Eroskay, 1985). It includes sandstones, claystone, shale - graywacke and crystallized limestone formations. According to weathering, their colours vary as dark grey - green or greyish - brown. The best known rock types of this formation sandstone units however limestone and conglomerate interbeds or lenses are found between layers. The Trakya formation is very intensely folded, faulted, fractured, and is also weathered which is well developed along discontinuities (Tugrul and Undül, 2006).

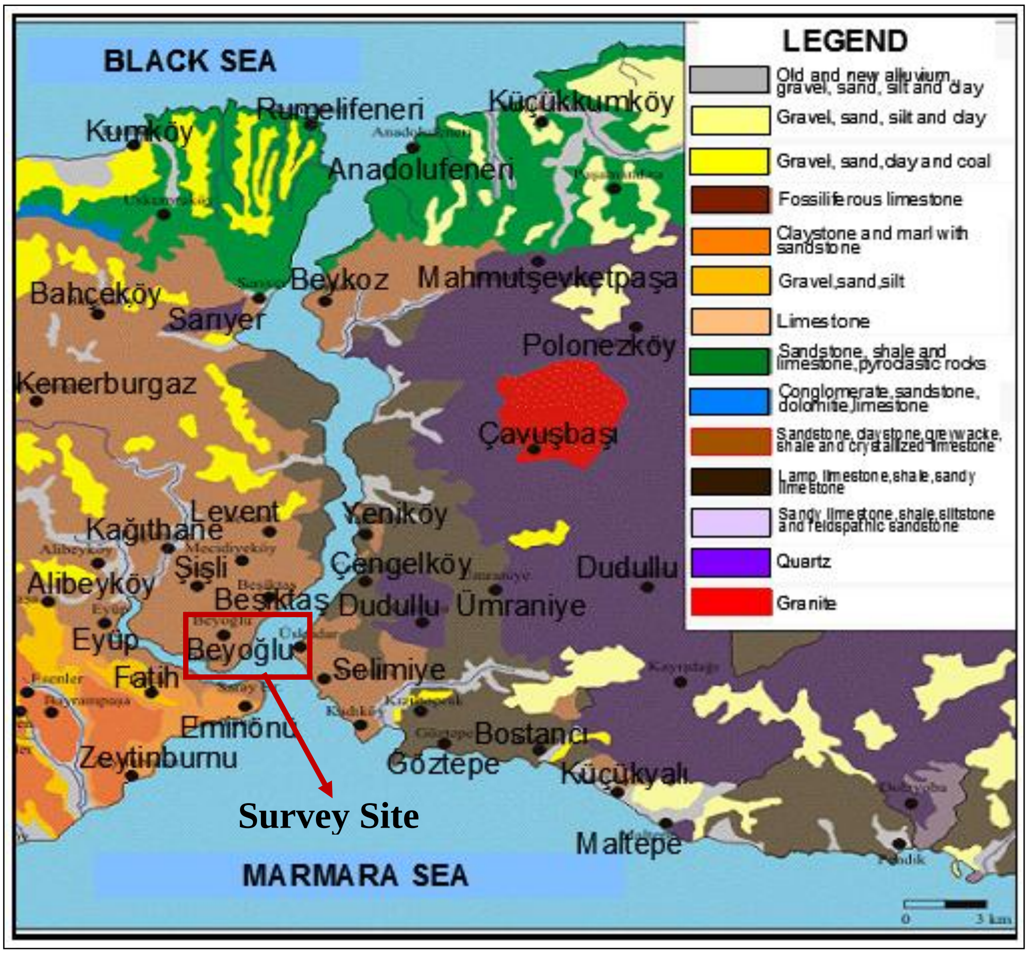


Fig. 2. General geology map of İstanbul (modified from Ketin (1981), Undül and Tugrul, (2006))

3.2. Description of Survey Site and Survey Datasets

The survey site is located in the military region at Kasımpasa-Istanbul, Turkey (Figure 2). The concrete structures at the survey site were built in ancient times. This area was effected from by the Gölcük earthquake (1999) with 7.4 magnitude. Some places of this area were damaged because of the liquefaction problems. Our aim was to determine the liquefaction potential of residential area. For this reason, 10 boreholes were drilled and a total of 97 data taken from boreholes were evaluated. Drilling depths varied between 20.00 - 30.00 m. and SPT were done each 1.5 m. Groundwater levels vary from 1.15 m to 1.90 m. Groundwater level map is an important parameter for the determination of building damages (Figure 3). The application area is drawn by red colour and boreholes drilled at the survey site were shown small red points. Groundwater levels (GWL) measured are indicated by the distribution of blue colour in Figure 3. There are many data on alluvial formations collected from boreholes and from observations throughout survey area. Details of drilling which include location, depth and numbers of SPT are given in Table 1. Samples were taken for laboratory tests. Types of soil, water contents and results of sieve analysis can be seen in Table 2. Classification of the Karargah soils are changes as CL, ML and SM. Water contents of Karargah boreholes vary from 11.6% to 34.2%. Classification of the Court Building soils are SC and SM. Water contents of these boreholes changes between 18.5% - 24.8%. Classification of the Kısla Building soils has lots of different types but the most important lithology is SM. Water contents of these boreholes changes between 17.5% - 30.4%.

Table 1. Depths of drilled boreholes and SPT blow count at the survey site

North Turkish Naval Forces		
Name of Boreholes	**Depth (m)**	**Number of SPT**
North Turkish Naval Forces Building of Karargah		
KAR_SK_1	20.00	8
KAR_SK_2	20.00	8
KAR_SK_3	20.00	6
KAR_SK_4	20.00	3
North Turkish Naval Forces Building of Court		
SAV_SK_1	20.00	3
SAV_SK_2	20.00	11
North Turkish Naval Forces Building of Kısla		
KIS_SK_1	21.50	14
KIS_SK_2	20.00	13
KIS_SK_3	30.00	19
KIS_SK_4	20.00	12

Table 2. Values of water content, sieve analysis and classification of soil at the boreholes

Name of Boreholes	Name of Sample	Depth (m)	Wn (%)	Sieve Analysis		Classification of Soil
				+4 (%)	-200 (%)	
North Turkish Naval Forces Building of Karargah						
KAR_SK_1	SPT-2	3.00-3.45	13.3	5	54	CL
	SPT-6	9.00-9.45	11.6	0	54	CL-ML
KAR_SK_2	SPT-1	1.50-1.95	34.2	29	19	SM
	SPT-3	4.50-4.95	-	31	16	SM
KAR_SK_3	SPT-2	3.00-3.45	-	17	24	SM
	SPT-4	6.00-6.45	26.9	14	20	SM
KAR_SK_4	SPT-2	3.00-3.45	17.7	4	37	SM
North Turkish Naval Forces Building of Court						

SAV_SK_1	SPT-2	3.00-3.45	22.9	13	34	SC
SAV_SK_2	SPT-2	3.00-3.45	19.0	8	25	SM
	SPT-4	6.00-6.45	18.5	17	18	SM
	SPT-8	12.0-12.45	24.8	4	27	SM
North Turkish Naval Forces Building of Kısla						
KIS_SK_1	SPT-2	3.00-3.45	25.7	12	31	SM
	SPT-4	6.00-6.45	24.3	3	23	SM
	SPT-8	12.0-12.45	-	20	22	SM*
	SPT-13	19.50-19.95	30.3	1	83	CL
KIS_SK_2	SPT-1	1.50-1.95	-	22	31	SM*
	SPT-3	4.50-4.95	-	23	22	SM*
	SPT-6	9.00-9.45	-	18	19	SM*
	SPT-10	15.0-15.45	-	3	17	SM*
KIS_SK_3	SPT-3	4.50-4.95	-	2	71	ML*
	SPT-5	7.50-7.95	-	1	68	MH*
	SPT-9	13.5-13.95	-	0	76	CL*
	SPT-14	21.0-21.45	-	0	68	CL-ML
	SPT-17	25.5-25.95	25.8	26	57	CL
KIS_SK_4	SPT-2	4.50-4.95	24.9	6	25	SM
	SPT-7	12.0-12.45	17.5	11	31	SM

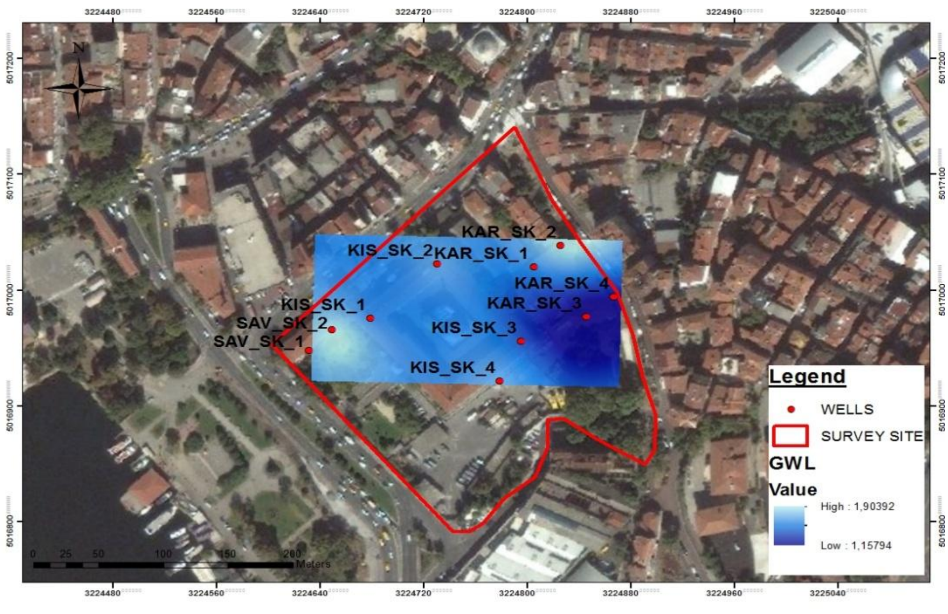
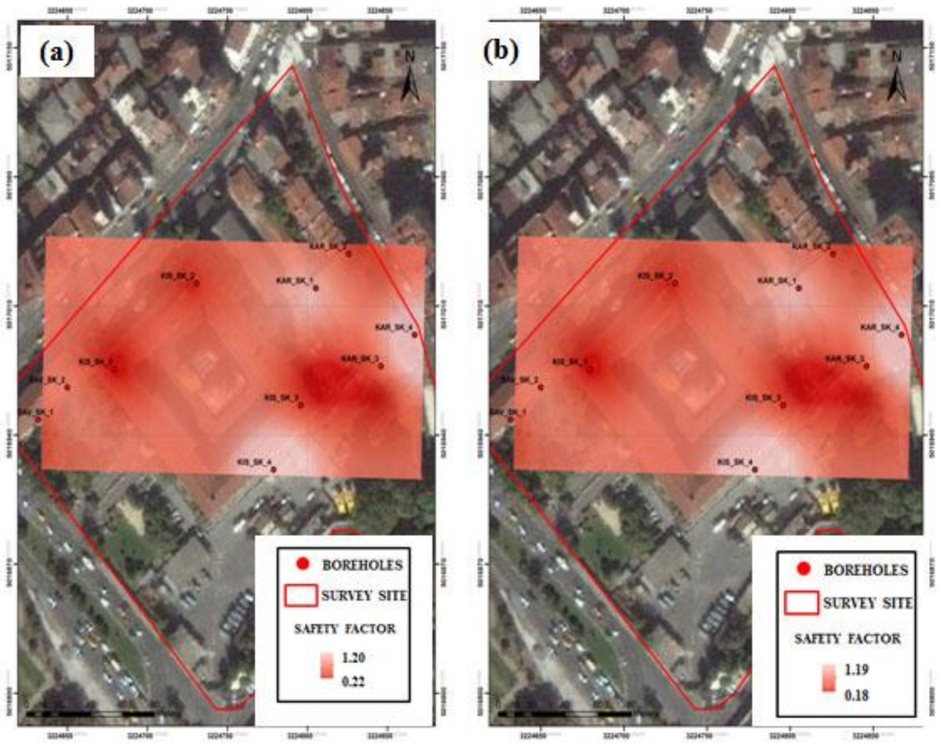


Figure 3. North Turkish Naval Forces site and measured groundwater levels from boreholes

Matlab software written for liquefaction analysis is based on the Seed and Idrıss method. The magnitude and accelerations of the earthquake in risk analysis were chosen as 7.5 and 0.40g, 0.50g, respectively. Safety factors are calculated at 1.5 m, 3.0 m and 5.00 m, respectively (Table 3). The safety factor distribution calculated for a selection of various depths and accelarations at the survey site can be seen in Figure 4 and 5. The colour palette changes from light red to dark red. Dark red indicates a potential risk of liquefaction.

Table 3. Calculated liquefaction safety factors for different depths and accelarations at the boreholes drilled on the survey site

Name of Boreholes	Depth (1.50 m) 0.4g	Depth (3.00 m) 0.4g	Depth (5.00 m) 0.4g	Depth (1.50 m) 0.5g	Depth (3.00 m) 0.5g	Depth (5.00 m) 0.5g
KIS_SK_1	0.34	0.26	0.44	0.27	0.20	0.35
KIS_SK_2	-	0.35	0.31	-	0.28	0.25
KIS_SK_3	0.23	0.18	0.17	0.18	0.15	0.13
KIS_SK_4	1.20	1.20	0.25	1.20	1.20	0.20
SAV_SK_1	0.57	0.45	1.20	0.45	0.36	1.20
SAV_SK_2	-	0.64	0.41	-	0.51	0.33
KAR_SK_1	0.96	0.80	0.37	0.76	0.64	0.29
KAR_SK_2	0.47	0.41	0.22	0.37	0.32	0.18
KAR_SK_3	0.63	0.33	0.35	0.50	0.26	0.28
KAR_SK_4	0.53	1.20	0.42	1.20	1.20	0.53



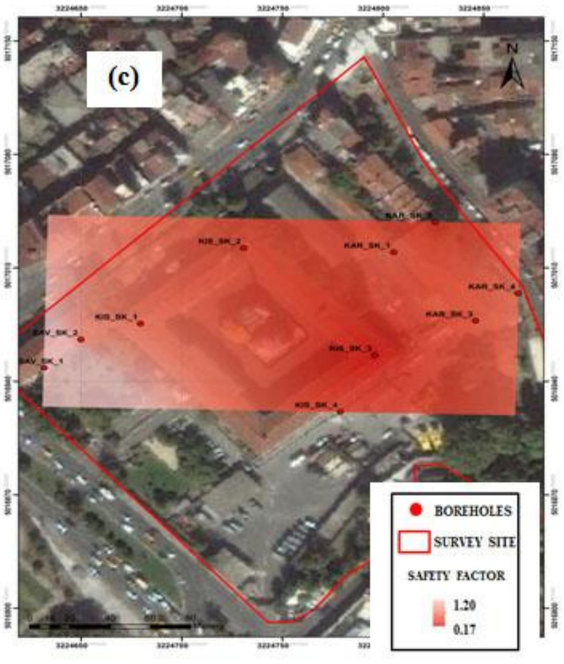
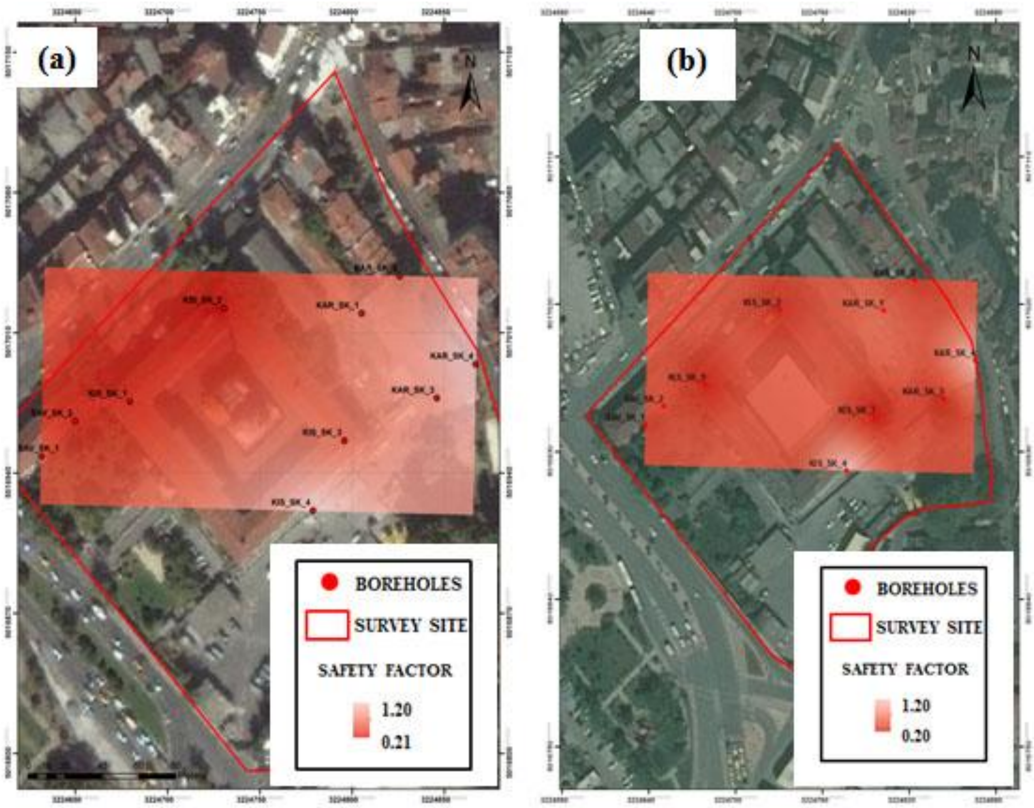


Figure 4. Safety factor distribution at the survey site (a) For 1.50m - 0.4g, (b) For 3.00 m -0.4g , (c) For 5.00 m - 0.4g



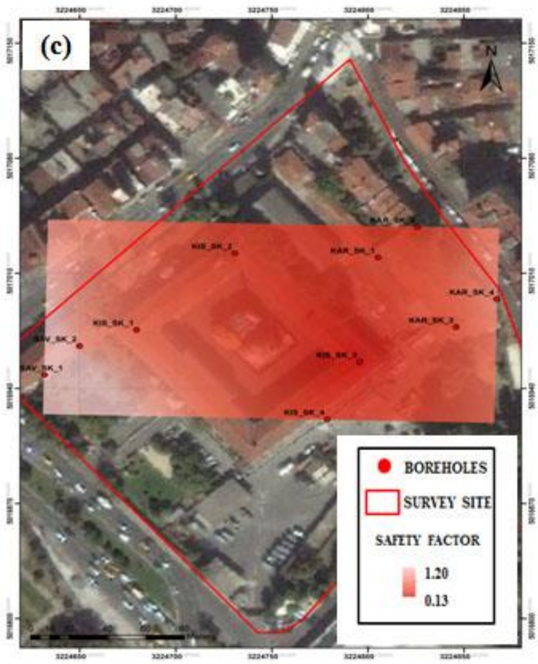


Figure 5. Safety factor distribution at the survey site (a) for 1.50m - 0.5g , (b) for 3.00 m - 0.5g, (c) for 5.00 m - 0.5g

The safety factors calculated were almost all smaller than 1 at the survey area. Whenever the magnitudes and the acceleration values exceed 0.4 g and 0.5 g, all sides of the study area will be under liquefaction risk.

4. Conclusions

The North Turkish Naval Forces site in Kasımpaşa, where military buildings had been damaged in by former earthquakes is analyzed for liquefaction risk. According to boreholes drilled, it has become clear that overburden layer at the study area includes alluvial deposits and ground water levels are high. SPT tests were done and liquefaction analyses were calculated using the Seed-Idriss method with laboratory tests taken from samples at 10 boreholes. Geographic Information Systems (GIS) maps of groundwater level and liquefaction potential were established with the help of the acquired parameters. It is understood that if the magnitudes and the acceleration values were increased, liquefaction potential of the survey site where alluvial formations occur will increase. Liquefaction potential has been identified all over the survey site. When a new earthquake occurs, this situation will have to be considered.

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References

1. Barka A., (1992) The North Anatolian fault zone, *Annales Tectonicae*, 6, 164-195.
2. Bektas O., Eyüpoğlu Y., Maden N., (2007) Different modes of stress transfer in a strike-slip fault zone: an example from the North Anatolian Fault system in Turkey, *Turkish Journal of Earth Sciences*, 16, 1-12.
3. Duman E.S., Ikizier S B., Angin Z., Demir G., (2014) Assessment of liquefaction potential of the Erzincan, Eastern Turkey, *Geomech. Eng. Int. J.*, 7(6), 589-612.
4. Eroskay S.O., (1985) Graywackes of İstanbul Region, Proceedings of International Symposium on Design of Supports to Deep Excavations Turkish Group of Soil Mechanics Bosphorus University, 41–44.
5. Fırat S., Arman H., Kutanis M., (2009) Assesment of liquefaction susceptibility of Adapazarı city after 17th August 1999, Marmara Earthquake, *Scientific Research and Essay*, 4(10), 1012 -1023.
6. Hamid S., Nath S., (2016) Liquefaction potential analysis of the Kashmir valley alluvium NW Himalaya, *Soil Dynamics and Earthquake Engineering*, 11-18.
7. Iwasaki T., Tokida K., Tatsuoka F., Watanabe S., Yasuda S., Sato H., (1982) Microzonation for Soil liquefaction potential using simplified methods, 3th International Earthquake Microzonation Conference, 1319-1330.
8. Juang C.H., Jiang T., Andrus R.D., (2002) Assessing probability-based methods for liquefaction potential evaluation, *Journal of Geotechnical and Geoenvironmental Engineerin*g, 128(7), 580-589.
9. Ketin I., (1991) Geology map of ISTANBUL, General Directorate of Mineral Research and Exploration, Ankara.
10. Kumar V., Venkatesh K., Tiwari R. P., Kumar Y., (2012) Application of ANN to predict liquefaction potential, *International Journal of Computational Engineering Research*, 2250-3005.
11. Le Pichon X., Sengor A.M.C., Demirbag E., Rangin C., Imren C., Armijo R., Gorur N., Cagatay N., Lepinay B. M., Meyer B., Saatcilar R.,Tok B., (2001) The active main Marmara fault, *Earth and Planetary Science Letters*, 192(4), 595-616.
12. Liao S.S.C., Whitman R.V., (1986) Overburden correction factors for SPT in sand, *Journal of Geotechnical Engineering*, 112, 373-377.
13. Mollamahmutoğlu M., Kayabalı K., Beyaz T., Kolay E., (2003) Liquefaction related building damage in Adapazarı during the Turkey Earthquake of August 17, *Engineering Geology*, 67, 297-307.
14. Okay A.I., Kaşlılar Ö.A., İmren C., Boztepe G.A., Demirbağ E., Kuşçu I., (2000) Active faults and evolving strike-slip basins in the Marmara Sea northwest Turkey multichannel Seismic reflection study, *Tectonophysics*, 321, 189-218.
15. Ozcep F., Karabulut S., Özel O., Ozçep T., Zarif H., (2009) Liquefaction-induced settlement, site efects and damage in the vicinity of Yalova City during the 1999 İzmit Earthquake Turkey, *Journal of Earth System Science*, 123(1), 73-89.
16. Öztunalı Ö., Satır M., (2009) Petrography and petrology of Çavuşoğlu crystalline rocks, Proceedings of Earth Science Congress in the 50th Anniversary of Republic of Turkey, 445-456 (in Turkish)
17. Özaydın K., (2007) Liquefaction on Soils, 6, Eartquake Engineering Congress in Istanbul, Turkey, 231-255.

18. Parke J.R., Minshull T.A., Anderson G., White R.S., McKenzie D., Kuscu I., Bull J., Gorur N., Sengor A.M.C., (1999) Active faults in the Sea of Marmara, Western Turkey, imaged by seismic reflection profiles, *Terra Nova*, 11, 223-227.
19. Rezaei S., Choobbasti A., (2014) Liquefaction assessment using microtremor measurement, conventional method and artificial neural network (Case study: Babol, Iran), *Frontiers of Structural and Civil Engineering*, 292-307.
20. Rockwell T., Barka A., Dawson T., Throup K., Akyüz S., (2001) Paleoseismicity of Gaziköy – Saros segment of the North Anatolian fault northwestern Turkey – Comparison of the historical and paleoseismic records, implications of regional seismic hazard, and models of earthquake recurrence, *International Journal of Seismicity*, 5(3), 433-448.
21. Seed H.B., Idriss I.M., (1971) Simplified procedure for evaluating soil liquefaction potential. Journal of Soil Mechanics and Foundations Divisions, *ASCE*, 97(9), 1249-1273.
22. Seed H.B., Tokimatsu K., Harder L.F., Chung R.M., (1984) The influence of SPT Procedures in soil liquefaction resistance evaluations, Earthquake Engineering Research Center Report No: UCB/EERC, 84/15, University of California at Berkeley.
23. Seed H.B., Tokimatsu K., Harder L.F., Chung R.M., (1985) The influence of SPT Procedures in soil liquefaction resistance evaluations, *Journal of Geotechnical Engineering, ASCE*, 111(12), 1425-1445.
24. Sengor A.M.C., (1979) The North Anatolian Transform Fault: Its age, offset and tectonic significance, *Journal of the Geological Society of London*, 136, 269-282.
25. Shahri A.A., Esfandiyari B., Rajablou B., (2012) A proposed geotechnical-based method for evaluation of liquefaction potential analysis subjected to earthquake provocations (case study: Korzan earth dam, Hamedan province, Iran), *Arabian Journal of Geosciences*, 5(4), 555-564.
26. Smith A.D., Taymaz T., Okay F.Y., Yüce H., Alpar B., Başaran H., Jackson J. A., Kara S., Şimşek M., (1995) High resolution seismic profiling in the sea of Marmara (NW Turkey) Late Quaternary sedimentation and sea-level changes *Bull. Geol. Soc. Am*., 107(8), 923-936.
27. Undül Ö., Tuğrul A., (2006) The engineering geology of the İstanbul, Turkey, IAEG, Engineering Geology for tomorrow's cities, 34.
28. Tugrul A., Undül Ö., (2006) Engineering geological characteristics of Istanbul greywackes, Turkey, IAEG, 396.
29. Yılmaz I. , Yavuzer D., (2005) Liquefaction potential and susceptibility mapping in the city of Yalova – Turkey, *Enviromental Geology*, 47, 175-184.
30. Youd T.L., Idriss I.M., Evaluation of Liquefaction resistance of soils Proceedings of the NCEER Workshop Technical Report NCEER-97-0022. National for Earthquake Engineering Research, 1997.